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Section 4

PHOSPHOR DATA

4.1 Description of Data*

This section presents information about inorganic phosphors, either from Lehmann's *Phosphor Cookbook* or from Lehmann's *Phosphor Tables*. Almost all inorganic phosphors consist of a host material into which small amounts of an activator impurity have been dissolved. The chemical formula corresponding to the host crystal generally is well established but the crystal structure may not be available. The activation includes only the activator and its ionic state as far as it is known. Additional impurities (co-activators, etc.) are specified only in some cases where they have a strong effect on the final luminescence of the phosphor.

The phosphor composition and a brief description of the preparation conditions used by Lehmann are given in his *Phosphor Cookbook* but not in the *Phosphor Tables*. Optical properties summarize the emissions of the phosphors. The emission color is that as it appears to the human eye. Many emission spectra consist of diffuse bands extending over a certain range; others are complex in shape or consist of discrete (although sometimes somewhat diffuse) lines. The emission peak corresponds to the spectral position where the diffuse band has a maximum, to the spectral range of the main part of a complex emission, or to one or two strongest lines in case of line emission. The width corresponds only to band emission and indicates the width of the band at half of its peak intensity (full width at half maximum—FWHM). Both the peak and bandwidth frequently depend on preparation conditions and are reproducible only within about ± 0.1 to 0.2 eV.

Because efficiencies obtained on poor phosphor samples are of limited usefulness, only observed efficiencies of the best samples known to Lehmann are shown. (Lehmann notes that one should keep in mind that an efficiency improvement of a phosphor, perhaps by using modified preparation conditions, is always a possibility that cannot be ruled out.)

Efficiencies under optical excitation, by either 365- or 254-nm ultraviolet (UV) — both the main emissions of a Hg discharge lamp — are given in Lehmann's *Phosphor Tables* in terms of quanta (i.e., the ratio of emitted light quanta over irradiated UV quanta). The symbols mean:

- ++ = efficiencies in the 50–100% range,
- + = efficiencies in the 10–50% range,
- = efficiencies below 10%.

The efficiencies by electron beam excitation in vacuum are described by the energy ratio (i.e., the ratio of emitted light energy over irradiated electron beam energy). In this instance the symbols mean:

- ++ = efficiencies of 10% or more,
- + = efficiencies in the 1–10% range,
- = efficiencies below 1%.

*This subsection is adapted from W. Lehmann's *Phosphor Cookbook*.

The luminescence decay time is the time for the emission either to decay to 1/10 or to 1/e of its initial value.

The emission and absorption spectra measured by Lehmann are all for room temperature and for the activator concentrations shown. These concentrations are close to, but not necessarily at the optimum in every case. The absorption spectra indicate where the materials may be excited (no absorption—no emission). Too few excitation spectra were available to be included. All spectra are plotted on a quantum basis; that is, the abscissa is calibrated in electron volts (eV) rather than wavelength units because luminescence processes are quantum processes. It is also easier to compare the widths of approximately Gaussian-shaped emission bands plotted in eV than it is to compare the widths of very non-Gaussian-shaped bands plotted in wavelength units. The simple conversion between wavelength (in nanometers, nm) and quantum energy (in eV) is

$$(\text{nm}) = 1240/(\text{eV})$$

Using this conversion, the two optical wavelengths used for excitation correspond to:

$$\begin{array}{l} 365 \text{ nm} \text{ — } 3.40 \text{ eV} \\ 254 \text{ nm} \text{ — } 4.88 \text{ eV} \end{array}$$

Only the main references to original publications are given. Absence of a reference means that none is known.

4.2 Simple Oxides

The following host compounds and activators are included in this subsection:

CaO:Bi³⁺
CaO:Cd²⁺
CaO:Cu⁺
CaO:Eu³⁺
CaO:Eu³⁺, Na⁺
CaO:Mn²⁺
CaO:Pb²⁺
CaO:Sb³⁺
CaO:Sm³⁺
CaO:Tb³⁺
CaO:Tl⁺
CaO:Zn²⁺
ZnO:Al³⁺, Ga³⁺
ZnO:Ga³⁺
ZnO:S
ZnO:Se
ThO₂:Eu³⁺
ThO₂:Pr³⁺
ThO₂:Tb³⁺
Y₂O₃:Bi³⁺
Y₂O₃:Er³⁺
Y₂O₃:Eu³⁺ (YOE)
Y₂O₃:Ho³⁺
Y₂O₃:Tb³⁺
La₂O₃:Bi³⁺
La₂O₃:Eu³⁺
La₂O₃:Pb²⁺

CaO:Bi³⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| CaCO ₃ | 100 | 100 |
| CaF ₂ | 0.5 | 0.390 |
| Bi ₂ O ₃ | 0.01 (of Bi) | 0.023 |

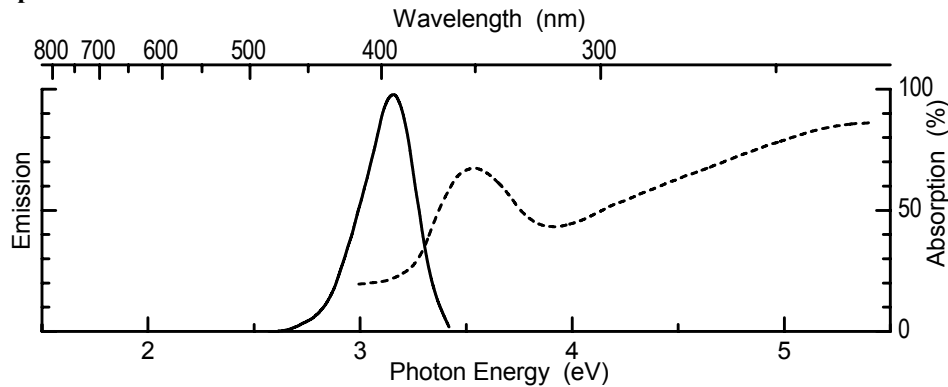
Preparation

- Mix by slurring in water or methanol.
- Dry in air. Powderize when dry.
- Fire in capped quartz tubes, stagnant air, 1200°C, 1 hour.
- Powderize.
- Store in well-closed container. Keep dry.

Optical Properties

Emission color: Violet + UV
Emission peak: 3.17 eV
Emission width (FWHM): 0.29 eV
Excitation efficiency by UV: ++ (3.4 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: 5%

Spectra



Remark

This phosphor is very sensitive to traces of Mn. Use only purest CaCO₃.

References

1. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).
2. Hughes, A.E., and Pells, G.P., Luminescence spectra of Bi³⁺ ions in MgO and CaO, *Phys. Status Solidi B*, 71, 707 (1975).
3. Yamashita, N., and Asano, A., Luminescence-centers of Ca(S,Se):Bi³⁺ and CaO:Bi³⁺ phosphors, *J. Phys. Soc. Jpn.*, 40, 144 (1976).

CaO: Cd²⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | | |
|-------------------|-----|-------|
| Mole % | | |
| By weight (g) | | |
| CaCO ₃ | 100 | 100 |
| CdO | 0.3 | 0.385 |

Preparation

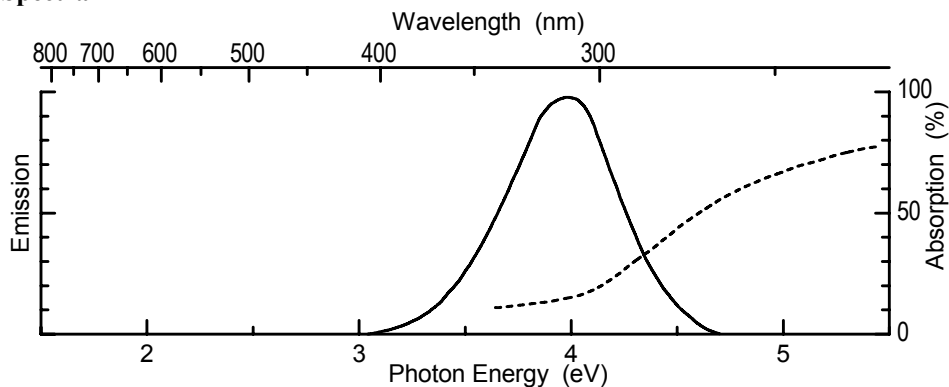
Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, stagnant air, 1200°C, 1 hour.
Powderize.
Store in well-closed container. Keep dry.

Optical Properties

Emission color: UV
Emission peak: Somewhat uncertain, may vary between about 3.90 and 4.00 eV

Emission width (FWHM): 0.63 eV
 Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
 Excitation efficiency by e-beam: 6–7%
 Decay to 10% : Exponential, about 230 μ sec

Spectra



References

1. Lange, H., *Tech. Wise. Abh. OSRAM Ges.*, 10, 87 (1969).
2. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).



Structure: Cubic (NaCl)I

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| CaF ₂ | 0.5 | 0.380 |
| CuSO ₄ ·5H ₂ O | 0.01 | 0.025 |

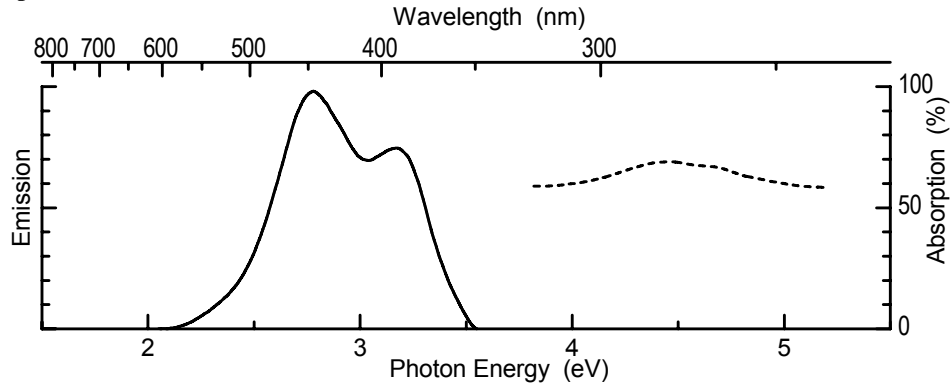
Preparation

Dissolve the copper sulfate in a little water; add solution to the CaCO₃ + CaF₂ mix.
 Slurry in water.
 Dry in air. Powderize when dry.
 Fire in capped quartz tubes, CO, 1200°C, 1 hour.
 Powderize.
 Store in well-closed container. Keep dry.

Optical Properties

Emission color: Bluish + UV
 Emission peak: Two overlapping bands, ~2.77 and ~3.18 eV
 Emission width (FWHM): 0.75 eV
 Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)
 Excitation efficiency by e-beam: 2%

Spectra



Reference

1. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).



Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 100 | 100 |
| CaF ₂ | 1.5 | 1.2 |
| Eu ₂ O ₃ | 1.2 (of Eu) | 2.1 |

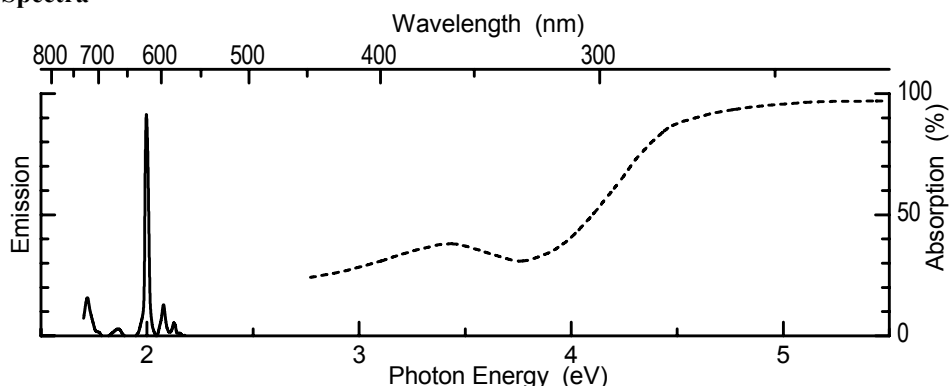
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1200°C, 2 hours.
Powderize.
 2. Fire in open quartz boats, N₂ loaded with H₂O, 1200°C, 1 hour. After this firing, quench again to room temperature as quickly as possible.
Powderize.
 3. Fire in open quartz boats, stagnant air, 1200°C, ~20 min. After this firing, quench again to room temperature as quickly as possible.
Powderize.
Store in well-closed container. Keep dry.

Optical Properties

Emission color: Red, slightly deeper red than that of YOE
Emission peak: Main line at 2.015 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV), can be sensitized for excitation at 3.40 eV by addition of Bi (see CaO:Bi³⁺)
Excitation efficiency by e-beam: Poor

Spectra



Remarks

1. The fluorine in the above recipe can be replaced by chlorine or bromine but a phosphor so prepared is badly hygroscopic probably because of leftover CaCl₂ or CaBr₂.
2. The phosphor reacts to a “bad” temperature range (~800–1100°C) by greatly reduced efficiency. Top efficiency requires that the phosphor passes through this range as rapidly as possible after second and third firings.
3. The red Eu³⁺ emission shown in the preceding figure appears only if no alkali is present. Addition of Li, Na, or K (perhaps for charge compensation, Li⁺ + Eu³⁺ = 2Ca²⁺) causes the red line at 2.015 eV to appear.
4. This CaO:Eu³⁺ phosphor has been tested in fluorescent lamps. It performs very poorly.

References

1. Brauer, P., *Z. Naturforsch. Pt. A*, 6, 561 (1951), and *Über eu-ionen in erdalkalioxyden und erdalkali-sulfiden*, *Z. Naturforsch. Pt. A*, 12, 233 (1957).
2. Lehmann, W., *Calcium oxide phosphors*, *J. Lumin.*, 6, 455 (1973).



Structure: Cubic (NaCl)

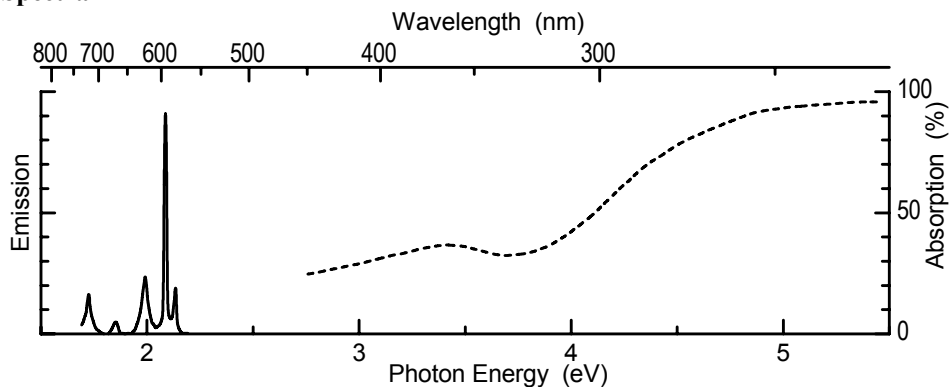
Optical Properties

Emission color: Orange-yellow

Emission peak: 2.10 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



CaO:Mn²⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| CaF ₂ | 0.5 | 0.390 |
| MnCO ₃ | 0.1 | 0.115 |

Preparation

Mix by slurring in water.

Dry in air. Powderize when dry.

Fire in capped quartz tubes, CO, 1200°C, 1 hour.

Powderize.

Store in well-closed container. Keep dry.

Optical Properties

Emission color: Orange-yellow

Emission peak: 2.07 eV

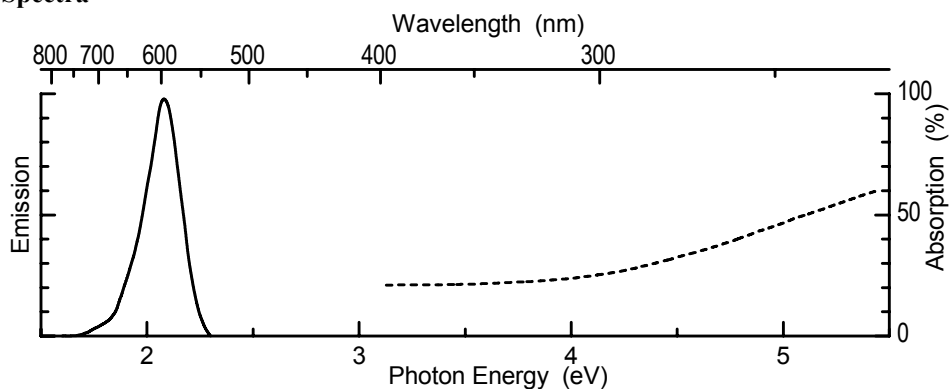
Emission width (FWHM): 0.20 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV); can be sensitized to respond to 4.88 eV by addition of Pb (see CaO:Pb²⁺); can be sensitized to respond to 3.40 eV by addition of Bi (see CaO:Bi³⁺)

Excitation efficiency by e-beam: 5%

Decay to 10%: Exponential, about 22 msec

Spectra



Remarks

1. The Mn concentration is not critical. Strong Mn²⁺ emission appears from about 1 ppm to 10% of Mn or Ca.
2. The phosphor must be fired in a reducing atmosphere; otherwise the Mn stays separate as MnO₂.

References

1. Ewles, J., and Lee, N., Studies on the concept of large activator centers in crystal phosphors. 1. Dependence of luminescent efficiency on concentration of activator size of luminescent centers, *J. Electrochem. Soc.*, 100, 392 (1953).

2. Sancier, K.M., Wise, H., and Fredericks, W.J., Luminescence of solids excited by surface recombination of atoms. 1. Luminescence spectra, *J. Chem. Phys.*, 37, 854 (1962).
3. Hühninger, M., and Ruffler, A., *Techn. Wise. Abh. OSRAM Ges.*, 37, 41 (1963).
4. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).

CaO:Pb²⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| CaF ₂ | 0.5 | 0.390 |
| PbO | 0.01 | 0.022 |

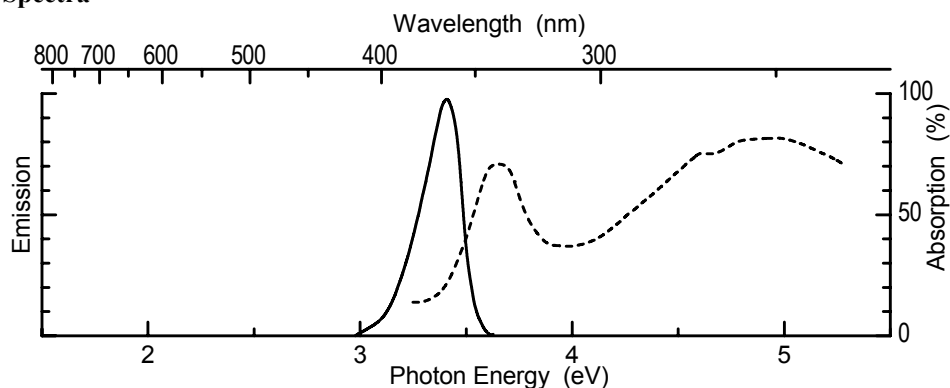
Preparation

Mix by slurring in water or methanol.
 Dry in air. Powderize when dry.
 Fire in capped quartz tubes, stagnant air, 1200°C, 1 hour.
 Powderize.
 Store in well-closed container. Keep dry.

Optical Properties

Emission color: UV
 Emission peak: 3.42 eV
 Emission width (FWHM): 0.21 eV
 Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
 Excitation efficiency by e-beam: 10%

Spectra



Reference

1. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).

CaO:Sb³⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 100 | 100 |
| Sb ₂ O ₃ | 0.1 (of Sb) | 0.145 |
| NaHCO ₃ | 1 | 0.840 |

Preparation

Mix by slurring in water.

Dry in air. Powderize when dry.

Fire in capped quartz tubes, CO, 1200°C, 1 hour.

Powderize.

Store in well-closed container. Keep dry.

Optical Properties

Emission color: Yellow-green

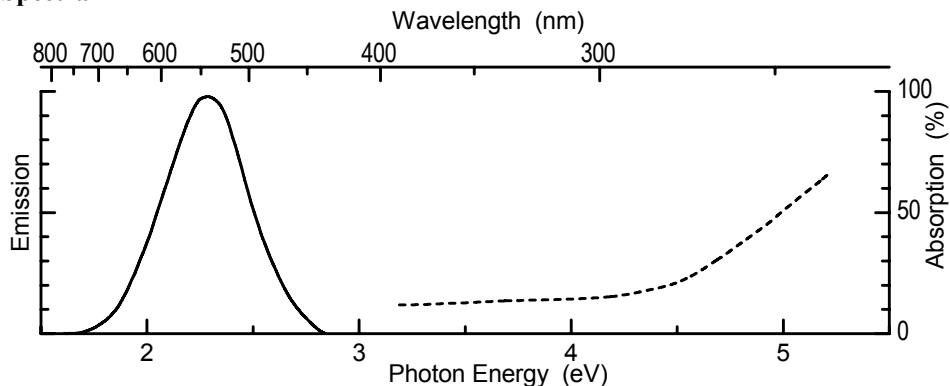
Emission peak: 2.30 eV

Emission width (FWHM): 0.51 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV); can be sensitized for excitation by 4.88 and 3.40 eV UV by addition Bi (see CaO:Bi³⁺)

Excitation efficiency by e-beam: Poor

Spectra



References

1. Witzmann, H., Herzog, G., and Kunstler, K., Zur lumineszenz antimonaktivierter erdalkalioxide insonderheit des systems CaO-Sb, *Z. Phys. Chem. (Leipzig)*, 227, 56 (1964).
2. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).

CaO:Sm³⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 100 | 100 |
| CaF ₂ | 0.5 | 0.380 |
| Sm ₂ O ₃ | 0.3 (of Sm) | 0.520 |

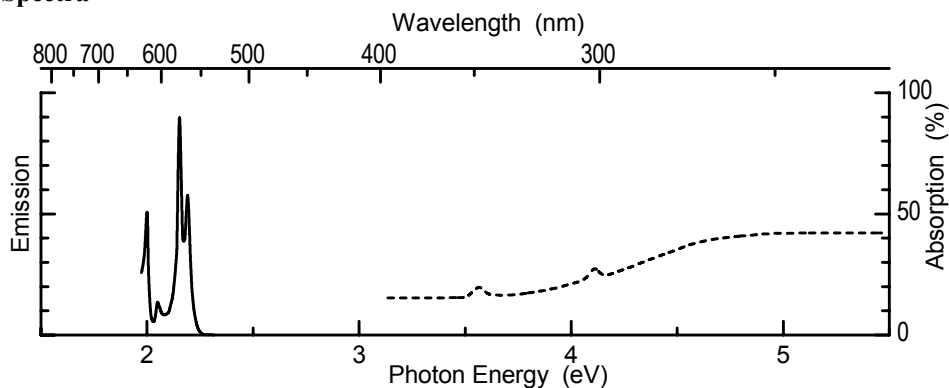
Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, stagnant air, 1200°C, 1 hour.
Powderize.
Store in well-closed container. Keep dry.

Optical Properties

Emission color: Orange-yellow
Emission peak: 2.00, 2.16, and 2.19 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV); can be sensitized to respond to 4.88 eV by addition of Pb (see CaO:Pb²⁺); can be sensitized for 4.88 and 3.40 eV excitation by addition of Bi (see CaO:Bi³⁺)

Spectra



References

1. Crozet, A., Fiquet, J., and Janin, J., *J. Phys. Rad.*, 14, 125 (1953).
2. Runciman, W.A., Atomic configurations in luminescent centres, *Br. J. Appl. Phys.*, S78, Suppl. 4 (1955).
3. Witzmann, H., Herzog, G., and Wuntke, K., *Z. Phys. Chem. (Leipzig)*, 225, 332 (1964).
4. Herzog, G., and Rath, R., Beitrag zur thermolumineszenz des samariumaktivierten calciumoxids, *Z. Phys. Chem. (Leipzig)*, 228, 13 (1965).
5. Herzog, G., and Abel, W., Thermoluminescence of phosphors CaO-Sm and CaO-Bi (calcium oxide-samarium and-bismuth), *Z. Phys. Chem. (Leipzig)*, 243, 33 (1970).
6. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).

CaO:Tb³⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 100 | 100 |
| CaF ₂ | 0.5 | 0.380 |
| Tb ₄ O ₇ | 1.5 (of Tb) | 2.8 |

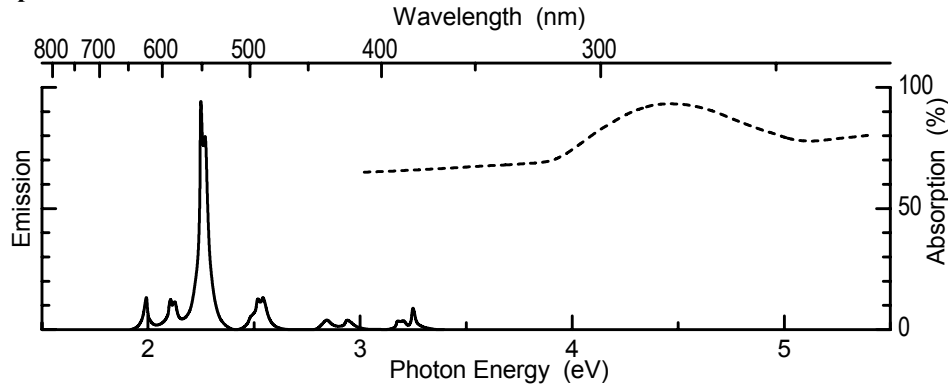
Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, CO, 1200°C, 1 hour.
Powderize.
Store in well-closed container. Keep dry.

Optical Properties

Emission color: Pale green
Emission peak: Many lines; strongest near 2.26–2.28 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV); low because of dark body color
Excitation efficiency by e-beam:

Spectra



Reference

1. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).

CaO:Tl⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaO | 100 | 56 |
| TlOH | 0.03 | 0.066 |
| NH ₄ Cl | 1 | 0.540 |

Preparation

First mix only the CaO and NH₄Cl by dry grinding.

1. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.

Now admit the TiOH by dry grinding.

2. Fire in capped quartz tubes, stagnant air, 1200°C, 1 hour.
Powderize

Store in well-closed container. Keep dry.

Optical Properties

Emission color: Pale yellow + IR

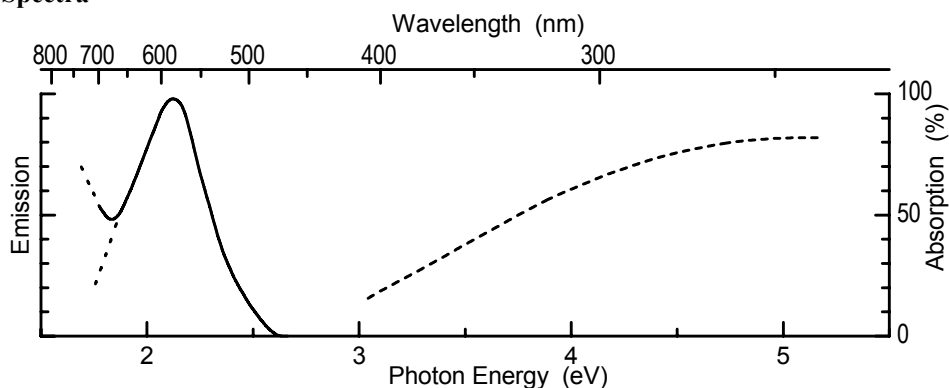
Emission peaks: 2.11 and 1.5 eV (IR)

Emission width (FWHM): 0.48 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: 3% (Including both bands)

Spectra



References

1. Anderson, H., Zur photoelektrischen messung geringer lumineszenzintensitäten, *Z. Phys. Chem. (Leipzig)*, 227, 130 (1964).
2. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).



Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| CaF ₂ | 0.5 | 0.390 |
| ZnO | 0.3 | 0.240 |

Preparation

Mix by slurring in water or methanol.

Dry in air. Powderize when dry.

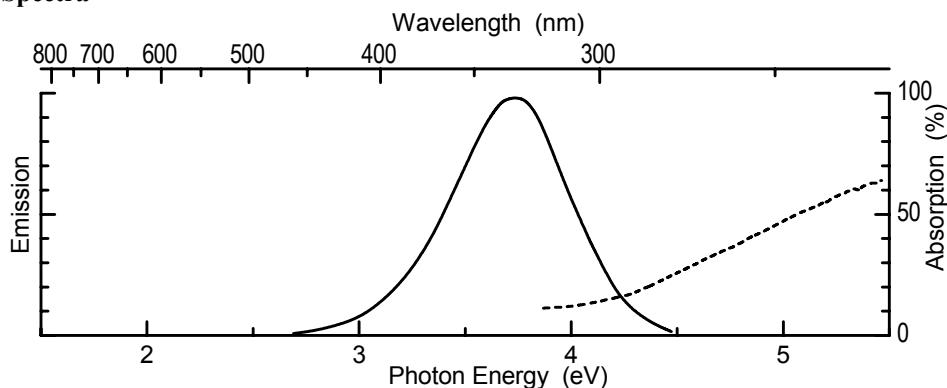
Fire in capped quartz tubes, stagnant air, 1200°C, 1 hour.

Powderize.
Store in well-closed container. Keep dry.

Optical Properties

Emission color: UV
Emission peak: Somewhat uncertain, varying between about 3.65 and 3.80 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: 10%
Decay to 10%: Exponential, about 300 μ sec

Spectra



Reference

1. Lehmann, W., Calcium oxide phosphors, *J. Lumin.*, 6, 455 (1973).



Structure: Hexagonal (wurtzite)

Optical Properties

Emission color: UV
Emission peak: 3.20 eV
Emission width (FWHM): 0.13 eV
Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: +

References

1. Lehmann, W., Edge emission of n-type conducting ZnO and CdS, *Solid State Electron.*, 9, 1107 (1966).
2. Luckey, D., A fast inorganic scintillator, *Nucl. Instrum. Methods*, 62, 119 (1968);
Luckey, D., Correction, *Nucl. Instrum. Methods*, 63, 358 (1968).

ZnO:Ga³⁺

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------|---------------|
| ZnO | 100 | 81 |
| Ga ₂ O ₃ | 0.3 | 0.280 |
| ZnCl ₂ | 1 | 1.4 |

Preparation

Mix by slurring in water or methanol. Dry in air. Fire when dry.

1. Fire in capped quartz tubes, stagnant air, 1100°C, 1 hour.
When cool, inspect under UV lamp. Material should be almost or completely dead.
Remove any suspicious parts.
Powderize. Screen through 200 mesh (stainless steel sieve OK).
2. Fire in open quartz boats, slowly flowing H₂, 800°C, 1 hour.
When cool, inspect again under UV lamp. Material should show deep violet luminescence, nothing else. Remove all portions which look different.

Optical Properties

Emission color: Deep violet + UV

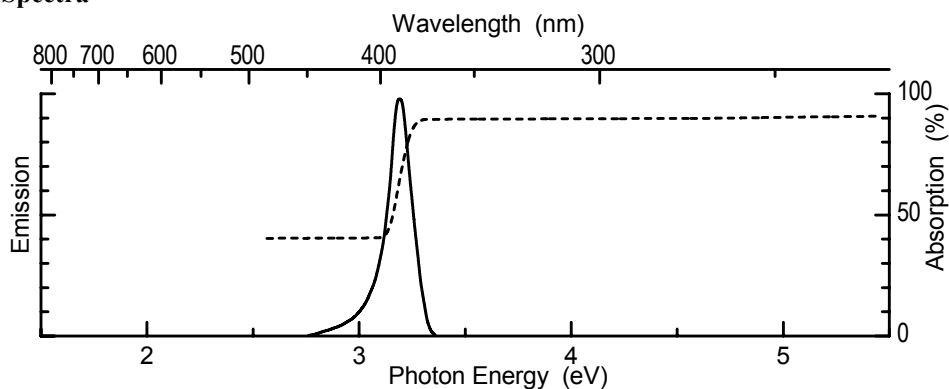
Emission peak: 3.195 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: 1–1.2%

Decay to 10%: Less than 1 nsec

Spectra



Remarks

1. This material is sensitive to traces of sulfur during preparation. Avoid all sulfur like the plague.
2. Phosphor has gray (not white) body color. It is thermally in a semi-stable state. Do not heat to greater than 300°C, except in H₂.

References

1. Lehmann, W., Edge emission of n-type conducting ZnO and CdS, *Solid State Electron.*, 9, 1107 (1966).
2. Luckey, D., A fast inorganic scintillator, *Nucl. Instrum. Methods*, 62, 119 (1968).
3. Luckey, D., Correction, *Nucl. Instrum. Methods*, 63, 358 (1968).

ZnO:S

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------|--------|---------------|
| ZnO | 100 | 81 |
| S | ~0.2 | ~0.064 |

Preparation

Fire in capped tubes, CO, 900°C, 1 hour.

Optical Properties

Emission color: Blue-green

Emission peak: 2.45 eV

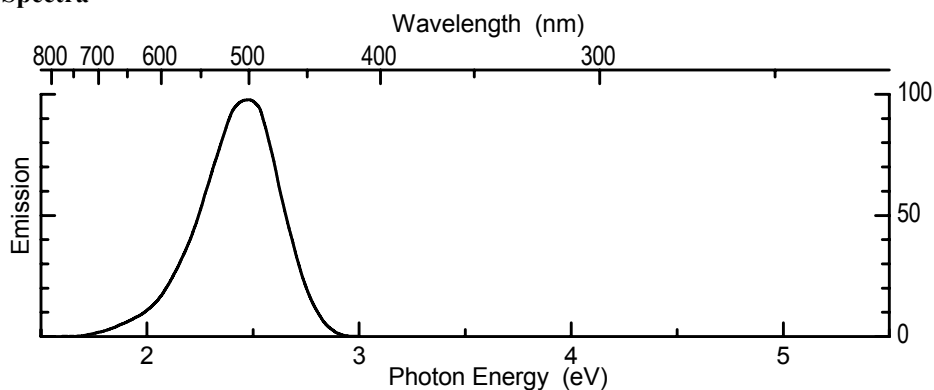
Emission width (FWHM): 0.41 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV); $\approx 60\%$

Excitation efficiency by e-beam: +

Decay to 10%: In the 1–10 μsec range

Spectra



Remarks

1. This common bluish-green emission of ZnO is greatly enhanced by the addition of sulfur during firing.
2. The emission can be shifted towards blue by replacing 20% of the Zn by Mg, and towards yellow by replacing 10% of the Zn by Cd.

References

1. Thomsen, S.M., Sulfide in zinc-oxide luminophors, *J. Chem. Phys.*, 18, 770 (1950).
2. Smith, A.L., Zinc-magnesium oxide and zinc-magnesium sulfide phosphors, *J. Electrochem. Soc.*, 99, 155 (1952).
3. Lehmann, W., Zinc oxide and zinc-cadmium oxide phosphors, *J. Electrochem. Soc.*, 115, 538 (1968).

ZnO:Se

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------|--------|---------------|
| ZnO | 100 | 81 |
| Se | ~0.2 | 0.160 |

Preparation

Fire in capped quartz tubes, CO, 900°C, 1 hour.

Optical Properties

Emission color: Orange

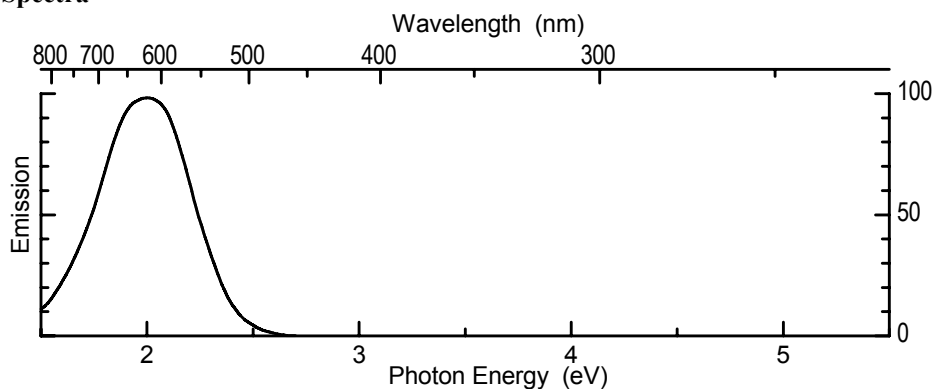
Emission peak: 1.98 eV

Emission width (FWHM): 0.51 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV); \approx 50–60%

Excitation efficiency by e-beam: Afterglow tail observed into the millisecond range

Spectra



Remark

This material can be obtained also by “burning” (i.e., oxidizing) of ZnSe in air but the efficiency of this ZnO:Se is lower.

References

1. Markovski, L.Y., and Oshanskaya, N.S., *Optics and Spectr.*, 9, 40 (1960).
2. Lehmann, W., Zinc oxide and zinc-cadmium oxide phosphors, *J. Electrochem. Soc.*, 115, 538 (1968).

ThO₂:Eu³⁺

Structure: Rutile

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| ThO ₂ | 100 | 232 |
| Eu ₂ O ₃ | 1.5 (of Eu) | 2.3 |
| NH ₄ F | 10 | 3.7 |

Preparation

Mix by slurring in water.

Dry in air. Powderize when dry.

Fire in capped quartz tubes, N₂, 1300°C, 1 hour.

Powderize.

Wash in concentrated nitric acid and then in water until neutral.

Dry.

Optical Properties

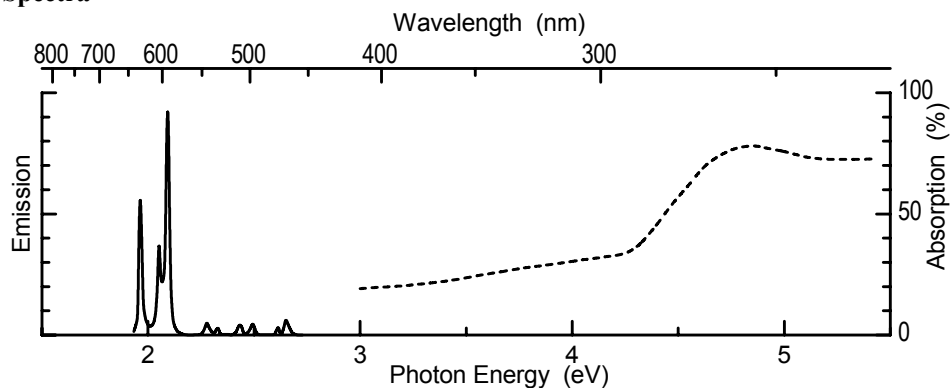
Emission color: Pinkish orange-red

Emission peak: Three strongest lines, 1.97, 2.04, and 2.095 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: 4%

Spectra



Remark

This phosphor has been proposed for X-ray excitation because of the high stopping power of ThO₂ for x-rays.

References

1. Fok, M.V., *Optika I Spektrosk.*, 2, 127 (1957).
2. Borchard, H.J., U.S. Pat., 3 408 303 (1968).

ThO₂:Pr³⁺

Structure: Rutile

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| ThO ₂ | 100 | 232 |
| Pr ₂ O ₃ | 0.2 (of Pr) | 0.330 |
| NH ₄ F | 10 | 3.7 |

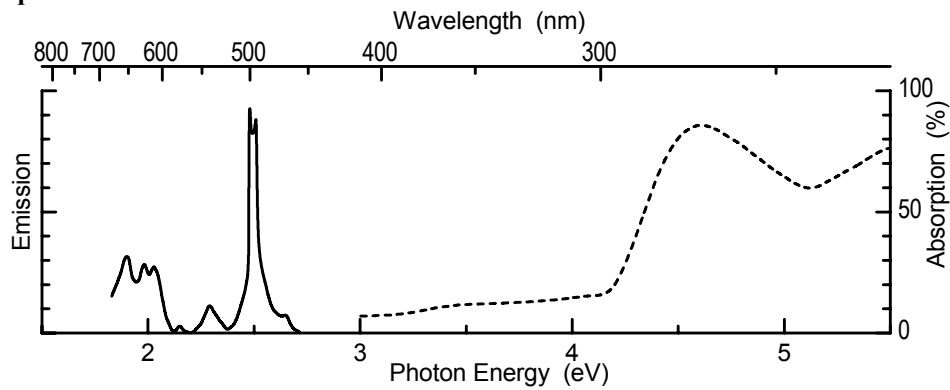
Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, N₂, 1300°C, 1 hour.
Powderize.
Wash in concentrated nitric acid and then in water until neutral.
Dry.

Optical Properties

Emission color: Blue-greenish white
Emission peak: Strongest lines: at 1.89, 2.48, and 2.52 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: 3%

Spectra



ThO₂:Tb³⁺

Structure: Rutile

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| ThO ₂ | 100 | 232 |
| Tb ₄ O ₇ | 0.2 (of Tb) | 0.375 |
| NH ₄ F | 10 | 3.7 |

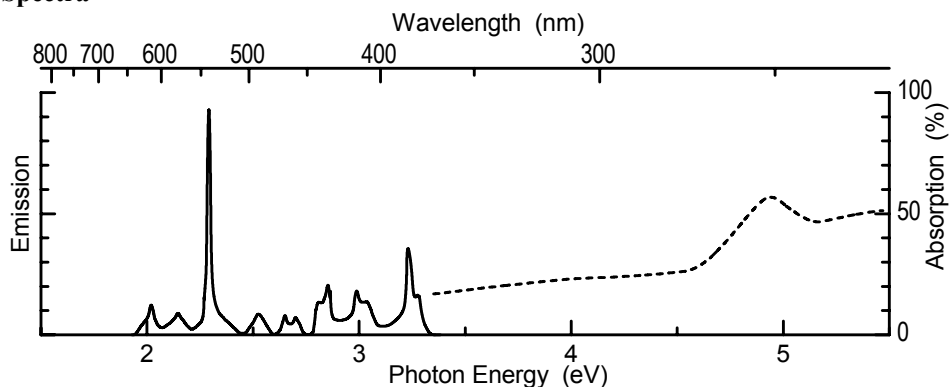
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, CO, 1300°C, 1 hour.
Powderize.
Wash in concentrated nitric acid and then in water until neutral.
Dry.

Optical Properties

Emission color: Bluish-greenish
Emission peak: Strongest at 2.285 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: 3%

Spectra

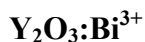


Remark

This phosphor has been proposed for X-ray excitation (high stopping power of ThO₂ for X-rays).

Reference

1. Borchard, H.J., U.S. Pat., 3 408 303 (1968).



Structure: Cubic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| Y ₂ O ₃ | 100 (of Y) | 108 |
| Bi ₂ O ₃ | 0.1 (of Bi) | 0.230 |
| CaF ₂ | 2.5 | 1.95 |

Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, stagnant air, 1300°C, 1 hour.

Optical Properties

Emission color: Pale blue-greenish white

Emission peak: 2.35 and 3.00 eV, frequently only the 2.35 eV band showing up

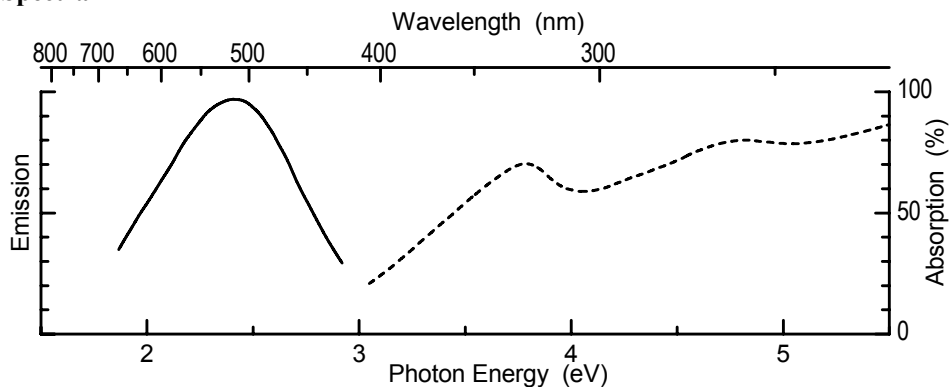
Emission width (FWHM): 0.83 eV (for 2.35 eV peak)

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: Low in either case

Decay to 10%: ≈ 1 μ sec

Spectra



Remark

The Bi^{3+} emission in Y_2O_3 is very poorly expressed. Sometimes it is difficult to recognize the bands in the very diffuse emission spectrum.

References

1. Datta, R.K., Luminescent behavior of bismuth in rare-earth oxides, *J. Electrochem. Soc.*, 114, 1137 (1967).
2. Toma, S.Z., and Palumbo, D.T., Luminescence of some bismuth-activated oxides, *J. Electrochem. Soc.*, 116, 274 (1969).
3. Blasse, G., and Bril, A., Investigations on Bi^{3+} -activated phosphors, *J. Chem. Phys.*, 48, 217 (1968).
4. Boulon, G. et al., *Proc. Intern. Conf. Lumin.*, Leningrad, p. 530 (1972).



Structure: Cubic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| Y_2O_3 | 100 (of Y) | 108 |
| Bi_2O_3 | 0.1 (of Bi) | 0.230 |
| CaF_2 | 2.5 | 1.95 |

Preparation

Mix by slurring in water or methanol.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, stagnant air, 1300°C, 1 hour.

- Powderize.
2. Fire in capped quartz tubes, stagnant air, 1300°C, 1 hour.

Optical Properties

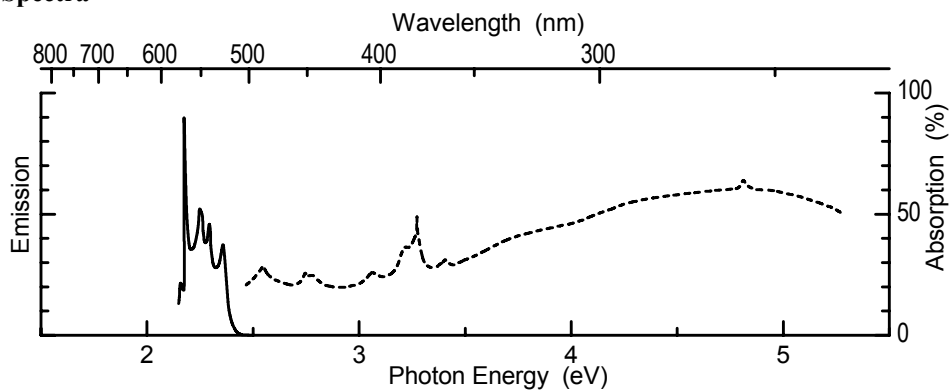
Emission color: Pale green

Emission peak: Strongest line at 2.206 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: Efficiency not tested; is low for the visible part because of strong competition by IR emission

Spectra



Y₂O₃:Eu³⁺ (YOE)

Structure: Cubic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| Y ₂ O ₃ | 100 (of Y) | 108 |
| Bi ₂ O ₃ | 0.1 (of Bi) | 0.230 |
| CaF ₂ | 2.5 | 1.95 |

Preparation

Mix by slurring in water or methanol. Dry in air. Powderize when dry.

Fire in capped quartz tubes, stagnant air, 1300°C, 1 hour. Powderize.

Fire in open quartz boats, air, 1300°C, 1 hour.

Optical Properties

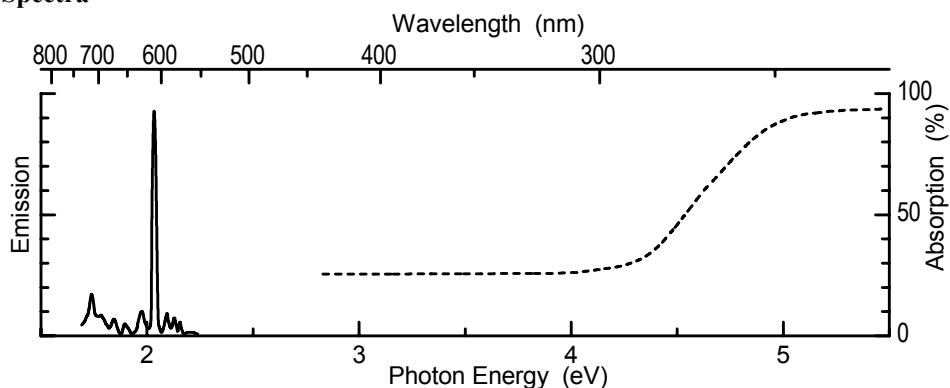
Emission color: Red

Emission peak: Strongest line at 2.03 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV); ≈ 80%

Excitation efficiency by e-beam: 7–8% (if Eu conc: = 3%, see below)

Spectra



Remarks

1. The above recipe gives a phosphor optimized for excitation by 4.88 eV. To obtain a phosphor optimized for e-beam excitation use only $\frac{1}{2}$ of the above Eu concentration.
2. Sensitization by Bi causes excitability by 3.40 eV UV but reduces the efficiency for excitation by 4.88 eV UV.

References

1. Chang, N.C., Fluorescence and stimulated emission from trivalent europium in yttrium oxide, *J. Appl. Phys.*, 34, 3500 (1963).
2. Wickersheim, K.A., and Lefever, R.A., Luminescent behavior of the rare earths in yttrium oxide and related hosts, *J. Electrochem. Soc.*, 111, 47 (1964).
3. Ropp, R.C., Spectral properties of rare earth oxide phosphors, *J. Electrochem. Soc.*, 111, 311 (1964).
4. Ropp, R.C., Luminescence of europium in ternary system — $\text{A}_2\text{O}_3\text{-Gd}_2\text{O}_3\text{-Y}_2\text{O}_3$, *J. Electrochem. Soc.*, 112, 181 (1965).
5. Datta, R.K., Luminescent behavior of bismuth in rare-earth oxides, *J. Electrochem. Soc.*, 114, 1137 (1967).



Structure: Cubic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| Y_2O_3 | 100 (of Y) | 108 |
| Bi_2O_3 | 0.1 (of Bi) | 0.230 |
| CaF_2 | 2.5 | 1.95 |

Preparation

Mix by slurring in water or methanol.

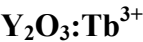
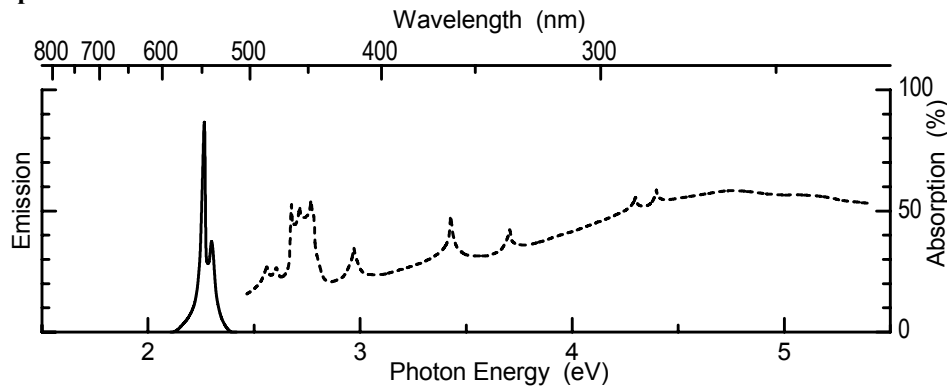
Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, stagnant air, 1300°C, 1 hour.
Powderize.
2. Fire in capped quartz tubes, stagnant air, 1300°C, 1 hour.

Optical Properties

Emission color: Yellow-green
Emission peak: Two lines in the visible at 2.266 and 2.30 eV, plus many lines in the IR
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: Efficiency not tested; is low for the visible part because of the strong competition by IR emission

Spectra



Structure: Cubic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| Y_2O_3 | 100 (of Y) | 108 |
| Bi_2O_3 | 0.1 (of Bi) | 0.230 |
| CaF_2 | 2.5 | 1.95 |

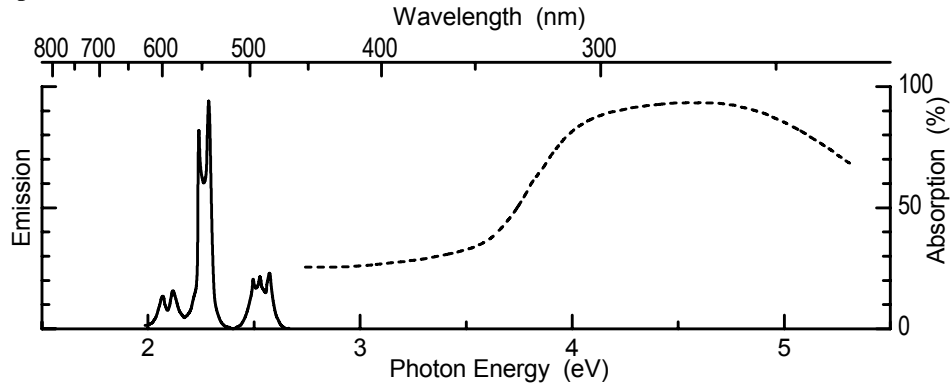
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, CO, 1300°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, CO, 1300°C, 1 hour.

Optical Properties

Emission color: Pale green
Emission peak: Strongest lines at 2.253 and 2.286 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: 2–3% (if Tb conc. = 1%, see below)

Spectra

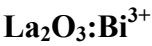


Remarks

- 1. The above recipe gives a phosphor optimized for excitation by 4.88 eV. To obtain a phosphor optimized for e-beam excitation use only 1% (instead of 2.5%) of Tb.
- 2. This phosphor must be fired in reducing atmosphere; otherwise Tb³⁺ oxidizes to Tb⁴⁺.

Reference

- 1. Ropp, R.C., Spectral properties of rare earth oxide phosphors, *J. Electrochem. Soc.*, 111, 311 (1964).



Structure: Cubic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 100 (of Y) | 163 |
| Bi ₂ O ₃ | 0.1 (of Bi) | 0.230 |
| CaF ₂ | 2.5 | 1.95 |

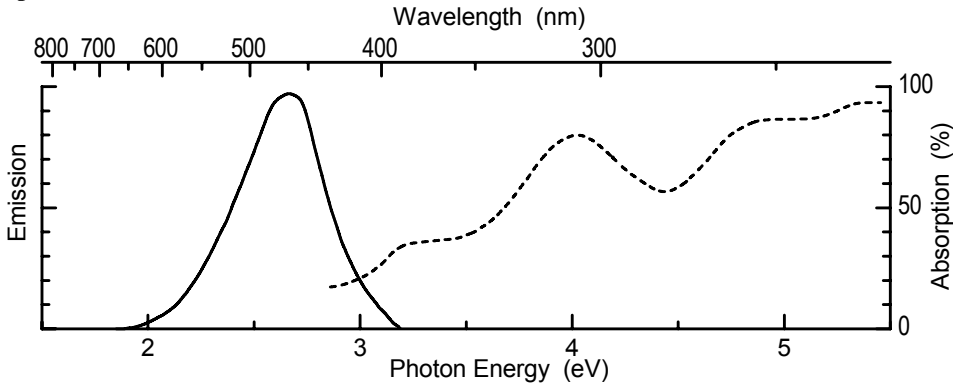
Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, stagnant air, 1200°C, 1 hour.
Powderize.
Re-fire, same conditions as above.
Powderize.
Store in well-closed container.

Optical Properties

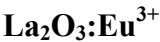
Color: Bluish
Emission peak: 2.67 eV
Emission width (FWHM): 0.49 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Decay to 1/e: 0.27 μsec

Spectra



References

1. Datta, R.K., Luminescent behavior of bismuth in rare-earth oxides, *J. Electrochem. Soc.*, 114, 1137 (1967).
2. Ropp, R.C., Luminescence of europium in ternary system — $\text{A}_2\text{O}_3\text{-Gd}_2\text{O}_3\text{-Y}_2\text{O}_3$, *J. Electrochem. Soc.*, 112, 124 (1965).
3. Bril, A., Wanmaker, W.L., and deLaat, C., Fluorescent properties of red-emitting europium-activated phosphors with cathode ray excitation, *J. Electrochem. Soc.*, 112, 111 (1965).



Structure: Cubic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| La_2O_3 | 100 (of Y) | 163 |
| Bi_2O_3 | 0.1 (of Bi) | 0.230 |
| CaF_2 | 2.5 | 1.95 |

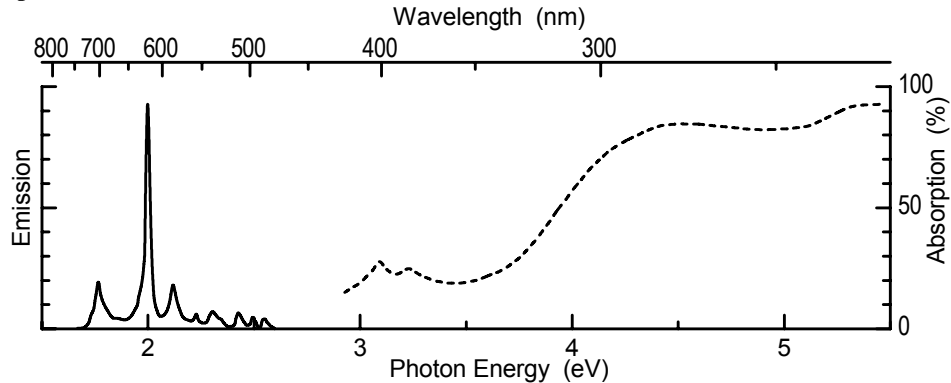
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, stagnant air, 1300°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, stagnant air, 1300°C, 1 hour.
Powderize.
Store in well-closed container.

Optical Properties

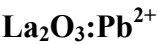
Emission color: Red
Emission peak: Strongest line at 1.985 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Spectra



References

1. Ropp, R.C., Spectral properties of rare earth oxide phosphors, *J. Electrochem. Soc.*, 111, 311 (1964).
2. Ropp, R.C., Luminescence of europium in ternary system — $\text{A}_2\text{O}_3\text{-Gd}_2\text{O}_3\text{-Y}_2\text{O}_3$, *J. Electrochem. Soc.*, 112, 181 (1965).
3. Bril, A., Wanmaker, W.L., and deLaat, C., Fluorescent properties of red-emitting europium-activated phosphors with cathode ray excitation, *J. Electrochem. Soc.*, 112, 111 (1965).
4. Barasch, G.E., and Dieke, G.H., Fluorescence decay of rare-earth ions in crystals, *J. Chem. Phys.*, 43, 988 (1965).
5. Datta, R.K., Luminescent behavior of bismuth in rare-earth oxides, *J. Electrochem. Soc.*, 114, 1137 (1967).
6. Wickersheim, K.A., and Lefever, R.A., Luminescent behavior of the rare earths in yttrium oxide and related hosts, *J. Electrochem. Soc.*, 111, 47 (1964).
7. Chang, N.C., Fluorescence and stimulated emission from trivalent europium in yttrium oxide, *J. Appl. Phys.*, 34, 3500 (1963).



Structure: Cubic

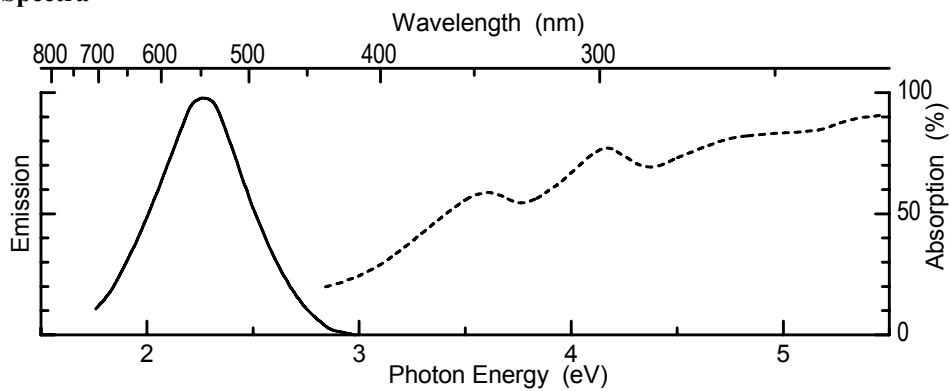
Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| La_2O_3 | 100 (of Y) | 163 |
| Bi_2O_3 | 0.1 (of Bi) | 0.230 |
| CaF_2 | 2.5 | 1.95 |

Optical Properties

Emission color: Yellow-green
Emission peak: 2.27 eV
Emission width (FWHM): 0.51 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Spectra



4.3 Silicates

The following host compounds and activators are included in this subsection:

CaSiO₃:Ce³⁺
CaSiO₃:Eu²⁺
CaSiO₃:Pb²⁺
CaSiO₃:Ti⁴⁺
CaSiO₃:Pb²⁺, Mn²⁺
Be₂SiO₄:Mn²⁺
Mg₂SiO₄:Mn²⁺
Zn₂SiO₄:Mn²⁺
Zn₂SiO₄:Mn²⁺, P
Zn₂SiO₄:Mn²⁺, As⁵⁺
Zn₂SiO₄:Ti⁴⁺
(Zn+Be)₂SiO₄:Mn²⁺
Sr₂SiO₄:Eu²⁺
SrBaSiO₄:Eu²⁺
Ba₂SiO₄:Eu²⁺
Ba₂SiO₄:Ce³⁺, Li⁺, Mn²⁺
BaSi₂O₅:Eu²⁺
BaSi₂O₅:Pb²⁺
Y₂SiO₅:Ce³⁺
CaMgSi₂O₆:Eu²⁺
CaMgSi₂O₆:Eu²⁺, Mn²⁺
Ca₂MgSi₂O₇:Eu²⁺
Ca₂MgSi₂O₇
Ca₂MgSi₂O₇:Eu²⁺, Mn²⁺
Sr₂MgSi₂O₇:Eu²⁺
Ba₂MgSi₂O₇:Eu²⁺
BaMg₂Si₂O₇:Eu²⁺
BaSrMgSi₂O₇:Eu²⁺
Ba₂Li₂Si₂O₇:Eu²⁺
Ba₂Li₂Si₂O₇:Sn²⁺
Ba₂Li₂Si₂O₇:Sn²⁺, Mn²⁺
MgSrBa₂Si₂O₇:Eu²⁺
MgBa₃Si₂O₈:Eu²⁺
MgSr₃Si₂O₈:Eu²⁺, Mn²⁺
Sr₃MgSi₂O₈:Eu²⁺
Ca₅B₂SiO₁₀:Eu³⁺
Ca₃Al₂Si₃O₁₂:Eu²⁺
LiCeBa₄Si₄O₁₄:Mn²⁺
LiCeSrBa₃Si₄O₁₄:Mn²⁺

CaSiO₃:Ce³⁺

Structure: Triclinic (pseudowollastonite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 97 | 97 |
| SiO ₂ | 100 | 100 |
| TiO ₂ | 1 | 0.80 |
| CaF ₂ | 2 | 1.56 |

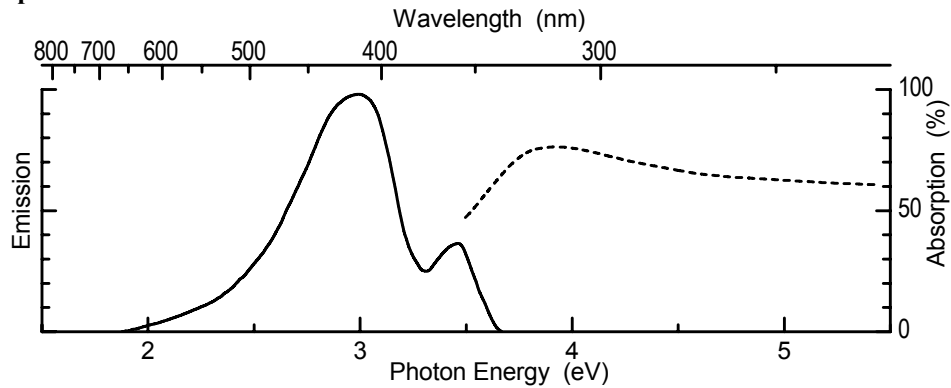
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, CO, 1100°C, 1 hour.

Optical Properties

Emission color: Violet + UV
Emission peak: 3.00 eV, 3.42 eV
Excitation efficiency by UV: + (4.88 eV)
Excitation efficiency by e-beam: +

Spectra



Reference

1. Kröger, F.A., *Some Aspects of the Luminescence of Solids*, Elsevier, Amsterdam (1948).

CaSiO₃:Eu²⁺

Structure: Triclinic (pseudowollastonite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 98 | 98 |
| SiO ₂ | 100 | 60 |
| Eu ₂ O ₃ | 0.1 (of Eu) | 0.176 |
| CaF ₂ | 2 | 1.56 |

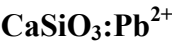
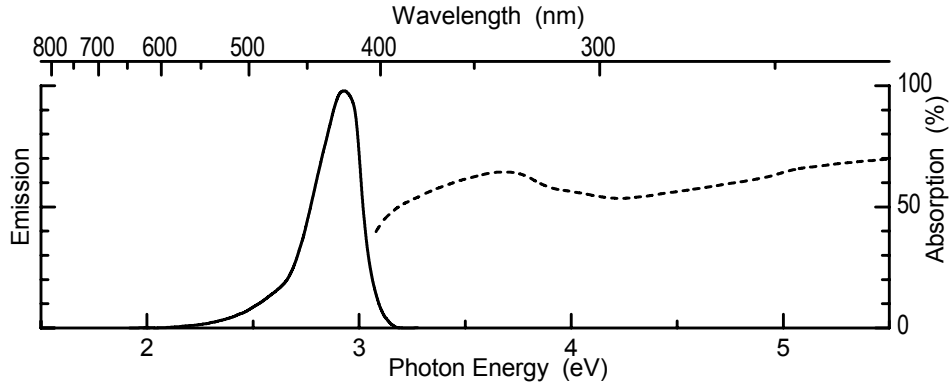
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, CO, 1100°C, 1 hour.

Optical Properties

Emission color: Violet
Emission peak: 2.93 eV
Emission width (FWHM): 0.25 eV
Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Spectra



Structure: Triclinic (pseudowollastonite)

Composition

| <hr/> | | |
|-------------------|-----|------|
| Ingredient | | |
| Mole % | | |
| By weight (g) | | |
| <hr/> | | |
| CaCO ₃ | 97 | 97 |
| SiO ₂ | 100 | 60 |
| PbO | 1 | 2.23 |
| CaF ₂ | 2 | 1.56 |

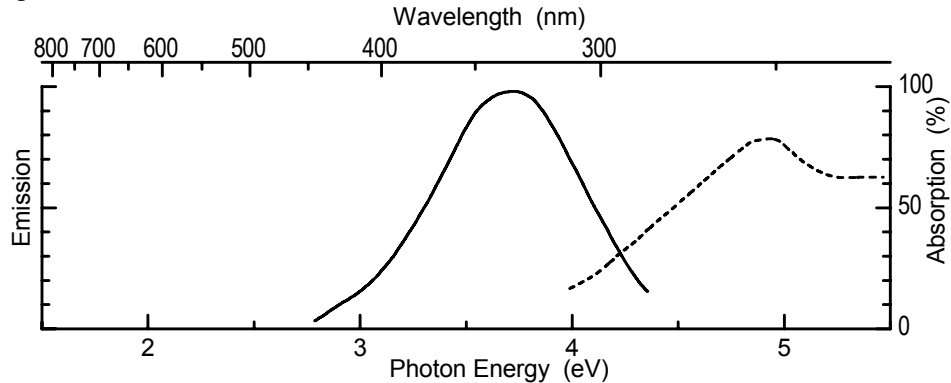
Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, N₂, 1100° C, 1 hour.

Optical Properties

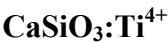
Emission color: UV
Emission peak: 3.70 eV
Emission width (FWHM): 0.87 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

1. Schulman, J.H., Ginther, R.J., and Klick, C.C., A study of the mechanism of sensitized luminescence of solids, *J. Electrochem. Soc.*, 97, 123 (1950).
2. Schulman, J.H., Ginther, R.J., and Claffy, E.W., Note on the properties of calcium silicate phosphors, *J. Opt. Soc. Am.*, 43, 318 (1953).
3. Bril, A., and Hoekstra, W., *Philips Res. Rep.*, 16, 356 (1961).
4. Bril, A., and Hoekstra, W., *Philips Res. Rep.*, 19, 269 (1964).
5. Hüniger, M., and Ruffler, H., *Tech. Wiss. Abh. OSRAM Ges.*, 8, 41 (1963).
6. Mooney, R.W., Optical properties of tin-activated and lead-activated calcium metasilicate phosphors, *J. Electrochem. Soc.*, 106, 955 (1959).
7. Harrison, D.E., and Hoffman, M.V., The calcium silicate Mn + Pb phosphor phase relationships and preparation, *J. Electrochem. Soc.*, 106, 800 (1959).
8. Nagy, R., Wei, C.K.L., and Wollentin, R.W., Calcium zinc silicate phosphor, *J. Electrochem. Soc.*, 99, 137 (1952).
9. Butler, K.H., *Fluorescent Lamp Phosphors*, Pennsylvania University Press, University Park (1980).
10. Lange, H., Die manganbanden und ihre trennung im lumineszenzspektrum von calciumsilikat (Mn,Pb), *Z. Phys.*, 139, 346 (1954).



Structure: Triclinic (pseudowollastonite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 97 | 97 |
| SiO ₂ | 100 | 100 |
| TiO ₂ | 1 | 0.80 |
| CaF ₂ | 2 | 1.56 |

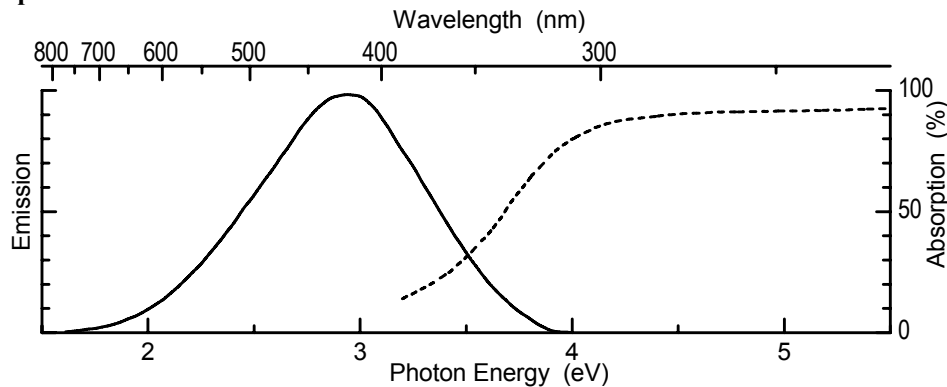
Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, air, 1100°C, 1 hour.

Optical Properties

Emission color: Bluish
Emission peak: 2.93 eV
Emission width (FWHM): 0.92 eV
Excitation efficiency by UV: + (4.88 eV)

Spectra



Structure: Triclinic (pseudowollastonite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 97.5 | 97.5 |
| SiO ₂ | 100 | 60 |
| PbO | 0.5 | 1.12 |
| MnCO ₃ | 2 | 2.3 |
| CaF ₂ | 2 | 1.56 |

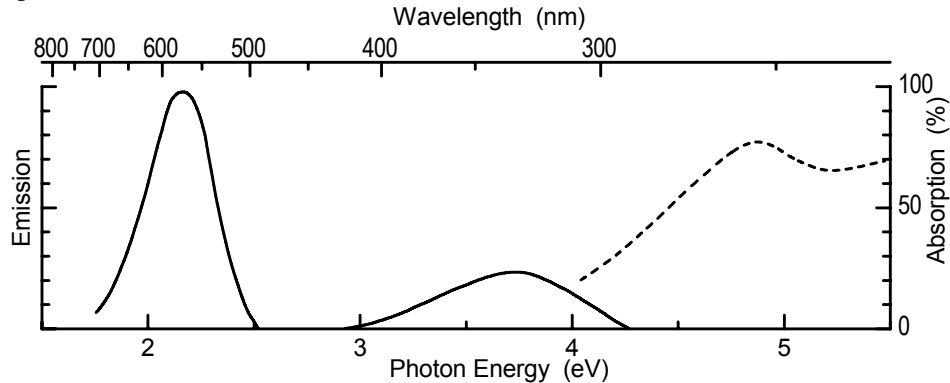
Preparation

- Mix by slurring in methanol plus a few cubic centimeters water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, CO, 1150°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

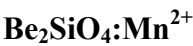
Emission color: Orange
Emission peak: 2.17 eV
Emission width (FWHM): 0.42 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: 60% (estimated)
Decay to 10% : Slightly non exponential (≈ 35 msec) followed by a long but weaker afterglow tail extending into seconds

Spectra



Reference

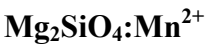
1. Smith, A.L., Some new complex silicate phosphors containing calcium, magnesium, and beryllium, *J. Electrochem. Soc.*, 96, 287 (1949).



Structure: Trigonal (phenakite)

Optical Properties

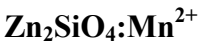
Emission color: Orange-red
Emission peak: 1.97 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +



Structure: Orthorhombic (forsterite)

Optical Properties

Emission color: Red
Emission peak: 1.88 eV
Emission width (FWHM): eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +



Structure: Trigonal (willemite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| ZnO | 194 | 158 |
| SiO ₂ | 110 | 66 |
| MnCO ₃ | 6 | 6.9 |

Preparation

Mix by ball-milling in water about 2 hours.

Dry in air.

Powderize when dry.

1. Fire in open quartz containers, forming gas, 1200°C, 1 hour.
Powderize by dry milling.
2. Fire in open quartz containers, air, 1200°C, 1 hour.

Optical Properties

Emission color: Green

Emission peak: 2.35 eV

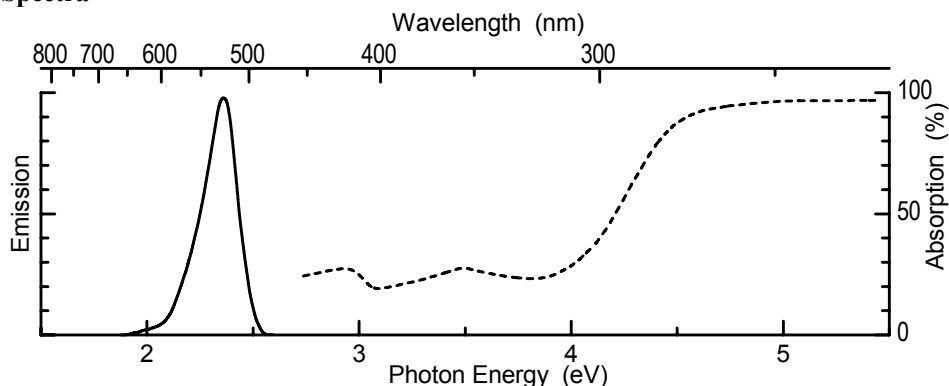
Emission width (FWHM): 0.18 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV); 80–90%

Excitation efficiency by e-beam: 7%/+

Decay: Near exponential with time constant ~10 msec (22–25 msec to 1/10)

Spectra



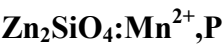
Remarks

1. Very thorough mixing of the ingredients is essential.
2. Up to ~20% of the Zn can be replaced by Mg without visible effect of the Mg on the emission.
3. Parts or all of the Si can be replaced by Ge (but not by Sn).
4. Emission peak moves slightly to longer wavelength with increasing Mn concentration.
5. Efficiency for excitation by UV and by e-beam, and decay after excitation by e-beam pulse, depend on the Mn concentration used.

References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York, and Chapman & Hall, London (1950).
2. Bull, C., and Garlick, G.F., The thermoluminescence characteristics of silicate phosphors activated by manganese and arsenic, *J. Electrochem. Soc.*, 98, 371 (1951).
3. Stevels, A.L.N., and Vink, A.T., *J. Lumin.*, 8, 443, (1974).
4. Segnit, E.R., and Holland, A.E., System MgO-ZnO-SiO₂, *J. Am. Ceram. Soc.*, 48, 409 (1965).
5. Bauer, G.T., Kinetics of X-ray irradiation-caused degradation of photoluminescence of some phosphors, *J. Electrochem. Soc.*, 123, 79 (1976).
6. Palumbo, D.T., and Brown, J.J., Electronic states of Mn²⁺-activated phosphors. 1. Green-emitting phosphors, *J. Electrochem. Soc.*, 117, 1184 (1970).
7. Chang, I.F., and Shafer, M.W., Efficiency enhancement in manganese-doped zinc silicate phosphor with AlPO₄ substitution, *Appl. Phys. Lett.*, 35, 229 (1979).

8. Klick, C.C., and Schulman, J.H., On the luminescence of divalent manganese in solids, *J. Opt. Soc. Am.*, 42, 910 (1952).

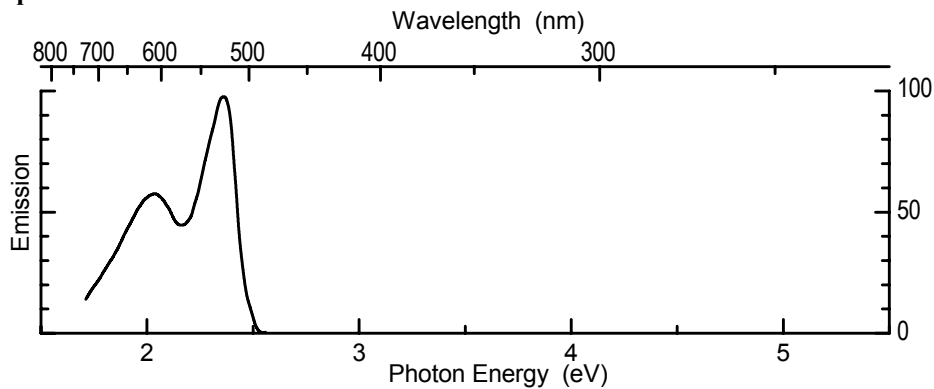


Structure: Trigonal (willemite)

Optical Properties

Emission color: Green, orange
Emission peak: 2.04 and 2.35 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



Structure: Trigonal (willemite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| ZnO | 200 | 163 |
| MnCO ₃ | 0.2 | 0.230 |
| SiO ₂ * | 102 | 62.1 |
| As ₂ O ₃ | 0.02 (of As) | 0.02 |

(* This requires extremely fine SiO₂, commercially available as “Silanox,” “Cab-O-Sil,” etc.)

Preparation

Mix by ball-milling in water about 2 hours.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, air, 1200°C, 1 hour.

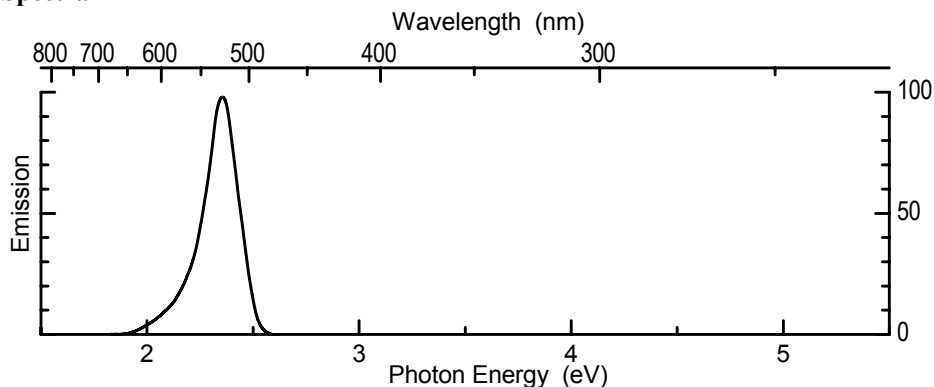
Optical Properties

Emission color: Green
Emission peak: 2.35 eV
Emission width (FWHM): 0.18 eV

Excitation efficiency by e-beam: 3–4%

Decay: Decay consisting of two subsequent branches, first branch near-exponential with time constant (to $1/e$) ≈ 12 msec, later part non-exponential and extending to several seconds or longer

Spectra



Remarks

1. Very thorough mixing of the ingredients is important.
2. Ordinary silicic acid cannot be used for this phosphor (too coarse).
3. The afterglow due to As⁵⁺ appears only when the phosphor has been fired in oxidizing atmosphere.

References

1. Froelich, H.C., and Fonda, G.R., *J. Phys. Chem.*, 46, 878 (1942).
2. Bull, C., and Garlick, G.F., The thermoluminescence characteristics of silicate phosphors activated by manganese and arsenic, *J. Electrochem. Soc.*, 98, 371 (1951).



Structure: Trigonal (willemite)

Optical Properties

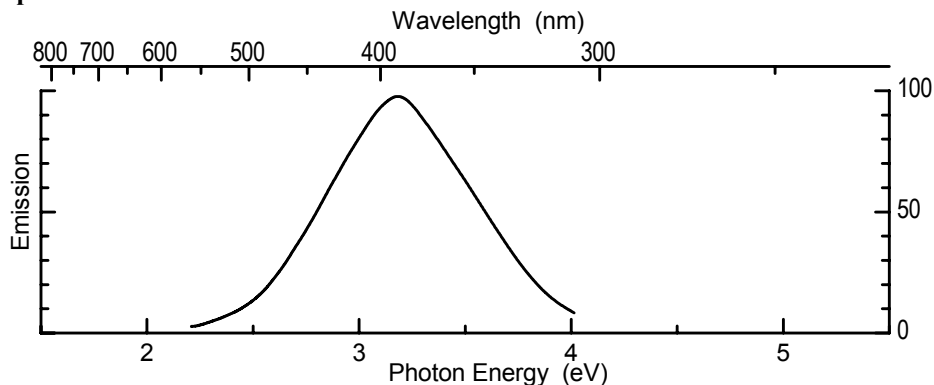
Emission color: Violet

Emission peak: 3.02 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Reference

1. Kröger, F.A., *Some Aspects of the Luminescence of Solids*, Elsevier, Amsterdam (1948), p.168.



Structure: Trigonal (willemite)

Optical Properties

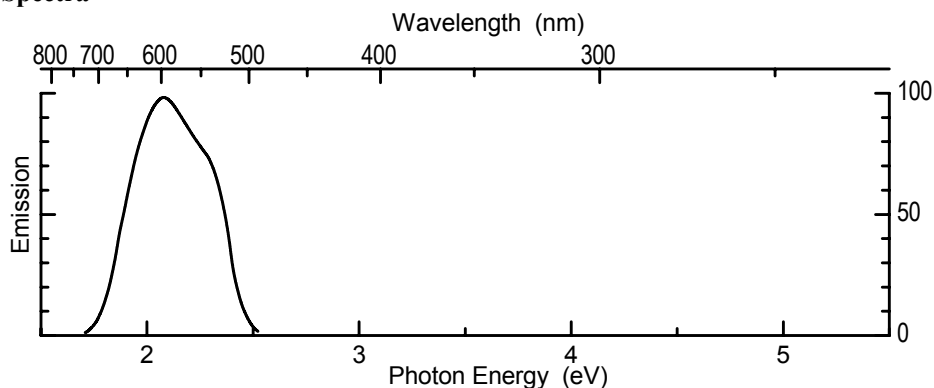
Emission color: Green, orange

Emission peak: 2.04 eV, 2.35 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Reference

1. Butler, K.H., *Fluorescent Lamp Phosphors*, Pennsylvania University Press, University Park (1980), p. 244.



Structure: Orthorhombic

Optical Properties

Emission color: Green-yellow

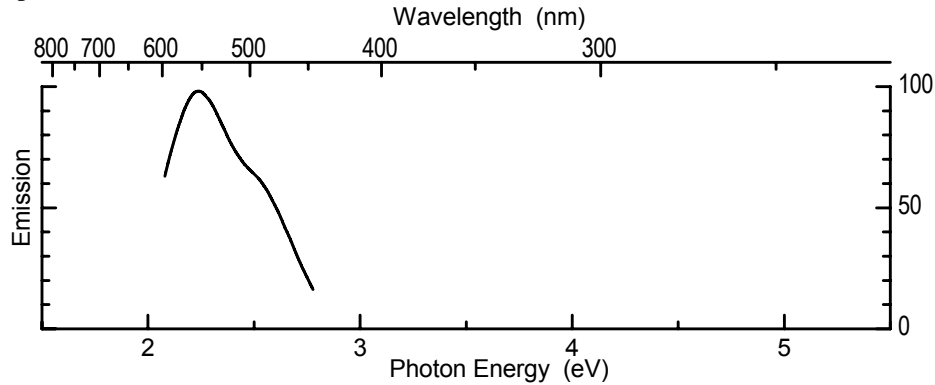
Emission peak: 2.23 eV

Emission width (FWHM): 0.60 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Blasse, G. et al., Fluorescence of Eu²⁺ activated silicates, *Philips Res. Rep.*, 23, 189 (1968).

2. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).

3. Barry, T.L., Equilibria and Eu²⁺ luminescence of subsolidus phases bounded by Ba₃MgSi₂O₈, Sr₃MgSi₂O₈, and Ca₃MgSi₂O₈, *J. Electrochem. Soc.*, 115, 733 (1968).

SrBaSiO₄:Eu²⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| SrCO ₃ | 98 | 145 |
| BaCO ₃ | 100 | 197 |
| SiO ₂ | 105 | 63 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| NH ₄ Cl | 10 | 5.4 |

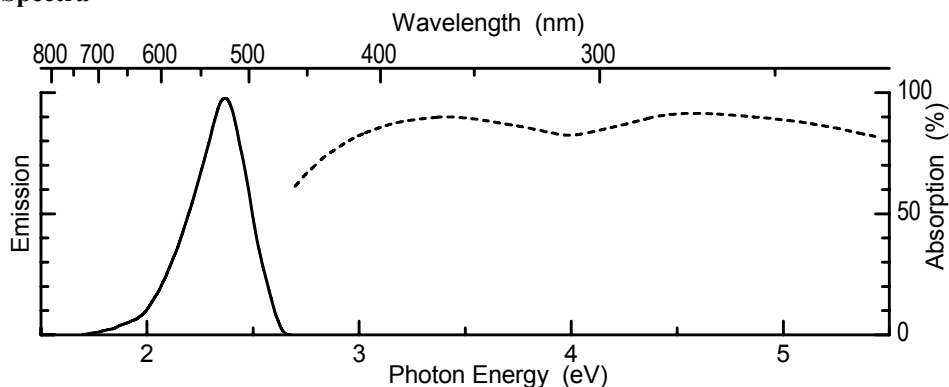
Preparation

- Mix by slurring in water. Then ball-mill in water. Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, CO, 1100°C, 1 hour. Powderize by dry milling. Add another 5.4 g NH₄Cl, mix by dry milling.
 2. Fire in capped quartz tubes, CO, 1100°C, 1 hour. Powderize. Wash in water several times (pH goes to ~10–12). Dry.

Optical Properties

Emission color: Yellow-green
Emission peak: 2.36 eV
Emission width (FWHM): 0.32 eV
Excitation efficiency by UV: ++ (4.88 eV) , + (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



Remark

This phosphor is an intermediate between Sr₂SiO₄:Eu²⁺ (yellow, stable in water) and Ba₂SiO₄:Eu²⁺ (green, unstable) which are miscible in any ratio. The stability of SrBaSiO₄:Eu²⁺ may not be good enough for use in lamps.

References

1. Barry, T.L., Equilibria and Eu²⁺ luminescence of subsolidus phases bounded by Ba₃MgSi₂O₈, Sr₃MgSi₂O₈, and Ca₃MgSi₂O₈, *J. Electrochem. Soc.*, 115, 733 (1968).
2. Barry, T.L., Fluorescence of Eu²⁺-activated phases in binary alkaline earth orthosilicate systems, *J. Electrochem. Soc.*, 115, 1181 (1968).

Ba₂SiO₄:Eu²⁺

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| BaCO ₃ | 198 | 390 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| SiO ₂ | 105 | 63 |
| NH ₄ Cl | 10 | 5.4 |

Preparation

Mix by milling or grinding.

1. Fire in capped quartz tubes, CO, 1100°C, 1 hour.
Powderize by hard milling or grinding. Add another ~5.4 g NH₄Cl, mix well.
2. Fire in capped quartz tubes, CO, 1000°C, 1 hour. Powderize.
Wash in water (to remove leftover halide). Dry in air.
Store in a well-closed container.

Optical Properties

Emission color: Blue-green

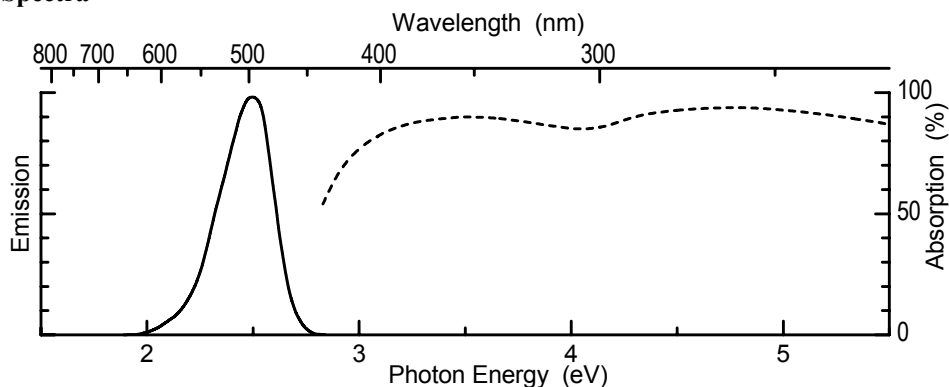
Emission peak: 2.44 eV

Emission width (FWHM): 0.28 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: +

Spectra

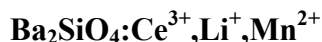


Remarks

1. Material is unstable in water.
2. Part or all of the Ba can be replaced by Sr causing increasing stability against water and shift of the emission towards yellow.

References

1. Blasse, G. et al., Fluorescence of Eu^{2+} activated silicates, *Philips Res. Rep.*, 23, 189 (1968).
2. Barry, T.L, Equilibria and Eu^{2+} luminescence of subsolidus phases bounded by $\text{Ba}_3\text{MgSi}_2\text{O}_8$, $\text{Sr}_3\text{MgSi}_2\text{O}_8$, and $\text{Ca}_3\text{MgSi}_2\text{O}_8$, *J. Electrochem. Soc.*, 115, 733 (1968), and Fluorescence of Eu^{2+} -activated phases in binary alkaline earth orthosilicate systems, *J. Electrochem. Soc.*, 115, 1181 (1968).



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------|------------|---------------|
| BaCO_3 | 75 | 148 |
| SiO_2 | 50 | 30 |
| CeO_2 | 10 | 17 |
| Li_2CO_3 | 20 (of Li) | 7.4 |
| MnCO_3 | 5 | 5.8 |
| NH_4Br | 10 | 10 |

Preparation

First mix by dry ball-milling or grinding only in the BaCO_3 , SiO_2 , and Li_2CO_3 , CeO_2 .

1. Fire in open quartz boats, H_2 , 900°C , 1 hour.
Powderize.
Now admit MnCO_3 and NH_4Br by slurring in methanol.
Dry in air. Powderize when dry.
2. Fire in capped quartz tubes, N_2 , 900°C , 1 hour.
Powderize.
3. Fire in open quartz boats, CO , 900°C , 1 hour.

Optical Properties

Emission color: Orange-red

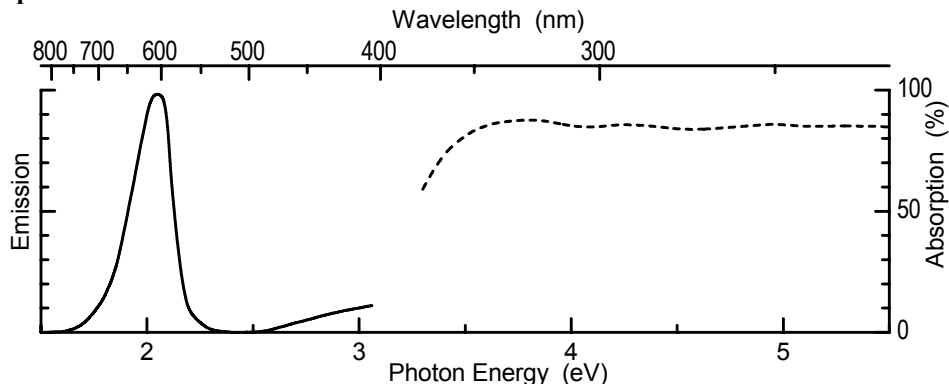
Emission peak: 2.015 eV

Emission width (FWHM): 0.24 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: Very poor

Spectra

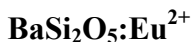


Remarks

1. Phosphor is believed to be a modification of Ba_2SiO_4 (in which Mn^{2+} is non-luminescent) with 25% of Ba replaced by 10% Ce, 10% Li, and 5% Mn.
2. Emission changes color from orange-red at room temperature to yellow at 150°C and whitish at 300°C.
3. Partial replacement of Ba by Sr shifts the emission into somewhat deeper red, improves temperature stability of the emission, and improves chemical stability of the material. Such phosphor has been known as "triple silicate" in England.

References

1. McKeag, A.H., and Steward, E.C., The luminescent properties and crystal structure of some new phosphor systems, *Br. J. Appl. Phys.*, 4, 26 (1955).
2. McKeag, A.H., Temperature characteristics of barium strontium lithium silicate phosphors, *J. Electrochem. Soc.*, 105, 78 (1958).



Structure: Orthorhombic

Optical Properties

Emission color: Blue-green

Emission peak: 2.46 eV

Emission width (FWHM): 0.50 eV

Excitation efficiency by UV: ++ (4.88 eV)

Excitation efficiency by e-beam: +

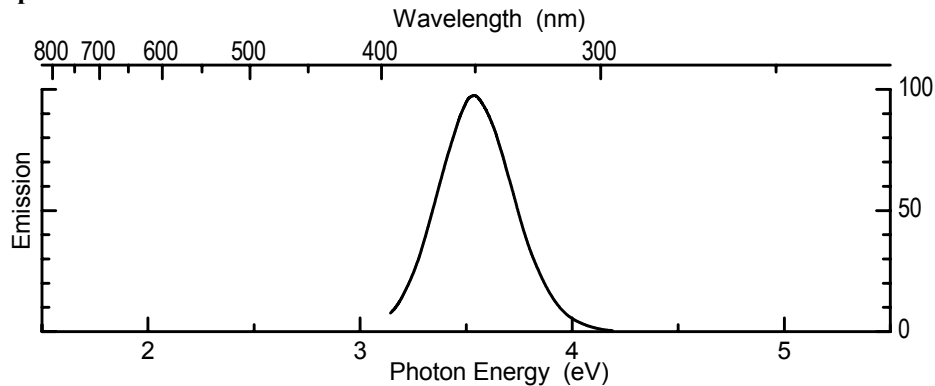


Structure: Orthorhombic

Optical Properties

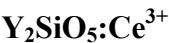
Emission color: UV
Emission peak: 3.54 eV
Emission width (FWHM): 0.39 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Ropp., R.C., Phosphors based on rare earth phosphates fast decay phosphors, *J. Electrochem. Soc.*, 115, 531 (1968).
2. Butler, K.H., *Fluorescent Lamp Phosphors*, Pennsylvania University Press, University Park (1980), p. 169.



Optical Properties

Emission color: Violet
Emission peak: 2.99 eV
Emission width (FWHM): eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: +



Structure: Monoclinic (diopside)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaO | 118 | 66 |
| MgO | 100 | 40 |
| SiO ₂ | 210 | 126 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| NH ₄ Cl | 40 | 21.4 |

Preparation

Mix by slurring in methanol plus a few cubic centimeters water.
Dry in air. Powderize when dry.

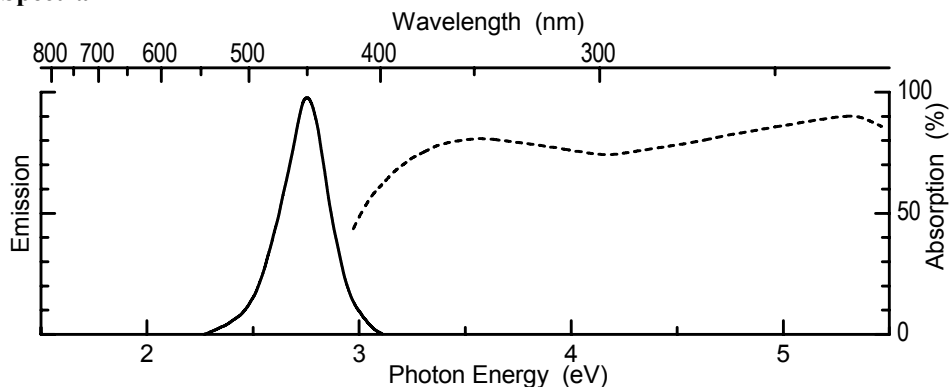
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.

- Powderize.
- Fire in capped quartz tubes, CO, 1150°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Blue
 Emission peak: 2.77 eV
 Emission width (FWHM): 0.25 eV
 Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV); 60% (estimated)

Spectra



Reference

- Smith, A.L., Some new complex silicate phosphors containing calcium, magnesium, and beryllium, *J. Electrochem. Soc.*, 96, 287 (1949).



Structure: Monoclinic (diopside)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaO | 114 | 64 |
| MgO | 100 | 40 |
| SiO ₂ | 210 | 126 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| MnCO ₃ | 4 | 4.6 |
| NH ₄ Cl | 40 | 21.4 |

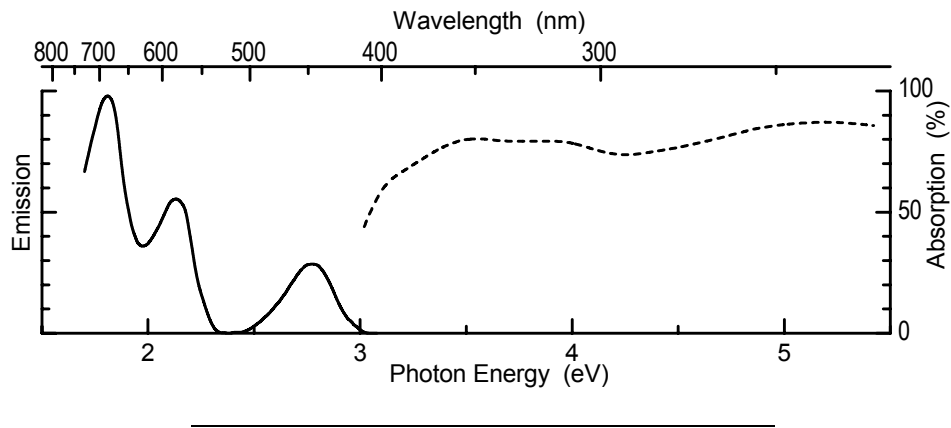
Preparation

- First mix by slurring in methanol plus a few cubic centimeters water.
 Dry in air. Powderize when dry.
- Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
 - Fire in capped quartz tubes, CO, 1150°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Reddish-purple.
Emission peak: 1.80 eV, 2.12 eV, 2.77 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV); ≈ 60% (estimated)

Spectra



Structure: Tetragonal (ackermanite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaO | 200 | 112 |
| MgO | 100 | 40 |
| SiO ₂ | 210 | 126 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| NH ₄ Cl | 40 | 21.4 |

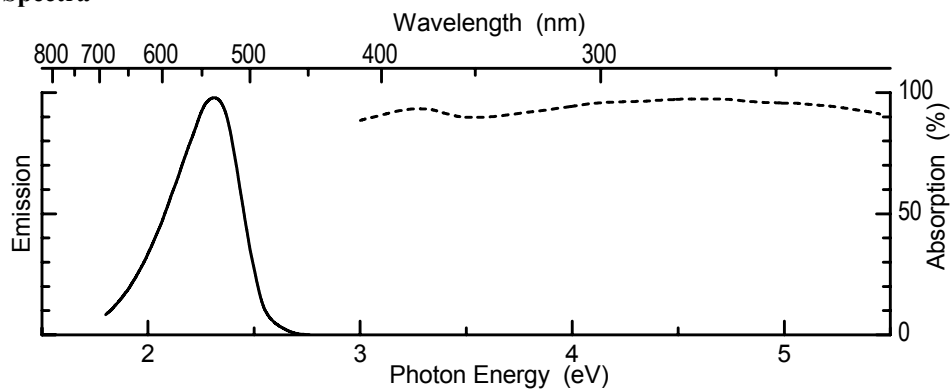
Preparation

First mix by slurring in methanol plus a few cubic centimeters water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour. Powderize.
2. Fire in capped quartz tubes, CO, 1150°C, 1 hour.

Optical Properties

Emission color: Yellow-green
Emission peak: 2.29 eV
Emission width (FWHM): 0.37 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV); ≈ 25%

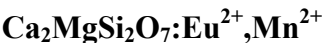
Spectra



Structure: Tetragonal (ackermanite)

Optical Properties

Emission color: UV
Emission peak: 3.17 eV
Excitation efficiency by e-beam: +



Structure: Tetragonal (ackermanite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaO | 205 | 115 |
| MgO | 100 | 40 |
| SiO ₂ | 210 | 126 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| MnCO ₃ | 8 | 9.2 |
| NH ₄ Cl | 10 | 5.4 |

Preparation

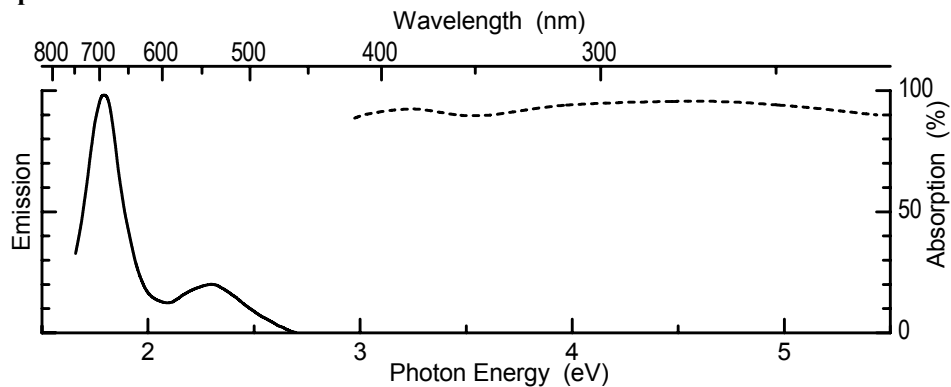
First mix by slurring in methanol plus a few cubic centimeters water.
Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
2. Fire in capped quartz tubes, CO, 1150°C, 1 hour.

Optical Properties

Emission color: Deep red plus weaker yellow-green
Emission peak: 1.80 eV, 2.29 eV
Emission width (FWHM): 0.21 eV
Excitation efficiency by UV: Excited by all UV plus visible blue

Spectra



References

1. Blasse, G., Wanmaker, W.L., and terVrugt, J.W., Some new classes of efficient Eu²⁺ activated phosphors, *J. Electrochem. Soc.*, 115, 673 (1968).
2. Blasse, G. et al., Fluorescence of Eu²⁺-activated silicates, *Philips Res. Rep.*, 23, 189 (1968).



Structure: Tetragonal (ackermanite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| SrCO ₂ | 187 | 276 |
| SrF ₂ | 10 | 12.6 |
| MgO | 100 | 40.3 |
| SiO ₂ | 210 | 126 |
| Eu ₂ O ₃ | 3 (of Eu) | 5.3 |

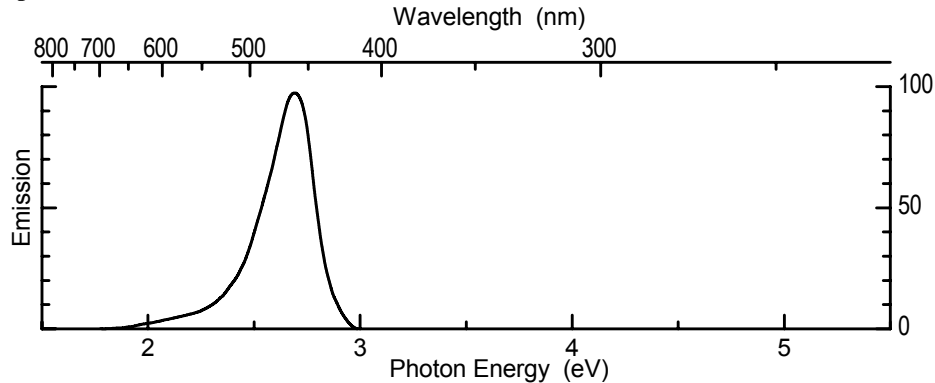
Preparation

- Mix by ball-milling in methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, CO, 1150°C, 1 hour.

Optical Properties

Emission color: Blue
Emission peak: 2.68 eV
Emission width (FWHM): 0.27 eV
Excitation efficiency by UV: + (4.88 eV)
Excitation efficiency by e-beam: +

Spectra



Reference

1. Blasse, G. et al., Fluorescence of Eu²⁺-activated silicates, *Philips Res. Rep.*, 23, 189, (1968).



Structure: Tetragonal (melinite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| BaCO ₃ | 187 | 369 |
| BaF ₂ | 10 | 17.5 |
| MgO | 100 | 40.3 |
| SiO ₂ | 210 | 126 |
| Eu ₂ O ₃ | 3 (of Eu) | 5.3 |

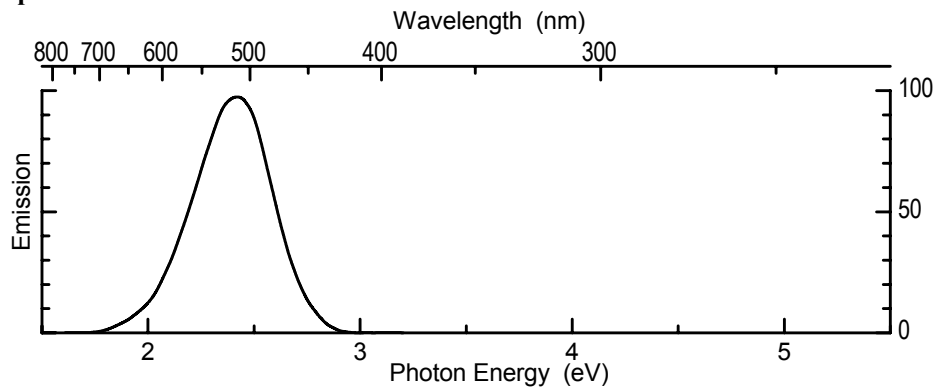
Preparation

- Mix by ball-milling in methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, CO, 1100°C, 1 hour.

Optical Properties

Emission color: Blue-green
Emission peak: 2.42 eV
Emission width (FWHM): 0.41 eV
Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

1. Blasse, G., Wanmaker, W.L., and terVrugt, J.W., Some new classes of efficient Eu²⁺ activated phosphors, *J. Electrochem. Soc.*, 115, 673 (1968).
2. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).



Structure: Tetragonal (melinite)

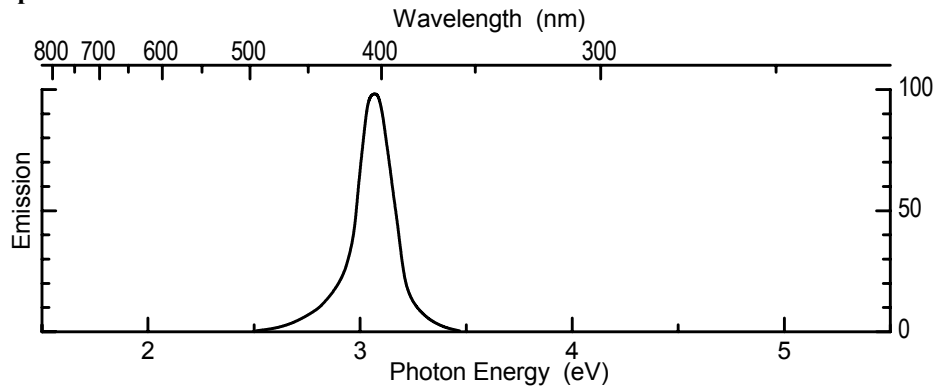
Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| BaCO ₃ | 187 | 369 |
| BaF ₂ | 10 | 17.5 |
| MgO | 100 | 40.3 |
| SiO ₂ | 210 | 126 |
| Eu ₂ O ₃ | 3 (of Eu) | 5.3 |

Optical Properties

Emission color: Violet + UV
Emission peak: 3.10 eV
Emission width (FWHM): 0.19 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Spectra



Reference

1. Barry, T.J., Luminescent properties of Eu^{2+} and $\text{Eu}^{2+} + \text{Mn}^{2+}$ activated $\text{BaMg}_2\text{Si}_2\text{O}_7$, *J. Electrochem. Soc.*, 117, 381 (1970).

BaSrMgSi₂O₇:Eu²⁺

Structure: Ackermanite

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| BaCO ₃ | 90 | 177.6 |
| SrCO ₃ | 97 | 143.2 |
| BaF ₂ | 10 | 17.5 |
| MgO | 100 | 40.3 |
| SiO ₂ | 210 | 126 |
| Eu ₂ O ₃ | 3 (of Eu) | 5.3 |

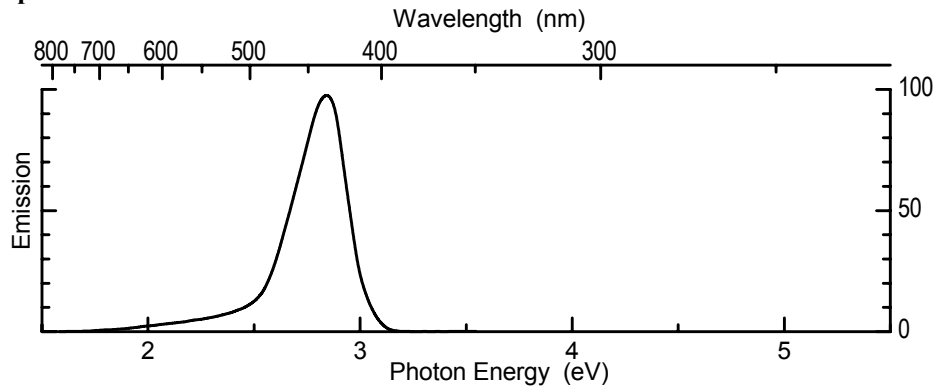
Preparation

- Mix by ball-milling in methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, CO, 1100°C, 1 hour.

Optical Properties

Emission color: Blue
Emission peak: 2.82 eV
Emission width (FWHM): 0.27 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

1. Blasse, G., Wanmaker, W.L., and terVrugt, J.W., Some new classes of efficient Eu^{2+} activated phosphors, *J. Electrochem. Soc.*, 115, 673 (1968).
2. Butler, K.H., *Fluorescent Lamp Phosphors*, Pennsylvania University Press, University Park, (1980).
3. Blasse, G. et al., Fluorescence of Eu^{2+} -activated silicates, *Philips Res. Rep.*, 23, 189 (1968).

Ba₂Li₂Si₂O₇:Eu²⁺

Composition

| Ingredient | Mole % | By weight (g) |
|---------------------------------|-------------|---------------|
| BaCO ₃ | 97 | 191 |
| Li ₂ CO ₃ | 110 (of Li) | 41 |
| SiO ₂ | 110 | 66 |
| Eu ₂ O ₃ | 3 (of Eu) | 5.3 |
| NH ₄ Br | 50 | 49 |

Preparation

First mix all ingredients but the NH₄Br by dry grinding or milling .

1. Fire in open quartz boats, H₂, 850°C, 1 hour.
Now admit the NH₄Br by slurring in methanol plus a few cubic centimeters water.
Dry in air. Powderize when dry.
2. Fire in capped quartz tubes, N₂, 850°C, 1 hour.
Powderize.
3. Fire in open quartz boats, CO, 850°C, 16 hours (overnight).
Powderize.
Store in a well-closed container.

Optical Properties

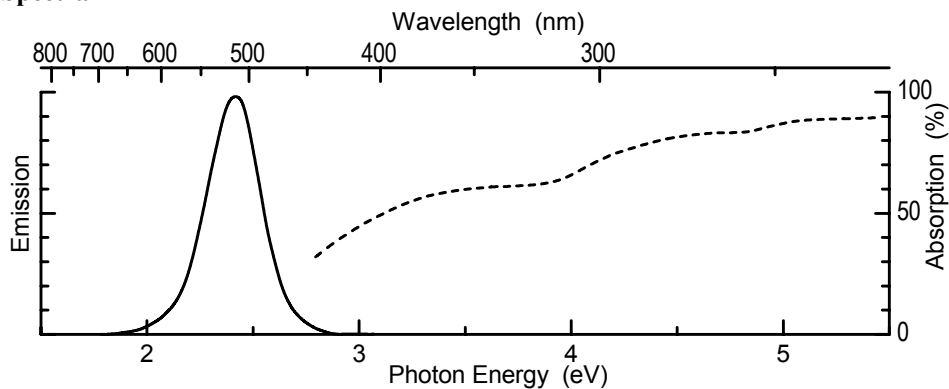
Emission color: Blue-green

Emission peak: 2.44 eV

Emission width (FWHM): 0.30 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV); excited by all UV

Spectra



Remarks

1. Phosphor is chemically unstable in water and deteriorates in moist air.
2. Gradual replacement of Ba by Sr causes rapid decrease of efficiency without visible change of color.

$\text{Ba}_2\text{Li}_2\text{Si}_2\text{O}_7:\text{Sn}^{2+}$

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------|-------------|---------------|
| BaCO_3 | 95 | 187 |
| Li_2CO_3 | 110 (of Li) | 41 |
| SiO_2 | 110 | 66 |
| SnO | 5 | 6.8 |
| NH_4Br | 50 | 49 |

Preparation

First mix by dry grinding or milling the $\text{BaCO}_3 + \text{Li}_2\text{CO}_3 + \text{SiO}_2$.

1. Fire in open boats, H_2 , 850°C , 1 hour.

Now admit the $\text{SnO} + \text{NH}_4\text{Br}$.

Make slurry in methanol and stir to uniformity.

Dry in air. Powderize when dry.

2. Fire in capped quartz tubes, N_2 , 850°C , 1 hour.

Powderize.

3. Fire in open quartz boats, CO , 850°C , ~16 hours (overnight).

Powderize.

Store in a well-closed container.

Optical Properties

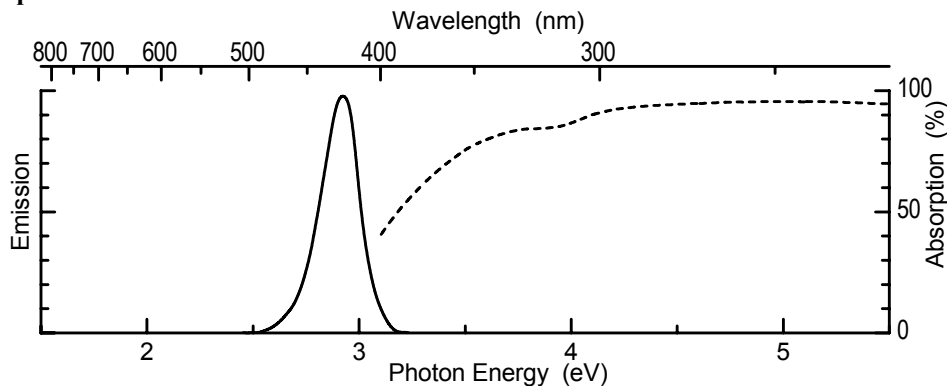
Emission color: Violet

Emission peak: 2.89 eV

Emission width (FWHM): 0.22 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV); QE fairly high

Spectra



Remarks

1. Phosphor is chemically unstable in water and deteriorates even in moist air.
2. Part or all of the Ba can be replaced by Sr, causing a shift of the emission towards blue-green.
3. The Sn^{2+} emission sensitizes Mn^{2+} (see: $\text{Ba}_2\text{Li}_2\text{Si}_2\text{O}_7:\text{Sn}^{2+},\text{Mn}^{2+}$).

Ba₂Li₂Si₂O₇:Sn²⁺,Mn²⁺

Composition

| Ingredient | Mole % | By weight (g) |
|---------------------------------|-------------|---------------|
| BaCO ₃ | 93.5 | 185 |
| Li ₂ CO ₃ | 110 (of Li) | 41 |
| SiO ₂ | 110 | 66 |
| SnO | 5 | 6.8 |
| MnCO ₃ | 1.5 | 1.7 |
| NH ₄ Br | 50 | 49 |

Preparation

First mix by dry grinding or milling the BaCO₃ + Li₂CO₃ + SiO₂.

1. Fire in open boats, H₂, 850°C, 1 hour.
Now admit the SnO + MnCO₃ + NH₄Br.
Make a slurry in methanol and stir to uniformity.
Dry in air. Powderize.
2. Fire in capped quartz tubes, N₂, 850°C, 1 hour.
Powderize.
3. Fire in open quartz boats, CO, 850°C, ~16 hours (overnight).
Powderize.
Store in a well-closed container.

Optical Properties

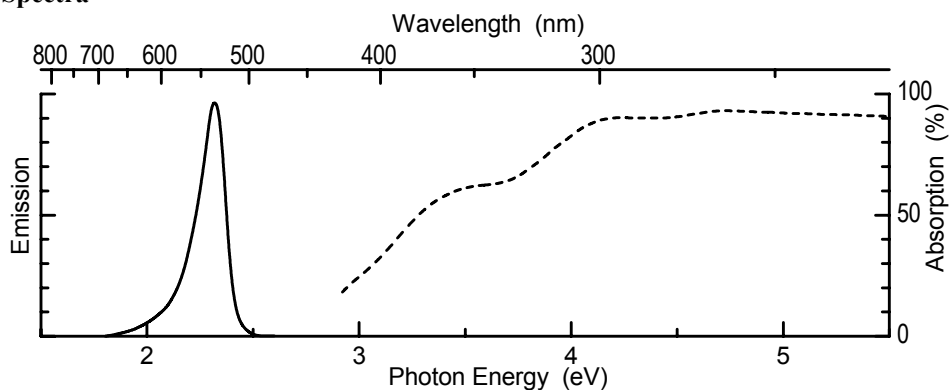
Emission color: Green

Emission peak: 2.32 eV

Emission width (FWHM): 0.16 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV); QE ≈ 60–70%
(estimated)

Spectra



Remarks

1. Phosphor is chemically unstable in water and deteriorates even in moist air.
2. Increasing replacement of Ba by Sr causes gradual shift of the emission towards red, broadening and slight deformation of the emission band, and decreasing efficiency.

MgSrBaSi₂O₇:Eu²⁺

Structure: Ackermanite

Optical Properties

Emission color: Blue

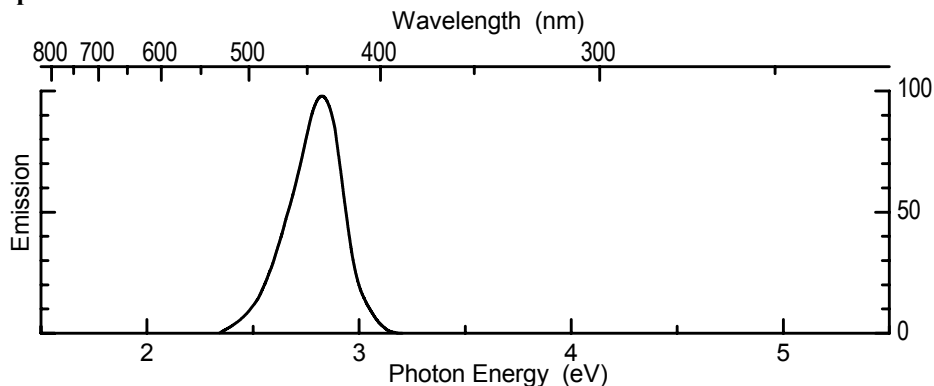
Emission peak: 2.82 eV

Emission width (FWHM): 0.27 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



MgBa₃Si₂O₈:Eu²⁺

Optical Properties

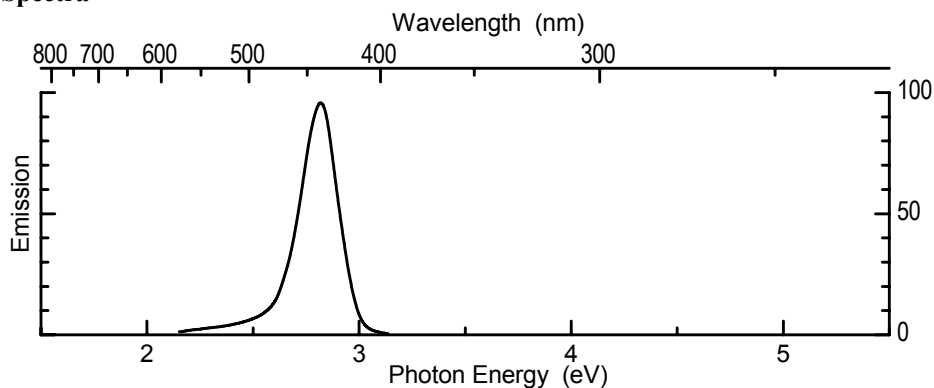
Emission color: Blue

Emission peak: 2.82 eV

Emission width (FWHM): 0.22 eV

Excitation efficiency by UV: ++ (4.88 eV)

Spectra



References

1. Barry, T.L., Equilibria and Eu²⁺ luminescence of subsolidus phases bounded by Ba₃MgSi₂O₈, Sr₃MgSi₂O₈, and Ca₃MgSi₂O₈, *J. Electrochem. Soc.*, 115, 733 (1968) and Fluorescence of Eu²⁺-activated phases in binary alkaline earth orthosilicate systems, *J. Electrochem. Soc.*, 115, 1181 (1968).
2. Blasse, G. et al., Fluorescence of Eu²⁺ activated silicates, *Philips Res. Rep.*, 23, 189 (1968).

MgSr₃Si₂O₈:Eu²⁺,Mn²⁺

Optical Properties

Emission color: Deep red
Emission peak: 1.82 eV
Excitation efficiency by UV: ++ (4.88 eV)

Sr₃MgSi₂O₈:Eu²⁺

Structure: Ackermanite

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| SrCO ₃ | 295 | 435 |
| MgO | 100 | 40 |
| SiO ₂ | 206 | 124 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| NH ₄ Cl | 30 | 16 |

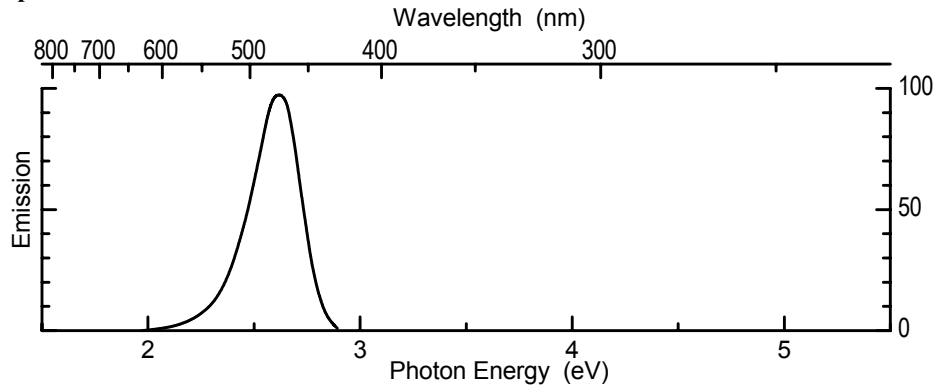
Preparation

- Mix by ball-milling in methanol about 1 hour.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize
 2. Fire in capped quartz tubes, CO, 1100°C, 1 hour.

Optical Properties

Emission color: Blue
Emission peak: 2.70 eV
Emission width (FWHM): 0.23 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV); QE ≈ 45%
Excitation efficiency by e-beam: η ≈ 3%
Decay: 0.2 μsec to 1/e

Spectra



References

1. Blasse, G. et al., Fluorescence of Eu²⁺-activated silicates, *Philips Res. Rep.*, 23, 189 (1968).
2. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).

$\text{Ca}_5\text{B}_2\text{SiO}_{10}:\text{Eu}^{3+}$

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-----------|---------------|
| CaCO_3 | 100 | 100 |
| H_3BO_3 | 50 | 31 |
| SiO_2 | 22 | 13.2 |
| Eu_2O_3 | 5 (of Eu) | 8.8 |

Preparation

Mix by dry milling or grinding.

1. Fire in open quartz boats, air, 1100°C, 1 hour.
Powderize by milling.
2. Fire in open quartz boats, air, 1200°C, 1 hour.
Powderize.
3. Fire in open quartz boats, air, 1300°C, 1 hour.

Optical Properties

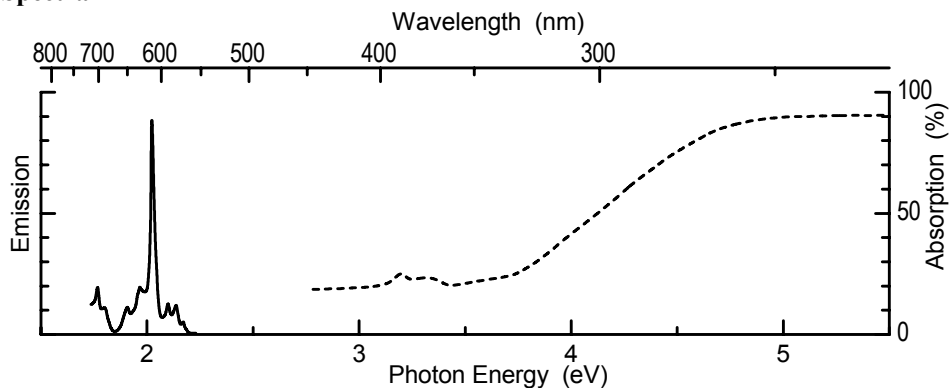
Emission color: Red

Emission peak: 2.03 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV); QE \approx 50–60%

Excitation efficiency by e-beam: Poor

Spectra



Remark

The chemical stability of this material is somewhat better than that of $\text{CaO}:\text{Eu}^{3+}$.

$\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}:\text{Eu}^{2+}$

Optical Properties

Emission color: Pale bluish-green

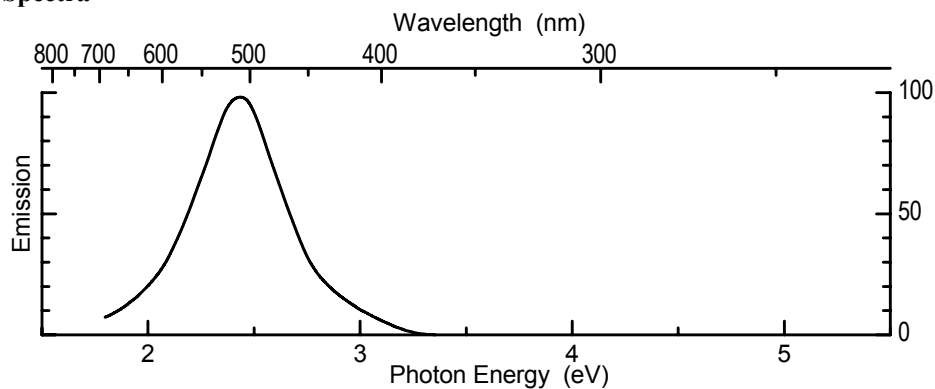
Emission peak: 2.41 eV

Emission width (FWHM): 0.47 eV

Excitation efficiency by UV: Excited by all UV but low QE (\approx 20%)

Excitation efficiency by e-beam: Very poor, $\eta \approx$ 0.5%

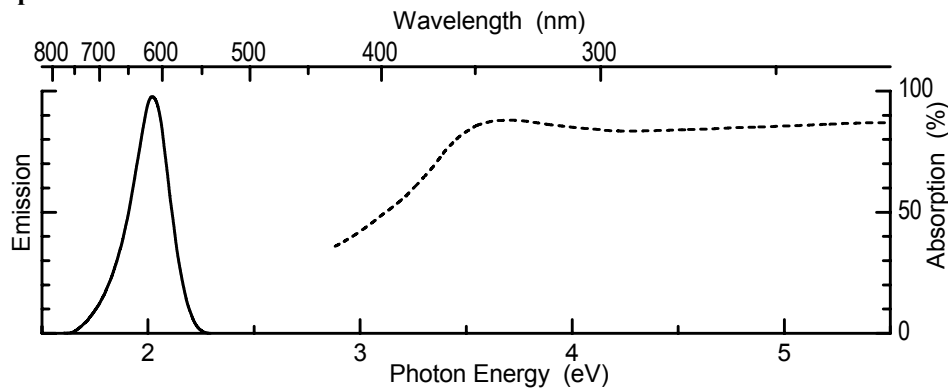
Spectra



Optical Properties

Emission color: orange-red
Emission peak: ~2.02 eV
Emission width (FWHM): 0.24 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

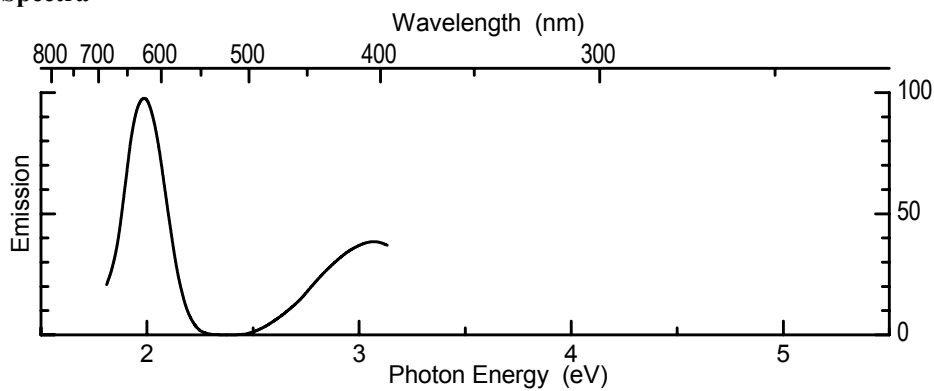
Spectra



Optical Properties

Emission color: Red
Emission peak: 1.99 eV
Emission width (FWHM): 0.23 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



4.4 Halosilicates

The following host compounds and activators are included in this subsection:

LaSiO₃Cl:Ce³⁺
LaSiO₃Cl:Ce³⁺,Tb³⁺
Ca₃SiO₄Cl₂:Pb²⁺
Ca₃SiO₄Cl₂:Eu²⁺
Ba₅SiO₄Cl₆:Eu²⁺
Sr₅Si₄O₁₀Cl₆:Eu²⁺

LaSiO₃Cl:Ce³⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 100 (of La) | 163 |
| SiO ₂ | 160 | 96 |
| CeO ₂ | 20 | 34 |
| NH ₄ Cl | 120 | 64 |

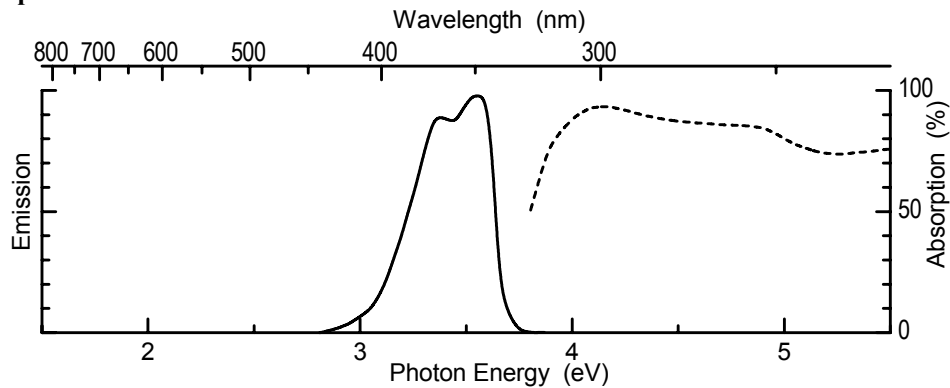
Preparation

- Mix by slurring in water (NH₃ develops).
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 500°C, 1 hour. Powderize.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour. Powderize.
 3. Fire in open quartz boats, CO, 1200°C, 1 hour. Powderize.
Wash in water several times.
Dry in air.

Optical Properties

Emission color: UV
Emission peak: 3.35 and 3.56 eV
Excitation efficiency by UV: ++ (4.88 eV); QE ≈ 90%
Excitation efficiency by e-beam: η ≈ 5%

Spectra



Remarks

- 1. F or Br can replace the Cl in the above recipe, but Cl seems to perform best.
- 2. Replacement of La by Y is possible but gives somewhat poorer phosphors.

Reference

- 1. Lehmann, W., and Isaaks, T.H.J., Lanthanum and yttrium halo-silicate phosphors, *J. Electrochem. Soc.*, 125, 445 (1978).



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 100 (of La) | 163 |
| SiO ₂ | 180 | 108 |
| CeO ₂ | 20 | 34 |
| Tb ₄ O ₇ | 14 (of Tb) | 26 |
| NH ₄ Cl | 130 | 60 |

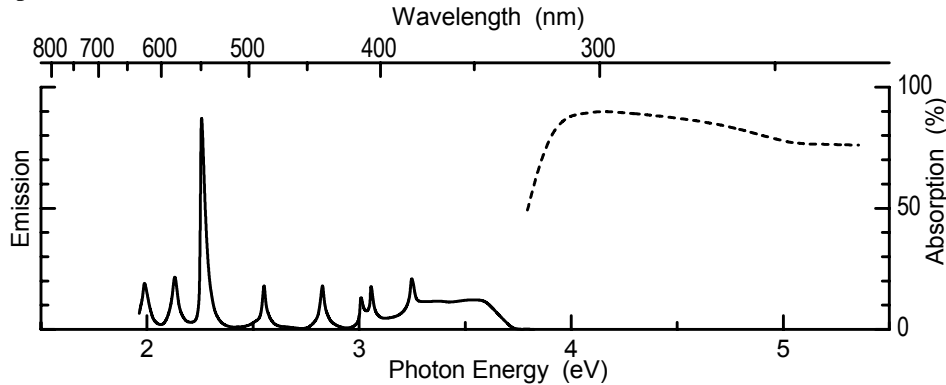
Preparation

- Mix by slurring in water (NH₃ develops).
Dry in air. Powderize when dry.
- 1. Fire in capped quartz tubes, N₂, ~500°C, ~1 hour. Powderize.
 - 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour. Powderize.
 - 3. Fire in open quartz boats, CO, 1200°C, 1 hour. Powderize.
- Wash in water several times.
Dry in air.

Optical Properties

- Emission color: Pale yellow-green
Emission peak: 2.29 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV); QE ≈ 80–90%
Excitation efficiency by e-beam: +/-4%

Spectra



Remarks

1. The Cl in the above recipe can be replaced by F or Br but Cl seems to perform best.
2. Replacement of La by Y is possible but gives somewhat poorer phosphors.

Reference

1. Lehmann, W., and Isaaks, T.H.J., Lanthanum and yttrium halo-silicate phosphors, *J. Electrochem. Soc.*, 125, 445 (1978).



Optical Properties

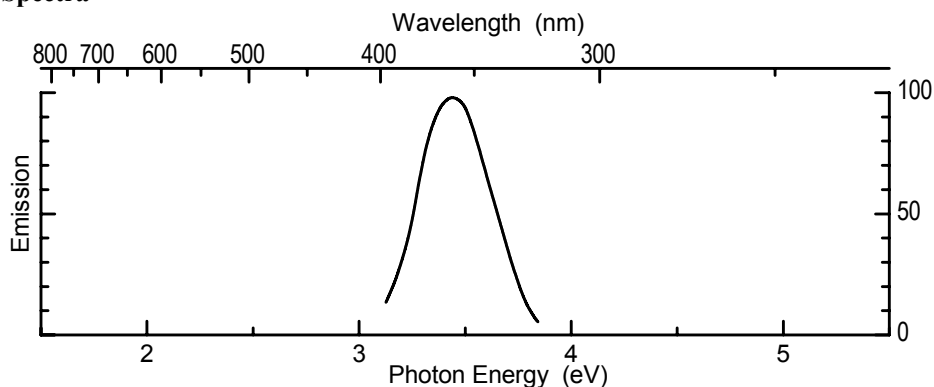
Emission color: UV

Emission peak: 3.44 eV

Emission width (FWHM): 0.39 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Wanmaker, W.L., and Verriet, J.G., Luminescence of phosphors with $\text{Ca}_3\text{SiO}_4\text{Cl}$, *Philips Res. Rep.*, 28, 80 (1973).



Optical Properties

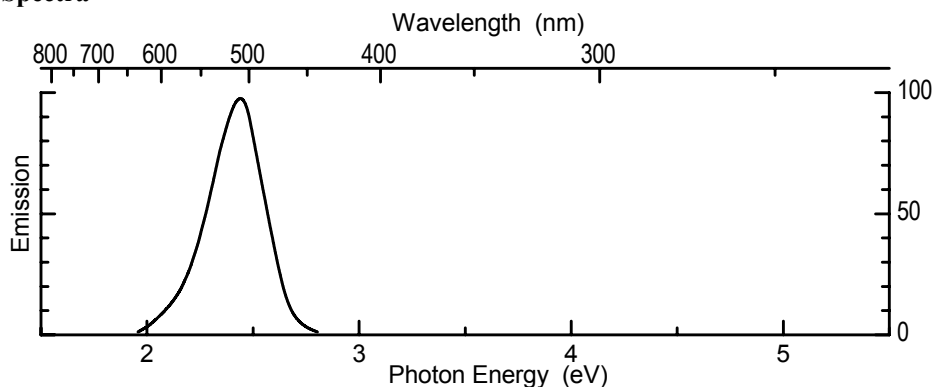
Emission color: Blue-green

Emission peak: 2.41 eV

Emission width (FWHM): 0.31 eV

Excitation efficiency by UV: + (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Wanmaker, W.L., and Verriet, J.G., Luminescence of phosphors with Ca₃SiO₄Cl, *Philips Res. Rep.*, 28, 80 (1973).



Optical Properties

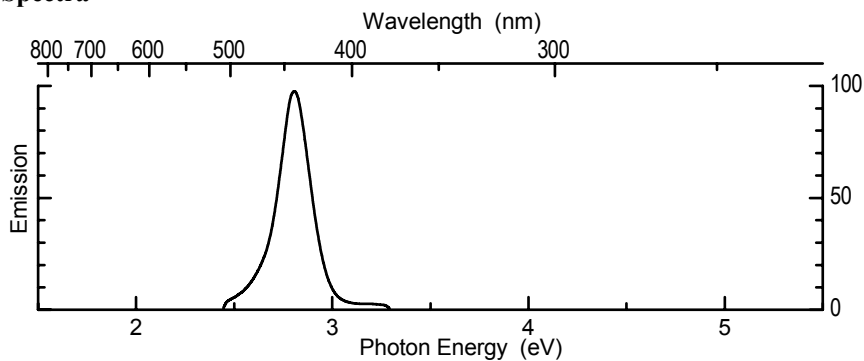
Emission color: blue

Emission peak: 2.82 eV

Emission width (FWHM): 0.19 eV

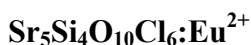
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Garcia, A, Latourette, B, and Fouassier, C., Ba₅SiO₄Cl₆:Eu, a new blue-emitting photo-luminescent material with high quenching temperature, *J. Electrochem. Soc.*, 126, 1734 (1979).



Optical Properties

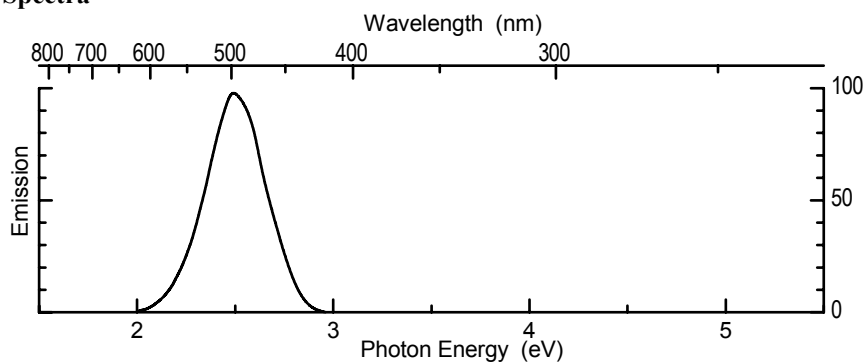
Emission color: Blue-green

Emission peak: 2.52 eV

Emission width (FWHM): 0.38 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



References

1. Burrus, H.L., Nicholson, K.P., and Rooksby, H.P., Fluorescence of Eu^{2+} -activated alkaline earth halosilicates, *J. Lumin.*, 3, 467 (1971).

4.5 Phosphates

The following host compounds and activators are included in this subsection:

YPO₄:Ce³⁺
YPO₄:Ce³⁺, Tb³⁺
YPO₄:Eu³⁺
YPO₄:Mn²⁺, Th⁴⁺
YPO₄:V⁵⁺
LaPO₄:Ce³⁺
LaPO₄:Eu³⁺
CaP₂O₆:Mn²⁺
Sr₂P₂O₇:Sn²⁺
Ca₂P₂O₇:Ce³⁺
Ca₂P₂O₇:Eu²⁺, Mn²⁺
Ca₂P₂O₇:Eu²⁺
Li₂CaP₂O₇:Ce³⁺, Mn²⁺
MgCaP₂O₇:Mn²⁺
BaTiP₂O₇
MgSrP₂O₇:Eu²⁺
MgBaP₂O₇:Eu²⁺
MgBaP₂O₇:Eu²⁺, Mn²⁺
β-Ca₃(PO₄)₂:Ce³⁺
CaB₂P₂O₉:Eu²⁺
α-Ca₃(PO₄)₂:Sn²⁺
β-Ca₃(PO₄)₂:Sn²⁺
α-Ca₃(PO₄)₂:Pb²⁺
α-Ca₃(PO₄)₂:Tl⁺
α-Ca₃(PO₄)₂:Ce³⁺
α-Ca₃(PO₄)₂:Eu²⁺
β-Ca₃(PO₄)₂:Eu²⁺
β-Ca₃(PO₄)₂:Eu²⁺, Mn²⁺
β-Sr₃(PO₄)₂:Sn²⁺, Mn²⁺(Al)
β-Sr₃(PO₄)₂:Sn²⁺
β-Sr₃(PO₄)₂:Eu²⁺
Ba₃(PO₄)₂:Eu²⁺
Na₃Ce(PO₄)₂:Tb³⁺
β-(Ca,Sr)₃(PO₄)₂:Sn²⁺, Mn²⁺
ZnMg₂(PO₄)₂:Mn²⁺
Zn₃(PO₄)₂:Mn²⁺
(Zn,Mg)₃(PO₄)₂:Mn²⁺
Mg₃Ca₃(PO₄)₄:Eu²⁺
MgSr₅(PO₄)₄:Sn²⁺
MgBa₂(PO₄)₂:Sn²⁺
CaSr₂(PO₄)₂:Bi³⁺
MgBa₂(PO₄)₂:U
Sr₂P₂O₇:Eu²⁺

YPO₄:Ce³⁺

Structure: Tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|--|------------|---------------|
| Y ₂ O ₃ | 97 (of Y) | 110 |
| Eu ₂ O ₃ | 3 (of Eu) | 5.2 |
| H ₃ PO ₄ solution, 85% | 105 (of P) | 64 ccm |

Preparation

Make a thin slurry of Y₂O₃ and Eu₂O₃ in methanol. Slowly add the H₃PO₄ solution while stirring. Dry in air. Powderize when dry.

1. Fire in open quartz boats, N₂, ~500–600°C, ~1 hour. Powderize. Add ~5 g of NH₄Cl; mix by dry grinding.
2. Fire in capped quartz tubes, N₂, ~1300°C, ~2 hours. Powderize.
3. Fire in open quartz boats, CO, 1300°C, ~1 hour.

Optical Properties

Emission color: UV

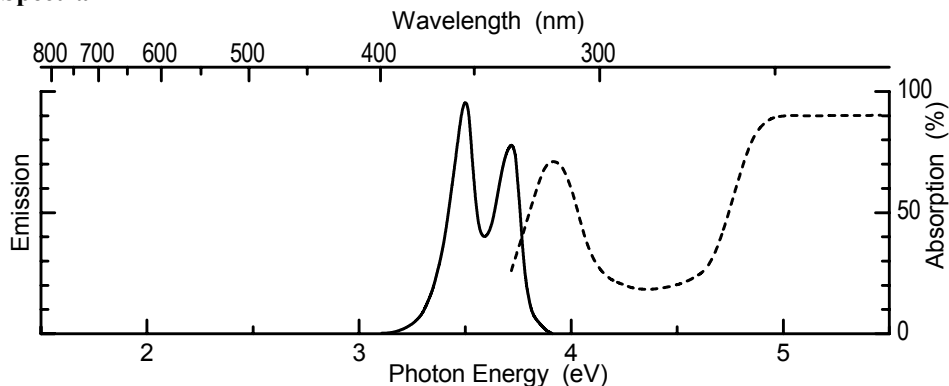
Emission peak: 3.49 and 3.71 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: 2–3%

Decay: Near exponential decay, ~80 nsec to 1/10

Spectra



References

1. Blasse, G., and Bril, A., The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).
2. Hoffman, M.V., Effect of thorium on Ce⁺³ phosphors, *J. Electrochem. Soc.*, 118, 1508 (1971).
3. Blasse, G., Ultraviolet-absorption bands of Bi³⁺ and Eu³⁺ in oxides, *J. Solid State Chem.*, 4, 52 (1972).
4. Bimburg, D., Robbins, D.R., Wright, D.R., and Jeser, J.P., CeP₅O₁₄, a new ultrafast scintillator, *Appl. Phys. Lett.*, 27, 67 (1975).
5. Mandel, G., Bauman, R.P., and Banks, E., Electronic transitions of rare earth ions in the infrared region, *J. Chem. Phys.*, 33, 192 (1960).

$\text{YPO}_4:\text{Ce}^{3+},\text{Tb}^{3+}$

Structure: Tetragonal

Optical Properties

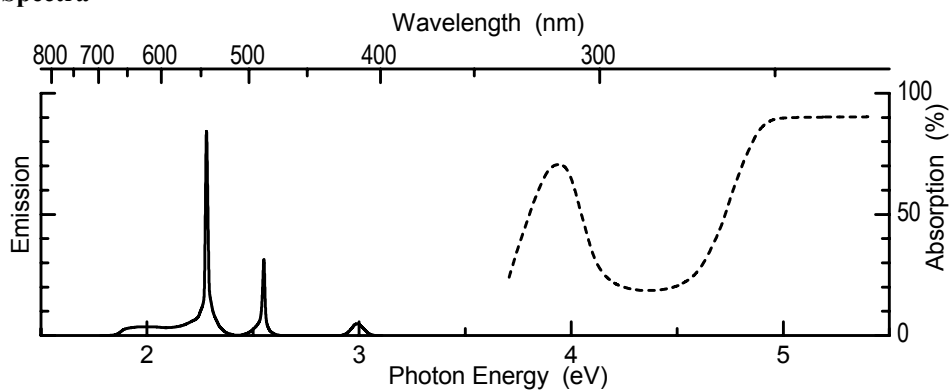
Emission color: Green

Emission peak: 2.28 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



$\text{YPO}_4:\text{Eu}^{3+}$

Structure: Tetragonal

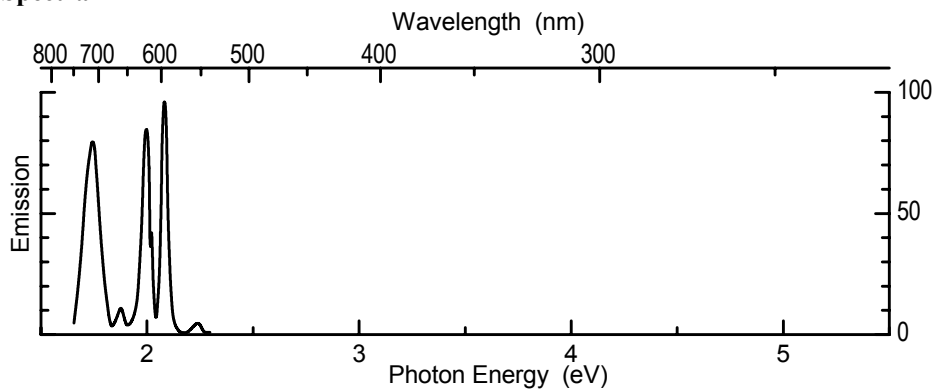
Optical Properties

Emission color: Orange-red

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Reference

1. Ropp, R.C., Phosphors based on rare earth phosphates. 1. Spectral properties of some rare earth phosphates, *J. Electrochem. Soc.*, 115, 841 (1968).

YPO₄:Mn²⁺,Th⁴⁺

Structure: Tetragonal

Optical Properties

Emission color: Blue-green

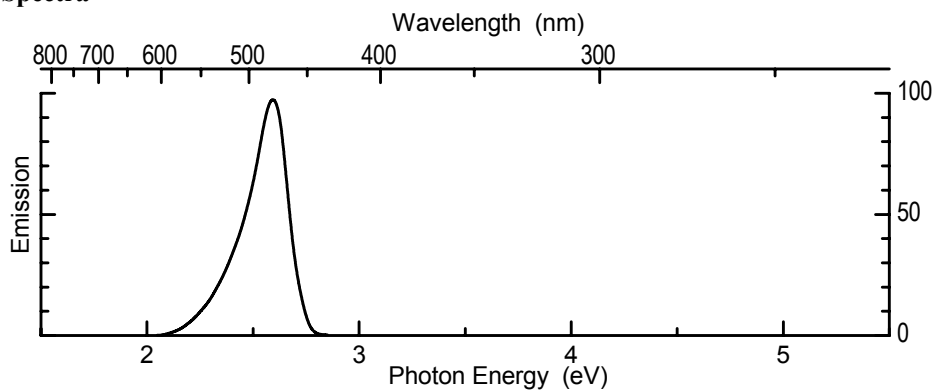
Emission peak: 2.59 eV

Emission width (FWHM): 0.23 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



YPO₄:V⁵⁺

Structure: Tetragonal

Optical Properties

Emission color: Blue

Emission peak: 2.99 eV

Emission width (FWHM): 0.56 eV

Excitation efficiency by UV: + (4.88 eV)

LaPO₄:Ce³⁺

Structure: Monoclinic (monazite)

Composition

| Ingredient | Mole % | By weight (g) |
|--|------------|---------------|
| La ₂ O ₃ | 98 (of La) | 160 |
| CeO ₂ | 2 | 3.44 |
| NH ₄ Cl | 10 | 5.4 |
| H ₃ PO ₄ solution, 85% | 105 (of P) | 64 ccm |

Preparation

Make a slurry of La₂O₃, CeO₂, and NH₄Cl in methanol.

Slowly add the H₃PO₄ solution while stirring.

Dry in air. Powderize when dry.

- 1 Fire in open quartz boats, N₂, 1250°C, 2 hours.
Powderize.
- 2 Fire in open quartz boats, CO, 1250°C, 1 hour.

Optical Properties

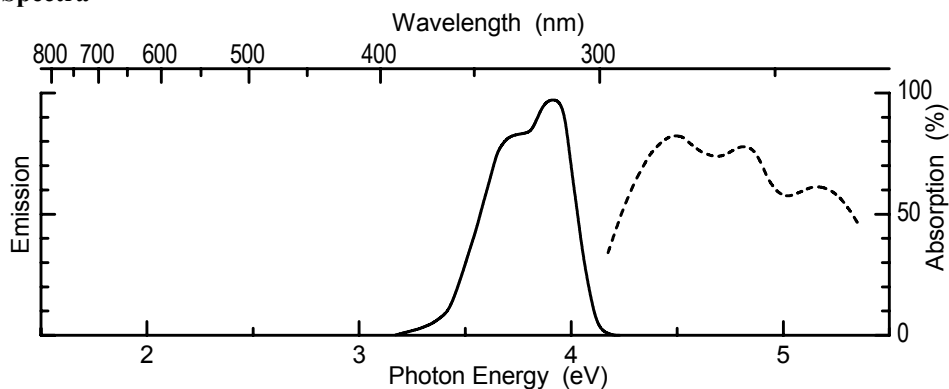
Emission color: UV

Emission peak: 3.67 and 3.94 eV

Excitation efficiency by UV: ++ (4.88eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Reference

1. Mandel, G., Bauman, R.P., and Banks, E., Electronic transitions of rare earth ions in the infrared region, *J. Chem. Phys.*, 33, 192 (1970).



Structure: Monoclinic (monazite)

Composition

| Ingredient | Mole % | By weight (g) |
|--|------------|---------------|
| La ₂ O ₃ | 95 (of La) | 155 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| NH ₄ Cl | 10 | 5.4 |
| H ₃ PO ₄ solution, 85% | 105 (of P) | 64 ccm |

Preparation

Make a slurry of La₂O₃, Eu₂O₃, and NH₄Cl in methanol.

Slowly add the H₃PO₄ solution while stirring.

Dry in air. Powderize when dry.

1. Fire in open quartz boats, N₂, 1250°C, 2 hours.
Powderize.
2. Fire in open quartz boats, air, 1250°C, 1 hour.

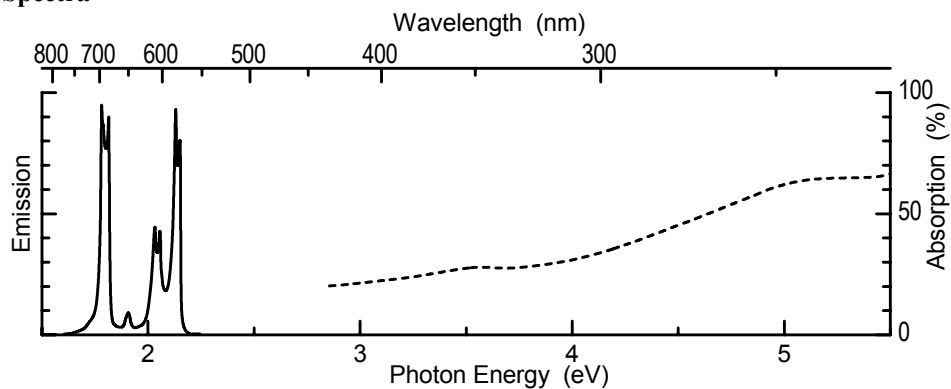
Optical Properties

Emission color: Orange-red

Emission peak: Strongest lines are at 1.784, 1.815, 2.097, and 2.117 eV

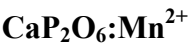
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



Reference

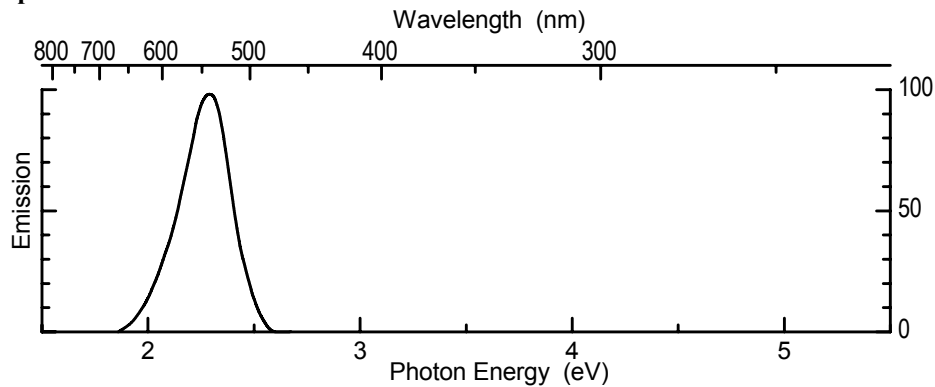
1. Wanmaker, W.L. et al., Luminescent properties of Eu-activated phosphors of type A_3BVO_4 , *Philips Tech. Rev.*, 21, 270 (1966).



Optical Properties

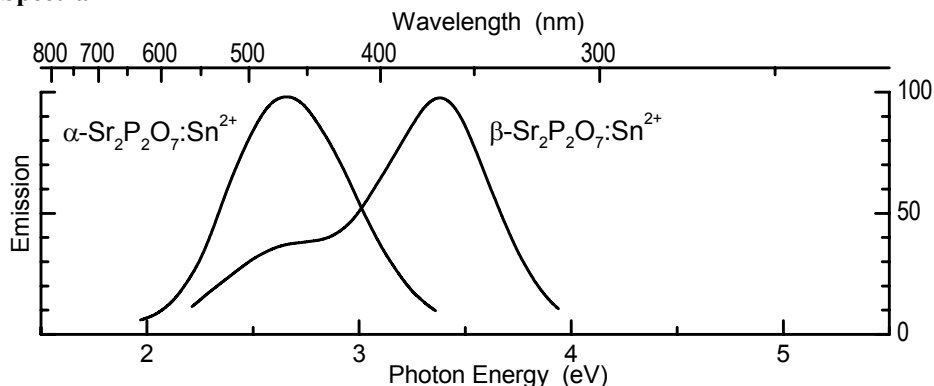
Emission color: Green
Emission peak: 2.30 eV
Emission width (FWHM): 0.29 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



$\text{Sr}_2\text{P}_2\text{O}_7:\text{Sn}^{2+}$

Spectra



Reference

1. Ropp., R.C., and Mooney, R.W., Tin-activated alkaline-earth pyrophosphate phosphors, *J. Electrochem. Soc.*, 107, 15 (1960).

$\text{Ca}_2\text{P}_2\text{O}_7:\text{Ce}^{3+}$

Structure: Tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|--|----------|---------------|
| CaHPO_4 | 96 | 130 |
| CeO_2 | 2 | 3.4 |
| NaHCO_3 | 2 | 1.7 |
| H_3PO_4 -solution, 85% | 6 (of P) | 4.1 ccm |

Preparation

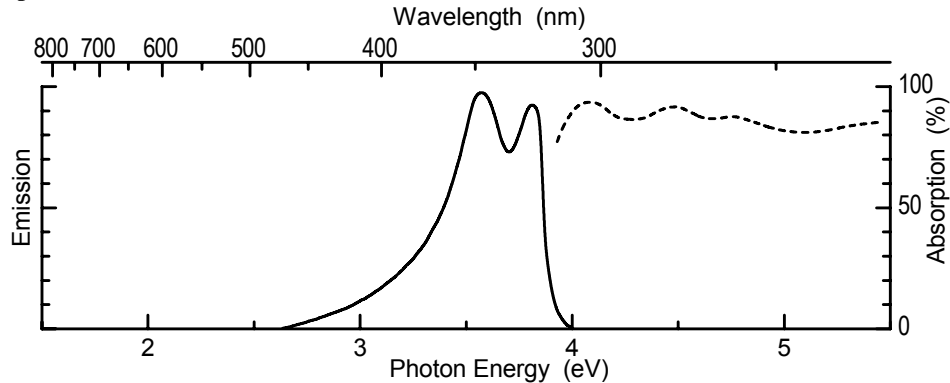
Make a slurry of CaHPO_4 , CeO_2 , and NaHCO_3 in water or methanol.
Add the H_3PO_4 solution while stirring; stir to uniformity.
Dry in air. Powderize when dry.

1. Fire in open quartz boats, N_2 , $\sim 500\text{--}600^\circ\text{C}$, $\sim 1/2$ hour.
Powderize.
2. Fire in open quartz boats, CO , 1200°C , 1 hour.

Optical Properties

Emission color: Pale bluish (most of the emission in the UV)
Emission peaks: 3.60 and 3.83 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Ranby, P.W., Mash, D.H., and Henderson, S.T., The investigation of new phosphors, with particular reference to the pyrophosphates, *Br. J. Appl. Phys., Suppl.* 4, 18 (1955).



Structure: Tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|--|-----------|---------------|
| CaHPO ₄ | 93 | 126 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| MnCO ₃ | 5 | 5.75 |
| H ₃ PO ₄ solution, 85% | 9 (of P) | 6.1 ccm |

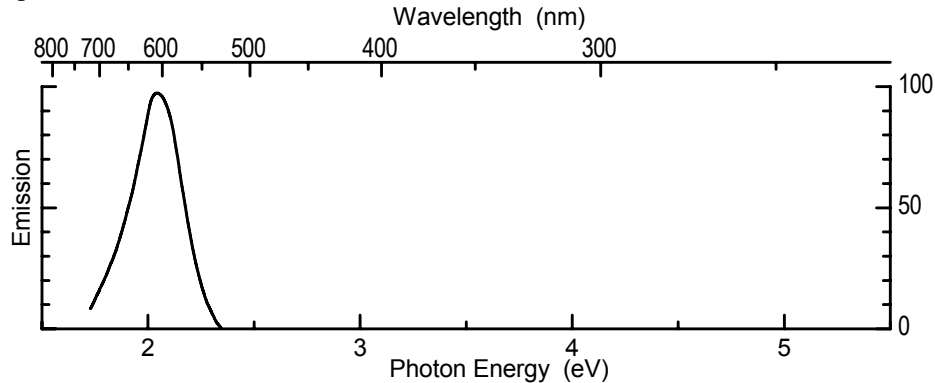
Preparation

- Make a slurry of CaHPO₄, Eu₂O₃ , and MnCO₃ in water or methanol.
Add the H₃PO₄ solution while stirring; stir to uniformity.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, N₂, ~500–600°C, ~1 hour.
Powderize.
 2. Fire in open quartz boats, CO, 1200°C, 1 hour.

Optical Properties

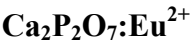
Emission color: Pink-orange
Emission peak: Orange Mn²⁺ band at ~2.06 eV; Violet Eu²⁺ band at ~2.98 eV
Emission width (FWHM): 0.28 eV (Mn²⁺ band)
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



References

1. Kröger, F.A. et al., *J. Electrochem. Soc.*, 96, 132 (1949).
2. Kinney, D.E., Modified calcium pyrophosphate phosphors, *J. Electrochem. Soc.*, 102, 676 (1955).
3. Ranby, P.W., Mash, D.H., and Henderson, S.T., The investigation of new phosphors, with particular reference to the pyrophosphates, *Br. J. Appl. Phys.*, S18, Suppl. 4 (1955).
4. Ropp, R.C., Manganese-activated cadmium pyrophosphate phosphors, *J. Electrochem. Soc.*, 109, 569 (1962).



Structure: Tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|--|-----------|---------------|
| CaHPO ₄ | 98 | 133 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| H ₃ PO ₄ solution, 85% | 4 (of P) | 2.7 ccm |

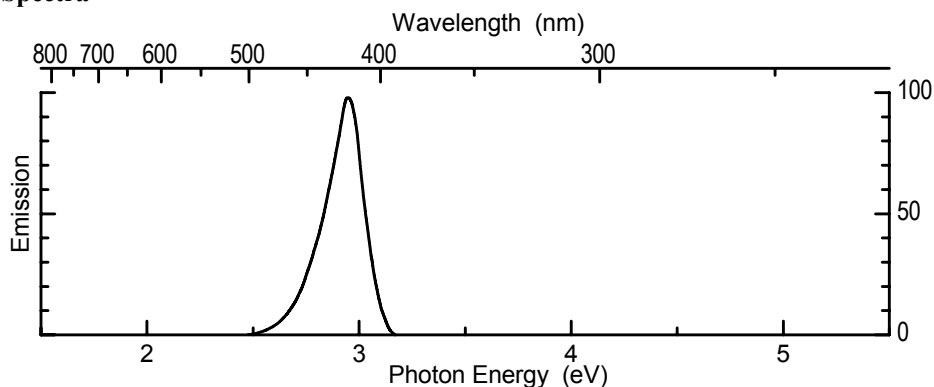
Preparation

- Make a slurry of CaHPO₄ + Eu₂O₃ in water or methanol.
Add the H₃PO₄ solution while stirring; stir to uniformity.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, N₂, ~500–600°C, ~1 hour.
Powderize.
 2. Fire in open quartz boats, CO, 1200°C, 1 hour.

Optical Properties

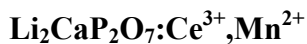
Emission color: Violet
Emission peak: 2.96 eV
Emission width (FWHM): 0.19 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



References

1. Kröger, F.A. et al., *J. Electrochem. Soc.*, 96, 132 (1949).
2. Kinney, D.E., Modified calcium pyrophosphate phosphors, *J. Electrochem. Soc.*, 102, 676 (1955).
3. Ranby, P.W., Mash, D.H., and Henderson, S.T., The investigation of new phosphors, with particular reference to the pyrophosphates, *Br. J. Appl. Phys.*, S18, Suppl. 4 (1955).
4. Ropp, R.C., Manganese-activated cadmium pyrophosphate phosphors, *J. Electrochem. Soc.*, 109, 569 (1962).



Composition

| Ingredient | Mole % | By weight (g) |
|--|-------------|---------------|
| Li ₂ CO ₃ | 205 (of Li) | 75.7 |
| CaHPO ₄ | 89 | 121 |
| CeO ₂ | 3 | 5.2 |
| MnCO ₃ | 5 | 5.75 |
| H ₃ PO ₄ solution, 85% | 115 (of P) | 70 ccm |

Preparation

Make a slurry of Li₂CO₃ + CaHPO₄ + CeO₂ + MnCO₃ in methanol.

Add the H₃PO₄ solution while stirring (CO₂ develops).

Dry in air. Powderize when dry.

1. Fire in open quartz boats, N₂, ~500–600°C.
Powderize.
2. Fire in open quartz boats, N₂, 700°C, 16 hours (overnight).

Optical Properties

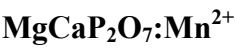
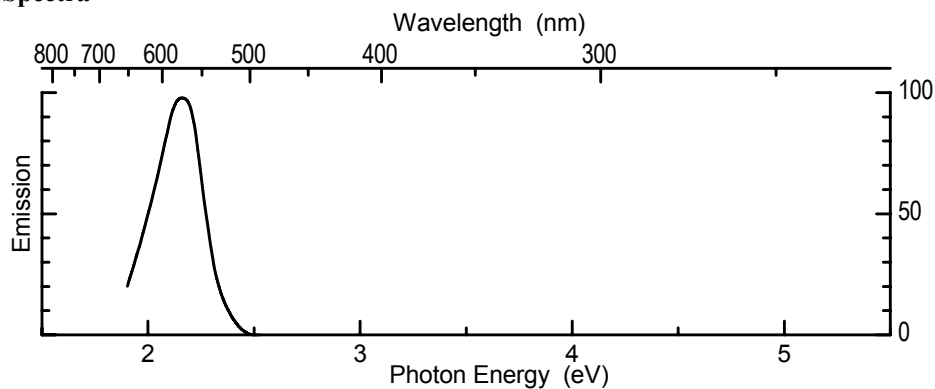
Emission color: Greenish-yellow

Emission peak: 2.16 eV

Emission width (FWHM): 0.28 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra

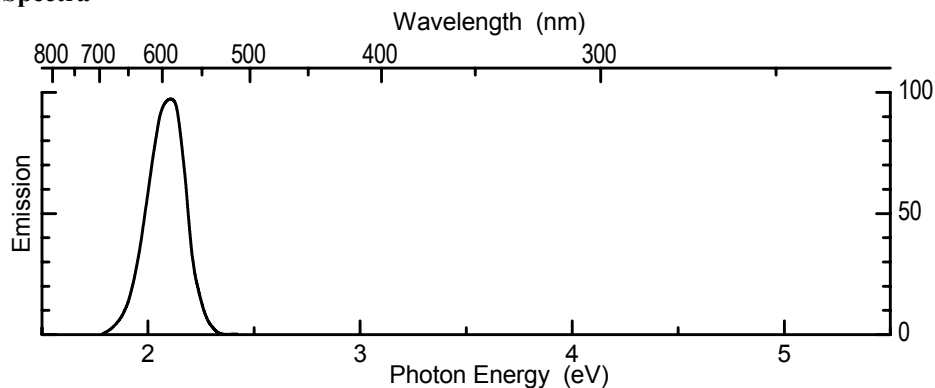


Structure: Monoclinic

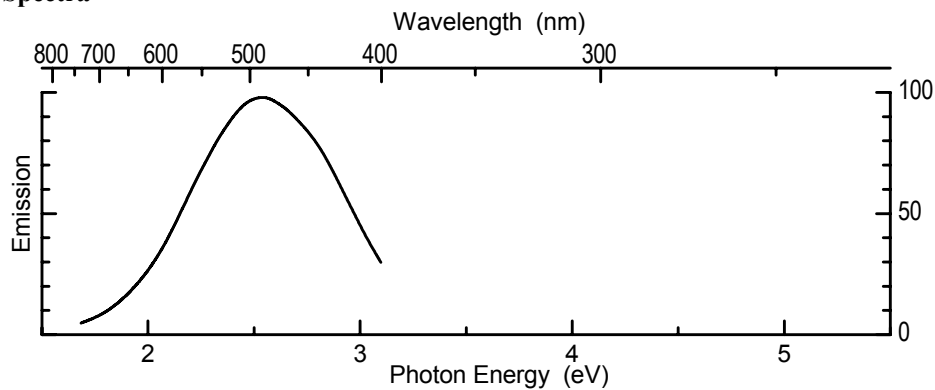
Optical Properties

Emission color: Yellow
Emission peak: 2.12 eV
Emission width (FWHM): 0.20 eV

Spectra



Spectra



Reference

1. Henderson, S.T., and Ranby, P.W., Barium titanium phosphate – a new phosphor, *J. Electrochem. Soc.*, 98, 479 (1951).

$\text{MgSrP}_2\text{O}_7:\text{Eu}^{2+}$

Structure: Monoclinic

Optical Properties

Emission color: Violet-UV

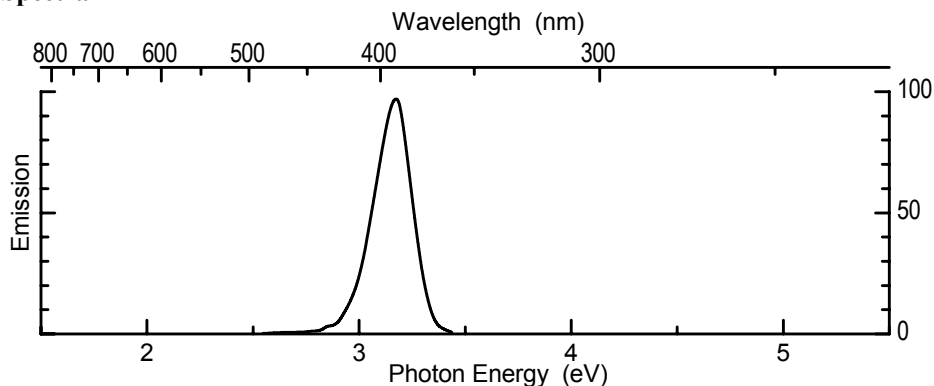
Emission peak: 3.16 eV

Emission width (FWHM): 0.20 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Hoffman, M.V., Eu^{+2} activation in some alkaline earth strontium phosphate compounds, *J. Electrochem. Soc.*, 115, 560 (1968).
2. Blasse, G., and Bril, A., The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).

$\text{MgBaP}_2\text{O}_7:\text{Eu}^{2+}$

Structure: Monoclinic

Optical Properties

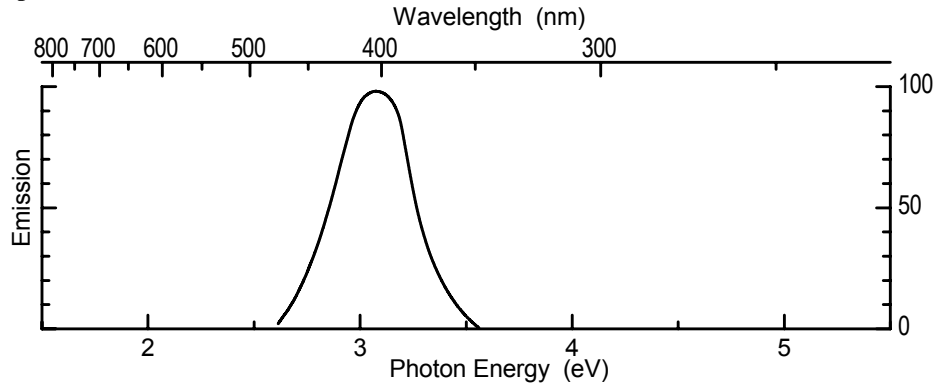
Emission color: Violet-UV

Emission peak: 3.04 eV

Emission width (FWHM): 0.35 eV

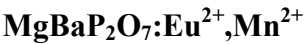
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Lagos, C.C., Luminescence of divalent europium in BaO-MgO-P₂O₅ system, *J. Electrochem. Soc.*, 115, 1271 (1968).



Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|---|------------|---------------|
| Mg ₂ P ₂ O ₇ | 90 (of Mg) | 100 |
| Ba ₂ P ₂ O ₇ | 96 (of Ba) | 215 |
| Eu ₂ O ₃ | 4 (of Eu) | 7 |
| MnCO ₃ | 10 | 11.5 |
| H ₃ PO ₄ -solution, 85% | 19 (of P) | 12.9 ccm |

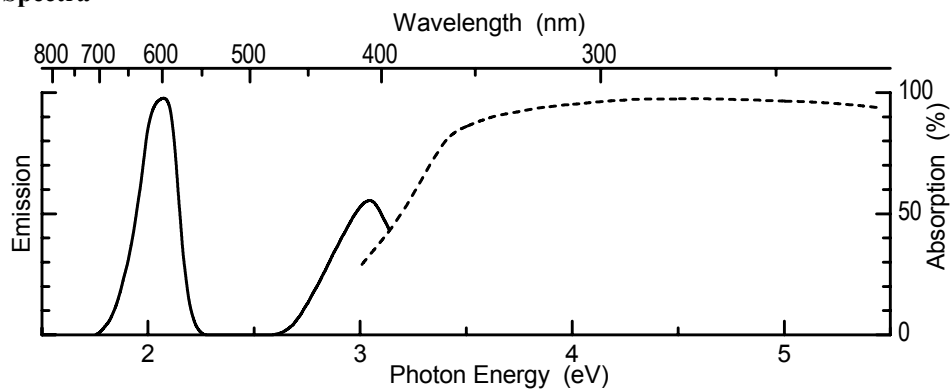
Preparation

- Make a slurry of Mg₂P₂O₇ + Ba₂P₂O₇ + Eu₂O₃ + MnCO₃ in water.
Add the H₃PO₄ solution while stirring.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, N₂, 500–600°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, N₂, 950°C, 2 hours.

Optical Properties

Emission color: Pinkish orange-red
Emission peak: Orange-red Mn²⁺ band at 2.07 eV, violet Eu²⁺ band at 3.06 eV
Emission width (FWHM): 0.18 eV (Mn²⁺ band)
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



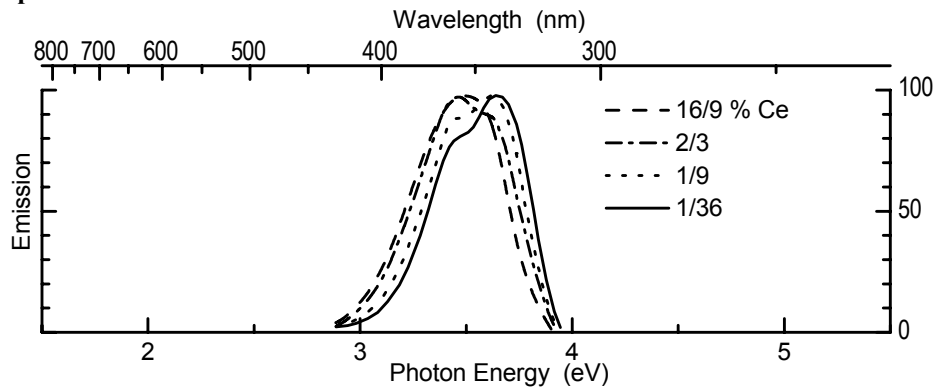
Structure: Trigonal

Optical Properties

Emission color: UV

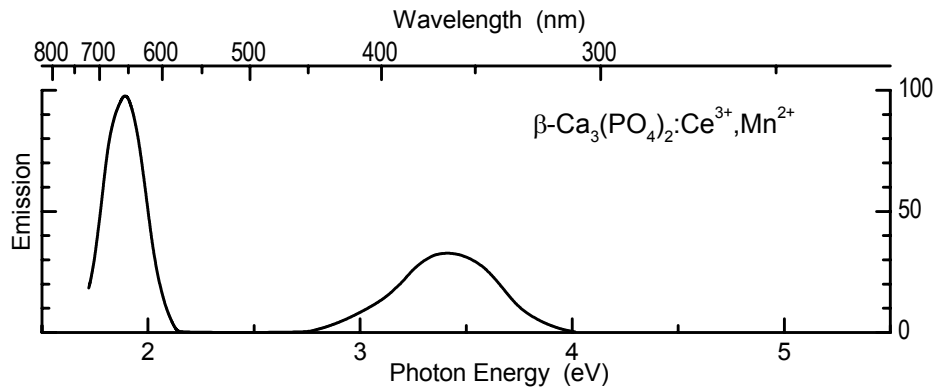
Excitation efficiency by UV: ++ (4.88 eV)

Spectra



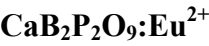
Reference

1. Botden, T.P.J., Transfer and transport of energy by resonance processes in luminescent solids, *Philips Res. Rep.*, 7, 197 (1952).



Reference

1. Froelich, H.C., and Margolis, J.M., Calcium phosphate phosphor activated with cerium and manganese, *J. Electrochem. Soc.*, 98, 400 (1951).



Composition

| Ingredient | Mole % | By weight (g) |
|--|-----------|---------------|
| CaHPO ₄ | 98 | 134 |
| H ₃ BO ₃ | 200 | 124 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| (NH ₄) ₂ HPO ₄ | 106 | 140 |

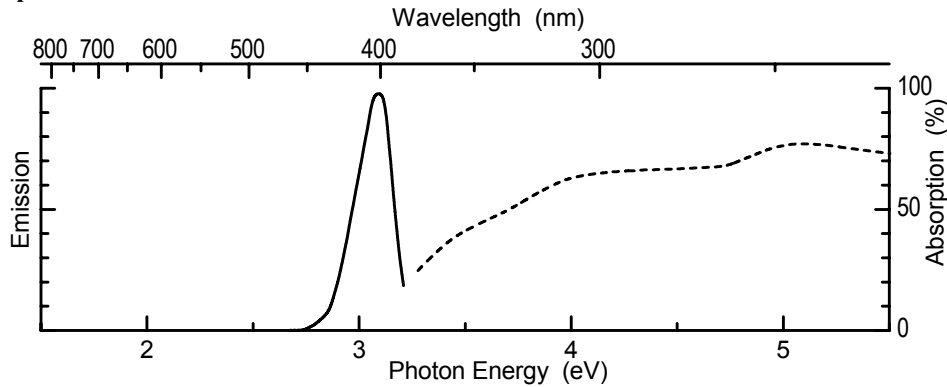
Preparation

- Make a slurry of the CaHPO₄ + Eu₂O₃ in methanol.
Dissolve the H₃BO₃ + (NH₄)₂HPO₄ together in a little water.
Add the solution to the slurry. Stir.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, air, ~500–600°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, N₂, 800°C, 1 hour.
Powderize.
 3. Fire in open quartz boats, CO, 1000°C, 1 hour.

Optical Properties

Emission color: Deep violet
Emission peak: 3.08 eV
Emission width (FWHM): 0.21 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



α -Ca₃(PO₄)₂:Sn²⁺

Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|---|--------|---------------|
| CaCO ₃ | 10 | 10 |
| CaHPO ₄ | 75 | 90 |
| SnO | 1 | 1.35 |
| (NH ₄) ₂ CO ₄ | 12 | 2 |

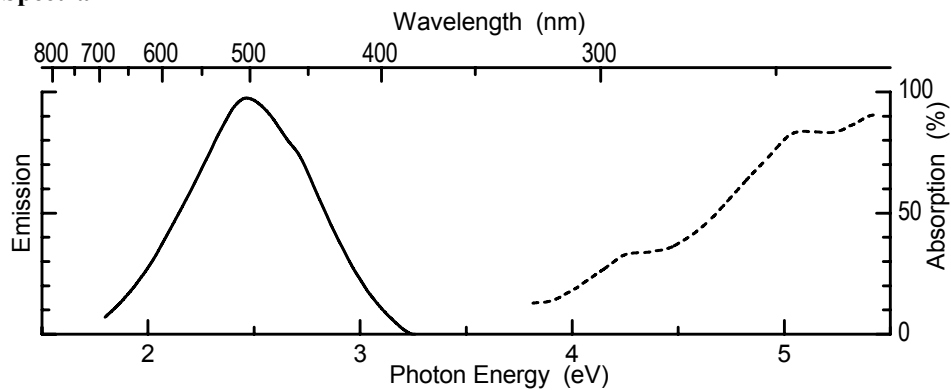
Preparation

Mix the CaCO₃ + CaHPO₄ + SnO by slurring in methanol.
Dry in air. Powderize when dry.
Now add the crushed (NH₄)₂CO₄ by dry mixing.
Fire in capped quartz tubes, N₂, 1250°C, 1 hour.

Optical Properties

Emission color: Pale blue-green
Emission peak: 2.44 eV
Emission width (FWHM): 0.61 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

1. Kröger, F.A., A proof of the associated-pair theory for sensitized luminophors, *Physica*, 15, 801 (1949).
2. Kreidler, E.R., Phase equilibria and tin-activated luminescence in system Ca₃(PO₄)₂-Ba₃(PO₄)₂, *J. Electrochem. Soc.*, 118, 923 (1971).

β -Ca₃(PO₄)₂:Sn²⁺

Structure: Trigonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 5 | 5 |
| CaHPO ₄ | 75 | 90 |
| SnO | 5 | 6.75 |

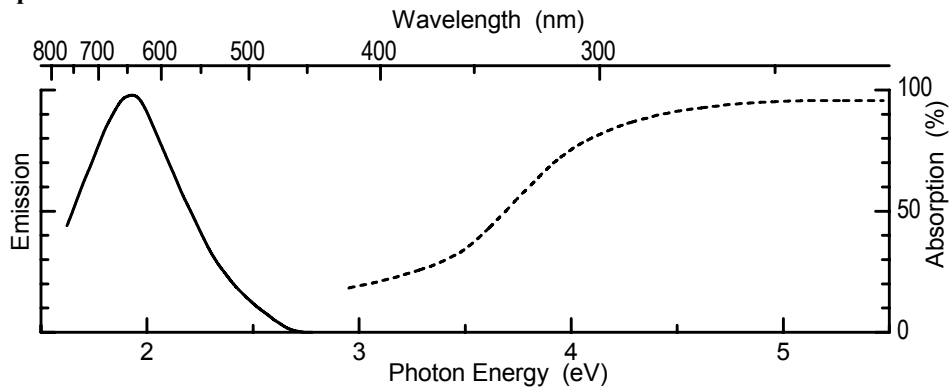
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1100°C, 2 hours.
Powderize by dry milling.
 2. Fire in capped quartz tubes, CO, 1100°C, 2 hours.

Optical Properties

Emission color: Pale orange
Emission peak: 1.92 eV
Emission width (FWHM): 0.55 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Kröger, F.A., A proof of the associated-pair theory for sensitized luminophors, *Physica*, 15, 801 (1949).
2. Kreidler, E.R., Phase equilibria and tin-activated luminescence in system Ca₃(PO₄)₂-Ba₃(PO₄)₂, *J. Electrochem. Soc.*, 118, 923 (1971).



Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 24 | 24 |
| CaHPO ₄ | 75 | 90 |
| PbO | 1 | 2.3 |

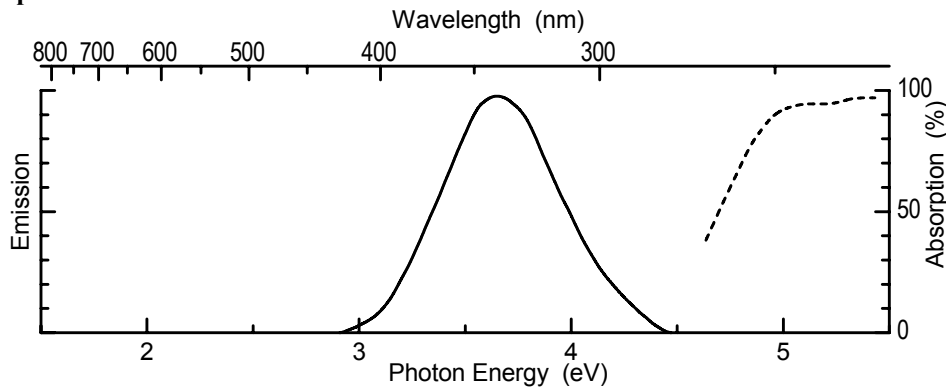
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, ~500°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, CO, 1250°C, 1 hour.

Optical Properties

Emission color: UV
Emission peak: 3.68 eV
Emission width (FWHM): 0.64 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Clapp, R.H., and Ginther, R.J., Ultraviolet phosphors and fluorescent sun tan lamps, *J. Opt. Soc. Am.*, 37, 355 (1947).



Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO ₃ | 22 | 22 |
| CaHPO ₄ | 75 | 90 |
| TiOH | 1 | 2.2 |
| Al ₂ O ₃ | 2 (of Al) | 1 |

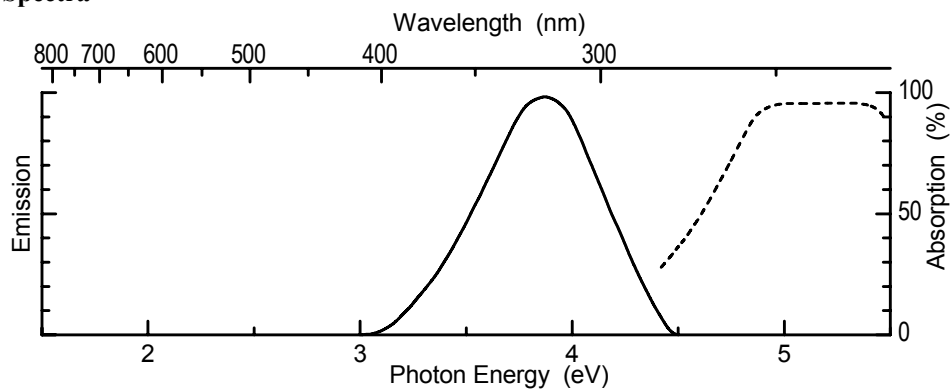
Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, stagnant air, 1250°C, 1 hour.

Optical Properties

Emission color: UV
Emission peak: 3.88 eV
Emission width (FWHM): 0.66 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Froelich, H.C., New ultraviolet phosphors, *J. Electrochem. Soc.*, 91, 241 (1947).
2. Witzmann, H., and Buhrow, J., Ein neuer schwarzlichtphosphor, *Naturwissenschaften*, 49, 180 (1962).
3. Clapp, R.H., and Ginther, R.J., Ultraviolet phosphors and fluorescent sun tan lamps, *J. Opt. Soc. Am.*, 37, 355 (1947).
4. Bril, A., and Hoekstra, W., *Philips Res. Rep.*, 16, 356, (1961), and *Philips Res. Rep.*, 19, 296 (1964).



Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 15 | 15 |
| CaHPO ₄ | 75 | 90 |
| CeO ₃ | 5 | 17 |
| NaHCO ₃ | 5 | 8.4 |

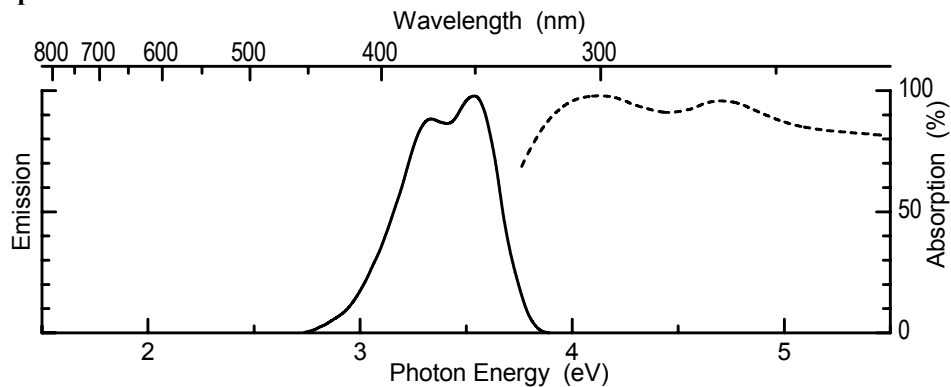
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in open quartz boats, CO, 1250°C, 1 hour.

Optical Properties

Emission color: UV
Emission peak: 3.33 eV, 3.57 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Froelich, H.C., and Margolis, J.M., Calcium phosphate phosphor activated with cerium and manganese, *J. Electrochem. Soc.*, 98, 400 (1951).
2. Botden, T.P.J., Transfer and transport of energy by resonance processes in luminescent solids, *Philips Res. Rep.*, 7, 197 (1952).



Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO ₃ | 24 | 24 |
| CaHPO ₄ | 75 | 90 |
| Eu ₂ O ₃ | 1 (of Eu) | 1.76 |

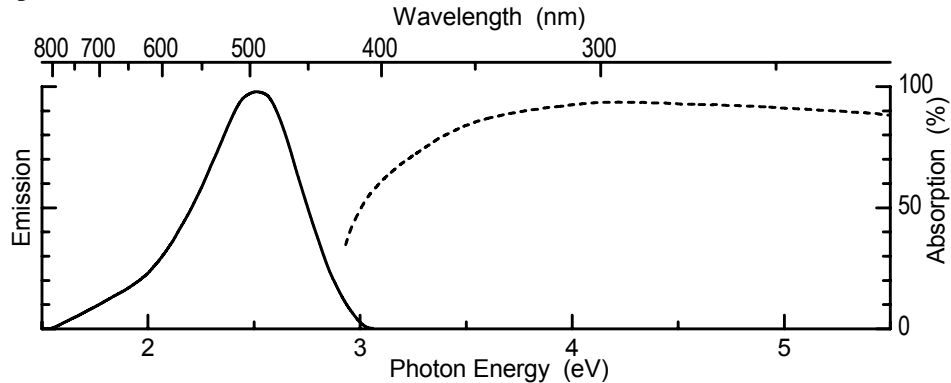
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in open quartz boats, CO, 1250°C, 1 hour.

Optical Properties

Emission color: Whitish blue-green
Emission peak: ~2.52 eV
Emission width (FWHM): 0.53 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

1. Lagos, C.C., Luminescence of divalent europium in Ba-Ca, Ba-Sr, and Ca-Sr orthophosphate and pyrophosphate compositions, *J. Electrochem. Soc.*, 117, 1189 (1970).

2. McCauley, R.A., Hummel, F.A., and Hoffman, M.V., Phase equilibria and Eu²⁺-activated, Tb³⁺-activated, and Mn²⁺-activated luminescent phases in CaO-MgO-P₂O₅ system, *J. Electrochem. Soc.*, 118, 755 (1971).



Structure: Trigonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO ₃ | 24 | 24 |
| CaHPO ₄ | 75 | 90 |
| Eu ₂ O ₃ | 1 (of Eu) | 1.76 |

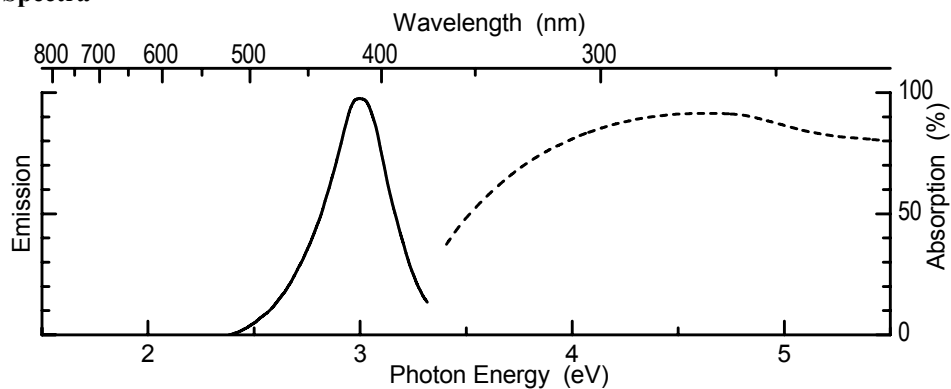
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in open quartz boats, CO, 1100°C, 2 hours.

Optical Properties

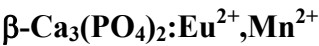
Emission color: Violet
Emission peak: 3.02 eV
Emission width (FWHM): 0.33 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Remark

This phosphor easily shows a weak green emission band due to the α -phosphate (see α - $\text{Ca}_3(\text{PO}_4)_2:\text{Eu}^{2+}$).



Structure: Trigonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO ₃ | 19 | 19 |
| CaHPO ₄ | 75 | 90 |
| Eu ₂ O ₃ | 1 (of Eu) | 1.76 |
| MnCO ₃ | 5 | 5.75 |

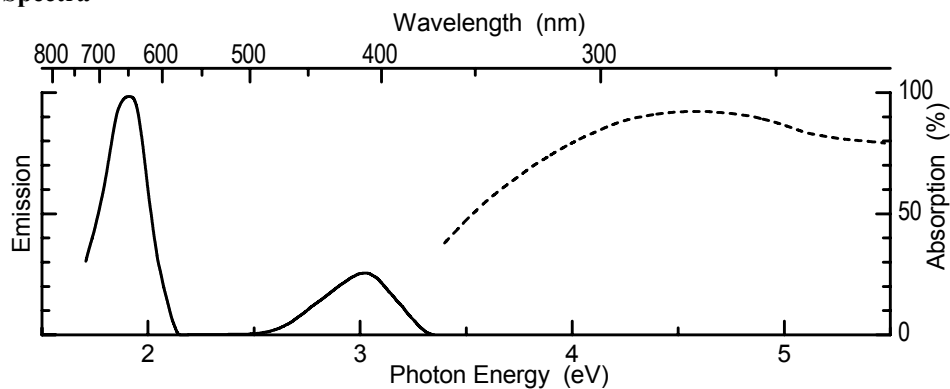
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in open quartz boats, CO, 1100°C, 2 hours.

Optical Properties

Emission color: Pinkish-red
Emission peak: ~1.91 eV (Mn^{2+} band), ~3.01 eV (Eu^{2+} band)
Emission width (FWHM): 0.24 eV (Mn^{2+} band)
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Structure: Trigonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| SrCO ₃ | 8 | 11.8 |
| SrHPO ₄ | 45 | 75.4 |
| Al ₂ O ₃ | 4 (of Al) | 2 |
| SnO | 1.5 | 2 |
| MnCO ₃ | 1 | 1.15 |

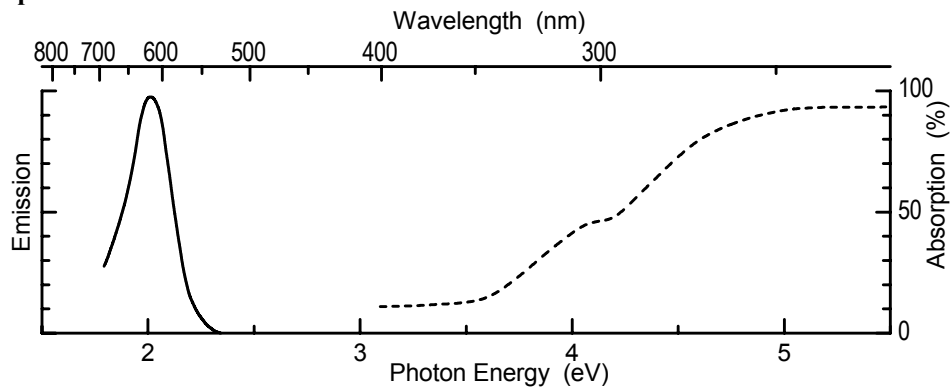
Preparation

Mix by ball-milling in water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, CO, 1100°C, 2 hours.

Optical Properties

Emission color: Orange-red
Emission peak: 2.02 eV
Emission width (FWHM): 0.25 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Remarks

- 1. This is a “tricky” phosphor, by no means yet understood or optimized.
- 2. Partial or complete replacement of Sr by Ca shifts the emission into deeper red.

References

- 1. Kröger, F.A., A proof of the associated-pair theory for sensitized luminophors, *Physica*, 15, 801 (1949).
- 2. Botden, T.P.J., Transfer and transport of energy by resonance processes in luminescent solids, *Philips Res. Rep.*, 7, 197 (1952).
- 3. Sarver, J.F., Hoffman, M.V., and Hummel, F.A., Phase equilibria and tin-activated luminescence in strontium orthophosphate systems, *J. Electrochem. Soc.*, 108, 1103 (1961).



Structure: Trigonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| SrCO ₃ | 20 | 29.5 |
| SrHPO ₄ | 75 | 138 |
| SnO | 5 | 6.75 |

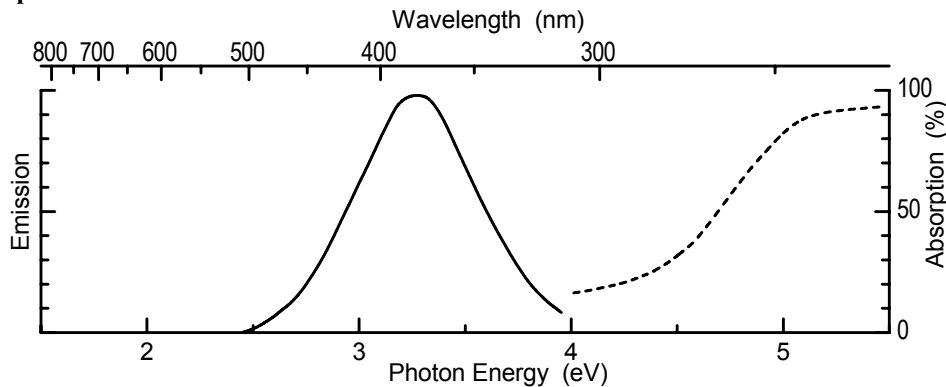
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, CO, 1100°C, 2 hours.

Optical Properties

Emission color: Violet + UV
Emission peak: 3.28 eV
Emission width (FWHM): 0.66 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

- 1. Botden, T.P.J., Transfer and transport of energy by resonance processes in luminescent solids, *Philips Res. Rep.*, 7, 197 (1952).

$\beta\text{-Sr}_3(\text{PO}_4)_2\text{:Eu}^{2+}$

Structure: Trigonal

Optical Properties

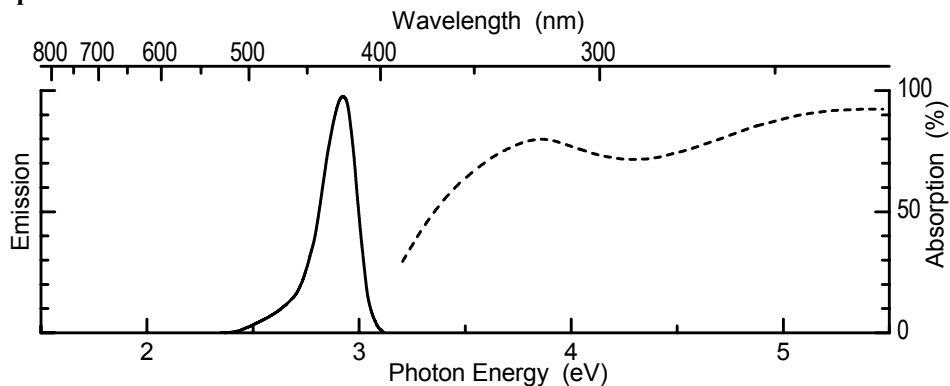
Emission color: Violet

Emission peak: 2.94 eV

Emission width (FWHM): 0.22 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Spectra



References

1. Lagos, C.C., Luminescence of divalent europium in Ba-Ca, Ba-Sr, and Ca-Sr orthophosphate and pyrophosphate compositions, *J. Electrochem. Soc.*, 117, 1189 (1970).
2. Hoffman, M.V., Eu^{+2} activation in some alkaline earth strontium phosphate compounds, *J. Electrochem. Soc.*, 115, 560 (1968).

$\text{Ba}_3(\text{PO}_4)_2\text{:Eu}^{2+}$

Optical Properties

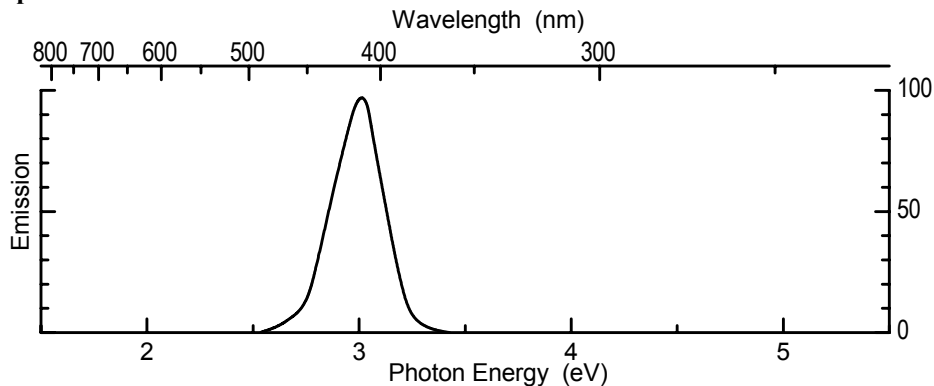
Emission color: Violet

Emission peak: 2.99 eV

Emission width (FWHM): 0.25 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Spectra



Reference

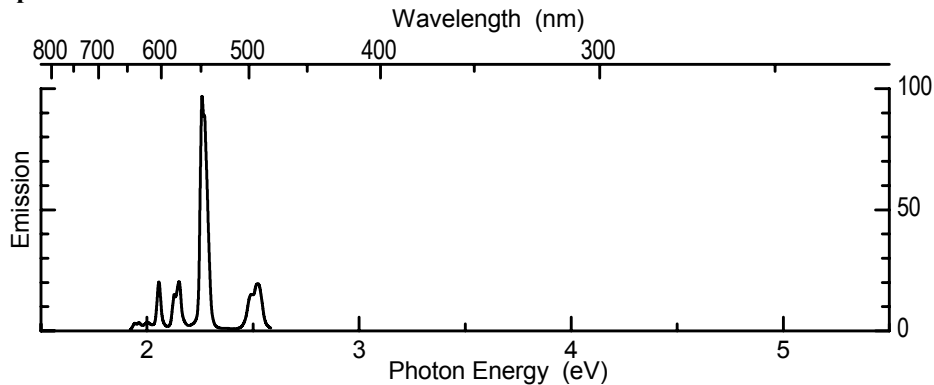
1. Lagos, C.C., Luminescence of divalent europium in Ba-Ca, Ba-Sr, and Ca-Sr orthophosphate and pyrophosphate compositions, *J. Electrochem. Soc.*, 117, 1189 (1970).



Optical Properties

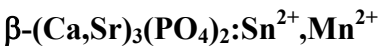
Emission color: Green
Emission peak: 2.27 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Fava, J. et al., Some new efficient luminophors with low-concentration quenching effects, *J. Lumin.*, 18/19, 389 (1979).



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 50 | 50 |
| SrCO ₃ | 32 | 47 |
| SrHPO ₄ | 205 | 376 |
| SnO | 10 | 13.5 |
| MnCO ₃ | 3 | 3.45 |

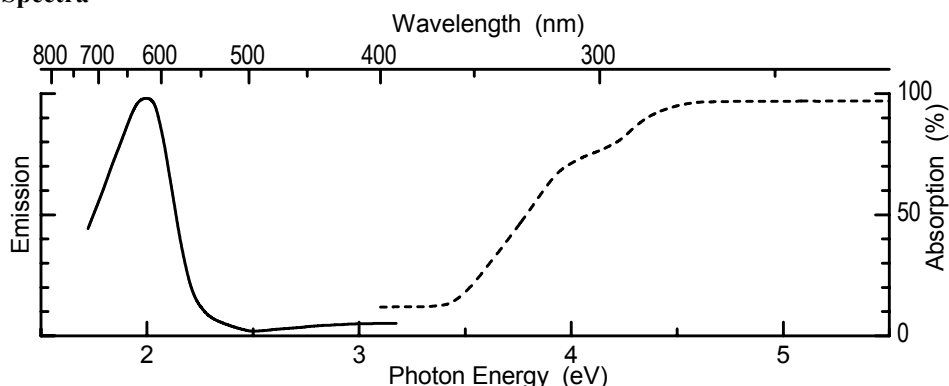
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, N₂, 500–600°C. Powderize.
 2. Fire in capped quartz tubes, CO, 1150°C, 2 hours.

Optical Properties

Emission color: Orange-red
Emission peak: 1.97 eV
Emission width (FWHM): 0.38 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Remarks

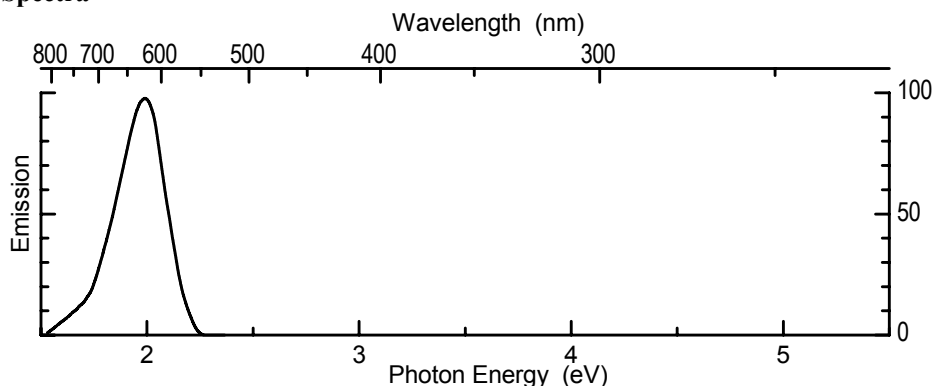
1. Increasing Mn concentration causes narrowing of the emission band but decreasing efficiency.
2. The β -phosphate structure is maintained from about Ca/Sr of 10/90 to 100/0. Increasing Ca/Sr causes a shift of the Mn^{2+} band into deeper red.

References

1. Butler, K.H., Alkaline earth orthophosphate phosphors, *J. Electrochem. Soc.*, 100, 250 (1953).
2. Koelmans, H., and Cox, A.P.M., Luminescence of modified tin-activated strontium orthophosphate, *J. Electrochem. Soc.*, 104, 442 (1957).
3. Mooney, R.W., Temperature dependence of fluorescence of tin-activated orthophosphates, *J. Electrochem. Soc.*, 105, 456 (1958).
4. Uehara, Y., Kobuke, Y., and Masuda, I., Copper-activated calcium orthophosphate and related phosphors, *J. Electrochem. Soc.*, 106, 200 (1959).
5. Wanmaker, W.L., and Bakker, C., Luminescence of copper-activated calcium and strontium orthophosphates, *J. Electrochem. Soc.*, 106, 1027 (1959).
6. Sarver, J.F., Hoffman, M.V., and Hummel, F.A., Phase equilibria and tin-activated luminescence in strontium orthophosphate systems, *J. Electrochem. Soc.*, 108, 1103 (1961).



Spectra



$\text{Zn}_3(\text{PO}_4)_2:\text{Mn}^{2+}$

Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| ZnO | 99 | 81 |
| MnCO ₃ | 1 | 1.15 |
| H ₃ PO ₄ solution | 62 (of P) | 47.6 ccm |

Preparation

Make a thin slurry of ZnO + MnCO₃ in water or methanol. Stir to uniformity as well as possible. Slowly add the H₃PO₄ solution while stirring (slurry heats up).

Ball-mill the slurry for about 1 hour. Dry in air. Powderize when dry.

1. Fire in open quartz boats, air, ~500°C, 1 hour. Powderize.
2. Fire in open quartz boats, air, 900°C, 1 hour. Powderize.
3. Fire in open quartz boats, air, 950°C, 2 hours.

Optical Properties

Emission color: Light red

Emission peak: 1.94 eV

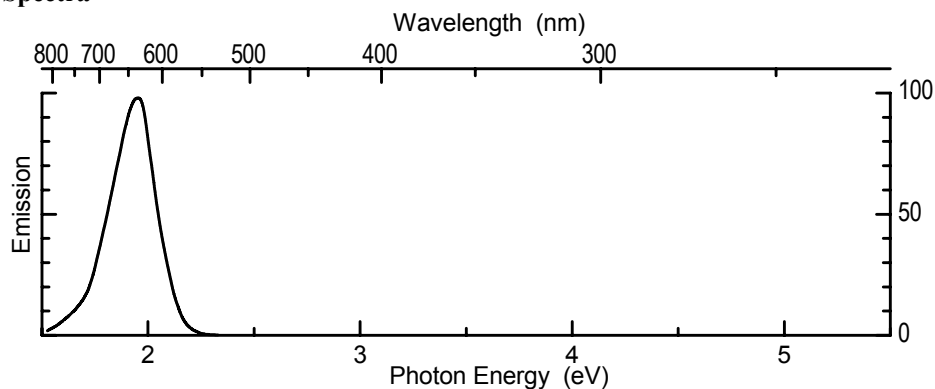
Emission width (FWHM): 0.25 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: ~7–8%

Decay: Near-exponential decay, 30 msec to 1/10

Spectra



Remarks

1. This is strictly a catholuminescent phosphor. It cannot be sensitized to respond to 4.88 or 3.40 eV UV.
2. This phosphor has been used as the red component in early color TV picture tubes.

Reference

1. Sarver, J.S., Katnack, F.L., and Hummel, F.A., Phase equilibria and manganese-activated fluorescence in the system Zn₃(PO₄)₂-Mg₃(PO₄)₂, *J. Electrochem. Soc.*, 106, 960 (1959).

$(\text{Zn,Mg})_3(\text{PO}_4)_2:\text{Mn}^{2+}$

Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| ZnO | 79 | 65 |
| MnO | 20 | 8.1 |
| MnCO ₃ | 1 | 1.15 |
| H ₃ PO ₄ solution | 62 (of P) | 46.7 ccm |

Preparation

Make a thin slurry of ZnO + MgO + MnCO₃ in water or methanol.

Stir to uniformity. Slowly add the H₃PO₄ solution while stirring.

Crush forming phosphate by wet mortaring or milling.

Dry in air. Powderize when dry.

1. Fire in open quartz boats, air, ~500–600°C, 1 hour. Powderize.
2. Fire in open quartz boats, air, 950°C, 2 hours.

Optical Properties

Emission color: Light red

Emission peak: 1.96 eV

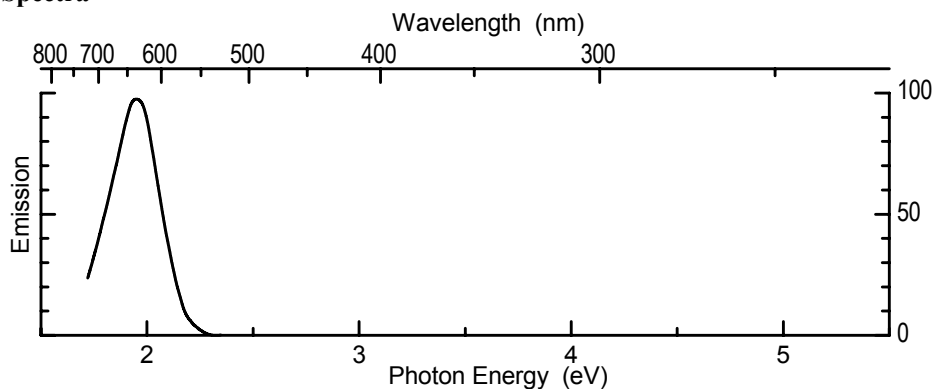
Emission width (FWHM): 0.27 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: ~6–8%

Decay: near-exponential decay, ≈ 100–1200 msec to 1/10

Spectra



Remarks

1. The 950°C firing temperature is critical; 900°C is too low; 1000°C is too high.
2. This is strictly a catholuminescent phosphor. It cannot be sensitized for UV excitation.
3. The decay of this phosphor is significantly longer than that of Zn₃(PO₄)₂:Mn²⁺ (~30 msec to 1/10).

Reference

1. Sarver, J.S., Katnack, F.L., and Hummel, F.A., Phase equilibria and manganese-activated fluorescence in the system Zn₃(PO₄)₂-Mg₃(PO₄)₂, *J. Electrochem. Soc.*, 106, 960 (1959).

$\text{Mg}_3\text{Ca}_3(\text{PO}_4)_4:\text{Eu}^{2+}$

Structure: Monoclinic

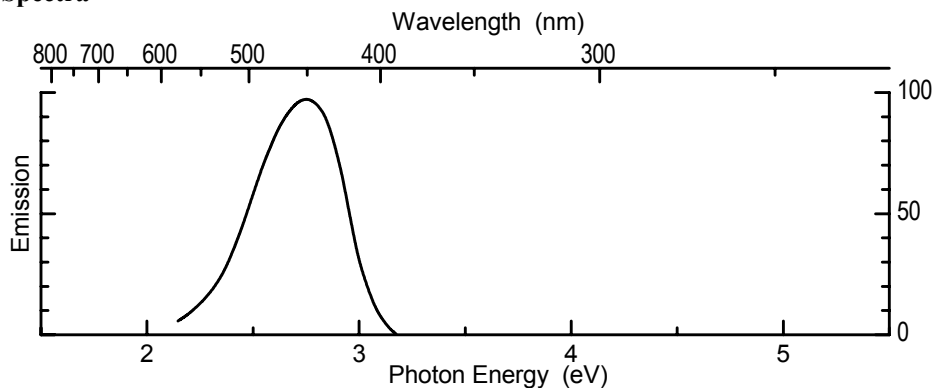
Optical Properties

Emission color: Blue

Emission peak: 2.80 eV

Emission width (FWHM): 0.48 eV

Spectra



Reference

1. McCauley, R.A., Hummel, F.A., and Hoffman, M.V., Phase equilibria and Eu^{2+} -activated, Tb^{3+} -activated, and Mn^{2+} -activated luminescent phases in $\text{CaO-MgO-P}_2\text{O}_5$ system, *J. Electrochem. Soc.*, 118, 755 (1971).

$\text{MgSr}_5(\text{PO}_4)_4:\text{Sn}^{2+}$

Optical Properties

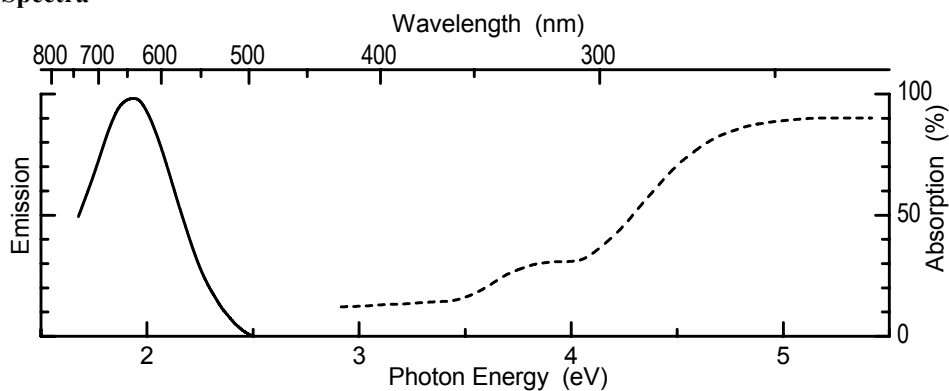
Emission color: Orange- red

Emission peak: 1.93 eV

Emission width (FWHM): 0.49 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra

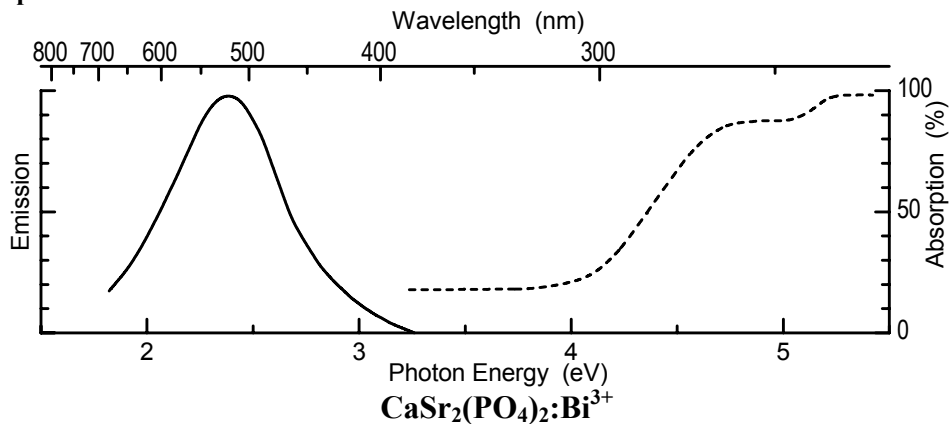


$\text{MgBa}_2(\text{PO}_4)_2:\text{Sn}^{2+}$

Optical Properties

Emission color: Greenish
Emission peak: 2.36 eV
Emission width (FWHM): 0.67 eV
Excitation efficiency by UV: ++ (4.88 eV)

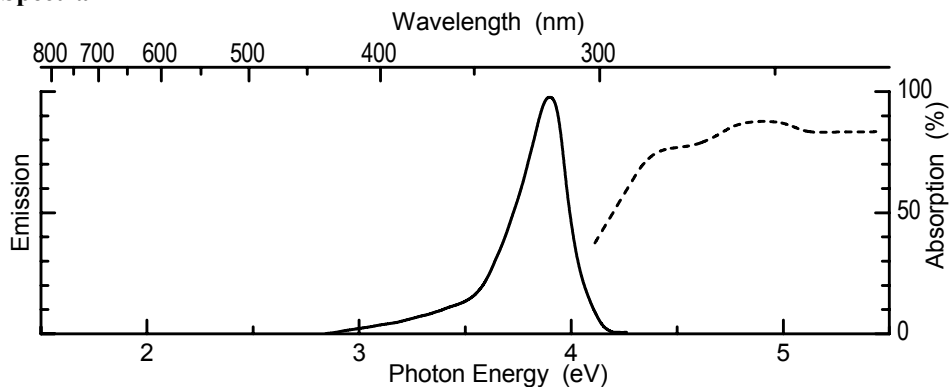
Spectra



Optical Properties

Emission color: UV
Emission peak: 3.89 eV
Emission width (FWHM): 0.27 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra

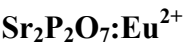
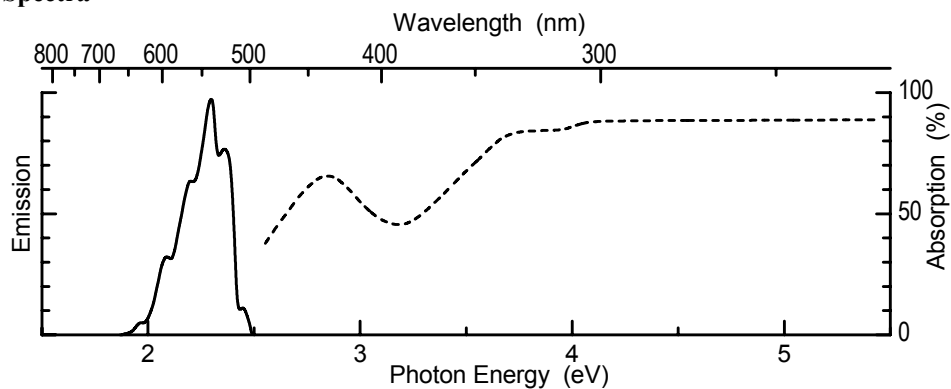


$\text{MgBa}_2(\text{PO}_4)_2:\text{U}$

Optical Properties

Emission color: Green
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: –

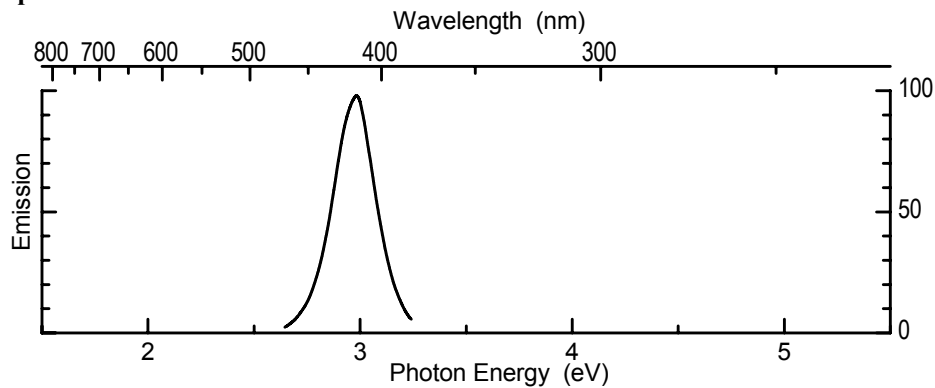
Spectra



Optical Properties

Emission color: Violet
Emission peak: 2.97 eV
Emission width (FWHM): 0.29 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



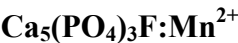
Reference

1. Butler, K.H., *Fluorescent Lamp Phosphors*, Pennsylvania University Press, University Park (1980), p. 274.

4.6 Halophosphates

The following host compounds and activators are included in this subsection:

Ca₅(PO₄)₃F:Mn²⁺
Ca₅(PO₄)₃F:Sb³⁺
Ca₅(PO₄)₃F:Sn²⁺
Ca₅(PO₄)₃Cl:Eu²⁺
Ca₅(PO₄)₃Cl:Mn²⁺
Ca₅(PO₄)₃Cl:Sb³⁺
Ca₅(PO₄)₃Cl:Sn²⁺
Sr₅(PO₄)₃Cl:Eu²⁺
Sr₅(PO₄)₃Cl:Mn²⁺
Sr₅(PO₄)₃Cl:Sb³⁺
Sr₅(PO₄)₃F:Mn²⁺
Sr₅(PO₄)₃F:Sb³⁺
Sr₅(PO₄)₃F:Sb³⁺,Mn²⁺
Sr₅(PO₄)₃Cl:Eu²⁺,Pr³⁺
Sr₅(PO₄)₃F:Sn²⁺
Ba₅(PO₄)₃Cl:Eu²⁺
Ba₅(PO₄)₃Cl:U
Ca₂Ba₃(PO₄)₃Cl:Eu²⁺



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 140 | 140 |
| CaHPO ₄ | 400 | 360 |
| CaF ₂ | 50 | 39 |
| MnCO ₃ | 10 | 11.5 |

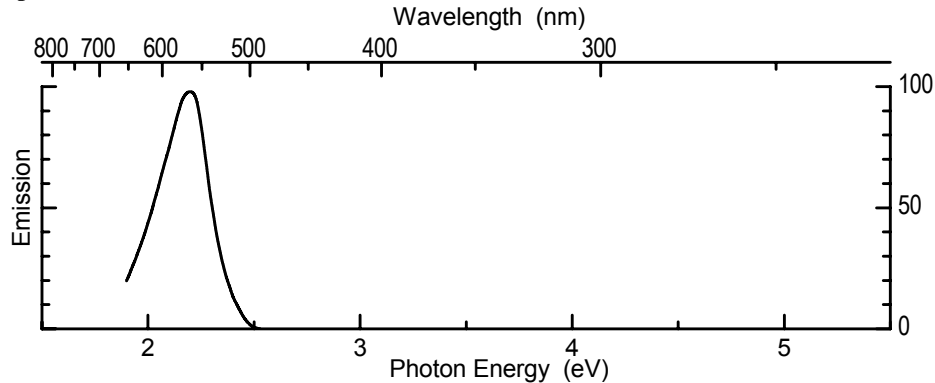
Preparation

Mix by ball-milling in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, N₂, 1100°C, 1 hour.

Optical Properties

Emission color: Yellow
Emission peak: 2.17 eV
Emission width (FWHM): 0.28 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +

Spectra

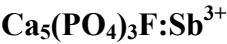


Remark

Can be sensitized for UV excitation by addition of Sn^{2+} , Sb^{3+} , or Ce^{3+} .

References

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).
2. Alonso, P.J., and Alcala, R. Excitation-spectra and fluorescent lifetime measurements of Mn^{2+} in CaF_2 and $\text{Ca}_5(\text{PO}_4)_3\text{F}_2$, *J. Lumin.*, 22, 321 (1981).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|------------|---------------|
| CaCO_3 | 140 | 140 |
| CaHPO_4 | 300 | 360 |
| CaF_2 | 50 | 39 |
| Sb_2O_3 | 10 (of Sb) | 14.6 |

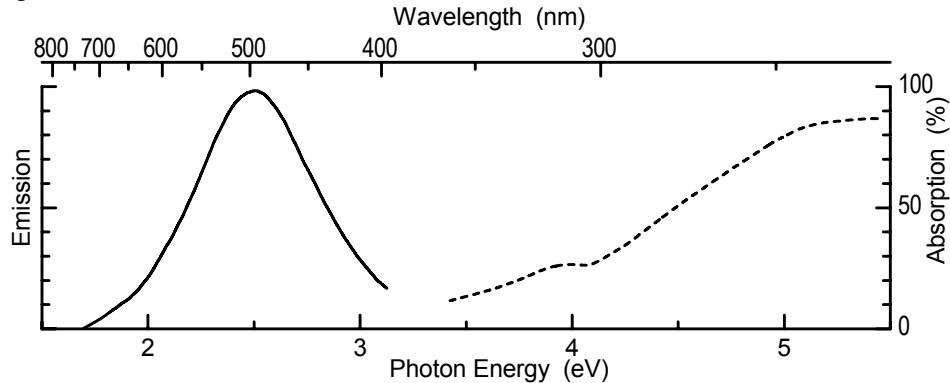
Preparation

Mix by ball-milling in water or methanol.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, N_2 , 1100°C, 1 hour.

Optical Properties

Emission color: Pale blue-green
Emission peak: 2.50 eV
Emission width (FWHM): 0.70 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra

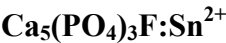


References

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).

2. Soules, T.F., Davis, T.S., and Kreidler, E.R., Molecular orbital model for antimony luminescent centers in fluorophosphate, *J. Chem. Phys.*, 55, 1056 (1971).

3. Soules, T.F. et al., Energy-transfer between antimony and manganese in fluorophosphate phosphors, *Phys. Rev. B*, 7, 1657 (1973).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 200 | 200 |
| CaHPO ₄ | 300 | 360 |
| CaF ₂ | 50 | 39 |
| SnO | 10 | 13.5 |

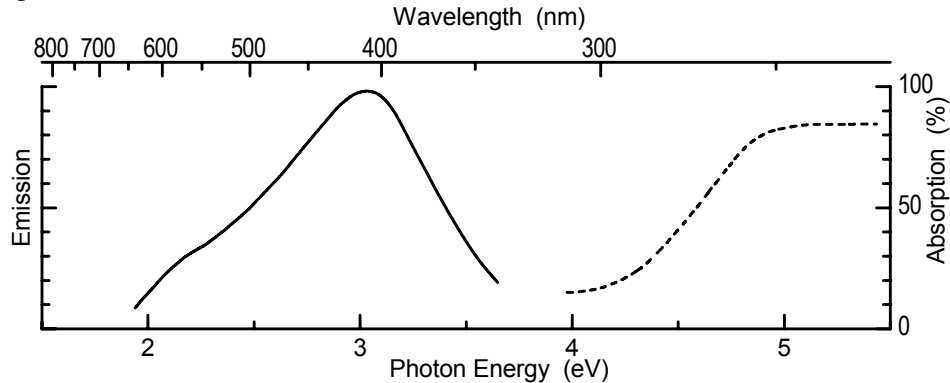
Preparation

Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, N₂, 1100°C, 1 hour.

Optical Properties

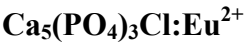
Emission color: Pale bluish
Emission peak: 3.00 eV
Emission width (FWHM): ~0.9 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO ₃ | 200 | 200 |
| CaHPO ₄ | 300 | 360 |
| NH ₄ Cl | 120 | 64 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |

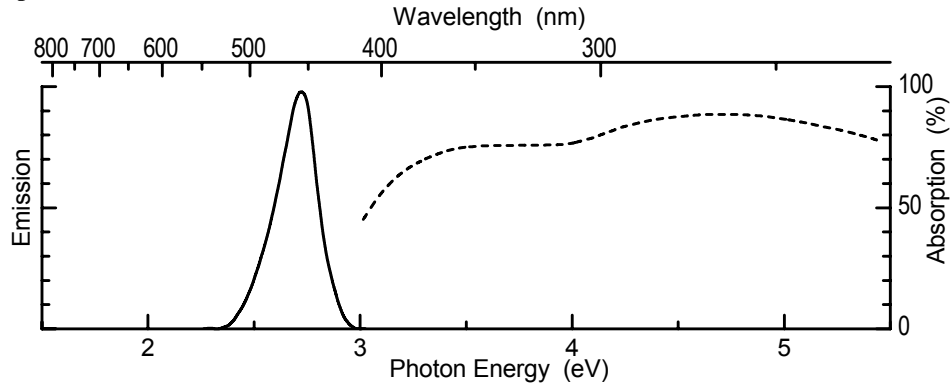
Preparation

- Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1100° C, 1 hour.
Powderize.
Add 32 g NH₄Cl; mix by dry grinding or milling.
 2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

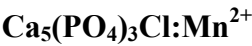
Emission color: Blue
Emission peak: 2.72 eV
Emission width (FWHM): 0.23 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

- 1. Wachtel, A., *Bloomfield Report*, BL-R-6-90102-29 (1968).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 200 | 200 |
| CaHPO ₄ | 300 | 360 |
| NH ₄ Cl | 120 | 64 |
| MnCO ₃ | 10 | 11.5 |

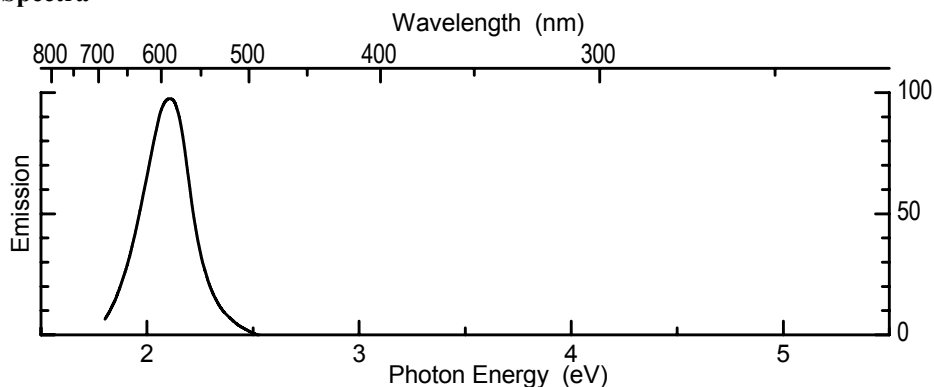
Preparation

- Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
- 1. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Add 32 g NH₄Cl; mix by dry grinding or milling.
 - 2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Orange-yellow
Emission peak: ~2.10 eV
Emission width (FWHM): 0.29 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Spectra

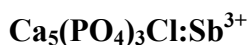


Remark

Can be sensitized for UV excitation by addition of Sn^{2+} , Sb^{3+} , Ce^{3+} , or Eu^{2+} .

Reference

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------------------|--------|---------------|
| CaCO_3 | 200 | 200 |
| CaHPO_4 | 300 | 360 |
| NH_4Cl | 120 | 64 |
| MnCO_3 | 10 | 11.5 |

Preparation

Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, N_2 , 1100°C, 1 hour.
Powderize.
Add 32 g NH_4Cl ; mix by dry grinding or milling.
2. Fire in capped quartz tubes, N_2 , 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

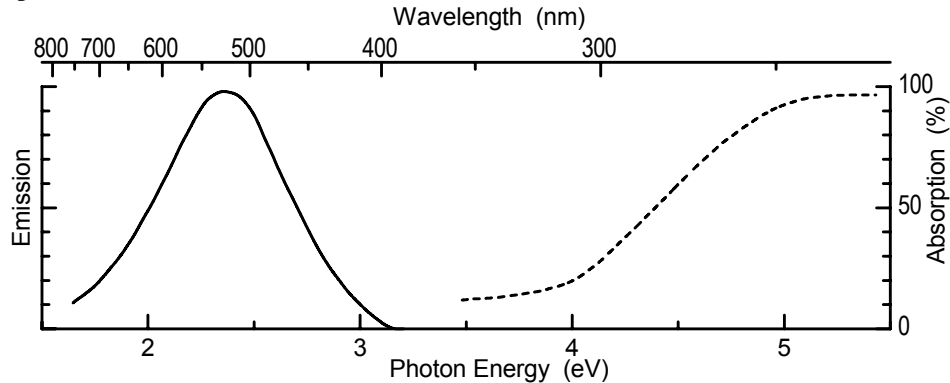
Emission color: Pale whitish-green

Emission peak: 2.38 eV

Emission width (FWHM): 0.70 eV

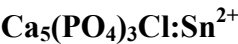
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 200 | 200 |
| CaHPO ₄ | 300 | 360 |
| NH ₄ Cl | 120 | 64 |
| SnO | 10 | 13.5 |

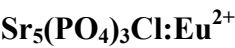
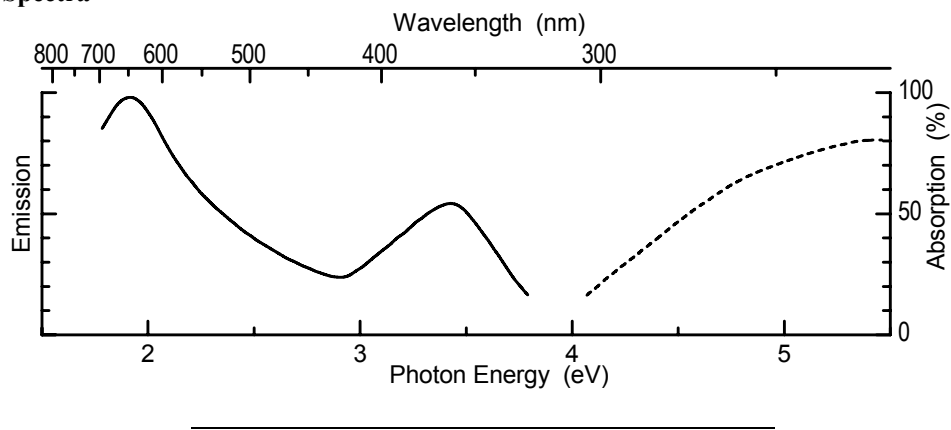
Preparation

- Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Add 32 g NH₄Cl; mix by dry grinding or milling.
 2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Pale pinkish-white
Emission peaks: Continuous distribution from the UV into the IR; the two peaks near 1.95 and 3.45 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| SrCO ₃ | 200 | 295 |
| SrHPO ₄ | 300 | 550 |
| NH ₄ Cl | 120 | 64 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |

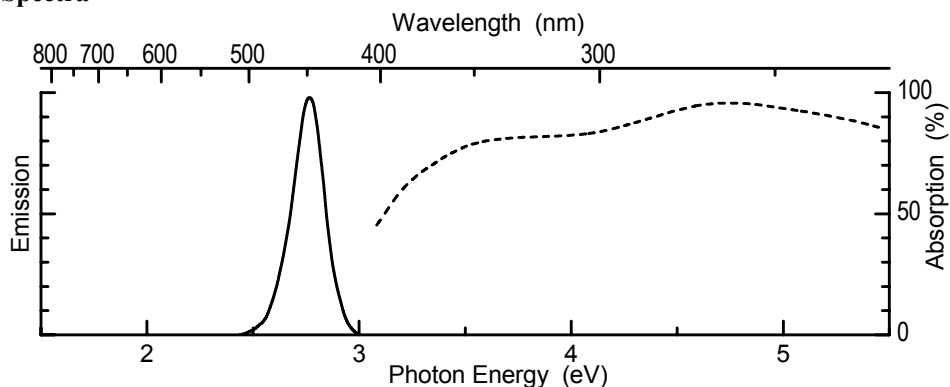
Preparation

- Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Add 32 g NH₄Cl; mix by dry grinding or milling.
 2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

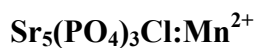
Emission color: Blue
Emission peak: 2.75 eV
Emission width (FWHM): 0.19 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Wachtel, A., *Bloomfield Report*, BL-R-6-90102-29 (1968).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| SrCO ₃ | 200 | 295 |
| SrHPO ₄ | 300 | 550 |
| NH ₄ Cl | 120 | 64 |
| MnCO ₃ | 10 | 11.5 |

Preparation

Mix by ball-milling methanol plus a little water.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Add 32 g NH₄Cl; mix by dry grinding or milling.
2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

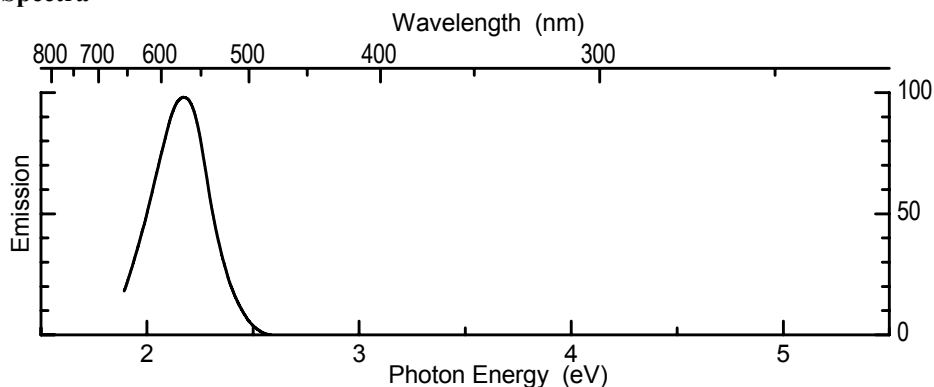
Emission color: Yellow

Emission peak: 2.16 eV

Emission width (FWHM): 0.32 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Spectra

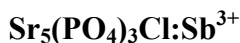


Remark

Can be sensitized for UV excitation by addition of Sn^{2+} , Sb^{3+} , Ce^{3+} , or Eu^{2+} .

Reference

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|------------|---------------|
| SrCO_3 | 200 | 295 |
| SrHPO_4 | 300 | 550 |
| NH_4Cl | 120 | 64 |
| Sb_2O_3 | 10 (of Sb) | 14.6 |

Preparation

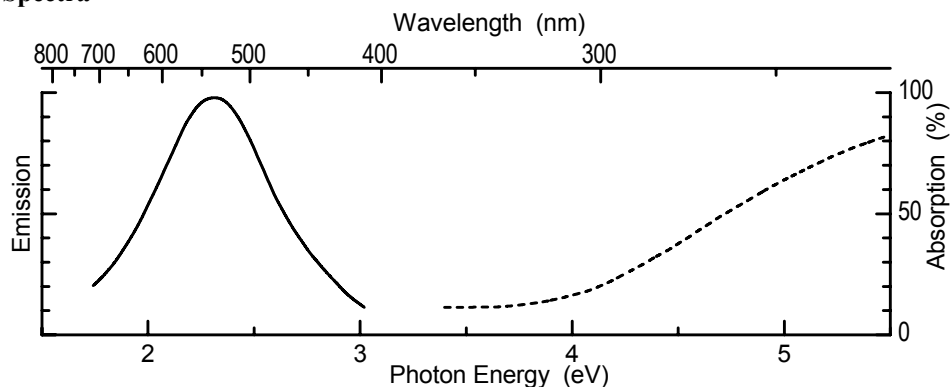
Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, N_2 , 1100°C, 1 hour.
Powderize.
Add 32 g NH_4Cl ; mix by dry grinding or milling.
2. Fire in capped quartz tubes, N_2 , 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

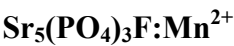
Emission color: Whitish-green
Emission peak: ~2.31 eV
Emission width (FWHM): 0.68 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------------|--------|---------------|
| SrCO_3 | 200 | 295 |
| SrHPO_4 | 300 | 550 |
| SrF_2 | 50 | 63 |
| MnCO_3 | 10 | 11.5 |

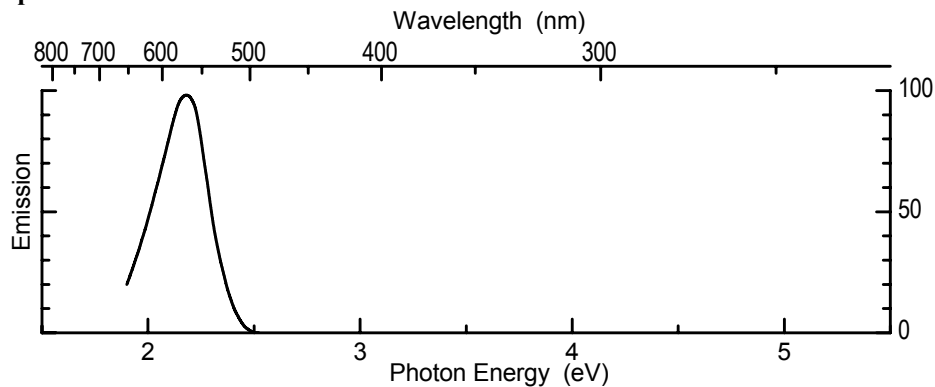
Preparation

Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, N_2 , 1100°C, 1 hour.

Optical Properties

Emission color: Yellow
Emission peak: ~2.17 eV
Emission width (FWHM): 0.28 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Spectra

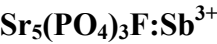


Remark

Can be sensitized for UV excitation by addition of Sn^{2+} , Sb^{3+} , or Ce^{3+} .

Reference

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|------------|---------------|
| SrCO_3 | 140 | 206 |
| SrHPO_4 | 300 | 550 |
| SrF_2 | 50 | 63 |
| Sb_2O_3 | 10 (of Sb) | 14.6 |

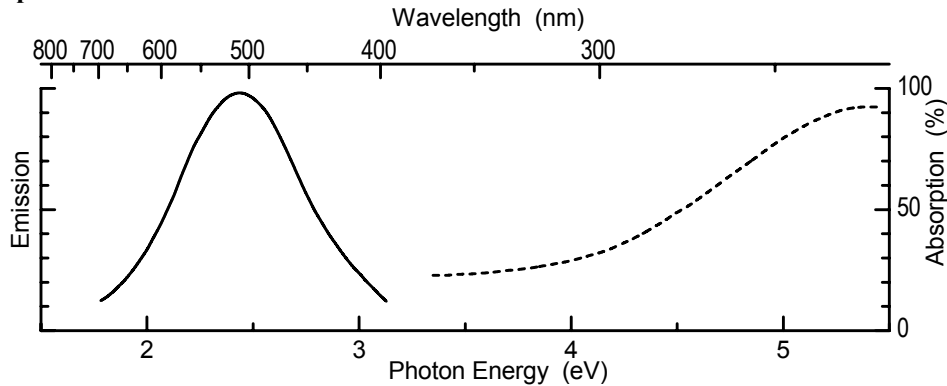
Preparation

Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, N_2 , 1100°C, 1 hour.

Optical Properties

Emission color: Pale whitish blue-green
Emission peak: ~2.43 eV
Emission width (FWHM): 0.75 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



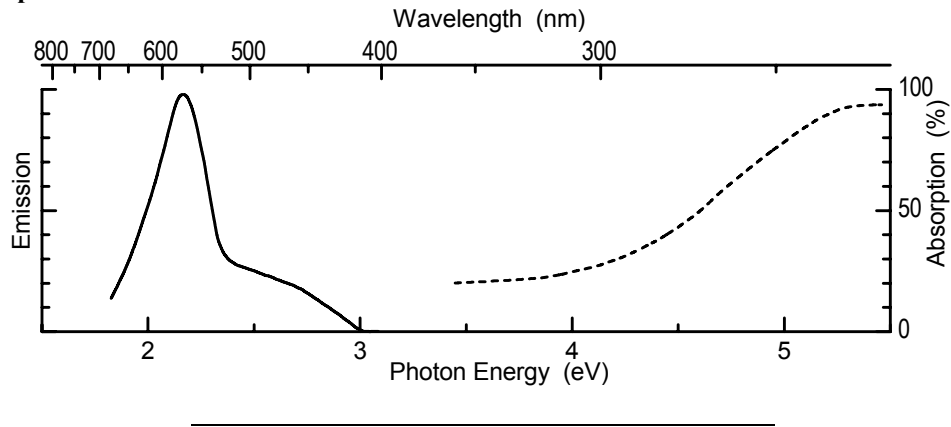
Reference

1. Jenkins, H.J., McKeag, A.H., and Ranby, P.W., Alkaline earth halophosphates and related phosphors, *J. Electrochem. Soc.*, 96, 1 (1949).

Sr₅(PO₄)₃F:Sb³⁺,Mn²⁺

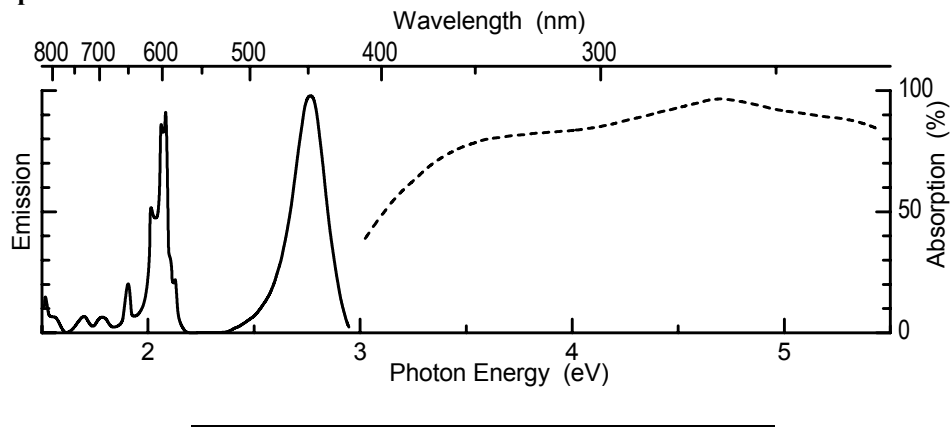
Structure: Hexagonal (apatite)

Spectra



Sr₅(PO₄)₃Cl:Eu²⁺,Pr³⁺

Spectra



Sr₅(PO₄)₃F:Sn²⁺

Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| SrCO ₃ | 140 | 206 |
| SrHPO ₄ | 300 | 550 |
| SrF ₂ | 50 | 63 |
| SnO | 10 | 13.5 |

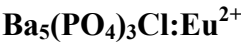
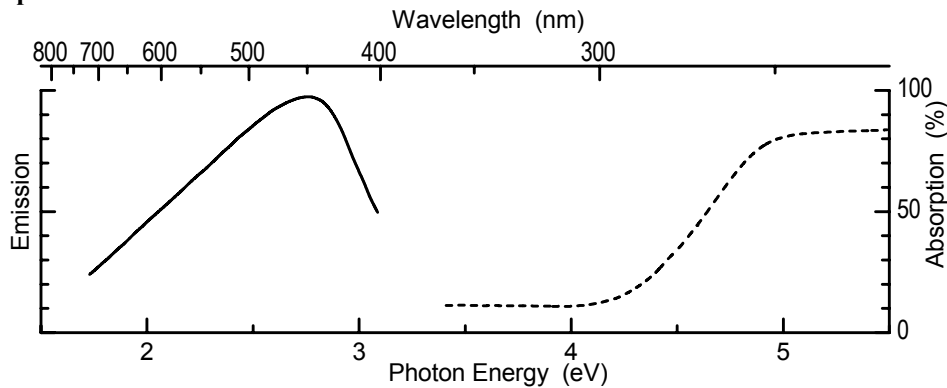
Preparation

Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
Fire in capped quartz tubes, N₂, 1100°C, 1 hour.

Optical Properties

Emission color: Bluish-white
Emission peak: ~2.75 eV
Emission width (FWHM): 0.75 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| BaCO ₃ | 200 | 395 |
| BaHPO ₄ | 300 | 700 |
| NH ₄ Cl | 120 | 64 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |

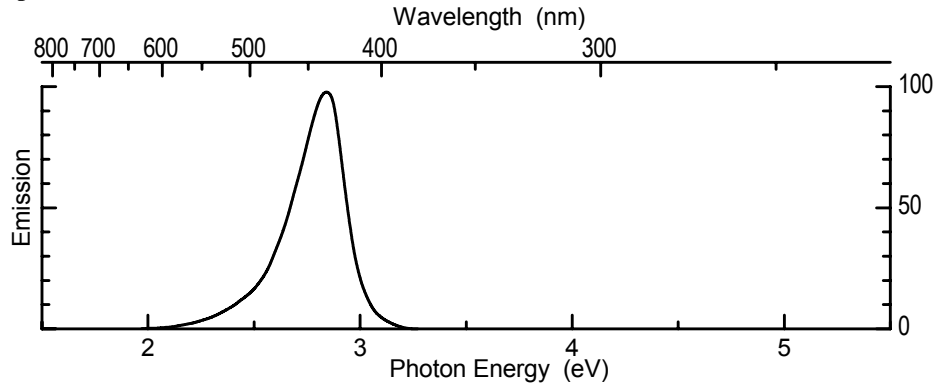
Preparation

- Mix by ball-milling methanol plus a little water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
Add 32 g NH₄Cl; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

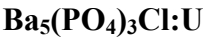
Emission color: Violet-blue
Emission peak: ~2.84 eV
Emission width (FWHM): 0.28 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Wachtel, A., *Bloomfield Report*, BL-R-6-90102-29 (1968).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--|--------|---------------|
| BaHPO ₄ | 190 | 443 |
| BaCO ₃ | 150 | 295 |
| NH ₄ Cl | 120 | 64 |
| UO ₂ (C ₂ H ₃ O ₂) ₂ · 2H ₂ O | 10 | 42 |

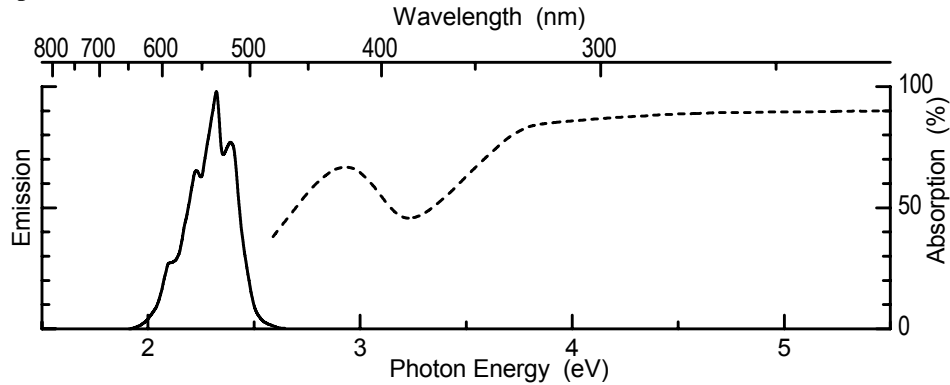
Preparation

- Make a slurry in methanol of BaHPO₄, BaCO₃, and NH₄Cl.
Dissolve the uranyl acetate in a little methanol, and add the solution to the slurry; stir to uniformity.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 850°C, 1 hour.
Powderize.
Add 32 g NH₄Cl; mix by dry grinding or milling.
 2. Fire in capped quartz tubes, N₂, 900°C, 2 hours.
Powderize.
Wash in water several times (stir, let settle, decant).
Dry.

Optical Properties

Emission color: Green
Emission peaks: 2.12–2.39 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV); QE ≈ 50%
Excitation efficiency by e-beam: Poor

Spectra



Reference

1. Anderson, J.T., and Wells, R.S., Luminescent barium and magnesium halophosphates, *J. Electrochem. Soc.*, 98, 414 (1951).



Structure: Hexagonal (apatite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO ₃ | 200 | 200 |
| BaHPO ₄ | 300 | 700 |
| NH ₄ Cl | 120 | 64 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |

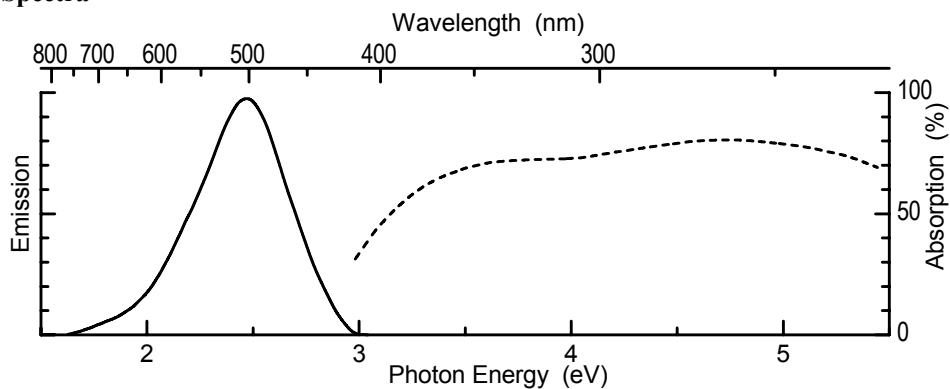
Preparation

- Mix by ball-milling in methanol plus a little water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Add 3.2 g NH₄Cl; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Pale blue-green
Emission peak: 2.46 eV
Emission width (FWHM): 0.49 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Wachtel, A., *Bloomfield Report*, BL-R-6-90102-29 (1968).

4.7 Borates

The following host compounds and activators are included in this subsection:

YBO₃:Ce³⁺
YBO₃:Eu³⁺
LaBO₃:Eu³⁺
β-SrO·3B₂O₃:Pb²⁺
β-SrO·3B₂O₃:Pb²⁺, Mn²⁺
SrO·3B₂O₃:Eu²⁺, Cl
α-SrO·3B₂O₃:Sm²⁺
MgB₂O₄:Mn²⁺
MgYBO₄:Eu³⁺
CaB₂O₄:Mn²⁺
CaB₂O₄:Pb²⁺
CaYBO₄:Bi³⁺
CaYBO₄:Eu³⁺
CaLaBO₄:Eu³⁺
ZnB₂O₄:Mn²⁺
Ca₂B₂O₅:Mn²⁺
LaAlB₂O₆:Eu³⁺
CaLaB₃O₇:Ce³⁺, Mn²⁺
SrB₄O₇:Eu²⁺ (F, Cl, Br)
SrB₄O₇:Pb²⁺
SrB₄O₇:Pb²⁺, Mn²⁺
Cd₂B₆O₁₁:Mn²⁺
YAl₃B₄O₁₂:Ce³⁺
YAl₃B₄O₁₂:Bi³⁺
YAl₃B₄O₁₂:Eu³⁺
YAl₃B₄O₁₂:Eu³⁺, Cr³⁺
YAl₃B₄O₁₂:Th⁴⁺, Ce³⁺, Mn²⁺
YAl₃B₄O₁₂:Ce³⁺, Tb³⁺
LaAl₃B₄O₁₂:Eu³⁺
BaB₈O₁₃:Eu²⁺
SrB₈O₁₃:Sm²⁺
Ca₂B₅O₉Cl:Eu²⁺
Ca₂B₅O₉Cl:Pb²⁺
Ca₂B₅O₉Br:Eu²⁺
Sr₂B₅O₉Cl:Eu²⁺
CaYB_{0.8}O_{3.7}:Eu³⁺
Ca₂La₂BO_{6.5}:Pb²⁺
YAl₃B₄O₁₂:Ce³⁺, Mn²⁺

YBO₃:Ce³⁺

Structure: Vaterite

Optical Properties

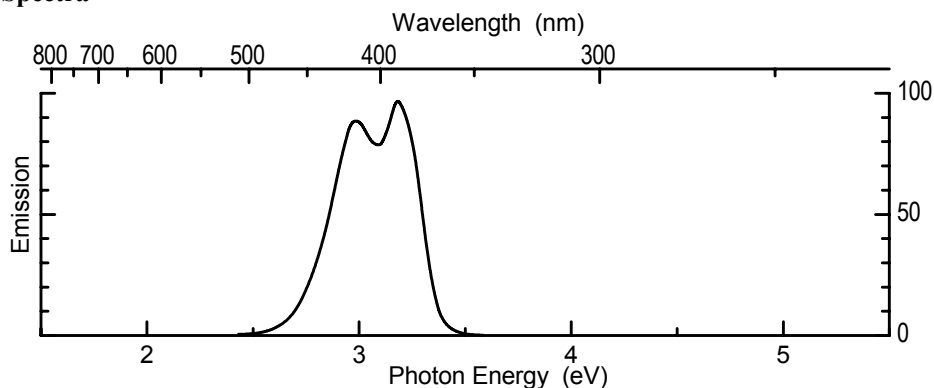
Emission color: Violet-UV

Emission peak: 3.00 and 3.22 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Blasse, G., and Bril, A., The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).
2. Avella, F.J., Sovers, O.J., and Wiggins, C.S., Rare earth cathodoluminescence in InBO₃ and related orthoborates, *J. Electrochem. Soc.*, 114, 613 (1967).
3. Blasse, G., and Bril, A., Fluorescence of Eu³⁺-activated sodium lanthanide titanates, *J. Chem. Phys.*, 48, 3652 (1968).
4. Blasse, G., Bril, A., and Poorter, J.A.D., Radiationless transitions in Eu³⁺ center in LaAlO₃, *J. Chem. Phys.*, 53, 4450 (1970).
5. Blasse, G., Ultraviolet-absorption bands of Bi³⁺ and Eu³⁺ in oxides, *J. Solid State Chem.*, 4, 52 (1972).
6. Bril, A., Blasse, G., and de Poorter, J.A., Fast-decay phosphors, *J. Electrochem. Soc.*, 117, 346 (1970).

YBO₃:Eu³⁺

Structure: Vaterite

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| Y ₂ O ₃ | 92 (of Y) | 104 |
| Eu ₂ O ₃ | 8 (of Eu) | 14 |
| H ₃ BO ₃ | 105 | 65 |

Preparation

Mix by dry grinding or milling.

1. Fire in open quartz boats, air, ~500°C, 1 hour.

- Powderize.
2. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
3. Fire in open quartz boats, air, 1250°C, 1 hour.

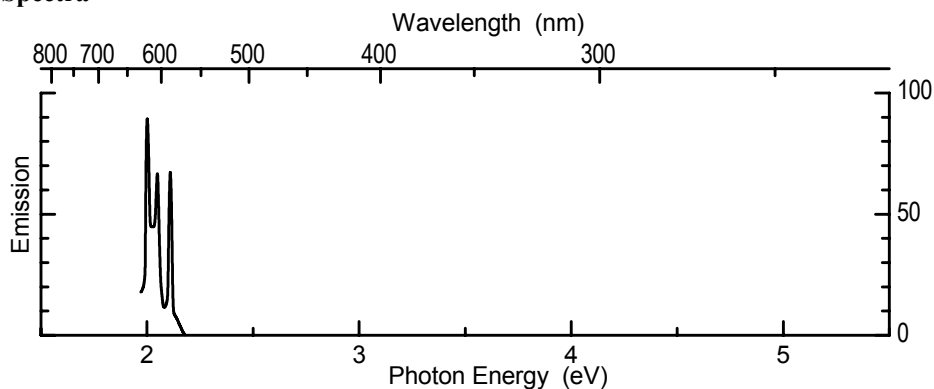
Optical Properties

Emission color: Red-orange

Emission peaks: 1.98–2.10 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



References

1. Avella, F.J., Sovers, O.J., and Wiggins, C.S., Rare earth cathodoluminescence in InBO₃ and related orthoborates, *J. Electrochem. Soc.*, 114, 613 (1967).
2. Veenis, A.W., and Bril, A., Fine structure in the low temperature luminescence of Zn₂SiO₄:Mn and Mg₄Ta₂O₉:Mn, *Philips J. Res.*, 33, 124 (1978).

LaBO₃:Eu³⁺

Structure: Orthorhombic (aragonite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|------------|---------------|
| La ₂ O ₃ | 92 (of La) | 150 |
| Eu ₂ O ₃ | 8 (of Eu) | 14 |
| H ₃ BO ₃ | 105 | 65 |

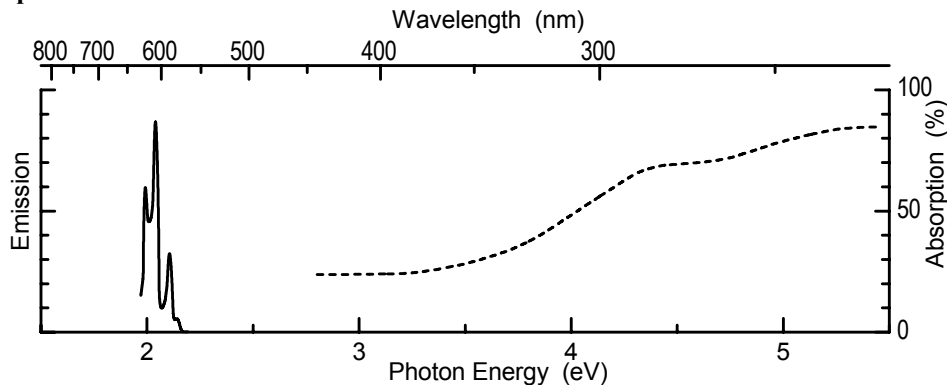
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, ~500°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
 3. Fire in open quartz boats, air, 1150°C, 2 hours.

Optical Properties

Emission color: Light red
Emission peaks: 1.995, 2.02, and 2.10 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



References

1. Avella, F.J., Sovers, O.J., and Wiggins, C.S., Rare earth cathodoluminescence in InBO₃ and related orthoborates, *J. Electrochem. Soc.*, 114, 613 (1967).
2. Bril, A., and Wanmaker, W.L., Fluorescent properties of some europium-activated phosphors, *J. Electrochem. Soc.*, 111, 1363 (1964).



Composition

| <hr/> | | |
|--------------------------------|--------|---------------|
| Ingredient | Mole % | By weight (g) |
| SrCO ₃ | 99 | 146 |
| PbO | 1 | 2.3 |
| H ₃ BO ₃ | 600 | 370 |
| NH ₄ Cl | 5 | 2.7 |

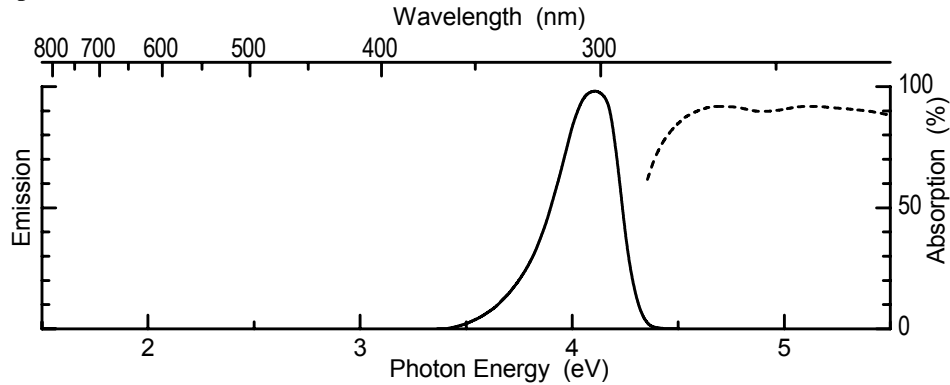
Preparation

- Mix by dry grinding or milling.
1. Fire in capped quartz tubes, air. Place into cold furnace, go slowly up with temperature to 600°C, and then take out.
Powderize.
 2. Fire in capped quartz tubes, N₂, 700°C, 2 hours.
Powderize.
 3. Fire in capped quartz tubes, N₂, 700°C, 16 hours (overnight).

Optical Properties

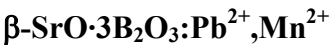
Emission color: UV
Emission peak: 4.09 eV
Emission width (FWHM): 0.33 eV
Excitation efficiency by UV: + (4.88 eV)

Spectra



References

1. Witzmann, H., Buhrow, J., and Müller, K., Zum emissionsvermögen blei-mangan-aktivierter kalziumboratphosphore (CaO.XB₂O₃-Pb,Mn), *Naturwissenschaften*, 51, 103 (1964).
2. Witzmann, H., and Schreiber, H., Zur lumineszenz kupfer- und kupferbleiaktivierter strontiumboratphosphore, *Naturwissenschaften*, 49, 181 (1962).
3. Witzmann, H., Müller, R., and Semisch, G., Boratluminophore MIT UV-emission, *Naturwissenschaften*, 43, 580 (1956).
4. Witzmann, H., and Treichler, W., Zur uv-emission bleiaktivierter strontium-boratluminophore, *Naturwissenschaften*, 45, 542 (1958).
5. Witzmann, H., and Müller, R., *Z. Phys. Chem. (Leipzig)*, 211, 307 (1959).
6. Witzmann, H., and Treichler, W., *Z. Phys. Chem. (Leipzig)*, 212, 205 (1959).



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------|---------------|
| SrCO ₃ | 98 | 180 |
| PbO | 1 | 2.28 |
| MnCO ₃ | 1 | 1.15 |
| H ₃ BO ₃ | 600 | 372 |
| NH ₄ Cl | 5 | 2.7 |

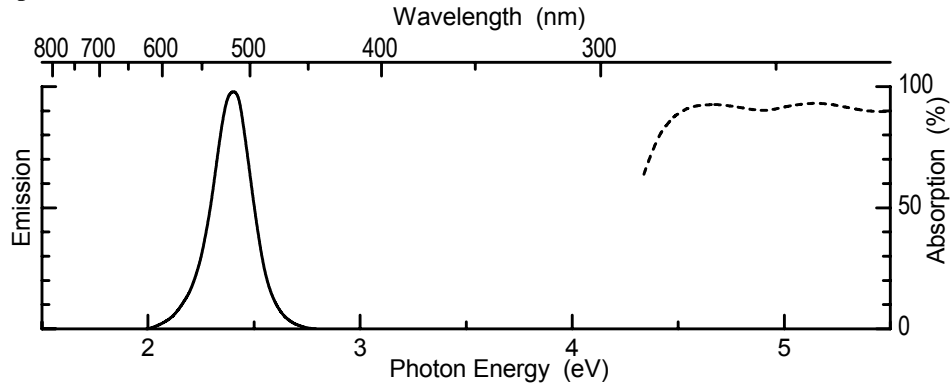
Preparation

- Mix by dry grinding or milling.
1. Fire in capped quartz tubes, air. Place into cold furnace, go slowly up with temperature to 600°C, and then take out. Powderize.
 2. Fire in capped quartz tubes, N₂, 700°C, 2 hours. Powderize.
 3. Fire in capped quartz tubes, N₂, 700°C, 16 hours (overnight).

Optical Properties

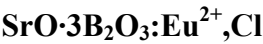
Emission color: Bluish-green
Emission peak: 2.41 eV
Emission width (FWHM): 0.22 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV); QE ≈ 45–50%

Spectra



Reference

1. Witzmann, H., and Schreiber, H., Zur lumineszenz kupfer- und kupferbleiaktivierter strontiumboratphosphore, *Naturwissenschaften*, 49, 181 (1962).



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| SrCO ₃ | 98 | 180 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| H ₃ BO ₃ | 620 | 384 |
| NH ₄ Cl | 50 | 27 |

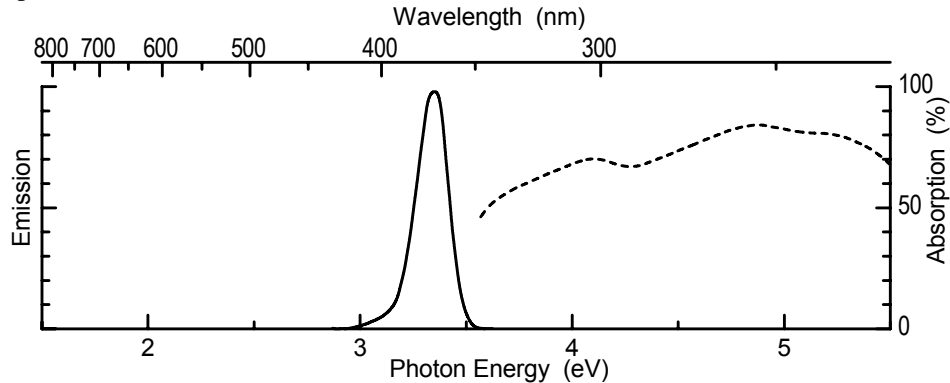
Preparation

- Mix all ingredients but the NH₄Cl by dry grinding or milling.
1. Fire in open quartz boats, air, ~500°C, ½ hour.
Powderize.
 2. Fire in open quartz boats, N₂ , 700°C, 1 hour.
Add the above NH₄Cl; mix by dry grinding.
Powderize.
 3. Fire in capped quartz tubes, CO , 850°C, 4 hours.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: UV
Emission peak: 3.37 eV
Emission width (FWHM): 0.16 eV
Excitation efficiency by UV: ++ (4.88 eV)

Spectra



Remarks

- 1. The exact chemical formula of this material is still unknown.
- 2. The Cl in this recipe can be replaced by F or Br.



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| SrCO ₃ | 99 | 146 |
| Sm ₂ O ₃ | 1 (of Sm) | 1.74 |
| H ₃ BO ₃ | 600 | 370 |

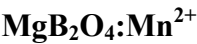
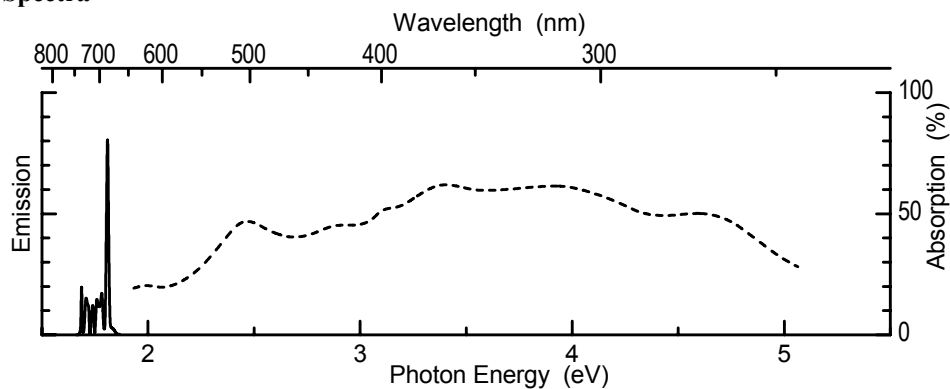
Preparation

- Mix by dry grinding or milling.
- 1. Fire in open quartz boats, air. Place into cold furnace, go slowly up with temperature to 600°C, and then take out.
Powderize.
 - 2. Fire in open quartz boats, N₂, 800°C, 1 hour.
Powderize.
 - 3. Fire in open quartz boats, CO, 900°C, 4 hours.

Optical Properties

Emission color: Deep red
Emission peak: 1.812 eV
Excitation efficiency by UV: ++ (3.40 eV); QE ≈ 60% (estimated)

Spectra



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------|---------------|
| MgO | 98 | 40 |
| MnCO ₃ | 2 | 2.3 |
| H ₃ BO ₃ | 205 | 127 |

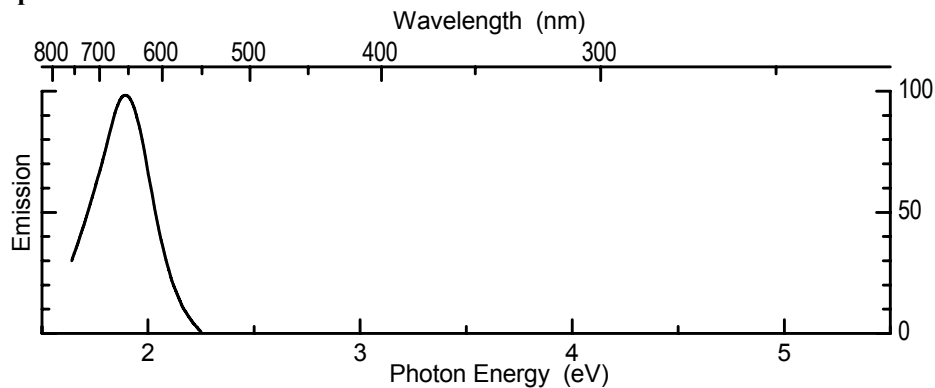
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, N₂, ~500°C. Powderize.
 2. Fire in open quartz boats, N₂, 700°C, 1 hour. Powderize.
 3. Fire in open quartz boats, N₂.
For α -structure, fire 2 hours at 1000°C.
For β -structure, fire 4 hours at 850°C.

Optical Properties

- Emission color: Red
Emission peak: 1.88 eV, 2.11 eV (see remark)
Emission width (FWHM): 0.32 eV, 0.39 eV (see remark)
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



Remarks

- 1. This material comes in two different modifications, the high-temperature α -phase, and the low-temperature β -phase. Peak position depends on modification.
- 2. It can be sensitized for UV excitation by addition of $Ce^{3+} + Li^{+}$.

Reference

- 1. Ranby, P.W., U.S. Pat., 3 014 817 (1961).



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| MgO | 100 | 40.3 |
| Y ₂ O ₃ | 95 (of Y) | 107 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| H ₃ BO ₃ | 205 | 63.2 |

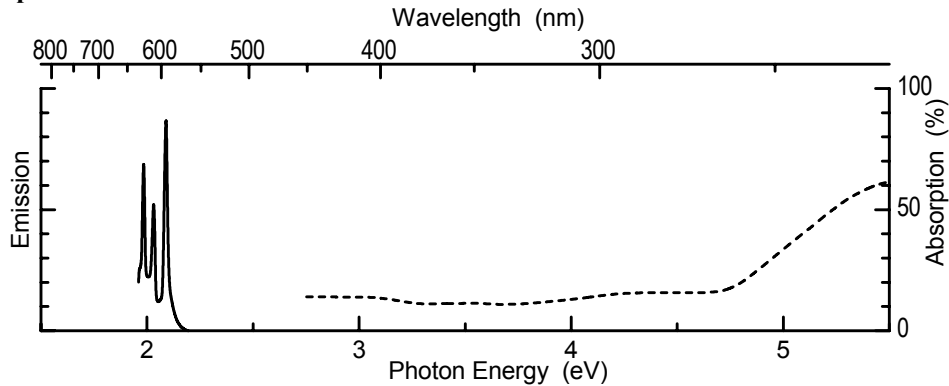
Preparation

- Mix by dry grinding or milling.
- 1. Fire in open quartz boats, air, ~500°C.
Powderize.
 - 2. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
 - 3. Fire in open quartz boats, air, 1200°C, 1 hour.

Optical Properties

Emission color: Orange-red
Emission peaks: 1.985, 2.035, and 2.098 eV
Excitation efficiency by UV: + (4.88 eV); QE \approx 25–30%

Spectra



CaB₂O₄:Mn²⁺

Structure: Orthorhombic

Optical Properties

- Emission color: Green
- Emission peak: 2.34 eV
- Emission width (FWHM): 0.23 eV
- Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
- Excitation efficiency by e-beam: +

Reference

1. Witzmann, H., Buhrow, J., and Müller, K., Zum emissionsvermögen blei-mangan-aktivierter kalziumboratphosphore (CaO·B₂O₃-Pb,Mn), *Naturwissenschaften*, 51, 103 (1964).

CaB₂O₄:Pb²⁺

Optical Properties

- Emission color: UV
- Emission peak: 3.82 eV
- Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Reference

1. Witzmann, H., Buhrow, J., and Müller, K., Zum emissionsvermögen blei-mangan-aktivierter kalziumboratphosphore(CaO·B₂O₃-Pb,Mn), *Naturwissenschaften*, 51, 103 (1964).

CaYBO₄:Bi³⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO | 100 | 100 |
| Y ₂ O ₃ | 99 (of Y) | 112 |
| Bi ₂ O ₃ | 1 (of Bi) | 2.3 |
| H ₃ BO ₃ | 105 | 65 |

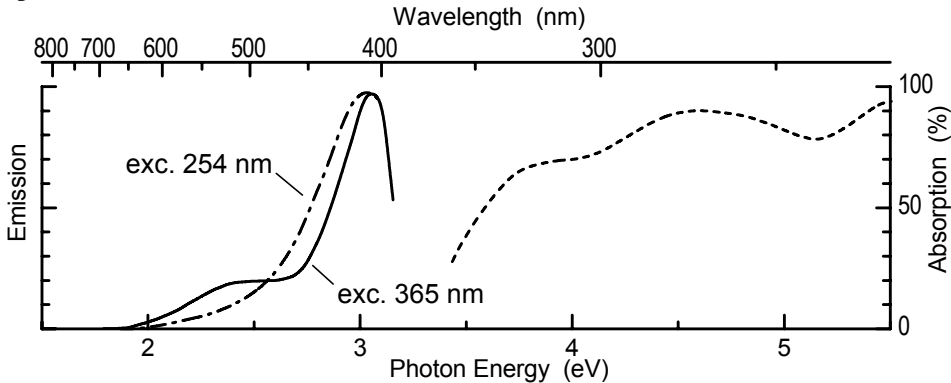
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, ~500°C, ½ hour.
Powderize.
 2. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
Add 2 g of NH₄Cl; mix by dry grinding.
 3. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.

Optical Properties

- Emission color: Blue
- Emission peak: 2.99 eV (for UV 4.88 eV), 3.02 eV (for UV 3.40 eV)
- Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



Remark

1. Peak position seems to depend on the excitation.



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO | 100 | 100 |
| Y ₂ O ₃ | 97 (of Y) | 110 |
| Eu ₂ O ₃ | 3 (of Eu) | 5.3 |
| H ₃ BO ₃ | 105 | 65 |

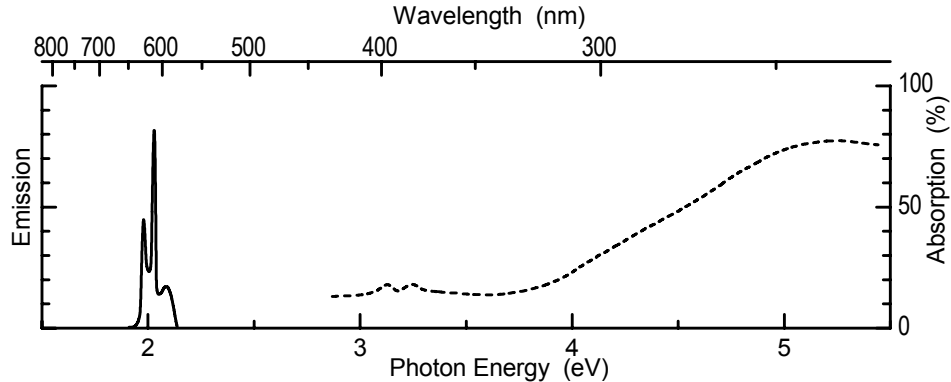
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, ~500°C, ½ hour.
Powderize.
 2. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
 3. Fire in open quartz boats, air, 1200°C, 1 hour.

Optical Properties

Emission color: Light red
Emission peak: 2.04 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Blasse, G., Ultraviolet-absorption bands of Bi^{3+} and Eu^{3+} in oxides, *J. Solid State Chem.*, 4, 52 (1972).

 $\text{CaLaBO}_4:\text{Eu}^{3+}$
Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|---------------|----------------------|
| CaCO_3 | 100 | 100 |
| La_2O_3 | 90 (of La) | 146.7 |
| Eu_2O_3 | 10 (of Eu) | 17.6 |
| H_3BO_3 | 102 | 63.2 |

Preparation

Mix by dry grinding or milling.

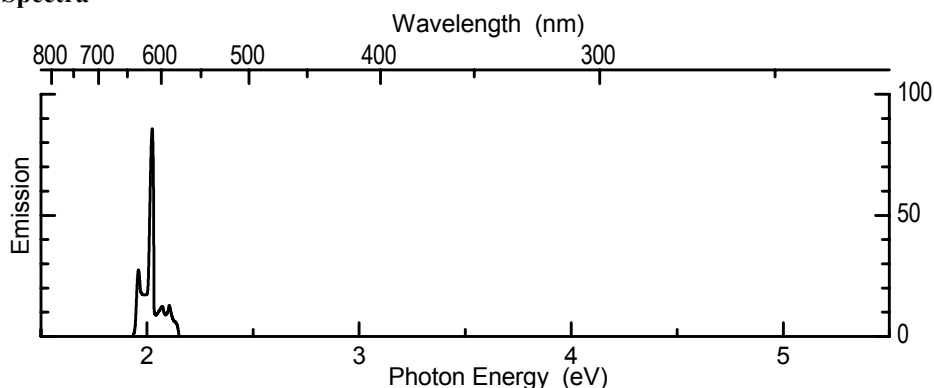
1. Fire in open quartz boats, air, $\sim 500^\circ\text{C}$. Powderize.
2. Fire in open quartz boats, N_2 , 1000°C , 1 hour. Powderize.
3. Fire in open quartz boats, N_2 , 1200°C , 1 hour. Powderize.
Add 5 g of NH_4Cl ; mix by dry grinding.
4. Fire in capped quartz tubes, N_2 , 1200°C , 16 hours (overnight).
Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: Light red

Emission peak: 2.03 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra**Remarks**

1. This phosphor is somewhat discolored and less efficient if fired in air or oxygen.
2. Spectrum resembles that of YOЕ.

Reference

1. Blasse, G., Ultraviolet-absorption bands of Bi^{3+} and Eu^{3+} in oxides, *J. Solid State Chem.*, 4, 52 (1972).

ZnB₂O₄:Mn²⁺**Composition**

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------|---------------|
| ZnO | 97 | 79 |
| MnCO ₃ | 3 | 3.5 |
| H ₃ BO ₃ | 205 | 127 |

Preparation

Mix by dry grinding or milling.

1. Fire in open quartz boats, air, ~500°C. Powderize.
2. Fire in open quartz boats, air, 700°C, 1 hour. Powderize.
3. Fire in open quartz boats, air, 900°C, 2 hours.

Optical Properties

Emission color: Yellow-green

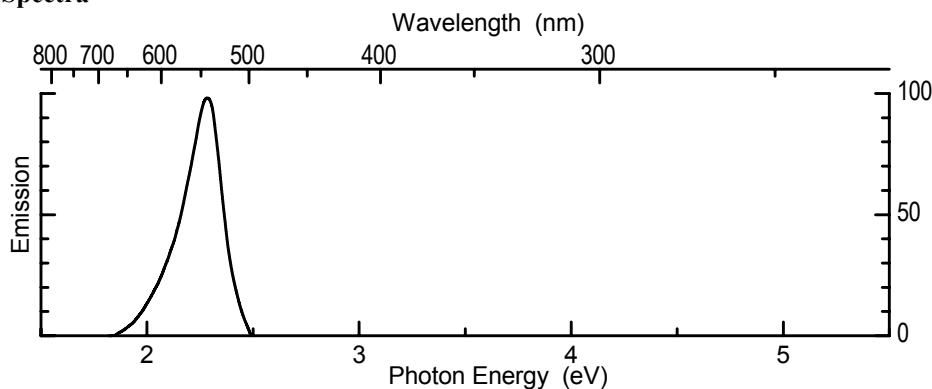
Emission peak: 2.29 eV

Emission width (FWHM): 0.21 eV

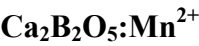
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +/4–5%

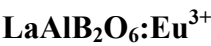
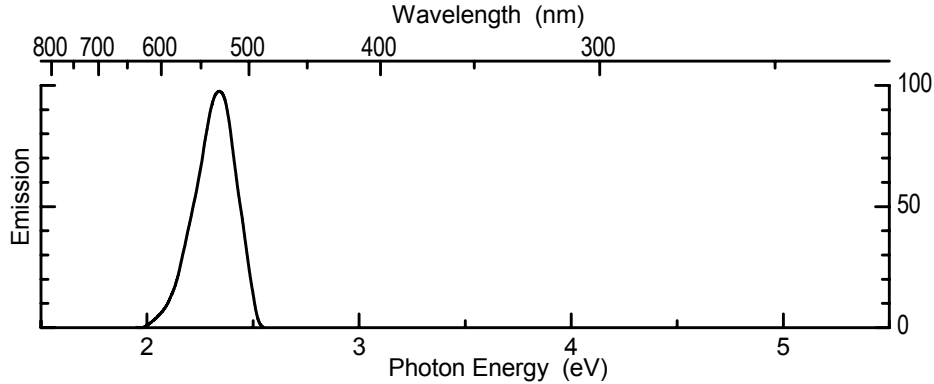
Decay: Exponential decay, about 26 msec to 1/10

Spectra**References**

1. Kröger, F.A., *Some Aspects of Luminescence of Solids*, Elsevier, Amsterdam (1948).
2. Strange, J.W., and Henderson, S.T., Cathodo-luminescence. 1. Growth and decay processes, *P. Phys. Soc. London*, 58, 369 (1946).
3. Randall, J.T., *Proc. R. Soc.*, A170, 272 (1939).
4. Harrison, D.E., and Hummel, F.A., Phase equilibria and fluorescence in the system zinc oxide-boric oxide, *J. Electrochem. Soc.*, 103, 491 (1956).
5. Terol, S., and Otero, M.J., Anhydrous zinc borate as a host crystal in luminescence, *Z. Naturforsch. Pt. A*, 16, 920 (1961).



Spectra



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 92 (of La) | 150 |
| Eu ₂ O ₃ | 8 (of Eu) | 14 |
| Al ₂ O ₃ | 100 (of Al) | 51 |
| H ₃ BO ₃ | 205 | 127 |

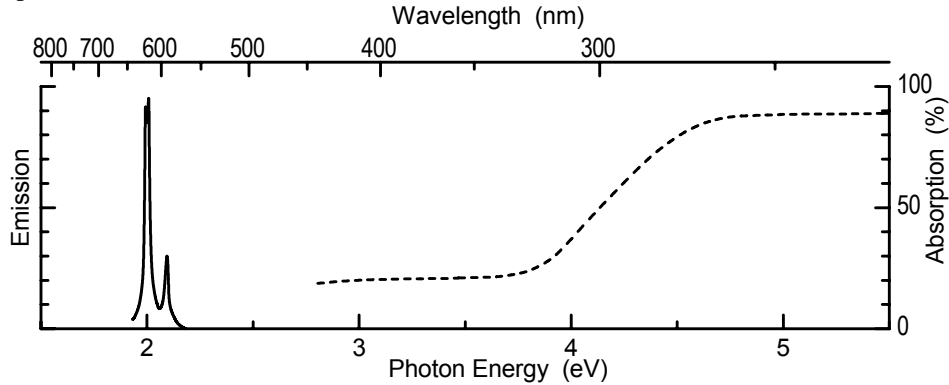
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, ~500°C.
Powderize.
 2. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
 3. Fire in open quartz boats, air, 1200°C, 1 hour.

Optical Properties

Emission color: Light red
Emission peaks: Two overlapping lines at 2.015 and 2.205 eV, additionally a weaker line at 2.10 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



CaLaB₃O₇:Ce³⁺,Mn²⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|------------|---------------|
| CaCO ₃ | 95 | 95 |
| La ₂ O ₃ | 98 (of La) | 160 |
| MnCO ₃ | 5 | 5.8 |
| CeO ₂ | 2 | 3.4 |
| H ₃ BO ₃ | 310 | 192 |

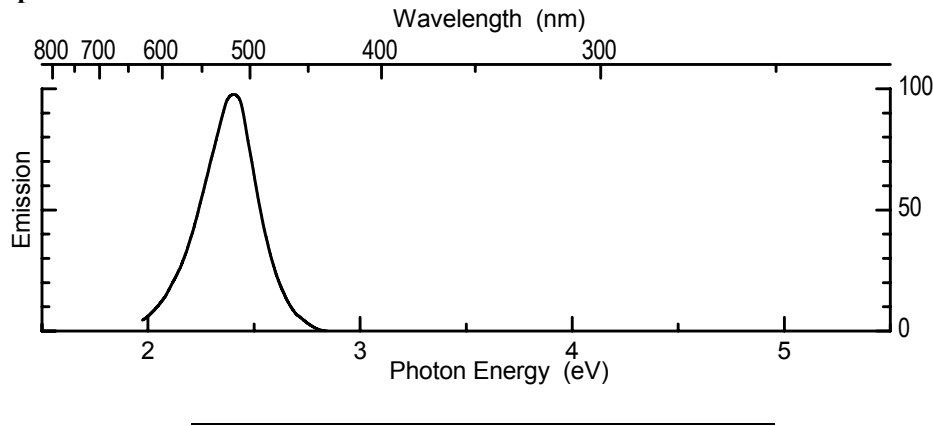
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, ~500°C.
Powderize.
 2. Fire in open quartz boats, N₂, 700°C, 1 hour.
Powderize.
 3. Fire in open quartz boats, CO, 900°C, 2 hours.

Optical Properties

Emission color: Green
Emission peak: 2.40 eV
Emission width (FWHM): 0.29 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra

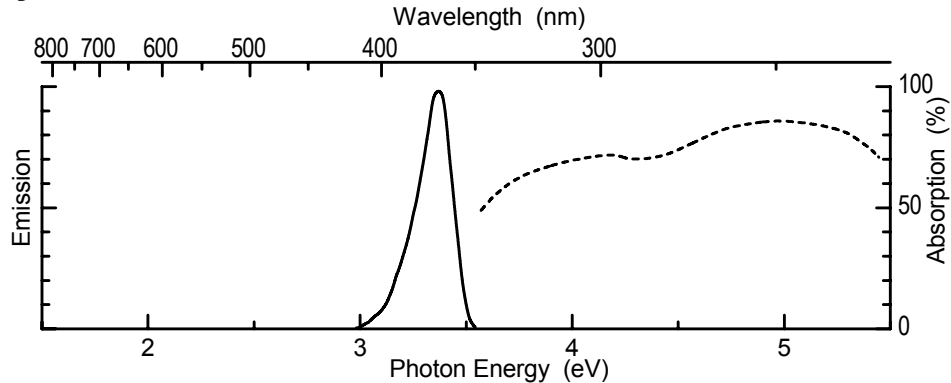


SrB₄O₇:Eu²⁺(F,Cl,Br)

Optical Properties

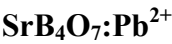
Emission color: UV
Emission peak: 3.37 eV
Emission width (FWHM): 0.16 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

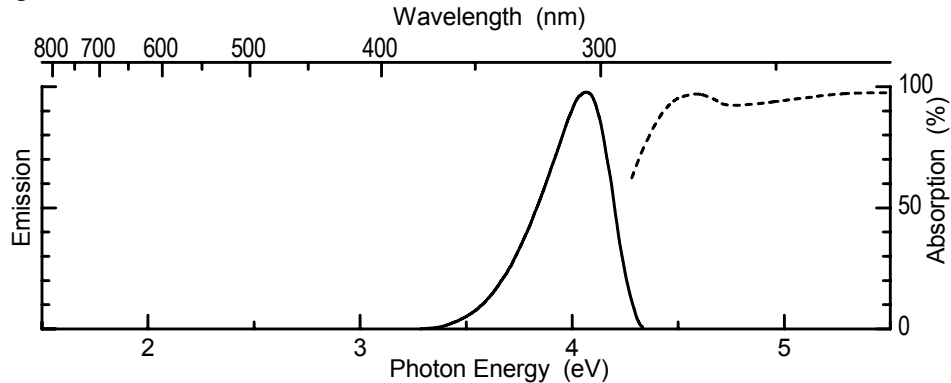
1. Machida, K., Adachi, G., and Shiokawa, J., Luminescence properties of Eu(II)-borates and Eu²⁺-activated Sr-borates, *J. Lumin.*, 21, 101 (1979).



Optical Properties

Emission color: UV
Emission peak: 4.09 eV
Emission width (FWHM): 0.34 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Witzmann, H., and Schreiber, H., Zur lumineszenz kupfer- und kupferbleiaktivierter strontiumboratphosphore, *Naturwissenschaften*, 49, 181 (1962).
2. Witzmann, H., Müller, R., and Semisch, G., Boratluminophore MIT UV-emission, *Naturwissenschaften*, 43, 580 (1956).

$\text{SrB}_4\text{O}_7:\text{Pb}^{2+},\text{Mn}^{2+}$

Optical Properties

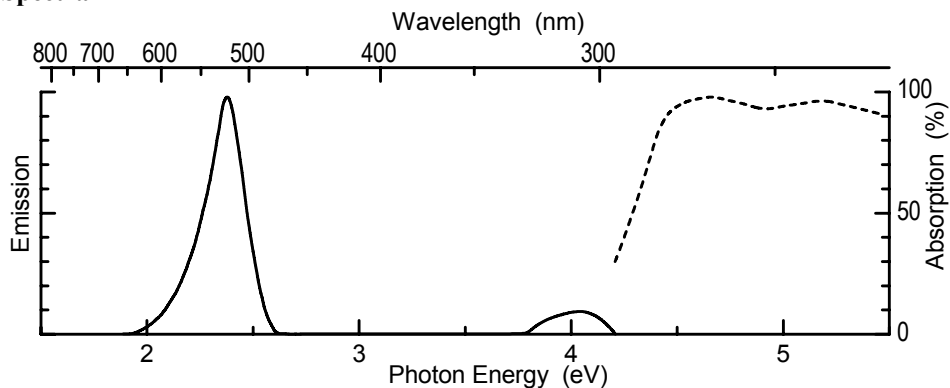
Emission color: Blue-green

Emission peak: 2.42, 4.03 eV

Emission width (FWHM): 0.22 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Witzmann, H., and Schreiber, H., Zur lumineszenz kupfer- und kupferbleiaktivierter strontiumboratphosphore, *Naturwissenschaften*, 49, 181 (1962).
2. Witzmann, H., Müller, R., and Semisch, G., Boratluminophore MIT UV-emission, *Naturwissenschaften*, 43, 580 (1956).

$\text{Cd}_2\text{B}_6\text{O}_{11}:\text{Mn}^{2+}$

Optical Properties

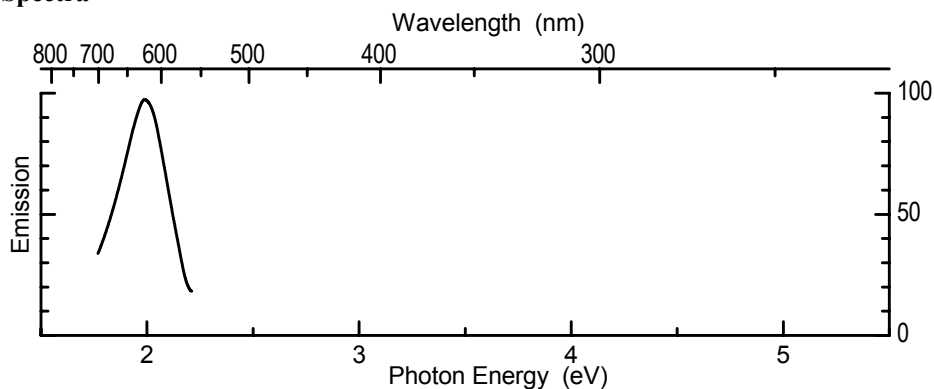
Emission color: Yellow-green

Emission peak: eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

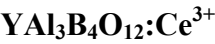
Excitation efficiency by e-beam: +

Spectra



References

1. Harrison, D.E., and Hummel, F.A., Phase equilibria and fluorescence in the system zinc oxide-boric oxide, *J. Electrochem. Soc.*, 103, 491 (1956).
2. Hummel, F.A., and Subbarao, E.C., The system cadmium oxide-boric oxide. 2. Fluorescence, *J. Electrochem. Soc.*, 104, 616 (1957).



Structure: Trigonal (huntite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| Y ₂ O ₃ | 90 (of Y) | 102 |
| CeO ₂ | 10 | 17.2 |
| Al ₂ O ₃ | 300 (of Al) | 153 |
| H ₃ BO ₃ | 410 | 254 |

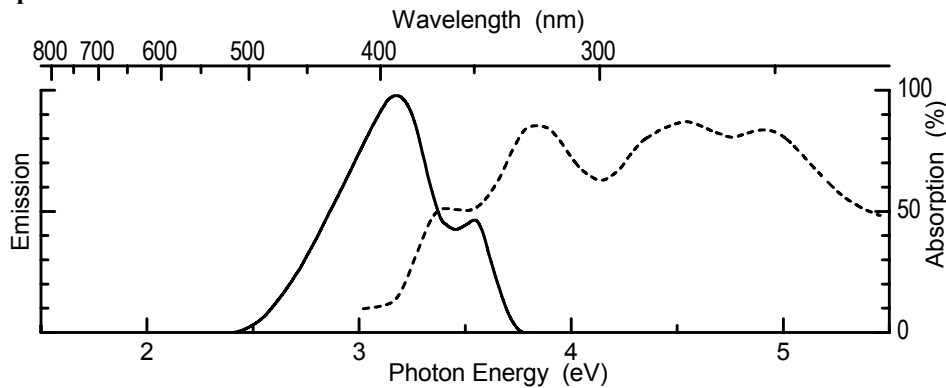
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, ~500°C. Powderize.
 2. Fire in open alumina crucibles, N₂, 900°C, 1 hour. Powderize.
 3. Fire in open alumina crucibles, CO, 1100°C, 1 hour. Powderize.
 4. Fire in open alumina crucibles, CO, 1200°C, 1 hour. Powderize.
- Wash in hot water several times. Dry.

Optical Properties

Emission color: Blue-violet + UV
Emission peaks: 3.20 and 3.57 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

1. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).
2. Blasse, G., Bril, A., and Poorter, J.A.D., Radiationless transitions in Eu³⁺ center in LaAlO₃, *J. Chem. Phys.*, 53, 4450 (1970).

- Blasse, G., Ultraviolet-absorption bands of Bi^{3+} and Eu^{3+} in oxides, *J. Solid State Chem.*, 4, 52 (1972).
- Danielmeyer, H.G., Efficiency and fluorescence quenching of stoichiometric rare-earth laser materials, *J. Lumin.*, 12, 179 (1976).
- Takahashi, T., and Yamada, O., Cathodoluminescent properties of yttrium terbium aluminum borate $\text{Y}_{1-x}\text{Tb}_x\text{Al}_3\text{B}_4\text{O}_{12}$ phosphors, *J. Electrochem. Soc.*, 124, 955 (1977).



Structure: Trigonal (huntite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| Y_2O_3 | 99.7 (of Y) | 113 |
| Bi_2O_3 | 0.3 (of Bi) | 0.700 |
| Al_2O_3 | 300 (of Al) | 153 |
| H_3BO_3 | 410 | 254 |

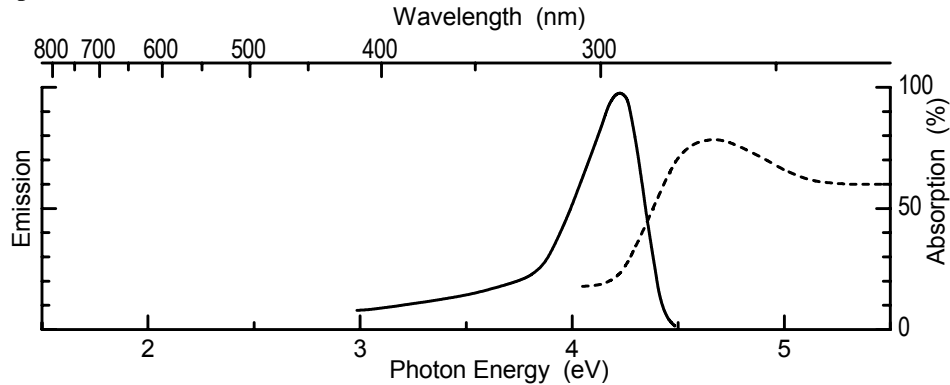
Preparation

- Mix by dry grinding or milling.
- Fire in open quartz boats, air, $\sim 500^\circ\text{C}$, 1 hour. Powderize.
 - Fire in open alumina crucibles, air, 900°C , 1 hour. Powderize.
 - Fire in open alumina crucibles, air, 1100°C , 1 hour. Powderize.
 - Fire in open alumina crucibles, air, 1200°C , 1 hour. Powderize.
- Wash in hot water several times. Dry.

Optical Properties

Emission color: UV
 Emission peak: 4.20 eV
 Emission width (FWHM): 0.33 eV
 Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



References

- Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).
- Blasse, G., and Bril, A., Fluorescence of Eu^{3+} -activated sodium lanthanide titanates, *J. Chem. Phys.*, 48, 3652 (1968).

- Blasse, G., Ultraviolet-absorption bands of Bi^{3+} and Eu^{3+} in oxides, *J. Solid State Chem.*, 4, 52 (1972).
- Blasse, G., and Bril, A., Photoluminescent efficiency of phosphors with electronic transitions in localized centers, *J. Electrochem. Soc.*, 115, 1067 (1968).
- Kellendonk, F., van Os, M.A., and Blasse, G., Luminescence of bismuth in yttrium aluminum borate, *Chem. Phys. Lett.*, 61, 239 (1979).

$\text{YAl}_3\text{B}_4\text{O}_{12}:\text{Eu}^{3+}$

Structure: Trigonal (huntite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| Y_2O_3 | 90 (of Y) | 102 |
| Eu_2O_3 | 10 (of Eu) | 17.6 |
| Al_2O_3 | 300 (of Al) | 153 |
| H_3BO_3 | 410 | 248 |

Preparation

Mix by dry grinding or milling.

- Fire in open quartz boats, air, $\sim 500^\circ\text{C}$, 1 hour. Powderize.
- Fire in open alumina crucibles, air, 900°C , 1 hour. Powderize.
- Fire in open alumina crucibles, air, 1100°C , 1 hour. Powderize.
- Fire in open alumina crucibles, air, 1200°C , 1 hour. Powderize.

Wash in hot water several times. Dry.

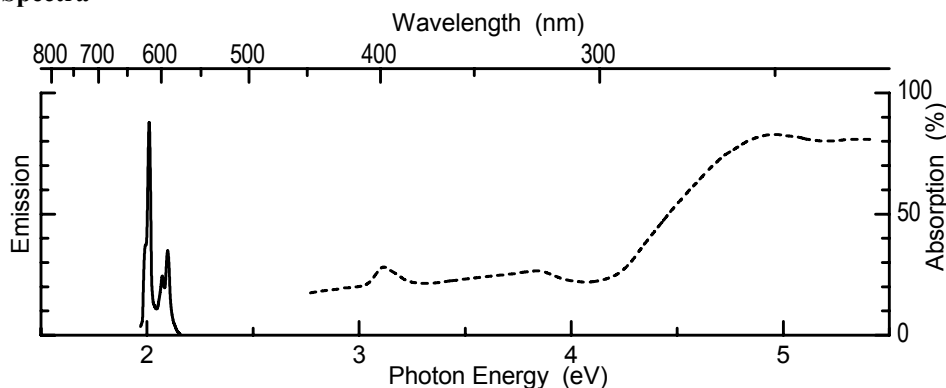
Optical Properties

Emission color: Red

Emission peaks: 2.01 and 2.035 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

- Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).
- Blasse, G., Ultraviolet-absorption bands of Bi^{3+} and Eu^{3+} in oxides, *J. Solid State Chem.*, 4, 52 (1972).
- Takahashi, T., and Yamada, O., Cathodoluminescent properties of yttrium terbium aluminum borate $\text{Y}_1\text{-X TbXAl}_3\text{B}_4\text{O}_{12}$ phosphors, *J. Electrochem. Soc.*, 124, 955 (1977).

YAl₃B₄O₁₂:Eu³⁺,Cr³⁺

Structure: Trigonal (huntite)

Optical Properties

Emission color: Deep red

Emission peak: 1.77 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Reference

1. Blasse, G., and Bril, A., Some observations on Cr³⁺ fluorescence in huntite structure, *Phys. Status Solidi*, 20, 551 (1967).

YAl₃B₄O₁₂:Th⁴⁺,Ce³⁺,Mn²⁺

Structure: Trigonal (huntite)

Emission color: green

Emission peak: 2.31 eV

Emission width (FWHM): 0.23 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

YAl₃B₄O₁₂:Ce³⁺,Tb³⁺

Structure: Trigonal (huntite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| Y ₂ O ₃ | 80 (of Y) | 90.4 |
| CeO ₂ | 10 | 17.2 |
| Tb ₄ O ₇ | 10 (of Tb) | 18.7 |
| Al ₂ O ₃ | 300 (of Al) | 153 |
| H ₃ BO ₃ | 410 | 254 |

Preparation

Mix by dry grinding or milling.

1. Fire in open quartz boats, air, ~500°C, 1 hour. Powderize.
 2. Fire in open alumina crucibles, N₂, 900°C, 1 hour. Powderize.
 3. Fire in open alumina crucibles, CO, 1100°C, 1 hour. Powderize.
 4. Fire in open alumina crucibles, CO, 1200°C, 1 hour. Powderize.
- Wash in hot water several times.

Dry.

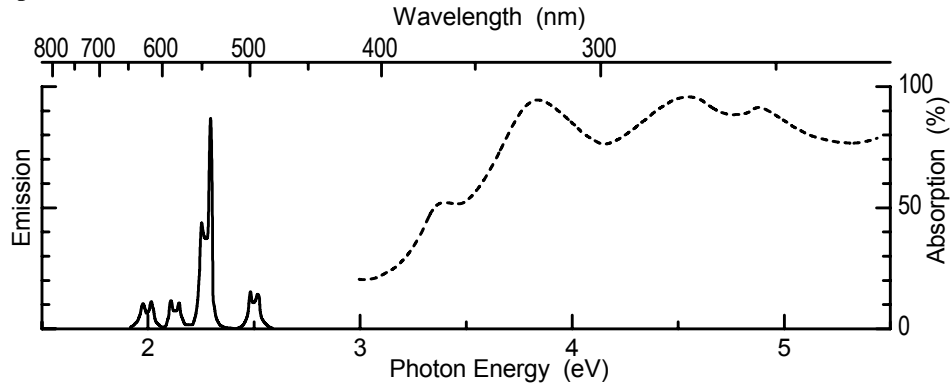
Optical Properties

Emission color: Green

Emission peak: 2.29 eV

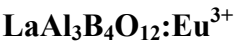
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).
2. Takahashi, T., and Yamada, O., Cathodoluminescent properties of yttrium terbium aluminum borate $Y_{1-x}Tb_xAl_3B_4O_{12}$ phosphors, *J. Electrochem. Soc.*, 124, 955 (1977).
3. Blasse, G., and Bril, A., Fluorescence of Eu^{3+} -activated lanthanide oxyhalides $LnOX$, *J. Chem. Phys.*, 46, 2579 (1967); and Study of energy transfer from Sb^{3+} , Bi^{3+} , Ce^{3+} to Sm^{3+} , Eu^{3+} , Tb^{3+} , Dy^{3+} , *J. Chem. Phys.*, 47, 1920 (1967).



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 90 (of La) | 147 |
| Eu ₂ O ₃ | 10 (of Eu) | 17.6 |
| Al ₂ O ₃ | 300 (of Al) | 153 |
| H ₃ BO ₃ | 410 | 254 |

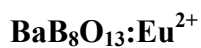
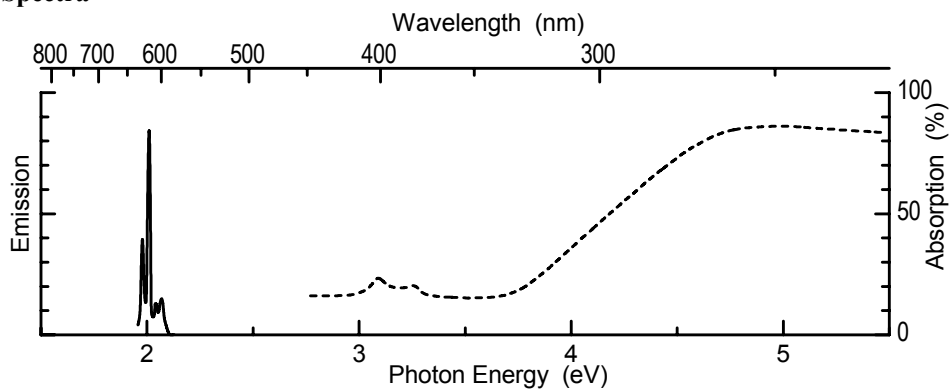
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, ~500°C.
Powderize.
 2. Fire in open quartz boats, air, 900°C, 1 hour.
Powderize.
 3. Fire in open quartz boats, air, 1200°C, 2 hours.

Optical Properties

Emission color: Red
Emission peak: 2.005 and 2.020 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



Optical Properties

Emission color: Violet-UV

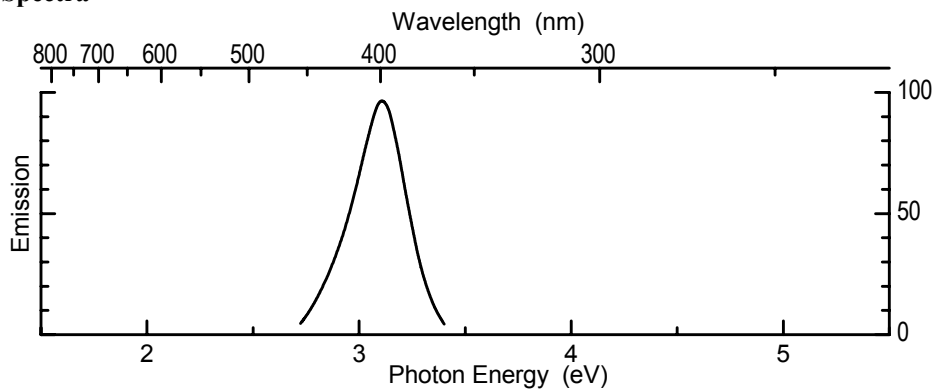
Emission peak: 3.10 eV

Emission width (FWHM): 0.28 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: –

Spectra



Reference

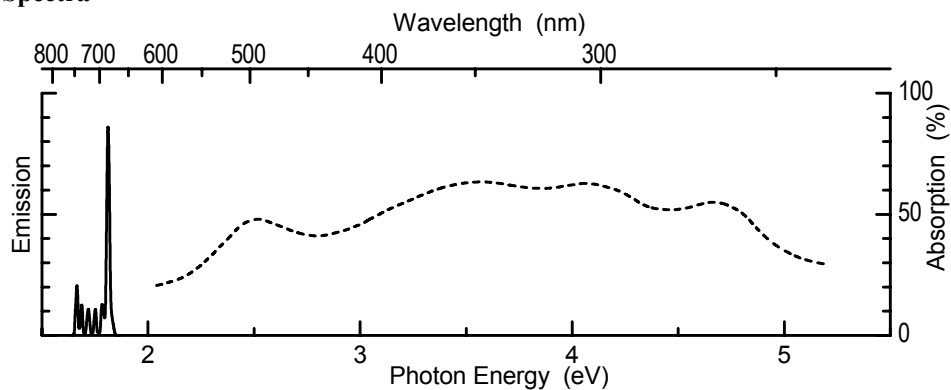
1. Blasse, G., Bril, A., and deVries, J., Fluorescence of Eu^{2+} -activated barium octaborate, *J. Electrochem. Soc.*, 115, 977 (1968).

$\text{SrB}_8\text{O}_{13}:\text{Sm}$

Optical Properties

Emission color: Deep red
Emission peak: 1.81 eV
Excitation efficiency by UV: + (4.88 eV), ++ (3.40 eV)

Spectra



Reference

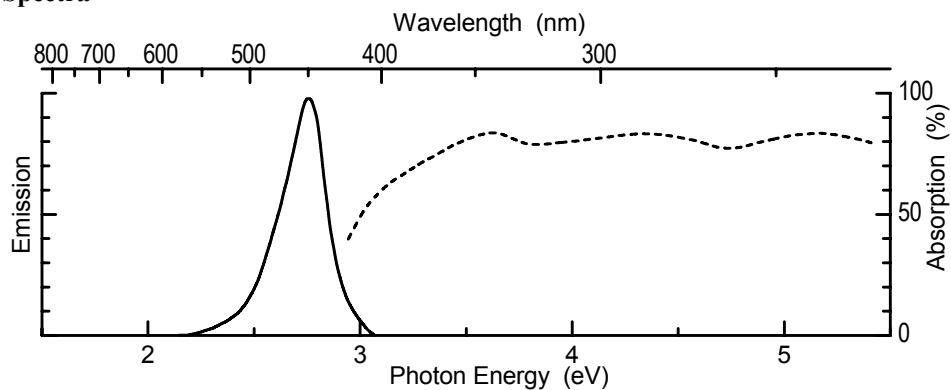
1. Chenot, C.F., U.S. Pat., 3 657 141 (1972).

$\text{Ca}_2\text{B}_5\text{O}_9\text{Cl}:\text{Eu}^{2+}$

Optical Properties

Emission color: Blue
Emission peak: 2.74 eV
Emission width (FWHM): 0.24 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



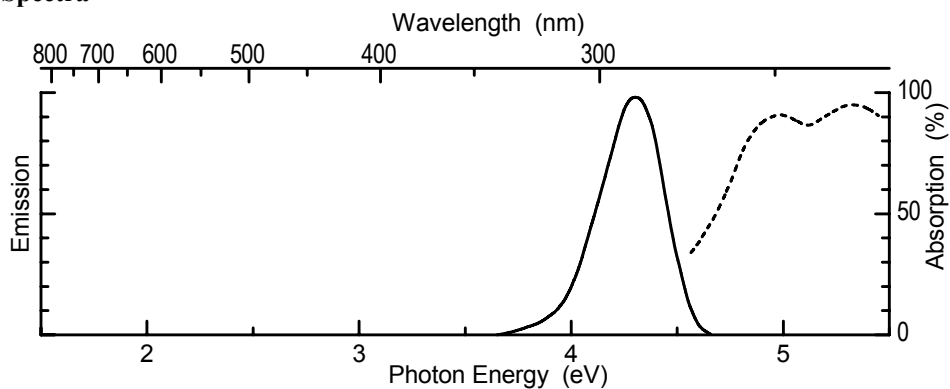
$\text{Ca}_2\text{B}_5\text{O}_9\text{Cl}:\text{Pb}^{2+}$

Optical Properties

Emission color: UV
Emission peak: 4.31 eV

Emission width (FWHM): 0.34 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

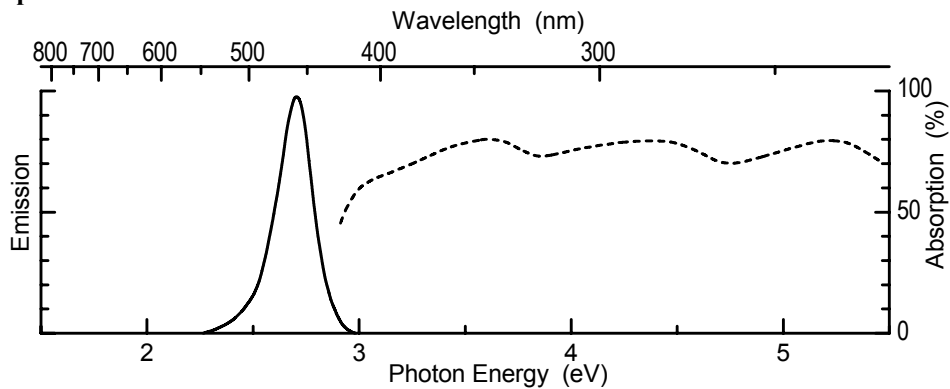
Spectra



Optical Properties

Emission color: Blue
Emission peak: 2.74 eV
Emission width (FWHM): 0.20 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

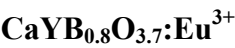
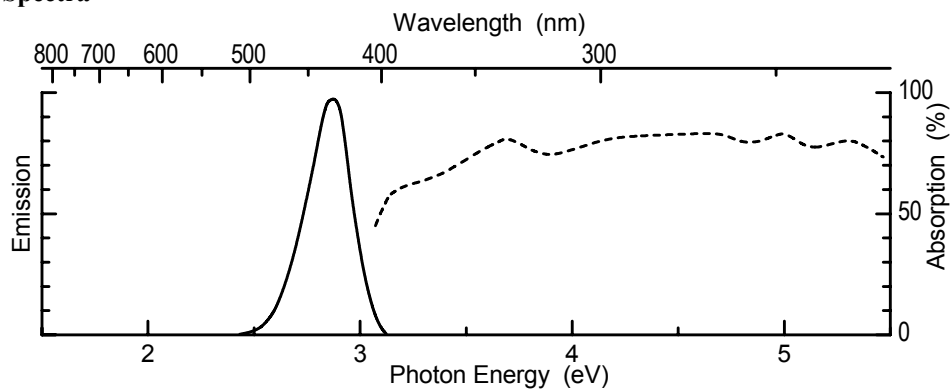
Spectra



Optical Properties

Emission color: Blue-violet
Emission peak: 2.92 eV
Emission width (FWHM): 0.24 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

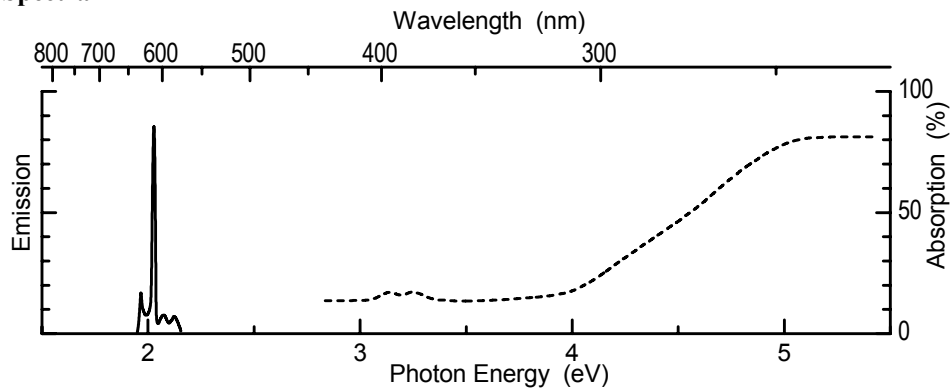
Spectra



Optical Properties

Emission color: Red
Emission peak: 2.03 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Lehmann, W., U.S. Pat., 4 202 794 (1980).



Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| CaCO_3 | 198 | 198 |
| La_2O_3 | 200 (of La) | 326 |
| PbO | 2 | 4.6 |
| H_3BO_3 | 105 | 65 |

Preparation

Mix by dry grinding or milling.

1. Fire in open quartz boats, air, ~500°C.
Powderize.
2. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
3. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.

Optical Properties

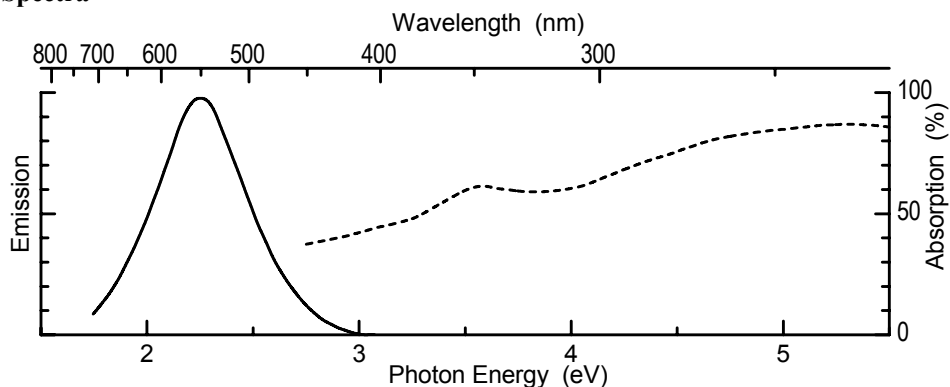
Emission color: Pale yellow-green

Emission peak: 2.28 eV

Emission width (FWHM): 0.48 eV

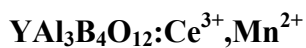
Excitation efficiency by UV: + (4.88 eV), ++ (3.40 eV)

Spectra

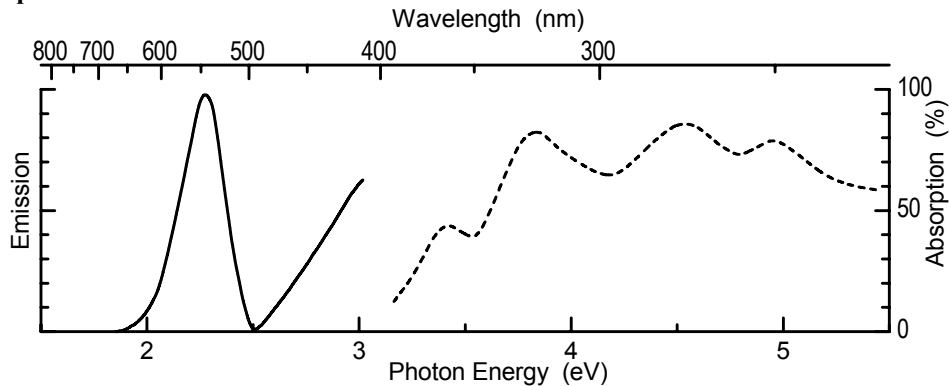


Remark

The formula of this peculiar material is still uncertain but the mole ratio Ca-La-B in the formula is close to 2:2:1



Spectra



4.8 Aluminates and Gallates

The following host compounds and activators are included in this subsection:

LiAlO₂:Fe³⁺
LiAlO₂:Mn²⁺
YAlO₃:Ce³⁺
YAlO₃:Eu³⁺
YAlO₃:Sm³⁺
YAlO₃:Tb³⁺
LaAlO₃:Eu³⁺
LaAlO₃:Sm³⁺
MgAl₂O₄:Mn²⁺
MgGa₂O₄:Mn²⁺
CaAl₂O₄:Mn²⁺
CaAl₂O₄:Eu²⁺
ZnAl₂O₄:Mn²⁺
ZnGa₂O₄:Mn²⁺
CaGa₂O₄:Mn²⁺
CaGa₄O₇:Mn²⁺
SrAl₂O₄:Eu²⁺
BaAl₂O₄:Eu²⁺
CaAl₄O₇:Pb²⁺,Mn²⁺
LiAl₅O₈:Fe³⁺
LiAl₅O₈:Mn²⁺
Y₄Al₂O₉:Eu³⁺
Y₃Al₅O₁₂:Ce³⁺
KAl₁₁O₁₇:Tl⁺
KGa₁₁O₁₇:Mn²⁺
BaMgAl₁₀O₁₇:Ce³⁺
Y₃Al₅O₁₂:Eu³⁺
BaMgAl₁₀O₁₇:Eu²⁺
BaMgAl₁₀O₁₇:Eu²⁺,Mn²⁺
Ca_{0.5}Ba_{0.5}Al₁₂O₁₉:Ce³⁺,Mn²⁺
SrAl₁₂O₁₉:Eu²⁺,Mn²⁺
SrGa₁₂O₁₉:Mn²⁺
SrAl₁₂O₁₉:Ce³⁺,Mn²⁺

LiAlO₂:Fe³⁺

Structure: NaCl

Composition

| Ingredient | Mole % | By weight (g) |
|---|-------------|---------------|
| Li ₂ CO ₃ | 101 (of Li) | 37.4 |
| Al ₂ O ₃ | 100 (of Al) | 51 |
| Fe(NO ₃) ₃ · 9H ₂ O | 0.6 | 2.4 |
| LiF | 2 | 0.520 |

Preparation

Dissolve iron nitrate in a little water; add solution to the mixture of other ingredients. Stir to uniformity. Dry in air. Powderize when dry.

1. Fire in covered alumina crucibles, air. Place crucibles into a cold furnace, go slowly up with temperature to 900°C, and then take out. Powderize.
2. Fire in covered alumina crucibles, air, 1250°C, 2 hours. Powderize. Wash in diluted acetic acid (~10%), and then in water until neutral. Add a solution of about 3 g $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ in little water; stir to uniformity. Dry in air. Powderize when dry.
3. Fire in open quartz boats, air, 1250°C, 1 hour.

Optical Properties

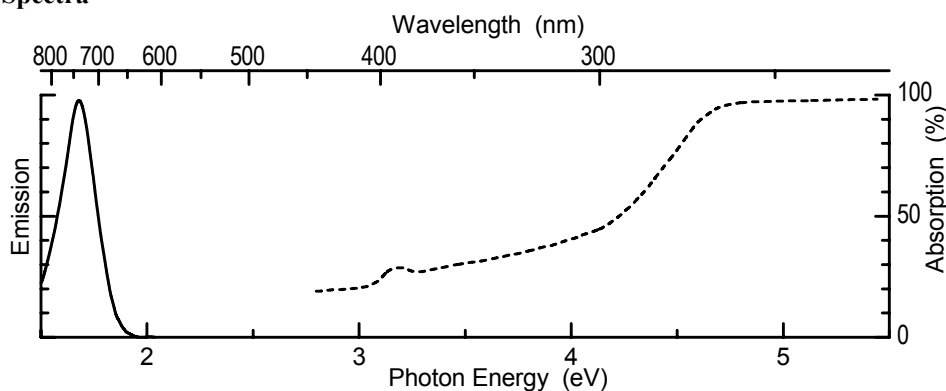
Emission color: Very deep red + IR

Emission peak: 1.67 eV

Emission width (FWHM): 0.20 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Hummel, F.A., and Sarver, J.F., The cathodoluminescence of Mn^{2+} activated and Fe^{3+} activated magnesium aluminate spinel, *J. Electrochem. Soc.*, 111, 252 (1964).
2. Palumbo, D.T., Electronic states of Fe^{3+} in $\text{LiAl}_5\text{O}_{12}$ and LiAl_5O_8 phosphors, *J. Lumin.*, 4, 19 (1971).
3. Rabatin, J., Luminescence of iron-activated lithium meta-gallate, *J. Electrochem. Soc.*, 125, 920 (1978).
4. Lehmann, W., and Watchtel, A., U.S. Pat., 3 857 054 (1974).
5. Kamiya, S., and Mizuno, H., *Phosphor Handbook*, CRC Press, Boca Raton, FL, Fig. 46, p. 422 (1998).
6. Van Broekhoven, J., Infrared emitting fluorescent lamp and applications, *J. Illum. Eng. Soc.*, 3, 234 (1974).
7. Stork, W.H.J., and Pott, G.T., Studies of compound formation on alkali-gamma-aluminum oxide catalyst systems using chromium, iron, and manganese luminescence, *J. Phys. Chem.*, 78, 2496 (1974).

LiAlO₂:Mn²⁺

Structure: NaCl

Composition

| Ingredient | Mole % | By weight (g) |
|---------------------------------|-------------|---------------|
| Li ₂ CO ₃ | 99 (of Li) | 36.6 |
| Al ₂ O ₃ | 499 (of Al) | 254 |
| MnCO ₃ | 2 | 2.3 |

Preparation

Mix by slurring in methanol. Dry in air. Powderize when dry.

1. Fire in covered alumina crucibles, N₂, 1200°C, 1 hour. Powderize.
2. Fire in open quartz boats, CO, 1250°C, 2 hours.

Optical Properties

Emission color: Green

Emission peak: 2.375 eV

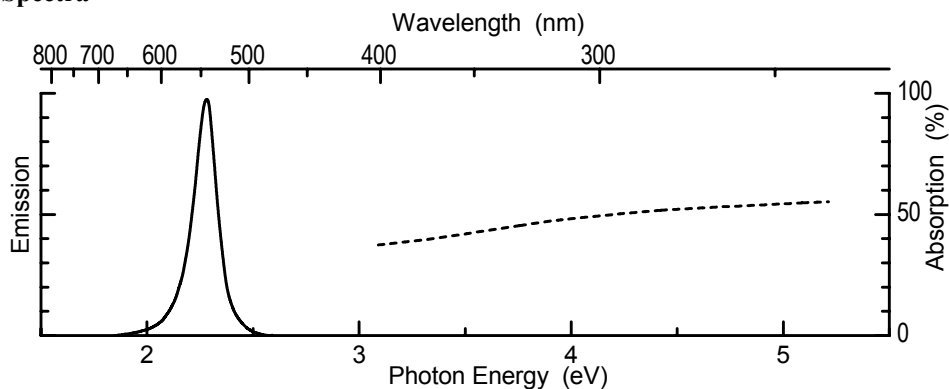
Emission width (FWHM): 0.15 eV

Excitation efficiency by UV: no sensitizer known to obtain response to this UV

Excitation efficiency by e-beam: ~6–8%

Decay to 10% (or 1/e, as given): Non-exponential decay, 1/10-time in the 10 msec range; long and strong phosphorescence

Spectra



References

1. Jaffe, P.M., Cathodoluminescence spectra and coordination of Mn²⁺, Fe³⁺, and Cr³⁺ in BeTaLiAl₅O₈, *J. Electrochem. Soc.*, 115, 1203 (1968).
2. Stork, W.H.J., and Pott, G.T., Studies of compound formation on alkali-gamma-aluminum oxide catalyst systems using chromium, iron, and manganese luminescence, *J. Phys. Chem.*, 78, 2496 (1974).

YAlO₃:Ce³⁺

Structure: Orthorhombic

Optical Properties

Emission color: UV

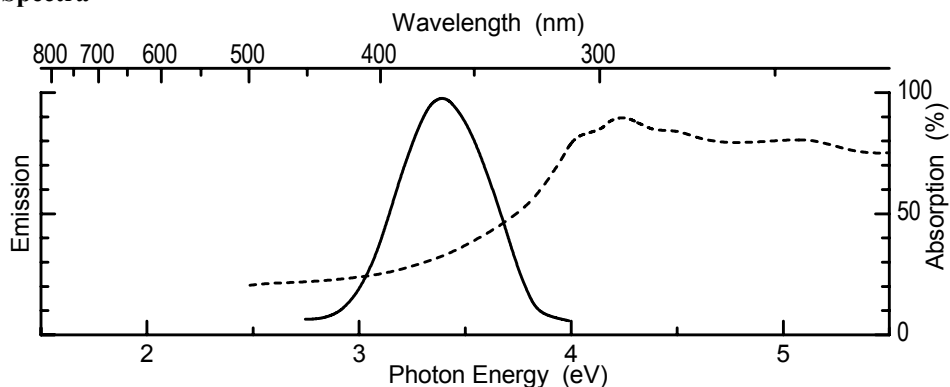
Emission peak: 3.40 eV

Emission width (FWHM): 0.5 eV

Excitation efficiency by UV: + (4.88 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Weber, M.J., Optical-spectra of Ce³⁺ and Ce³⁺-sensitized fluorescence in YAlO₃, *J. Appl. Phys.*, 44, 3205 (1973).
2. Takeda, T. et al., Fast decay UV phosphor YAlO₃-Ce, *J. Electrochem. Soc.*, 127, 438 (1980).

YAlO₃:Eu³⁺

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| Y ₂ O ₃ | 94 (of Y) | 83.6 |
| Al ₂ O ₃ | 100 (of Al) | 51 |
| Eu ₂ O ₃ | 6 (of Eu) | 10.6 |
| H ₃ BO ₃ | 10 | 6.2 |

Preparation

Mix by dry grinding or milling.

1. Fire in covered alumina crucibles, air, 1000°C, 1 hour.
Powderize.
2. Fire in covered alumina crucibles, air, 1300°C, 4 hours.

Optical Properties

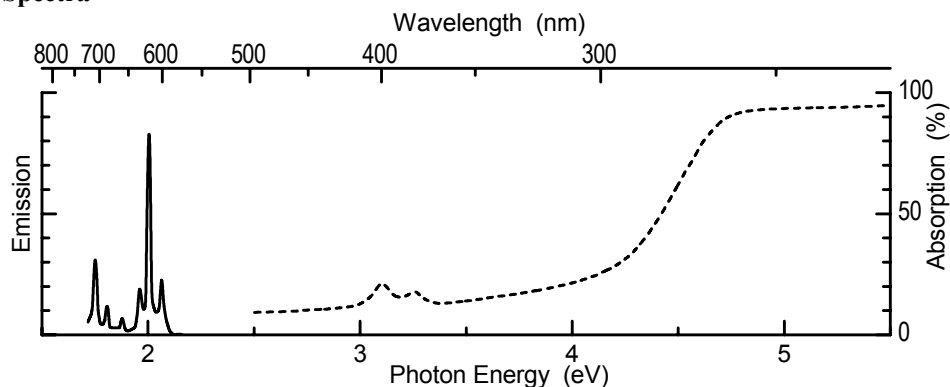
Emission color: Light red

Emission peaks: 1.785 – 2.015 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

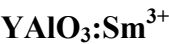
Excitation efficiency by e-beam: +

Spectra



Remark

Q yield (UV excitation) is about the same as that of YOE.



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| Y ₂ O ₃ | 98 (of Y) | 110 |
| Sm ₂ O ₃ | 2 (of Sm) | 3.6 |
| Al ₂ O ₃ | 100 (of Al) | 51 |
| CaF ₂ | 10 | 7.8 |

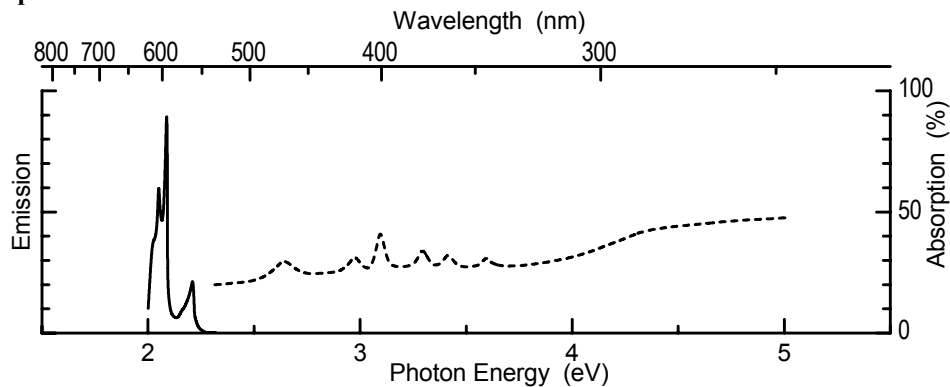
Preparation

- Mix by dry grinding or milling.
1. Fire in covered alumina crucibles, air, 1300°C, 1 hour.
Powderize.
 2. Fire in covered alumina crucibles, air, 1300°C, 4 hours.

Optical Properties

Emission color: Orange-yellow
Emission peaks: 2.008–3.06, 2.197 eV; strongest line at ~2.06 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



YAlO₃:Tb³⁺

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| Y ₂ O ₃ | 90 (of Y) | 102 |
| Tb ₄ O ₇ | 10 (of Tb) | 18.7 |
| Al ₂ O ₃ | 100 (of Al) | 51 |
| CaF ₂ | 10 | 7.8 |

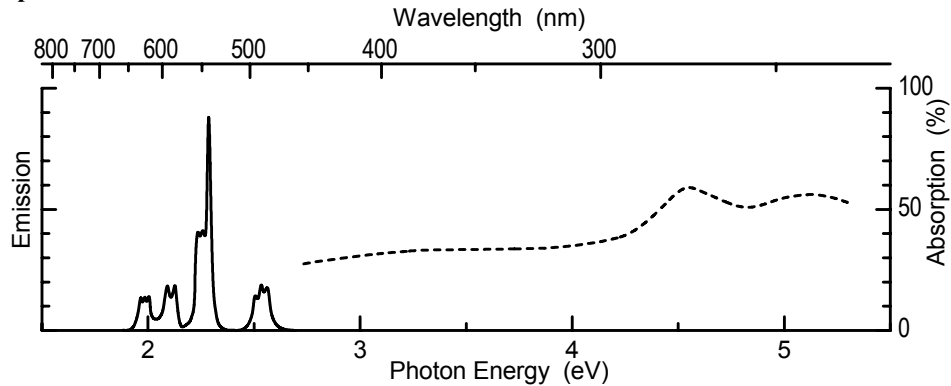
Preparation

- Mix by dry grinding or milling.
1. Fire in covered alumina crucibles, CO, 1300°C, 1 hour.
Powderize.
 2. Fire in covered alumina crucibles, CO, 1300°C, 4 hours.

Optical Properties

Emission color: Pale green
Emission peaks: Typical Tb³⁺ lines, strongest line at ~2.283 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: + (better than Y₂O₃:Tb³⁺)

Spectra



LaAlO₃:Eu³⁺

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 94 (of La) | 130.6 |
| Al ₂ O ₃ | 105 (of Al) | 53.6 |
| Eu ₂ O ₃ | 6 (of Eu) | 10.6 |
| H ₃ BO ₃ | 20 | 12.4 |

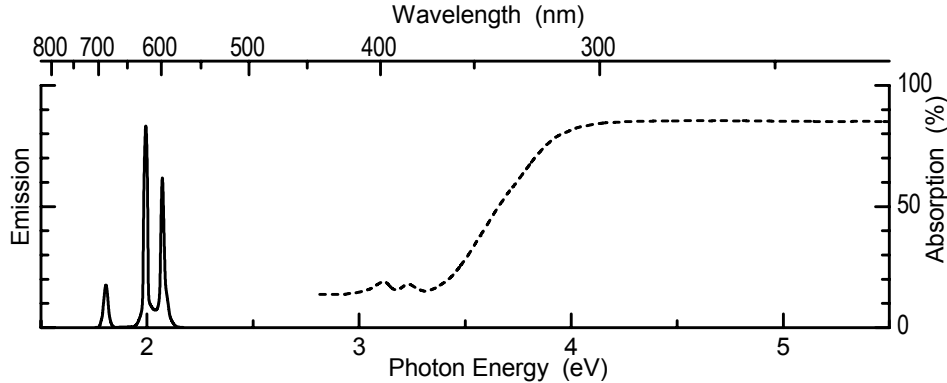
Preparation

- Mix by dry grinding or milling.
1. Fire in covered alumina crucibles, air, 1000°C, 1 hour.
Powderize.
 2. Fire in covered alumina crucibles, air, 1300°C, 4 hours.

Optical Properties

Emission color: Orange-red
Emission peaks: 2.01–2.10 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra

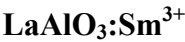


Remark

Q yield (UV excitation) is about ~75% of YOE.

Reference

1. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).



Structure: Trigonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 100 (of La) | 139 |
| Al ₂ O ₃ | 105 (of Al) | 53.6 |
| Sm ₂ O ₃ | 0.2 (of Sm) | 0.300 |
| H ₃ BO ₃ | 20 | 12.4 |

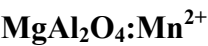
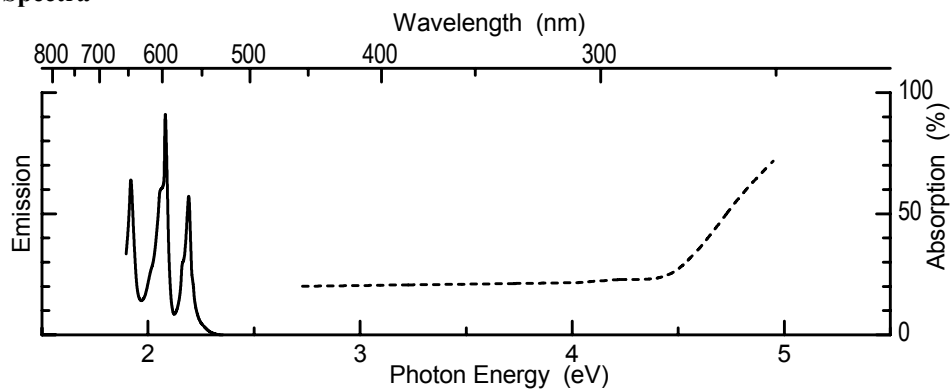
Preparation

- Mix by dry grinding or milling.
1. Fire in covered alumina crucibles, air, 1000°C, 1 hour.
Powderize.
 2. Fire in covered alumina crucibles, air, 1300°C, 4 hours.

Optical Properties

Emission color: Yellow
Emission peaks: 1.925–2.20 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



Structure: Tetragonal (spinel)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| MgO | 98 | 39 |
| MnCO ₃ | 1 | 1.15 |
| Al ₂ O ₃ | 210 (of Al) | 107 |
| MgF ₂ | 1 | 0.620 |

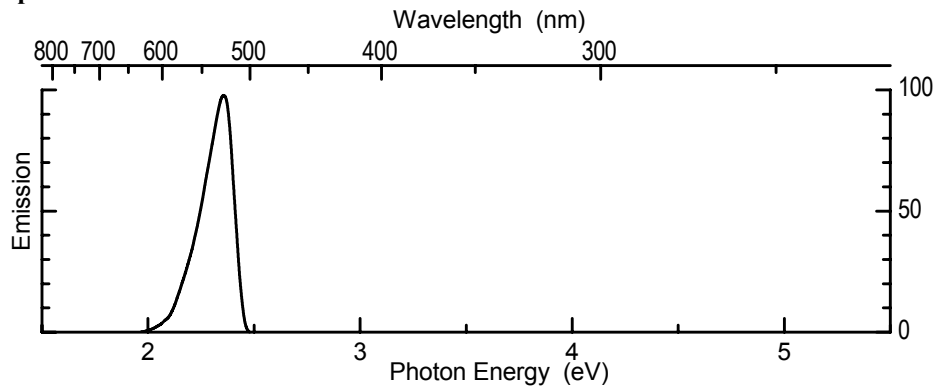
Preparation

Mix by dry ball-milling.
Fire in covered alumina crucibles, CO, 1250°C, 2 hours.

Optical Properties

Emission color: Green
Emission peak: 2.36 eV
Emission width (FWHM): 0.16 eV
Excitation efficiency by UV: no sensitizer known to obtain response to this UV
Excitation efficiency by e-beam: +/-7-8%
Decay: Slightly non-exponential decay, ≈ 20 msec to 1/10

Spectra



Remark

Reducing the Mn concentration from 1 to 0.2% reduces the efficiency of cathodoluminescence to ~4% and increases the 1/10 decay time to ~40 msec.

References

1. Kröger, F.A., *Some Aspects of Luminescence of Solids*, Elsevier, Amsterdam (1948).
2. Hummel, F.A., and Sarver, J.F., The cathodoluminescence of Mn^{2+} activated and Fe^{3+} activated magnesium aluminate spinel, *J. Electrochem. Soc.*, 111, 252 (1964).
3. Lehmann, W., *Res. Rep.*, 78-5F4-ZSIBM-R1 (1978).



Structure: Tetragonal (spinel)

Optical Properties

Emission color: Blue-green

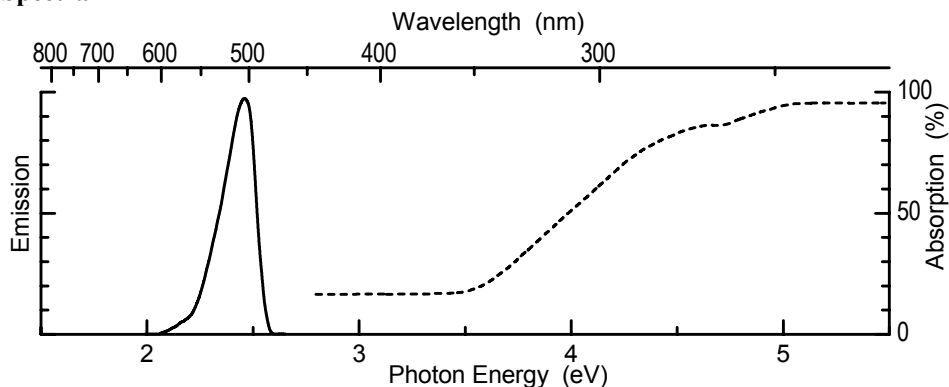
Emission peak: 2.46 eV

Emission width (FWHM): 0.15 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Palumbo, D.T., and Brown, J., Electronic states of Mn^{2+} -activated phosphors. 1. Green-emitting phosphors, *J. Electrochem. Soc.*, 117, 1184 (1970).
2. Brown, J., Manganese-activated luminescence in $\text{MgO-Al}_2\text{O}_3\text{-Ga}_2\text{O}_3$ system, *J. Electrochem. Soc.*, 114, 245 (1967).
3. Wanmaker, W.L., terVrugt, J.W., and deBres, J.G.M., Luminescence of manganese-activated aluminium-substituted magnesium gallate, *Philips Res. Rep.*, 22, 304 (1967).
4. Wanmaker, W.L., terVrugt, J.W., and Verlijsdonk, J.G., Luminescence of Mn^{2+} -activated spinels in $\text{MgO-Li}_2\text{O-ZnO-Ga}_2\text{O}_3\text{-Al}_2\text{O}_3$ system, *Philips Res. Rep.*, 25, 108 (1970).
5. Opstelten, J.J., Radielovic, D., and Wanmaker, W.L., Choice and evaluation of phosphors for application to lamps with improved color rendition, *J. Electrochem. Soc.*, 120, 1400 (1973).

CaAl₂O₄:Mn²⁺

Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 93 | 93 |
| Al ₂ O ₃ | 200 (of Al) | 102 |
| MnCO ₃ | 2 | 2.3 |
| CaF ₂ | 5 | 3.9 |

Preparation

Mix by slurring in water.

Dry in air. Powderize when dry.

1. Fire in covered alumina crucibles, CO, 1300°C, 1 hour.

Powderize.

2. Fire in open quartz boats, CO, 1200°C, 1 hour.

Wash in a solution of 20 g NH₄Cl in 1 liter of water and then several times in plain water.

Optical Properties

Emission color: Yellow-green

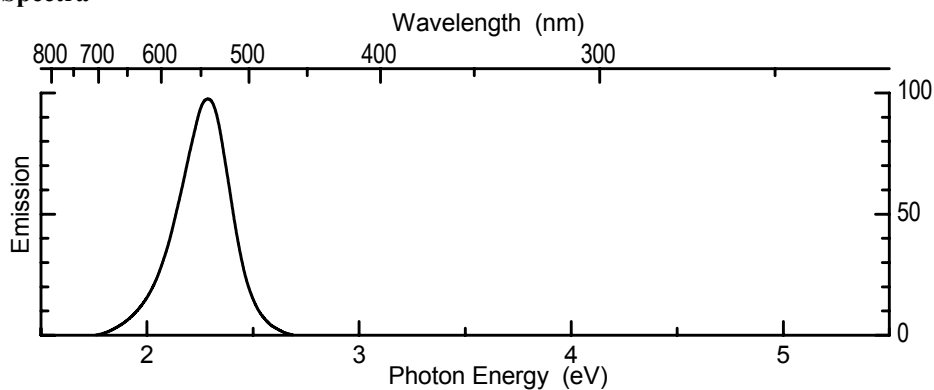
Emission peak: 2.28 eV

Emission width (FWHM): 0.27 eV

Excitation efficiency by UV: no sensitizer known to obtain response to this UV

Excitation efficiency by e-beam: ~ a few percent

Spectra



CaAl₂O₄:Eu²⁺

Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 98 | 98 |
| Al ₂ O ₃ | 210 (of Al) | 107 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| NH ₄ Cl | 10 | 5.4 |

Preparation

Mix by ball-milling in water.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, CO, 1200°C, 1 hour.
Powderize.
2. Fire in open quartz boats, CO, 1200°C, 1 hour.
Wash in a solution of ~20 g NH₄Cl in 1 liter of water and then several times in plain water.

Optical Properties

Emission color: Deep blue

Emission peak: Single Eu²⁺ band. 2.80 eV

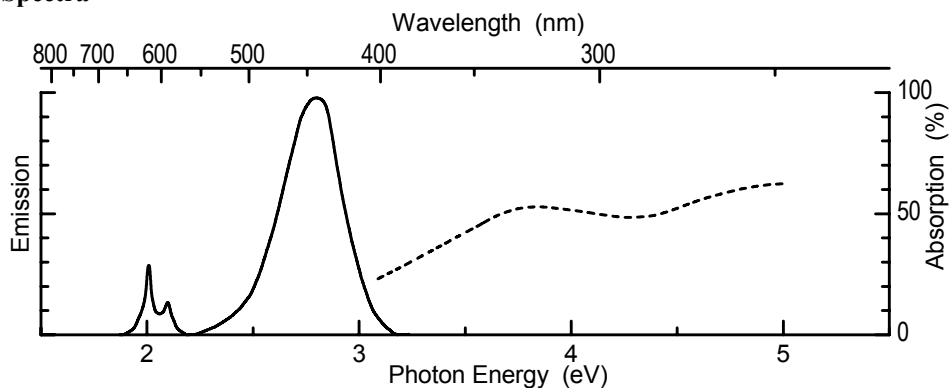
Emission width (FWHM): 0.34 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: ~ 1%

Decay: ~1 μsec to 1/10

Spectra



Structure: Tetragonal (spinel)

Optical Properties

Emission color: Blue-green

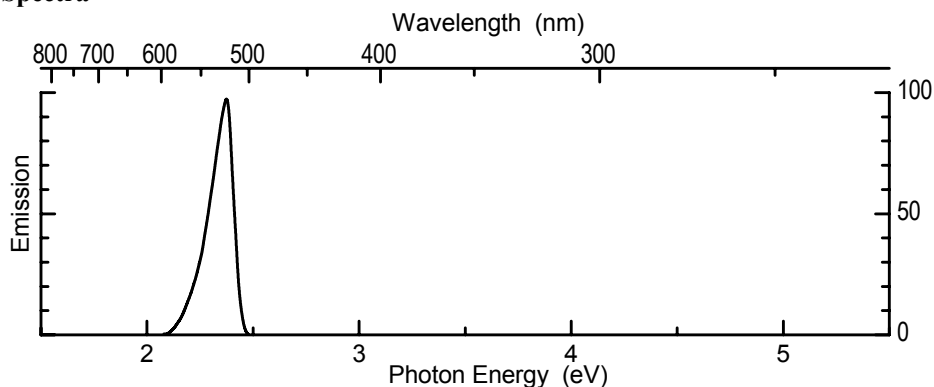
Emission peak: 2.41 eV

Emission width (FWHM): 0.13 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

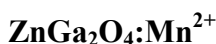
Excitation efficiency by e-beam: +

Spectra



References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).
2. Strange, J.W., and Henderson, S.T., Cathodo-luminescence. 1. Growth and decay processes, *P. Phys. Soc. London*, 58, 369 (1946).



Structure: Cubic (gahnite)

Optical Properties

Emission color: Blue-green

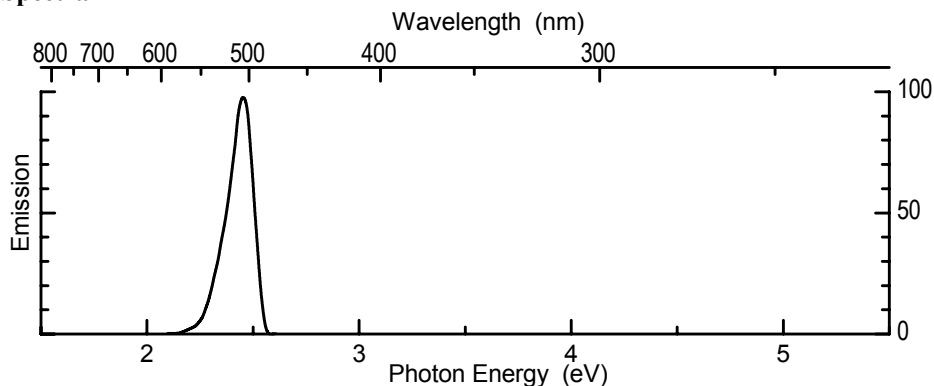
Emission peak: 2.47 eV

Emission width (FWHM): 0.13 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).
2. Wanmaker, W.L., terVrugt, J.W., and Verlijsdonk, J.G., Luminescence of Mn^{2+} -activated spinels in $\text{MgO-Li}_2\text{O-ZnO-Ga}_2\text{O}_3\text{-Al}_2\text{O}_3$ system, *Philips Res. Rep.*, 25, 108 (1970).
3. Wanmaker, W.L., and terVrugt, J.W., Luminescence of gallates, *J. Electrochem. Soc.*, 116, 871 (1969).

CaGa₂O₄:Mn²⁺

Structure: Monoclinic

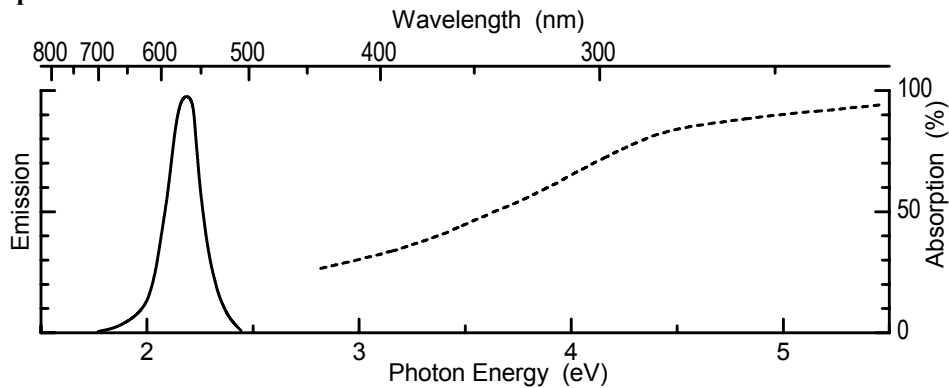
Optical Properties

Emission color: Yellow-green

Emission peak: 2.19 eV

Emission width (FWHM): 0.21 eV

Spectra



Reference

1. Brown, J.J., Can. Pat., 821 468 (1970).

CaGa₄O₇:Mn²⁺

Optical Properties

Emission color: Yellow

Emission peak: 2.10 eV

Emission width (FWHM): 0.21 eV

Reference

1. Brown, J.J., Can. Pat., 821 468 (1970).

SrAl₂O₄:Eu²⁺

Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| SrCO ₃ | 98 | 145 |
| Al ₂ O ₃ | 210 (of Al) | 107 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| NH ₄ Cl | 10 | 5.4 |

Preparation

Mix by ball-milling in water.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, CO, 1200°C, 1 hour.
Powderize.
2. Fire in open quartz boats, CO, 1200°C, 1 hour.
Wash in a solution of ~20 g NH₄Cl in 1 liter of water and then several times in plain water.
Dry.

Optical Properties

Emission color: Green

Emission peak: 2.37 eV

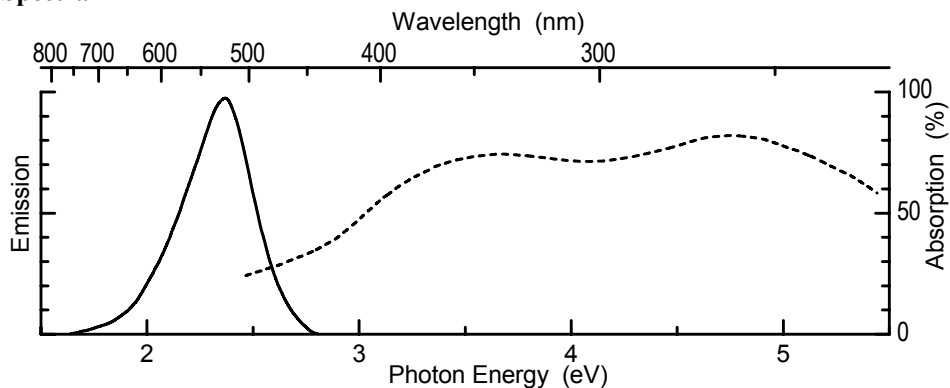
Emission width (FWHM): 0.34 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +/-1.5%

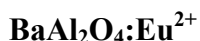
Decay: ~2 μsec to 1/10

Spectra



References

1. Blasse, G., and Bril, A., Fluorescence of Eu²⁺ activated alkaline-earth aluminates, *Philips Res. Rep.*, 23, 201 (1968).
2. Palilla, F.C., Levine, A.K., and Tomkus, M.R., Fluorescent properties of alkaline earth aluminates activated by divalent europium, *J. Electrochem. Soc.*, 115, 642 (1968).
3. Blasse, G., Wanmaker, W.L., and terVrugt, J.W., Some new classes of efficient Eu²⁺ activated phosphors, *J. Electrochem. Soc.*, 115, 673 (1968).
4. Abbruscato, V., Optical and electrical properties of SrAl₂O₄-Eu²⁺, *J. Electrochem. Soc.*, 118, 930 (1971).



Structure: Hexagonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| BaCO ₃ | 98 | 193 |
| Al ₂ O ₃ | 210 (of Al) | 107 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| NH ₄ Cl | 10 | 5.4 |

Preparation

Mix by ball-milling in water.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, CO, 1200°C, 1 hour.
Powderize.
2. Fire in open quartz boats, CO, 1200°C, 1 hour.
Wash in a solution of ~20 g NH₄Cl + 20 ccm NH₄OH in 1 liter of water and then several times in diluted ammonium hydroxide.
Dry.

Optical Properties

Emission color: Blue-green

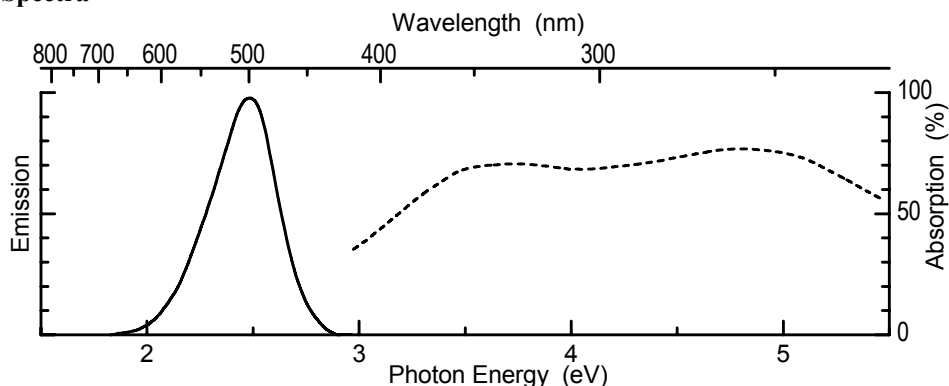
Emission peak: 2.47 eV

Emission width (FWHM): 0.35 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

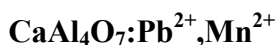
Excitation efficiency by e-beam: +

Spectra



References

1. Palilla, F.C., Levine, A.K., and Tomkus, M.R., Fluorescent properties of alkaline earth aluminates activated by divalent europium, *J. Electrochem. Soc.*, 115, 642 (1968).
2. Blasse, G., Wanmaker, W.L., and terVrugt, J.W., Some new classes of efficient Eu²⁺ activated phosphors, *J. Electrochem. Soc.*, 115, 673 (1968).
3. Blasse, G., and Bril, A., Phosphors based on lanthanide oxysulphates (Ln₂SO₆), *Philips Res. Rep.*, 23, 461 (1968).



Structure: Monoclinic

Optical Properties

Emission color: Yellow

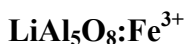
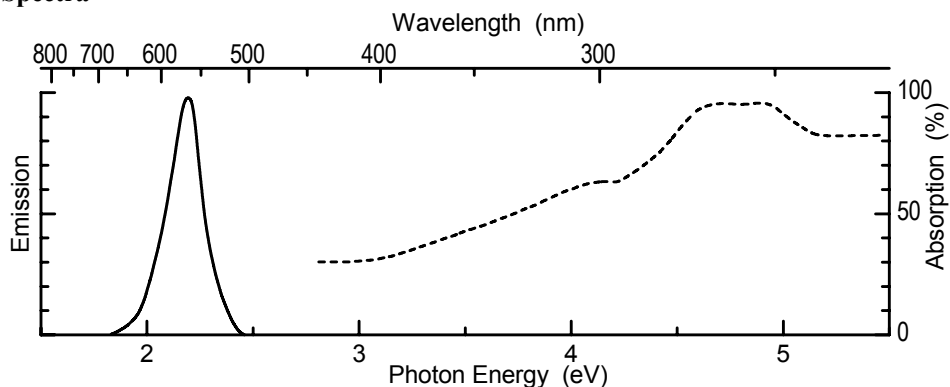
Emission peak: 2.20 eV

Emission width (FWHM): 0.24 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Structure: Cubic (spinel)

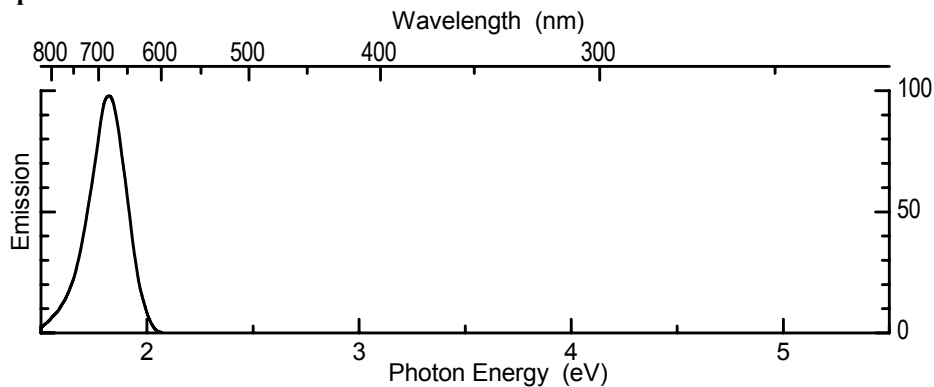
Optical Properties

Emission color: Very deep red

Emission peak: 1.82 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



References

1. Jaffe, P.M., Cathodoluminescence spectra and coordination of Mn^{2+} , Fe^{3+} and Cr^{3+} in $\text{BeTaLiAl}_5\text{O}_8$, *J. Electrochem. Soc.*, 115, 1203 (1968).
2. Melamed, N.T., Viccaro, P.J., Barros, F.D.S. et al., Optical properties of Fe^{3+} in ordered and disordered LiAl_5O_8 , *Phys. Rev. B* 5, 3377 (1972).
3. Neto, J.M., Abritta, T., Barros, F.D. et al., A comparative-study of the optical-properties of Fe^{3+} in ordered LiGa_5O_8 and LiAl_5O_8 , *J. Lumin.*, 22, 109 (1981).

LiAl₅O₈:Mn²⁺

Structure: Cubic (spinel)

Composition

| Ingredient | Mole % | By weight (g) |
|---------------------------------|-------------|---------------|
| Li ₂ CO ₃ | 99 (of Li) | 36.6 |
| Al ₂ O ₃ | 499 (of Al) | 254 |
| MnCO ₃ | 2 | 2.3 |

Preparation

Mix by slurring in methanol.

Dry in air. Powderize when dry.

1. Fire in open alumina crucibles, N₂, 1200°C, 1 hour.
Powderize.
2. Fire in open quartz boats, CO, 1250°C, 2 hours.

Optical Properties

Emission color: Green

Emission peak: 2.38 eV

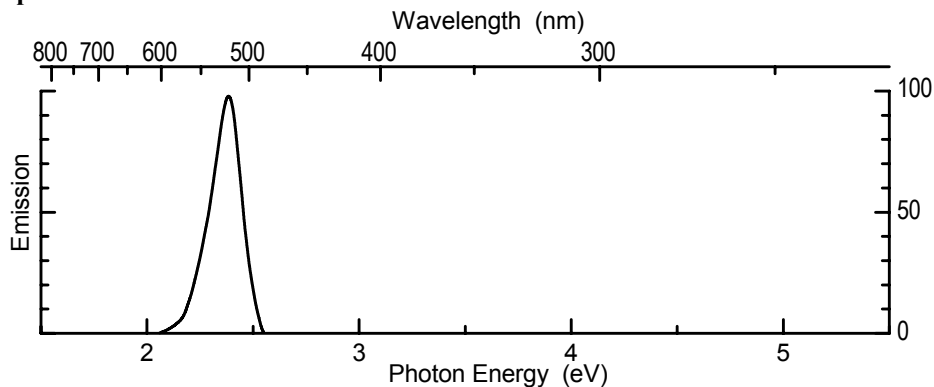
Emission width (FWHM): 0.15eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +/-6–8%

Decay: Non-exponential decay, 1/10 time in the 10 msec range; long and strong phosphorescence

Spectra



Reference

1. Jaffe, P.M., Cathodoluminescence spectra and coordination of Mn²⁺, Fe³⁺ and Cr³⁺ in BeTaLiAl₅O₈, *J. Electrochem. Soc.*, 115, 1203 (1968).

$\text{Y}_4\text{Al}_2\text{O}_9\text{:Eu}^{3+}$

Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|------------|---------------|
| Y_2O_3 | 95 (of Y) | 84.5 |
| Al_2O_3 | 50 (of Al) | 25.5 |
| Eu_2O_3 | 5 (of Eu) | 8.8 |
| H_3BO_3 | 10 | 6.2 |

Preparation

Mix by dry grinding or milling.

1. Fire in covered alumina crucibles, air, 1000°C , 1 hour.
Powderize.
2. Fire in covered alumina crucibles, air, 1300°C , 4 hours.

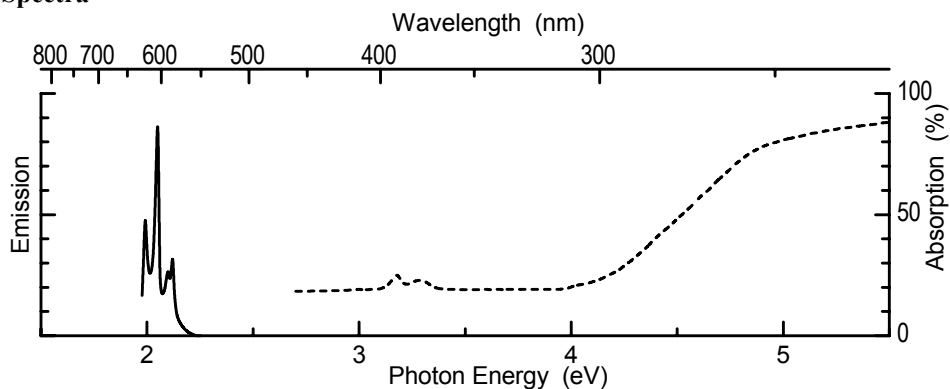
Optical Properties

Emission color: Light red

Emission peaks: Mainly three lines about 1.975, 2.03 eV, and 2.10 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



$\text{Y}_3\text{Al}_5\text{O}_{12}\text{:Ce}^{3+}$

Structure: Cubic (garnet)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|--------------|---------------|
| Y_2O_3 | 35.5 (of Y) | 40 |
| Al_2O_3 | 62.5 (of Al) | 32 |
| CeO_2 | 2 | 3.44 |
| NH_4Cl | 5 | 2.7 |

Preparation

Mix by slurring in water.

1. Fire in capped quartz tubes, CO, 1300°C, 1 hour. Powderize. Add another 2.7 g NH₄Cl; mix by dry grinding.
2. Fire in capped quartz tubes, 1300°C, 2 hours. Powderize.
3. Fire in open quartz boats, CO, 1300°C, 1 hour.

Optical Properties

Emission color: Yellow-green

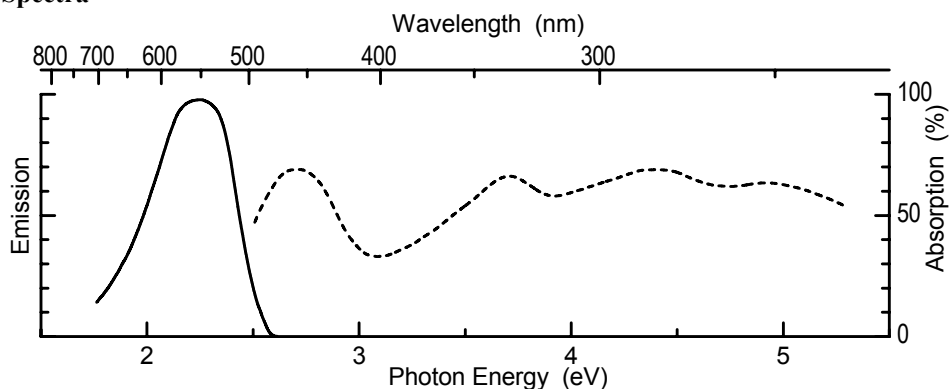
Emission peak: 2.37 eV

Emission width (FWHM): ~0.45 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

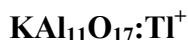
Excitation efficiency by e-beam: +/-2%

Spectra



References

1. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970); and A new phosphor for flying-spot cathode-ray tubes for color television—yellow-emitting Y₃Al₅O₁₂-Ce³⁺, *Appl. Phys. Lett.*, 11, 53 (1967).
2. Blasse, G., Bril, A., and Poorter, J.A.D., Radiationless transitions in Eu³⁺ center in LaAlO₃, *J. Chem. Phys.*, 53, 4450 (1970).
3. Blasse, G., and Bril, A., Gibbons, E.F. et al., Ce³⁺ activated Y₃Al₅O₁₂ and some of its solid-solutions, *J. Electrochem. Soc.*, 120, 278 (1973); and Gibbons, E.F. et al., Some factors influencing luminous decay characteristics of Y₃Al₅O₁₂ - Ce³⁺, *J. Electrochem. Soc.*, 120, 835 (1973).
4. Tien, T.Y. et al., Ce³⁺ activated Y₃Al₅O₁₂ and some of its solid-solutions, *J. Electrochem. Soc.*, 102, 278 (1973).
5. Sang, E., The signal generation mechanism in bistable storage-scan converters, *SID Digest*, 104 (1973).



Structure: Aluminate

Optical Properties

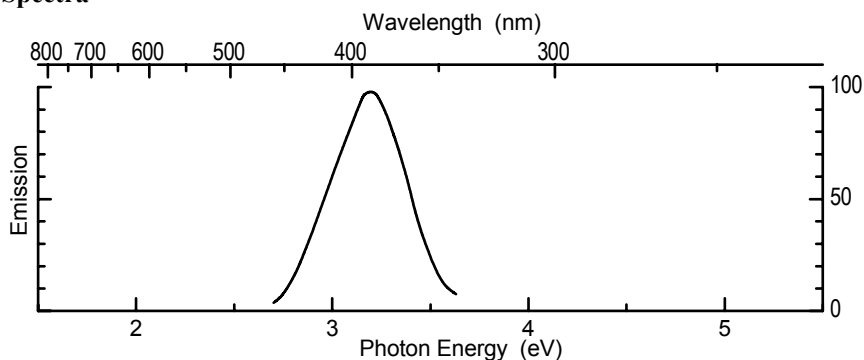
Emission color: Violet + UV

Emission peak: 3.14 eV

Emission width (FWHM): 0.49 eV

Excitation efficiency by UV: ++ (4.88 eV)

Spectra



References (see below)



Structure: Aluminate

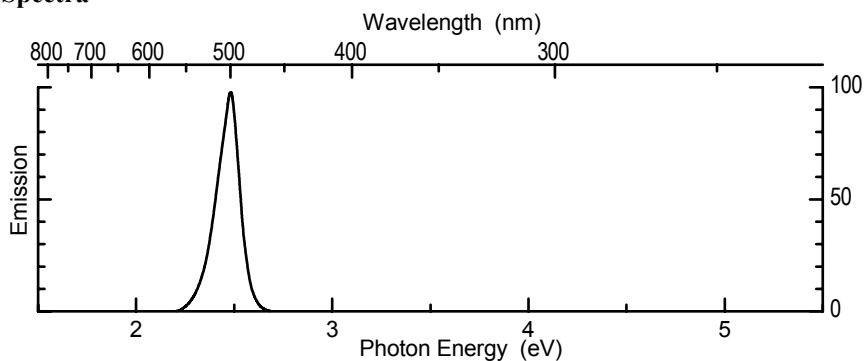
Optical Properties

Emission color: Blue-green

Emission peak: 2.49 eV

Emission width (FWHM): 0.14 eV

Spectra



References

1. Verstegen, J.M., Survey of a group of phosphors, based on hexagonal aluminate and gallate host lattices, *J. Electrochem. Soc.*, 121, 1623 (1974).
2. Verstegen, J.M.P.J., Somerdijk, J.L., and Bril, A., Luminescence of $\text{LiBaF}_3:\text{Eu}^{2+}$, *J. Lumin.*, 10, 411 (1975).



Structure: Aluminate

Optical Properties

Emission color: UV

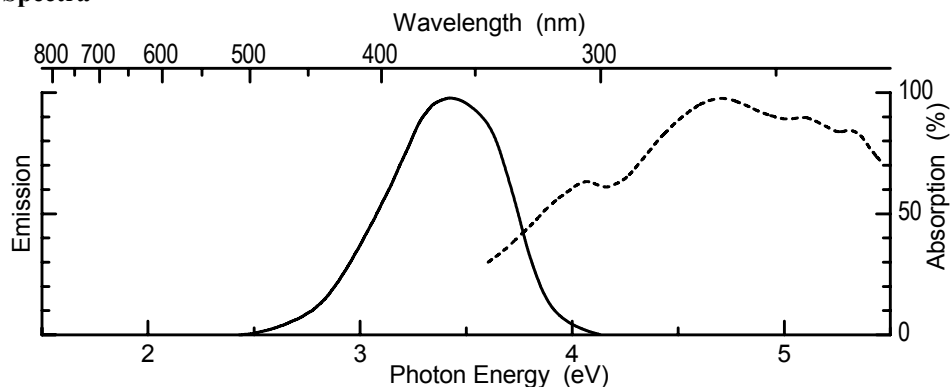
Emission peak: 3.40 eV

Emission width (FWHM): 0.65 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

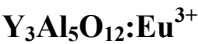
Excitation efficiency by e-beam: +

Spectra



Reference

1. Stevels, A.L.N., Ce³⁺ luminescence in hexagonal aluminates containing large divalent or trivalent cations, *J. Electrochem. Soc.*, 125, 588 (1978).

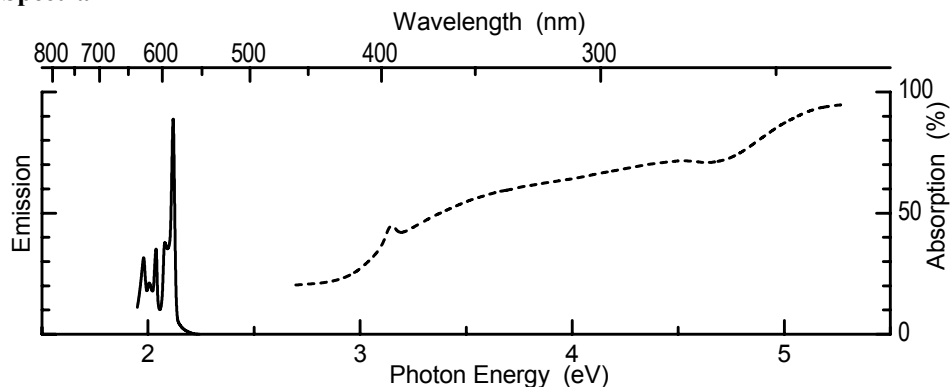


Structure: Cubic (garnet)

Optical Properties

Emission color: Orange-yellow
Emission peak: 2.10 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



BaMgAl₁₀O₁₇:Eu²⁺

Structure: Aluminate

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| BaCO ₃ | 80 | 158 |
| MgO | 100 | 40 |
| Al ₂ O ₃ | 1050 (of Al) | 536 |
| Eu ₂ O ₃ | 10 (of Eu) | 17.6 |
| BaF ₂ | 10 | 17.5 |

Preparation

Mix by ball-milling in methanol.

Dry in air. Powderize when dry.

1. Fire in covered alumina crucibles, N₂, 1250°C, 1 hour.
Powderize.
2. Fire in open quartz boats, forming gas, 1250°C, 1 hour.

Optical Properties

Emission color: Blue

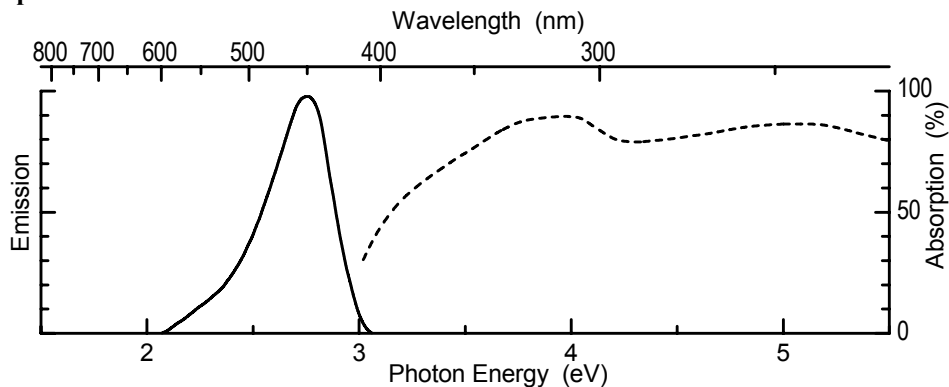
Emission peak: 2.77 eV

Emission width (FWHM): 0.34 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Stevels, A.L.N., and Schrama, A.D., Vapor-deposited CSi-Na layers. 1. Morphologic and crystallographic properties, *Philips Res. Rep.*, 29, 340 (1974).
2. Smets, B.M.J, and Verlijsdonk, J.G., The luminescence properties of Eu²⁺-doped and Mn²⁺-doped barium hexaaluminates, *Mater. Res. Bull.*, 21, 1305, Nov. (1986).

BaMgAl₁₀O₁₇:Eu²⁺,Mn²⁺

Structure: Aluminate

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| BaCO ₃ | 80 | 158 |
| MgO | 70 | 28.2 |
| Al ₂ O ₃ | 1050 (of Al) | 536 |
| Eu ₂ O ₃ | 10 | 17.6 |
| MnCO ₃ | 24 | 27.6 |
| BaF ₂ | 10 | 17.5 |

Preparation

Mix by ball-milling in methanol.

Dry in air. Powderize when dry.

1. Fire in open quartz boats, 500–600°C, ½ hour.
2. Fire in covered alumina crucibles, CO, 1250°C, 1 hour.
Powderize.
3. Fire in open quartz boats, forming gas, 1250°C, 1 hour.

Optical Properties

Emission color: Bluish-green

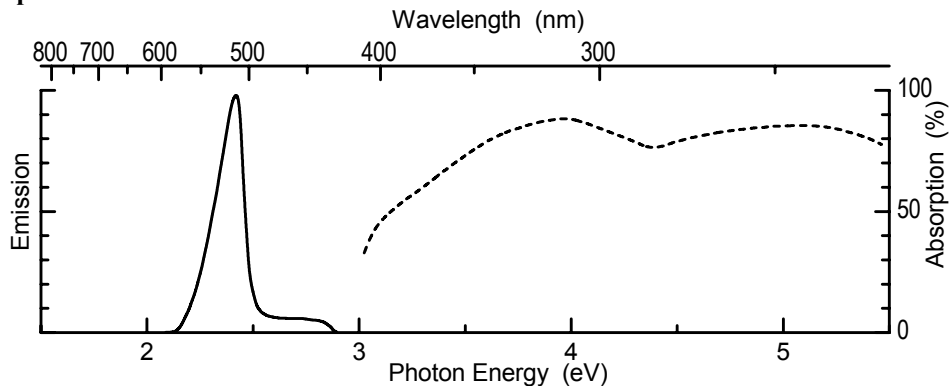
Emission peak: 2.40 eV

Emission width (FWHM): 0.13 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +

Spectra

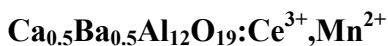


Remark

This phosphor retains its high efficiency to several 100°C. It may be useful for color correction in arc lamps.

References

1. Stevels, A.L.N., and Schrama, A.D.M., Vapor-deposited CSi-Na layers. 1. Morphologic and crystallographic properties, *Philips Res. Rep.*, 29, 340 (1974).
2. Stevels, A.L.N., and Schrama, A.D.M., *J. Electrochem. Soc.*, 123, 691 (1974).



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| CaCO ₃ | 25 | 25 |
| CaF ₂ | 10 | 7.8 |
| BaCO ₃ | 35 | 69 |
| Al ₂ O ₃ | 1210 (of Al) | 617 |
| CeO ₂ | 30 | 51.6 |
| MnCO ₃ | 24 | 27.6 |

Preparation

Mix by ball-milling in methanol.

Dry in air. Powderize when dry.

1. Fire in open quartz boats, N₂, ~500–600°C, ~½ hour.
2. Fire in covered alumina crucibles, CO, 1250°C, 1 hour.
Powderize.
3. Fire in open quartz boats, forming gas, 1250°C, 1 hour.

Optical Properties

Emission color: Bluish-green

Emission peak: 2.41 eV

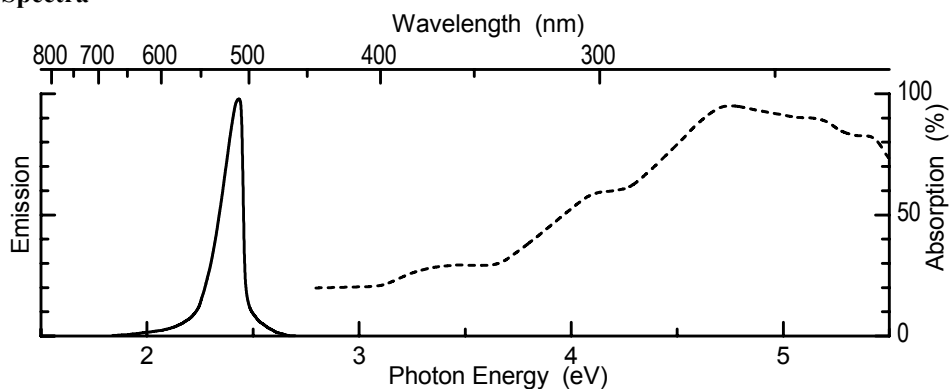
Emission width (FWHM): 0.125 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: ~2–2.5%

Decay: Near-exponential decay, ~15 msec to 1/10

Spectra



Remarks

1. This phosphor retains its high efficiency up to several 100°C.
2. This phosphor is sensitive to lamp-lehring conditions but very stable once it is in the lamp.

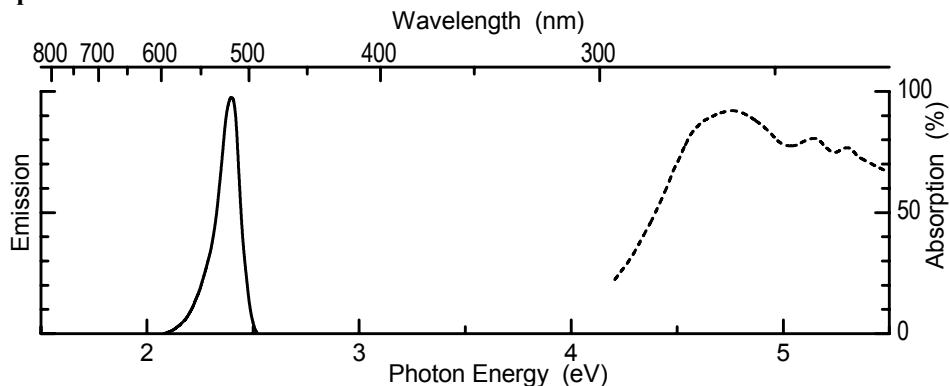
Reference

1. Stevels, A.L.N., and Verstegen, J.M.P.J., Eu²⁺-Mn²⁺ energy-transfer in hexagonal aluminates, *J. Lumin.*, 14, 207 (1976).

$\text{SrAl}_{12}\text{O}_{19}:\text{Eu}^{2+},\text{Mn}^{2+}$

Structure: Aluminate

Spectra



$\text{SrGa}_{12}\text{O}_{19}:\text{Mn}^{2+}$

Structure: Aluminate

Optical Properties

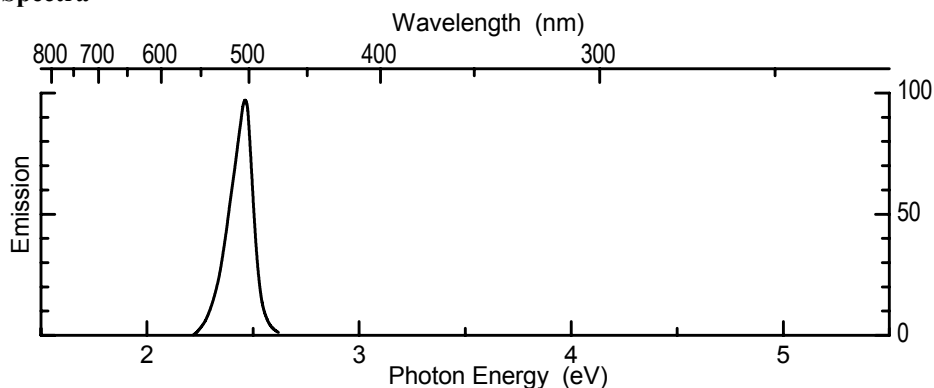
Emission color: Blue-green

Emission peak: 2.47 eV

Emission width (FWHM): 0.12 eV

Excitation efficiency by e-beam: +

Spectra



References

1. Verstegen, J.M., Survey of a group of phosphors, based on hexagonal aluminate and gallate host lattices, *J. Electrochem. Soc.*, 121, 1623 (1974).
2. Verstegen, J.M.P.J., Somerdijk, J.L., and Bril, A., Luminescence of $\text{LiBaF}_3:\text{Eu}^{2+}$, *J. Lumin.*, 10, 411 (1975).

$\text{SrAl}_{12}\text{O}_{19}:\text{Ce}^{3+},\text{Mn}^{2+}$

Structure: Aluminate

Optical Properties

Emission color: Green

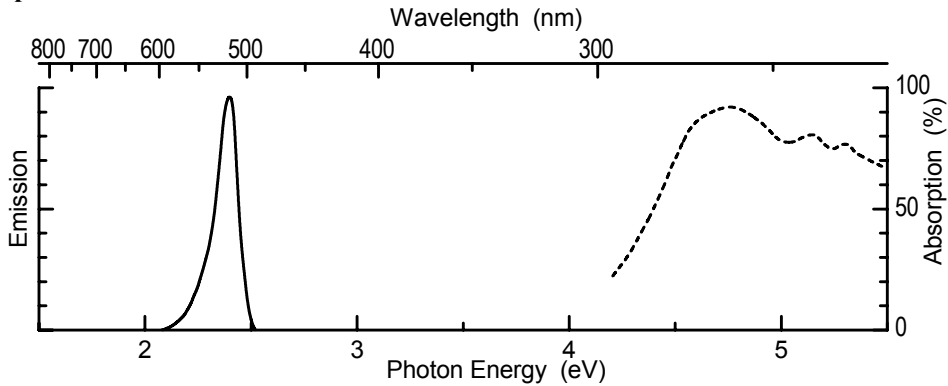
Emission peak: 2.39 eV

Emission width (FWHM): 0.14 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Reference

1. Stevels, A.L.N., and Verstegen, J.M.P.J. Eu^{2+} - Mn^{2+} energy-transfer in hexagonal aluminates, *J. Lumin.*, 14, 207 (1976).

4.9 Molybdates and Tungstates

The following host compounds and activators are included in this subsection:

CaMoO₄
CaMoO₄:Eu³⁺
SrMoO₄:U
MgWO₄
CaWO₄
Ca₃WO₆:U
Sr₃WO₆:U
Ba₃WO₆:U
La₂W₃O₁₂:Eu³⁺

CaMoO₄

Structure: Tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| MoO ₃ | 98 | 141 |

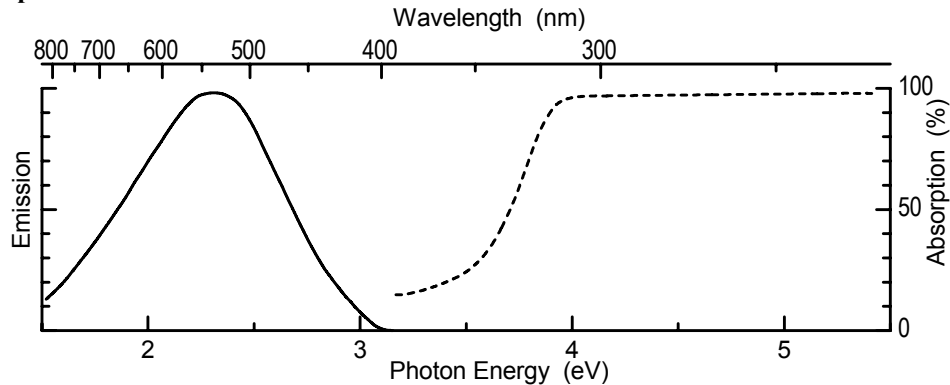
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, air, 1100°C, 1 hour.

Optical Properties

Emission color: Pale yellow-green
Emission peak: ~2.34 eV
Emission width (FWHM): ~0.82 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



CaMoO₄:Eu³⁺

Structure: Tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaCO ₃ | 90 | 90 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| NaHCO ₃ | 5 | 4.2 |
| MoO ₃ | 105 | 151 |

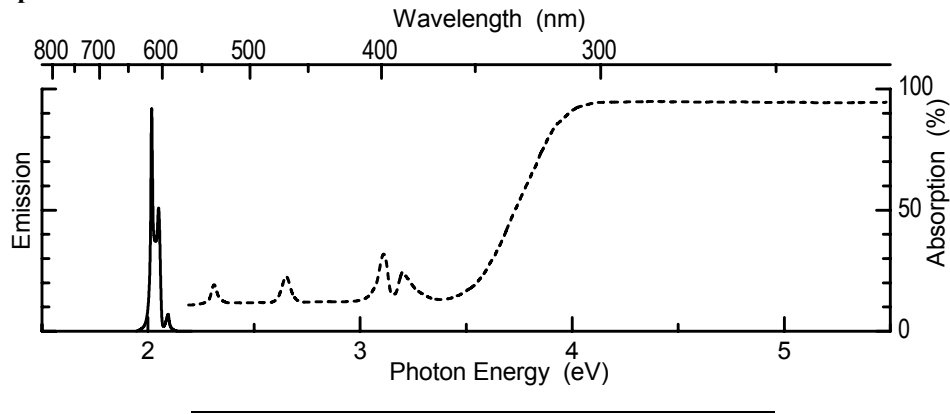
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, O₂, 1100°C, 1 hour.
Powderize.
- Wash in a strong solution of NaOH (or KOH) in water and then several times in plain water until neutral.
- Dry.

Optical Properties

Emission color: Red
Emission peaks: ~2.02 and ~2.03 eV
Excitation efficiency by UV: ++ (4.88 eV)
Excitation efficiency by e-beam: ~0.5–1%

Spectra



SrMoO₄:U

Structure: Tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| SrCO ₃ | 100 | 148 |
| MoO ₃ | 105 | 151 |
| UO ₂ (NO ₃) ₂ · 6H ₂ O | 0.2 | 1 |
| Li ₂ CO ₃ | 2 (of Li) | 0.740 |

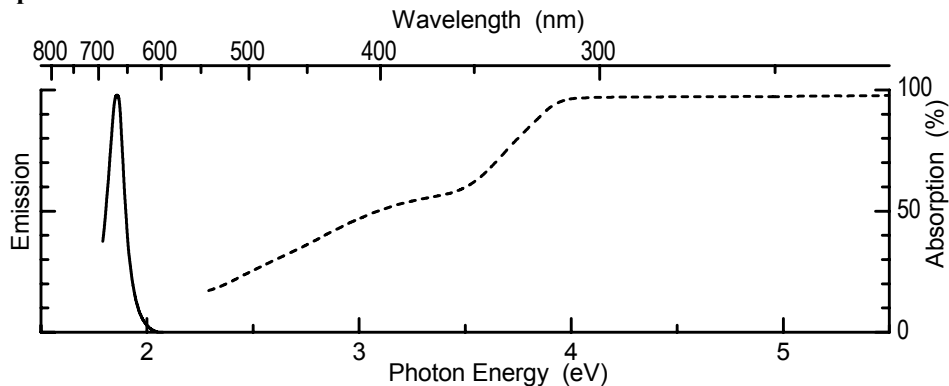
Preparation

- Dissolve the U-nitrate in a little methanol; add this solution to the other ingredients.
Add methanol to make a uniform slurry.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, air, 800°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, O₂, 1000°C, 2 hours.
Powderize.
- Wash in a strong solution of NaOH (or KOH) in water and then several times in plain water until neutral.
Dry.

Optical Properties

Emission color: Deep red
Emission peak: ~1.875 eV
Excitation efficiency by UV: – (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: –

Spectra



Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|-----------------|--------|---------------|
| MgO | 120 | 48 |
| WO ₃ | 100 | 232 |

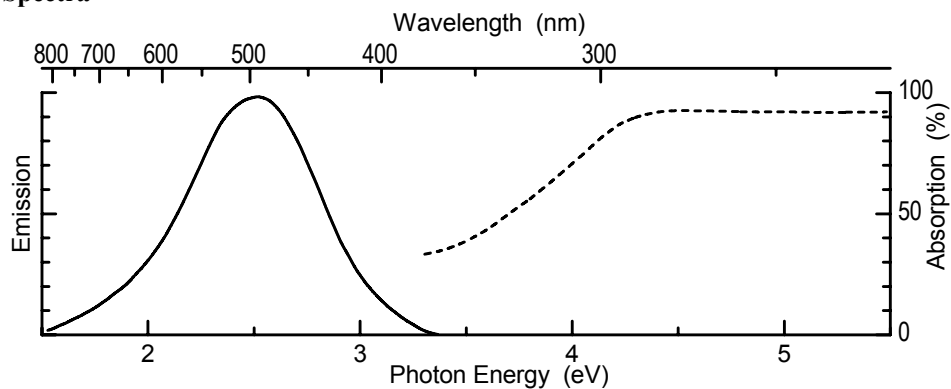
Preparation

- Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in open quartz boats, O₂, 1200°C, 16 hours (overnight).

Optical Properties

Emission color: Blue-greenish white
Emission peak: 2.50 eV
Emission width (FWHM): 0.75 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: ~2.5%
Decay: Near-exponential decay, ~20 μsec to 1/10

Spectra



Structure: Tetragonal (scheelite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 105 | 105 |
| WO ₃ | 100 | 232 |

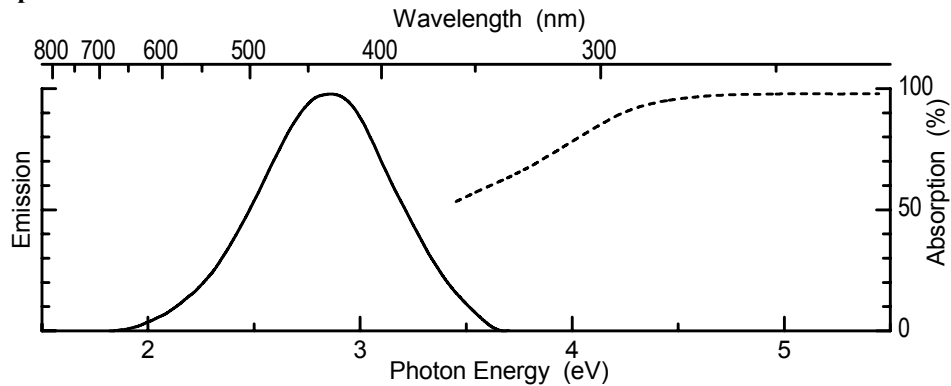
Preparation

Mix by slurring in water.
Dry in air. Powderize when dry.
Fire in open quartz boats, O₂, 1200°C, ~16 hours (overnight).

Optical Properties

Emission color: Pale blue
Emission peak: 2.87 eV
Emission width (FWHM): 0.77 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: ~2–2.5%
Decay: Near-exponential decay, ~10 μsec to 1/10

Spectra



Remark

This material is completely intersoluble with CaMoO₄ in any proportion.

References

1. Kröger, F.A., *Some Aspects of Luminescence of Solids*, Elsevier, Amsterdam (1948).
2. Cook, J.R., Photoconductivity in calcium tungstate, *P. Phys. Soc. London. B*, 68, 148 (1955).
3. Gobrecht, H., and Weiss, W., Lumineszenzuntersuchungen an uran-aktivierten erdalkaliwolframaten und erdalkalimolybdaten, *Z. Phys.*, 140, 139 (1955).
4. Grasser, R., and Scharmann, A., Luminescent sites in CaWO₄ and CaWO₄:Pb crystals, *J. Lumin.*, 12, 473 (1976).

Ca₃WO₆:U

Composition

| Ingredient | Mole % | By weight (g) |
|--|-----------|---------------|
| CaCO ₃ | 300 | 300 |
| WO ₃ | 100 | 232 |
| UO ₂ (NO ₃) ₂ ·6H ₂ O | 0.2 | 1 |
| Li ₂ CO ₃ | 2 (of Li) | 0.740 |

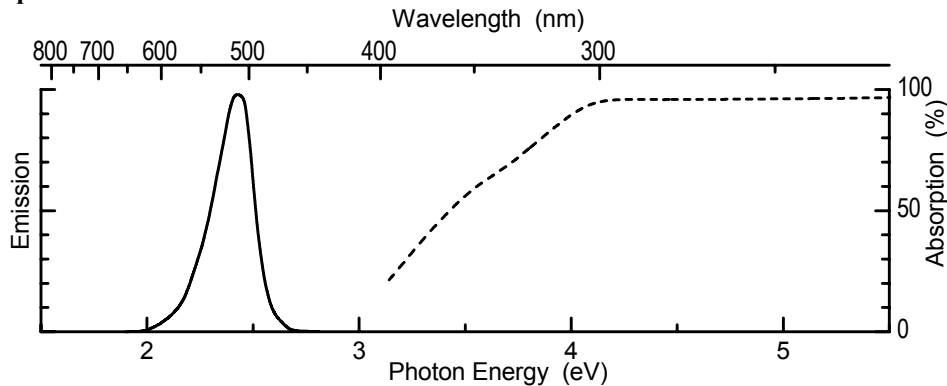
Preparation

- Dissolve the U-nitrate in a little methanol; add this solution to the other ingredients.
Add methanol to make a uniform slurry.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, air, 900°C, 1 hour.
Powderize by grinding or milling.
 2. Fire in open quartz boats, O₂, 1200°C, 2 hours.

Optical Properties

Emission color: Green
Emission peak: 2.41 eV
Emission width (FWHM): 0.23 eV
Excitation efficiency by UV: – (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: –

Spectra



Remark

U is non-luminescent in CaWO₄.

References

1. Kröger, F.A., *Some Aspects of Luminescence of Solids*, Elsevier, Amsterdam (1948).
2. Garlick, G.F.J., and Gibson, A.F., The luminescence of photo-conducting phosphors, *J. Opt. Soc. Am.*, 39, 935 (1949).
3. Gobrecht, H., and Weiss, W., Lumineszenzuntersuchungen an uran-aktivierten erdalkaliwolframaten und erdalkalimolybdaten, *Z. Phys.*, 140, 139 (1955).

Sr₃WO₆:U

Composition

| Ingredient | Mole % | By weight (g) |
|--|-----------|---------------|
| SrCO ₃ | 300 | 443 |
| WO ₃ | 100 | 232 |
| UO ₂ (NO ₃) ₂ ·6H ₂ O | 0.2 | 1 |
| Li ₂ CO ₃ | 2 (of Li) | 0.740 |

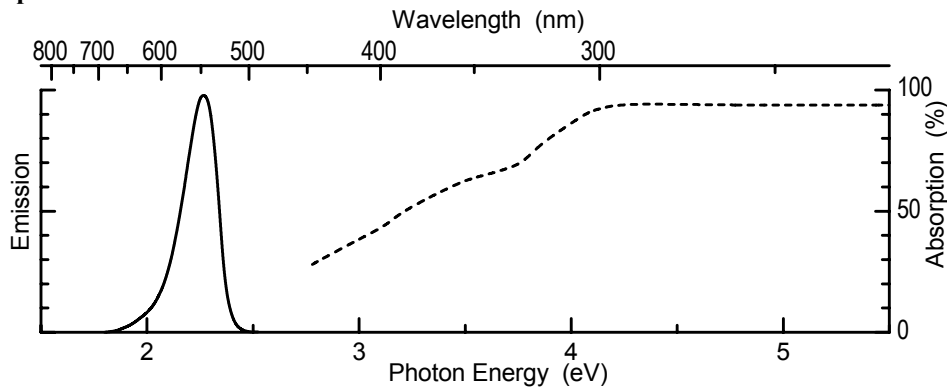
Preparation

- Dissolve the U-nitrate in a little methanol; add this solution to the other ingredients.
Add methanol to make a uniform slurry.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, air, 900°C, 1 hour.
Powderize by grinding or milling.
 2. Fire in open quartz boats, O₂, 1000°C, 2 hours.

Optical Properties

Emission color: Yellow-green
Emission peak: 2.25 eV
Emission width (FWHM): 0.19 eV
Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: Poor

Spectra



Remark

U is non-luminescent in SrWO₄.

Reference

1. Gobrecht, H., and Weiss, W., Lumineszenzuntersuchungen an uran-aktivierten erdalkaliwolframaten und erdalkalimolybdaten, *Z. Phys.*, 140, 139 (1955).

Ba₃WO₆:U

Composition

| Ingredient | Mole % | By weight (g) |
|--|-----------|---------------|
| BaCO ₃ | 300 | 592 |
| WO ₃ | 100 | 232 |
| UO ₂ (NO ₃) ₂ ·6H ₂ O | 0.2 | 1 |
| Li ₂ CO ₃ | 2 (of Li) | 0.740 |

Preparation

Dissolve the U-nitrate in a little methanol; add this solution to the other ingredients.

Add methanol to make a uniform slurry.

Dry in air. Powderize when dry.

1. Fire in open quartz boats, air, 900°C, 1 hour.
Powderize by grinding or milling.
2. Fire in open quartz boats, O₂, 1000°C, 2 hours.

Optical Properties

Emission color: Green-yellow

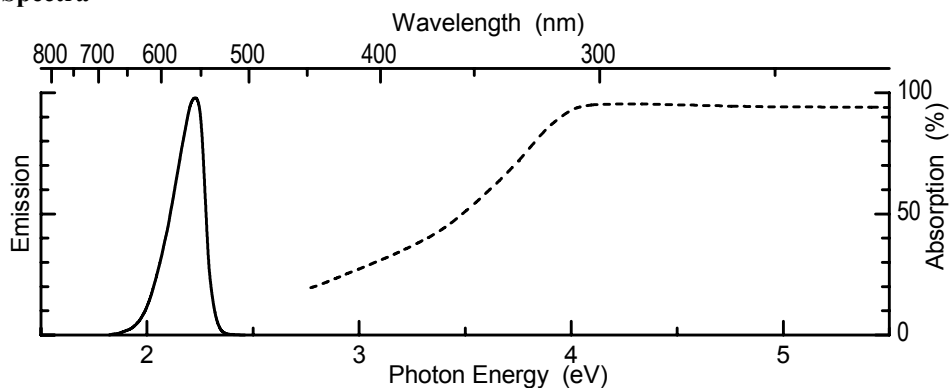
Emission peak: 2.20 eV

Emission width (FWHM): 0.17 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: Poor

Spectra



Remark

U is non-luminescent in BaWO₄.

References

1. Gobrecht, H., and Weiss, W., Lumineszenzuntersuchungen an uran-aktivierten erdalkaliwolframat und erdalkalimolybdaten, *Z. Phys.*, 140, 139 (1955).
2. Alberda, R.H., and Blasse, G., Luminescence in a new garnet phase with hexavalent metal-ions, *J. Lumin.*, 12-13, 687 (1976).

La₂W₃O₁₂:Eu³⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 190 (of La) | 310 |
| Eu ₂ O ₃ | 10 (of Eu) | 17.6 |
| WO ₃ | 300 | 696 |

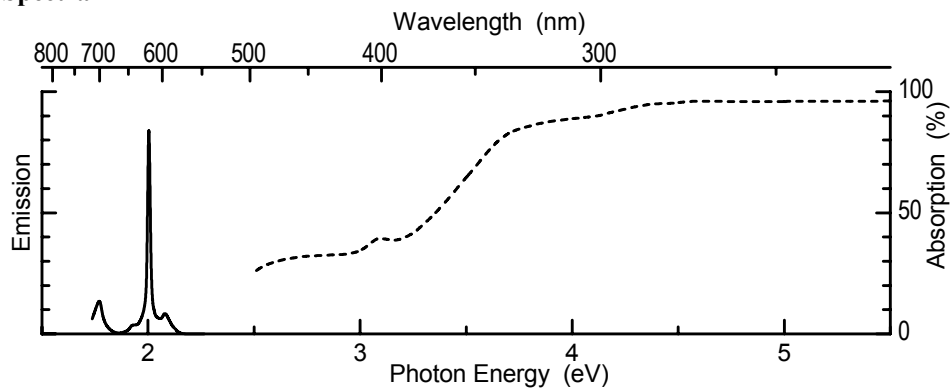
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, air, 1100°C, 1 hour.

Optical Properties

Emission color: Red
Emission peak: Strongest line at 2.018 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



4.10 Miscellaneous Oxides

The following host compounds and activators are included in this subsection:

LiInO₂:Eu³⁺
LiInO₂:Sm³⁺
LiLaO₂:Eu³⁺
NaYO₂:Eu³⁺
CaTiO₃:Pr³⁺
CaGeO₃:Mn²⁺
Mg₂TiO₄:Mn⁴⁺
Zn₂GeO₄:Mn²⁺
YVO₄:Eu³⁺
LaVO₄:Eu³⁺
YAsO₄:Eu³⁺
LaAsO₄:Eu³⁺
Ca₅(VO₄)₃Cl
Mg₈Ge₂O₁₁F₂:Mn⁴⁺
CaY₂ZrO₆:Eu³⁺
Mg₃SiO₃F₄:Ti⁴⁺

LiInO₂:Eu³⁺

Structure: tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|---------------------------------|-------------|---------------|
| In ₂ O ₃ | 98 (of In) | 136 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| Li ₂ CO ₃ | 101 (of Li) | 37.4 |

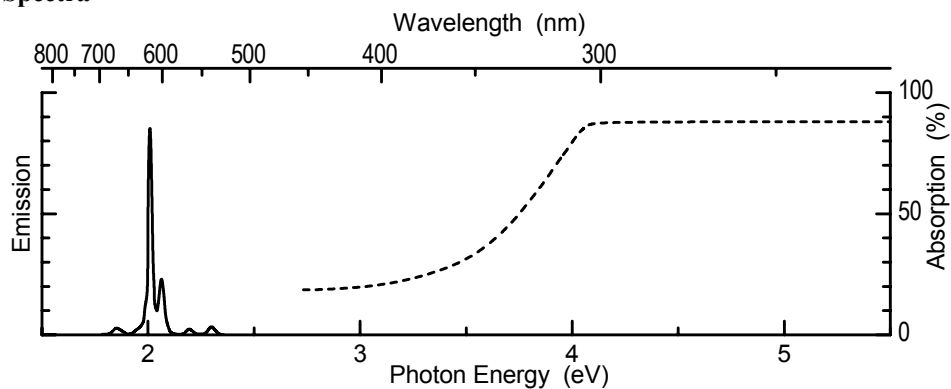
Preparation

- Mix by slurring in methanol.
1. Fire in open alumina crucibles, air, 700°C, 1 hour.
Powderize.
 2. Fire in open alumina crucibles, air, 950°C, 1 hour.

Optical Properties

Emission color: Red
Emission peaks: 2.03 eV and 2.08 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV); weakly excited at 4.0 eV
Excitation efficiency by e-beam: ~5%

Spectra



Reference

1. Blasse, G., and Bril, A., On Eu^{3+} fluorescence in mixed metal oxides. 5. Eu^{3+} fluorescence in rocksalt lattice, *J. Chem. Phys.*, 45, 3327 (1966).

$\text{LiInO}_2:\text{Sm}^{3+}$

Structure: tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------|--------------|---------------|
| In_2O_3 | 99.7 (of In) | 138 |
| Sm_2O_3 | 0.3 (of Sm) | 0.520 |
| Li_2CO_3 | 101 (of Li) | 37.4 |

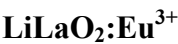
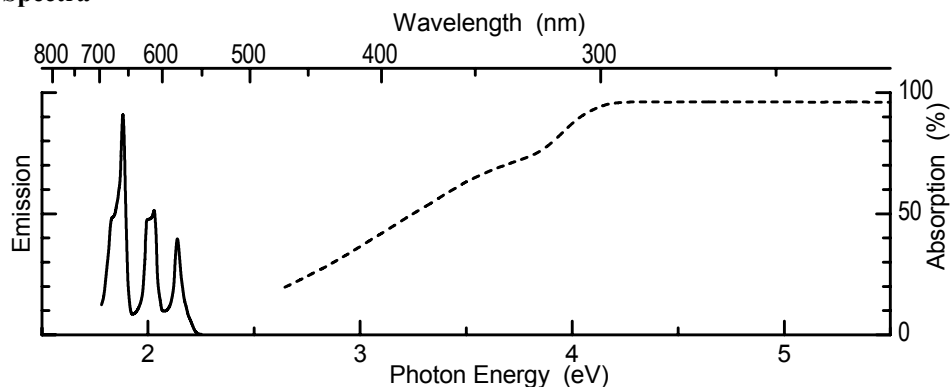
Preparation

- Mix by slurring in methanol.
Dry in air. Powderize when dry.
1. Fire in open alumina crucibles, air, 700°C, 1 hour.
Powderize.
 2. Fire in open alumina crucibles, air, 950°C, 1 hour.

Optical Properties

Emission color: Orange
Emission peaks: 1.85–2.15 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: ~5%

Spectra



Structure: tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------|-------------|---------------|
| La_2O_3 | 95 (of La) | 155 |
| Eu_2O_3 | 5 (of Eu) | 8.8 |
| Li_2CO_3 | 101 (of Li) | 37.4 |

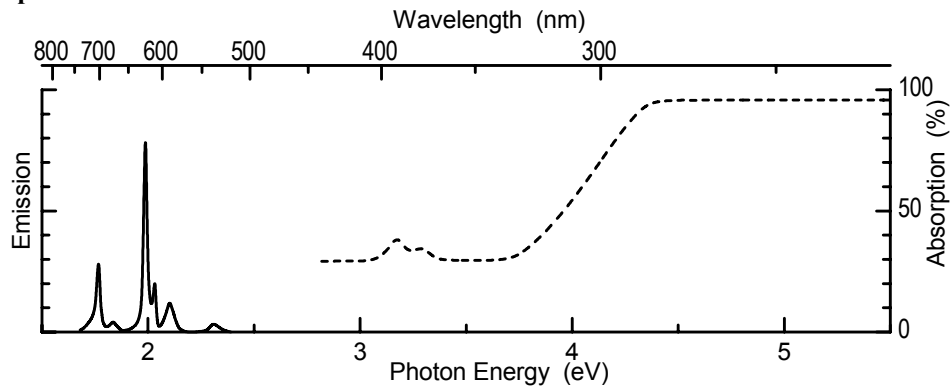
Preparation

- Mix by slurring in methanol.
Dry in air. Powderize when dry.
1. Fire in open alumina crucibles, air, $\sim 600^\circ\text{C}$. Powderize.
 2. Fire in open alumina crucibles, air, 1000°C , 1 hour. Powderize.
- Store in a well-closed container.

Optical Properties

Emission color: Red
Emission peaks: 1.775–2.02 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: $\sim 1\%$

Spectra

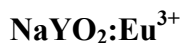


Remarks

1. This material is difficult to prepare; the reaction between Li_2CO_3 and La_2O_3 apparently does not go to completion.
2. This phosphor is slightly hygroscopic.

Reference

1. Blasse, G., and Bril, A., On Eu^{3+} fluorescence in mixed metal oxides. 5. Eu^{3+} fluorescence in rocksalt lattice, *J. Chem. Phys.*, 45, 3327 (1966).



Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-----------|---------------|
| Y_2O_3 | 95 (of Y) | 108 |
| Eu_2O_3 | 5 (of Eu) | 8.8 |
| NaHCO_3 | 101 | 85 |

Preparation

Mix by slurring in methanol.

Dry in air. Powderize when dry.

1. Fire in open alumina crucibles, air, $\sim 600^\circ\text{C}$, $\frac{1}{2}$ hour.
Powderize.
 2. Fire in open alumina crucibles, air, 900°C , 1 hour.
Powderize.
- Store in a well-closed container.

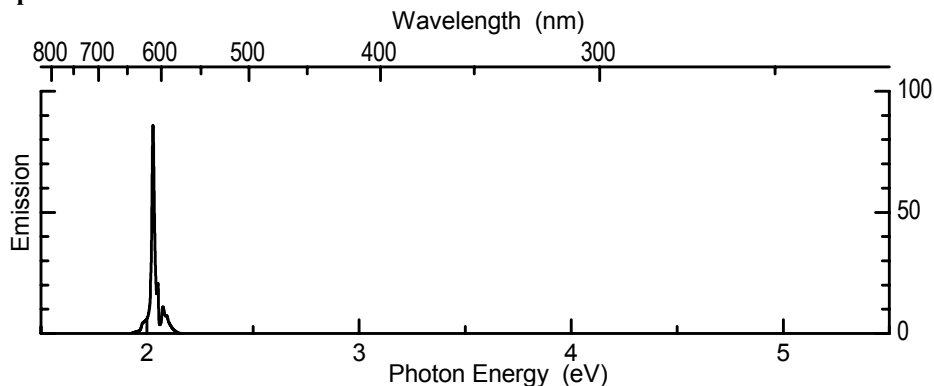
Optical Properties

Emission color: Red

Emission peak: 2.025 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



Remarks

1. This material is difficult to prepare; the reaction between Na_2O and Y_2O_3 apparently does not go to completion.
2. This phosphor is slightly hygroscopic.

Reference

1. Blasse, G., and Bril, A., On Eu^{3+} fluorescence in mixed metal oxides. 5. Eu^{3+} fluorescence in rocksalt lattice, *J. Chem. Phys.*, 45, 3327 (1966).

$\text{CaTiO}_3:\text{Pr}^{3+}$

Structure: Cubic (perovskite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|--------|---------------|
| CaCO_3 | 100 | 100 |
| Pr_2O_3 | 1 | 1.64 |
| TiO_2 | 100 | 80 |

Preparation

Mix by slurring in methanol.

Dry in air. Powderize when dry.

1. Fire in open quartz boats, air, 1300°C , 1 hour.
Powderize by grinding or milling.
2. Fire in open quartz boats, air, 1300°C , 1 hour.

Optical Properties

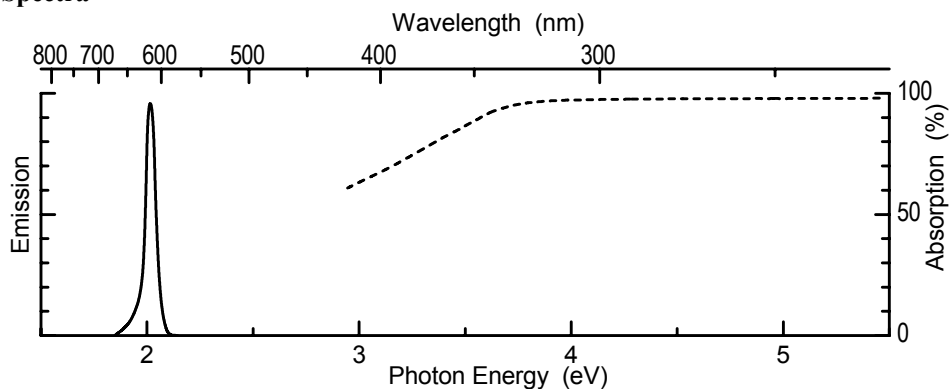
Emission color: Red

Emission peak: 2.025 eV

Emission width (FWHM): 0.05 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Spectra



Remark

The efficiency of this phosphor is not likely improvable because of:

- (a) much "dead" absorption of the Ti^{4+} -ion in the UV,
- (b) most likely an appreciable amount of emission in the IR.

CaGeO₃:Mn²⁺

Structure: Orthorhombic (wollastonite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 98 | 98 |
| MnCO ₃ | 2 | 2.3 |
| GeO ₂ | 105 | 110 |
| NH ₄ Br | 2 | 2 |

Preparation

Mix by slurring in water or methanol.

Dry in air. Powderize when dry.

Fire in capped quartz tubes, CO, 1150°C, 2 hours.

Optical Properties

Emission color: Orange

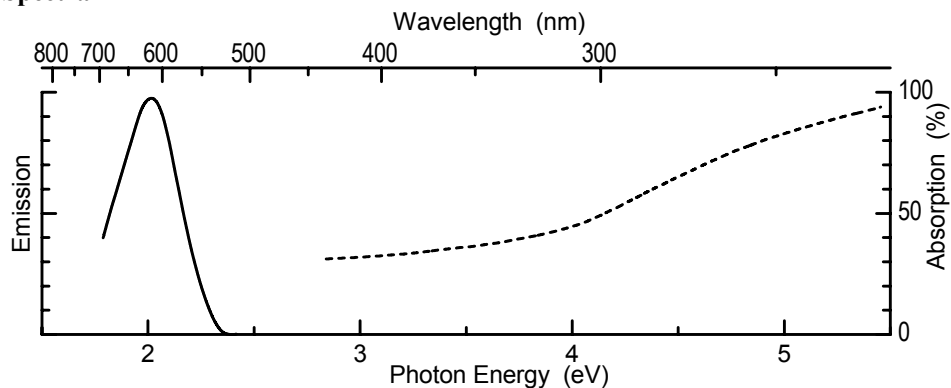
Emission peak: 2.01 eV

Emission width (FWHM): 0.30 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Remark

The excitation efficiency of QE ~50–60% under 4.88 eV was observed without addition of a sensitizer to the phosphor. Attempts to improve this efficiency by addition of various other impurities failed.

Reference

1. Koelmans, H., and Verhagen, C.M.C., The fluorescence of binary and ternary germanates of group-II elements, *J. Electrochem. Soc.*, 106, 677 (1959).

Mg₂TiO₄:Mn⁴⁺

Structure: Cubic (spinel)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| MgO | 300 | 121 |
| TiO ₂ | 99 | 79 |
| MnCO ₃ | 1 | 1.15 |

Preparation

Mix by slurring in water or methanol.

Dry in air. Powderize when dry.

1. Fire in open quartz boats, air, 1300°C, 1 hour.
Powderize by grinding or milling.
2. Fire in open quartz boats, O₂, 570°C, ~16 hours (overnight).

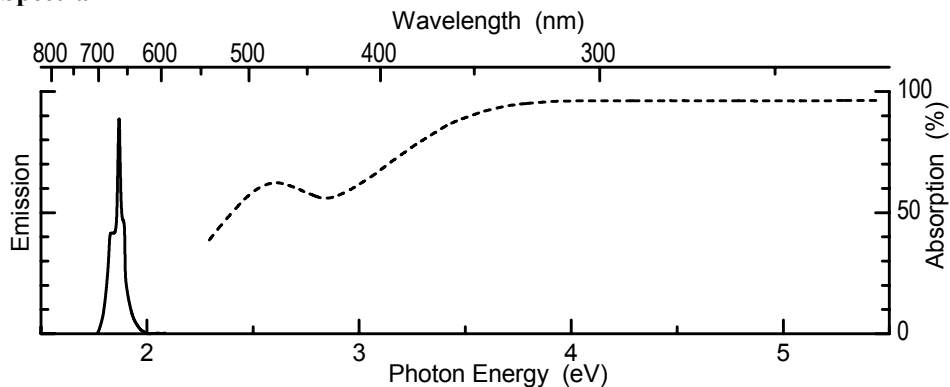
Optical Properties

Emission color: Deep red

Emission peak: 1.885 eV

Excitation efficiency by UV: – (4.88 eV), + (3.40 eV)

Spectra



Reference

1. Kröger, F.A., *Some Aspects of Luminescence of Solids*, Elsevier, Amsterdam (1948).

Zn₂GeO₄:Mn²⁺

Structure: Tetragonal (willemite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| ZnO | 90 | 73.2 |
| MgF ₂ | 5 | 3.1 |
| MnCO ₃ | 5 | 5.8 |
| GeO ₂ | 55 | 57.5 |

Preparation

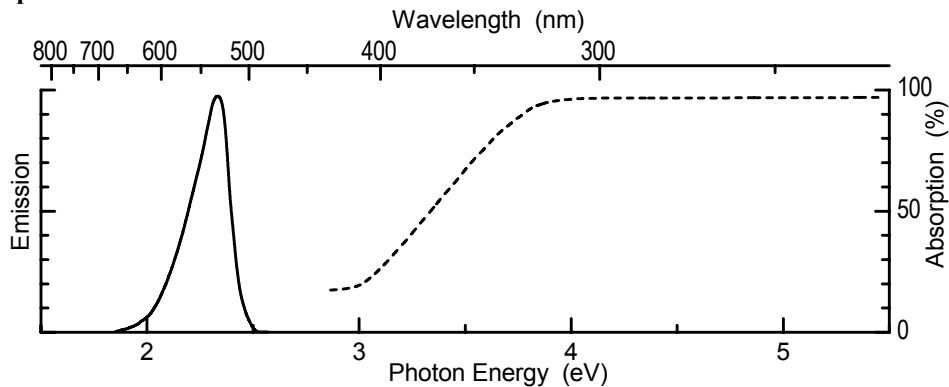
Mix by slurring in water. Dry in air. Powderize when dry.

- 1. Fire in capped quartz tubes, CO, 1100°C, 1 hour.
Powderize by grinding or milling.
- 2. Fire in open quartz boats, water steam, 1000°C, 1 hour.

Optical Properties

Emission color: Green
Emission peak: 2.31 eV
Emission width (FWHM): 0.20 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: + Comparable to that of Zn₂SiO₄:Mn²⁺

Spectra

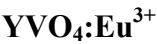


Remarks

- 1. The emission of this phosphor is thermally quenched a little above room temperature.
- 2. This material forms solid solutions with Zn₂SiO₄:Mn²⁺ in all proportions.

References

- 1. Bube, R.H., and Larach, S., Luminescence and trapping in phosphors containing gallium, *J. Chem. Phys.*, 21, 5 (1953).
- 2. Palumbo, D.T., and Brown, J.J., Electronic states of Mn²⁺-activated phosphors. 1. Green-emitting phosphors, *J. Electrochem. Soc.*, 117, 1814 (1971).
- 3. Schulman, J.H., Ginther, R.J., and Claffy, E.W., Manganese-activated zinc beryllium germanate phosphors, *J. Electrochem. Soc.*, 96, 57 (1949).



Structure: Tetragonal (xenotime)

Composition

| Ingredient | Mole % | By weight (g) |
|---------------------------------|-----------|---------------|
| Y ₂ O ₃ | 95 (of Y) | 107 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| NH ₄ VO ₃ | 110 | 129 |

Preparation

Mix by dry grinding or milling.

1. Fire in open quartz boats, air, 1000°C, 1 hour.
Powderize.
2. Fire in open quartz boats, air, 1200°C, 1 hour.
Powderize.
Wash in a strong solution of NaOH (or KOH) in water and then several times in plain water.
Dry.
3. Fire in open quartz boats, air, 1200°C, 1 hour.

Optical Properties

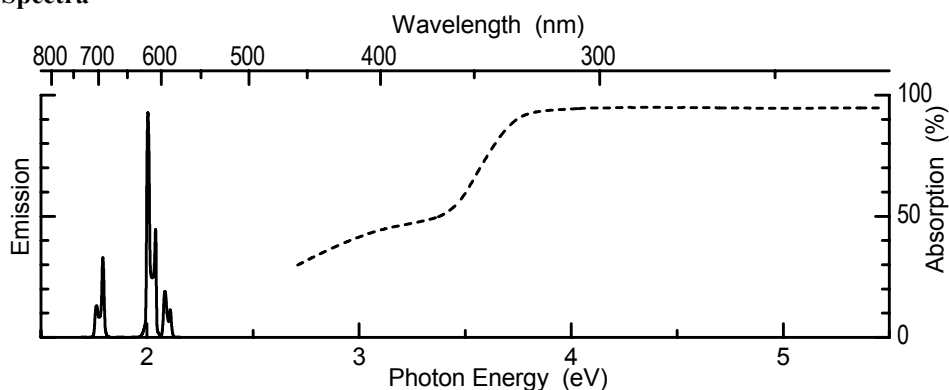
Emission color: Red

Emission peak: 2.00 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV); efficiency of 3.40 eV excitation improving considerably with increasing temperature

Excitation efficiency by e-beam: +/-7%

Spectra



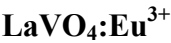
Remarks

1. Part of the V can be replaced by P.
2. This phosphor has been used for color correction of Hg arc lamps.
3. Optical absorption, and efficiency of luminescence, for 3.40 eV excitation can be somewhat improved by addition of Bi.

References

1. van Uitert, L.G. et al., Role of F-orbital electron wave function mixing in concentration quenching of Eu^{3+} , *J. Chem. Phys.*, 36, 702 (1962).
2. O'Connor, J.R., Unusual crystal-field energy levels and efficient laser properties of $\text{YVO}_4 - \text{Nd}$, *Appl. Phys. Lett.*, 9, 407 (1966).
3. Palilla, F.C., Levine, A.K., and Rinkevics, M., Rare earth activated phosphors based on yttrium orthovanadate and related compounds, *J. Electrochem. Soc.*, 112, 776 (1965).
4. Toma, S.Z., Mikus, F.F., and Mathers, J.E., Energy transfer and fluorescence processes in Bi^{3+} and Eu^{3+} activated YVO_4 , *J. Electrochem. Soc.*, 114, 953 (1967).
5. Ropp, R.C., Spectra of some rare earth vanadates, *J. Electrochem. Soc.*, 115, 940 (1968).
6. Levine, A.K. and Palilla, F.C., New highly efficient red-emitting cathodoluminescent phosphor ($\text{YVO}_4 - \text{Eu}$) for color television electron beam excitation, *Appl. Phys. Lett.*, 5, 118 (1964).

7. Palilla, F.C., and Levine, A.K., YVO₄-Eu- a highly efficient red-emitting phosphor for high pressure mercury lamps, *Appl. Optics*, 5, 1467 (1966).
8. Levine, A.K., and Palilla, F.C., YVO₄-Eu a new highly efficient phosphor for color television, *Electrochem. Technol.*, 4, 16 (1966).
9. Brixner, L.H., and Abramson, E., On luminescent properties of rare earth vanadates, *J. Electrochem. Soc.*, 112, 70, (1965).
10. Datta, R.K., Bismuth in yttrium vanadate and yttrium europium vanadate phosphors, *J. Electrochem. Soc.*, 114, 1057 (1967).
11. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).



Structure: Monoclinic

Composition

| Ingredient | Mole % | By weight (g) |
|---------------------------------|------------|---------------|
| La ₂ O ₃ | 95 (of La) | 155 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| NH ₄ VO ₃ | 110 | 129 |

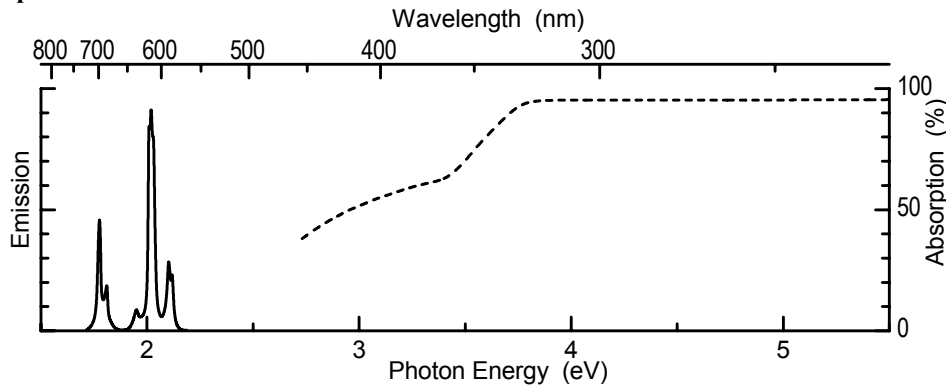
Preparation

- Mix by dry grinding or milling.
1. Fire in open quartz boats, air, 900°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, air, 1100°C, 1 hour.
Powderize.
Wash in a strong solution of NaOH (or KOH) in water and then several times in plain water.
Dry.
 3. Fire in open quartz boats, air, 1100°C, 1 hour.

Optical Properties

Emission color: Red
Emission peaks: 1.773–2.115 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Spectra



References

1. Wanmaker, W.L. et al., Luminescent properties of Eu-activated phosphors of type A_3BVO_4 , *Philips Res. Rep.*, 21, 270 (1966).
2. Aia, M.A., Structure and luminescence of phosphate-vanadates of yttrium gadolinium lutetium and lanthanum, *J. Electrochem. Soc.*, 114, 367 (1967).



Structure: Tetragonal (xenotime)

Composition

| Ingredient | Mole % | By weight (g) |
|------------|-------------|---------------|
| Y_2O_3 | 95 (of Y) | 107 |
| Eu_2O_3 | 5 (of Eu) | 8.8 |
| As_2O_3 | 100 (of As) | 75 |

Preparation

Mix by slurring in 30% H_2O_2 .

Gently heat up while stirring until reaction (boiling) indicates formations of H_3AsO_4 .

Dry in air. Powderize when dry.

1. Fire in open quartz boats, air, $\sim 500^\circ C$. Powderize.
2. Fire in open quartz boats, air, $1200^\circ C$, 1 hour.

Optical Properties

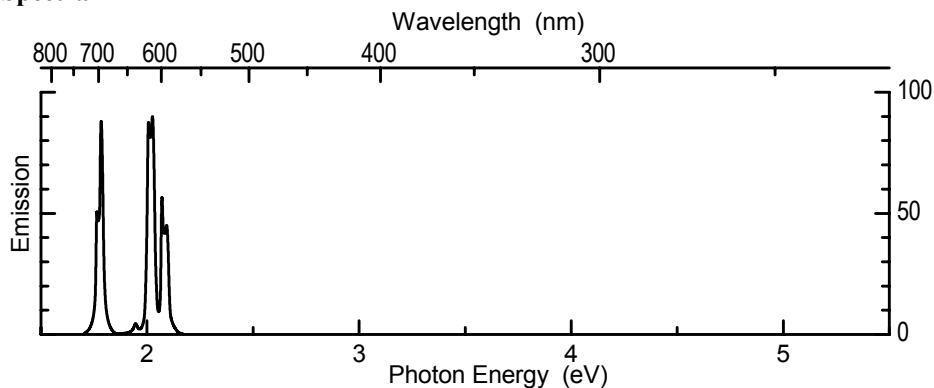
Emission color: Red

Emission peaks: 1.76–2.09 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Remarks

1. This phosphor becomes excitable by 4.88 and by 3.40 eV UV upon replacement of some As by V.
2. The material forms solid solutions with $YVO_4:Eu^{3+}$ in all proportions.

Reference

1. Wanmaker, W.L., et al., Luminescent properties of Eu-activated phosphors of type A_3BVO_4 , *Philips Res. Rep.*, 21, 270 (1966).

LaAsO₄:Eu³⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| La ₂ O ₃ | 95 (of La) | 155 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| As ₂ O ₃ | 100 (of As) | 75 |

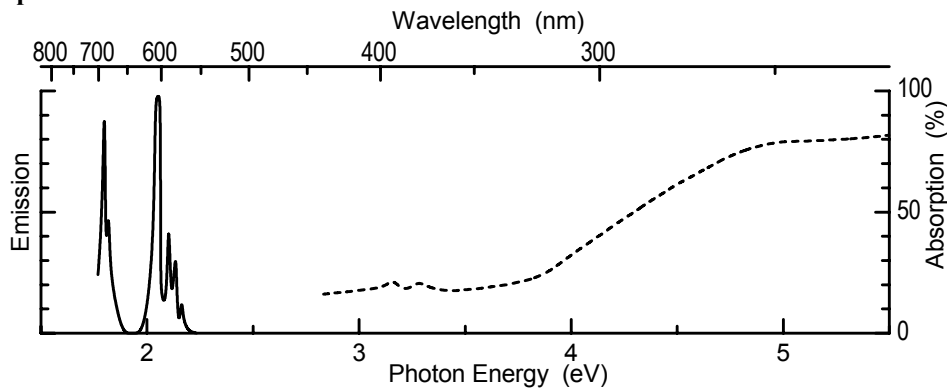
Preparation

- Mix by slurring in 30% H₂O₂.
Gently heat up while stirring until reaction (boiling) indicates formations of H₃AsO₄.
Dry in air. Powderize when dry.
1. Fire in open quartz boats, air, ~500°C.
Powderize.
 2. Fire in open quartz boats, air, 1000°C, 1 hour.

Optical Properties

Emission color: Red
Emission peaks: 1.785–2.149 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



Remarks

1. This material becomes excitable by 3.40 eV UV upon replacement of a few percent of the As by V.
2. The material forms solid solutions with LaVO₄ in all proportions.

$\text{Ca}_5(\text{VO}_4)_3\text{Cl}$

Structure: Apatite

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------|--------|---------------|
| CaO | 500 | 280 |
| NH_4VO_3 | 200 | 234 |
| NH_4Cl | 200 | 107 |

Preparation

Mix by dry grinding or milling (some NH_3 develops).

1. Fire in capped quartz tubes, air, $\sim 500^\circ\text{C}$, 16 hours (overnight). Powderize.
2. Fire in capped quartz tubes, air, 1000°C , 1 hour.

Optical Properties

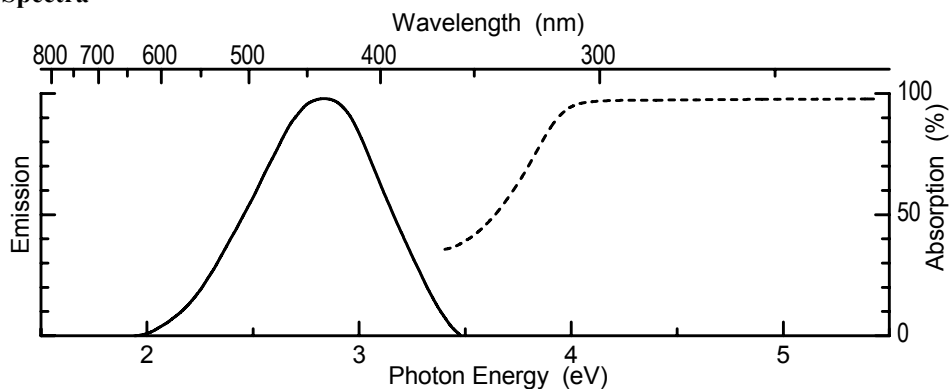
Emission color: Bluish

Emission peak: 2.85 eV

Emission width (FWHM): 0.73 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



Remarks

1. This phosphor requires a deficiency of V and an excess of Cl in the preparation.
2. The luminescence of this phosphor is due to the vanadate. Other impurities were tested as prospective activators but are either dead (Mn, Tb, Ho) or very poorly luminescent (Eu^{3+}).

Reference

1. Aia, M.A., and Lublin, P., Blue luminescence in calcium chlorovanadates, *J. Electrochem. Soc.*, 113, 1331 (1966).

$\text{Mg}_8\text{Ge}_2\text{O}_{11}\text{F}_2\text{:Mn}^{4+}$

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| MgO | 700 | 282 |
| MgF ₂ | 100 | 62 |
| MgCO ₃ | 8 | 9.2 |
| GeO ₂ | 192 | 201 |

Preparation

Mix by dry ball-milling.

1. Fire in capped quartz tubes, air, 1200°C, 2 hours.
Powderize by dry ball-milling.
2. Fire in open quartz boats, air, 1200°C, ~16 hours (overnight).

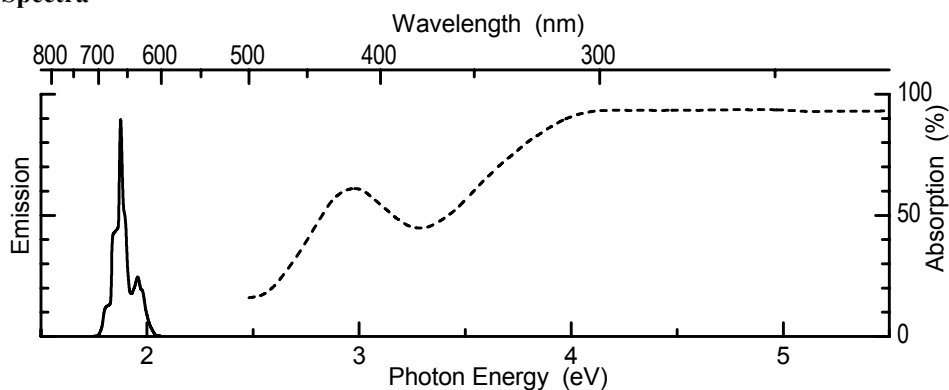
Optical Properties

Emission color: Deep red

Emission peak: 1.88 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Spectra



Remarks

1. The exact formula of this material is still uncertain. The above formula is only that of the raw mix; some parts (mainly Ge fluoride) sublimes out during firing.
2. This phosphor has been used for color correction of Hg arc lamps.

References

1. Thorington, L., Temperature dependence of the emission of an improved manganese-activated magnesium germanate phosphor, *J. Opt. Soc. Am.*, 40, 579 (1950).
2. Kemeny, G., and Haake, C.H., Activator center in magnesium fluorogermanate phosphors, *J. Chem. Phys.*, 33, 783 (1960).

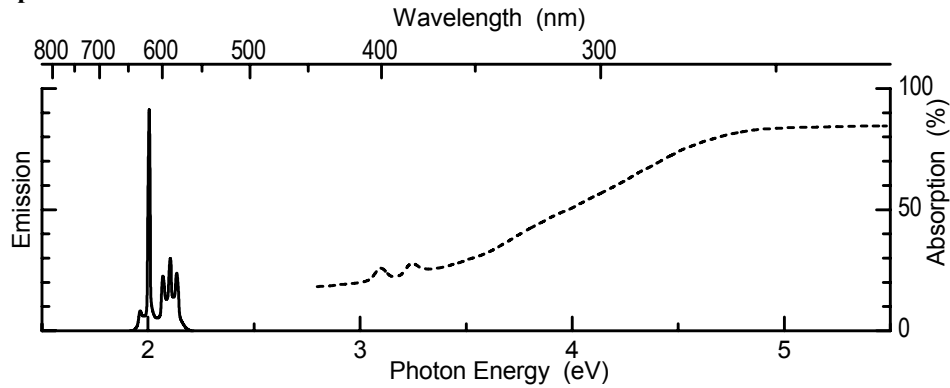
CaY₂ZrO₆:Eu³⁺

Structure: Perovskite

Optical Properties

Emission color: Red
Emission peak: 2.01 eV
Excitation efficiency by UV:++ (4.88 eV), – (3.40 eV)

Spectra

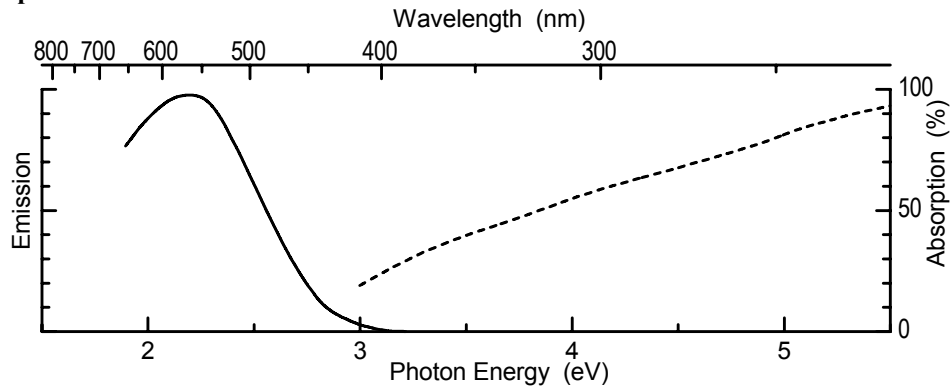


Mg₃SiO₃F₄:Ti⁴⁺

Optical Properties

Emission color: whitish-yellow
Emission peak: 2.15 eV
Excitation efficiency by UV:++ (4.88 eV), – (3.40 eV)

Spectra



4.11 Halides and Oxyhalides

The following host compounds and activators are included in this subsection:

MgF₂:Mn²⁺
CaF₂:Ce³⁺
CaF₂:Eu²⁺
CaF₂:Mn²⁺
CaF₂:Ce³⁺,Mn²⁺
CaF₂:Ce³⁺,Tb³⁺
CaF₂:U
CaCl₂:Eu²⁺ in SiO₂
CaCl₂:Eu²⁺,Mn²⁺ in SiO₂
CaBr₂:Eu²⁺ in SiO₂
CaI₂:Eu²⁺ in SiO₂
CaI₂:Eu²⁺,Mn²⁺ in SiO₂
SrF₂:Eu²⁺
SrCl₂:Eu²⁺ in SiO₂
Sr(Cl,Br,I)₂:Eu²⁺ in SiO₂
ZnF₂:Mn²⁺
Ba_xSr_{1-x}F₂:Eu²⁺
YF₃:Mn²⁺
YF₃:Mn²⁺,Th⁴⁺
KMgF₃:Eu²⁺
KMgF₃:Mn²⁺
LiAlF₄:Mn²⁺
K₂SiF₆:Mn⁴⁺
YOF:Eu³⁺
YOF:Ce³⁺
YOF:Eu³⁺
YOF:Eu³⁺
YOF:Tb³⁺
LaOF:Eu³⁺
LaOCl:Bi³⁺
LaOCl:Eu³⁺

MgF₂:Mn²⁺

Structure: Tetragonal (sellaite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| MgF ₂ | 99 | 62 |
| MnCO ₃ | 1 | 1.15 |

Preparation

Mix by slurring in methanol.
Add ~2 g of NH₄F (dissolved in a little water) and ~2–3 ccm of HF acid; stir to uniformity.
Dry. Powderize.
Fire in capped quartz tubes, N₂, 900°C, 1 hour.

Optical Properties

Emission color: Orange-yellow

Emission peak: 2.10 eV

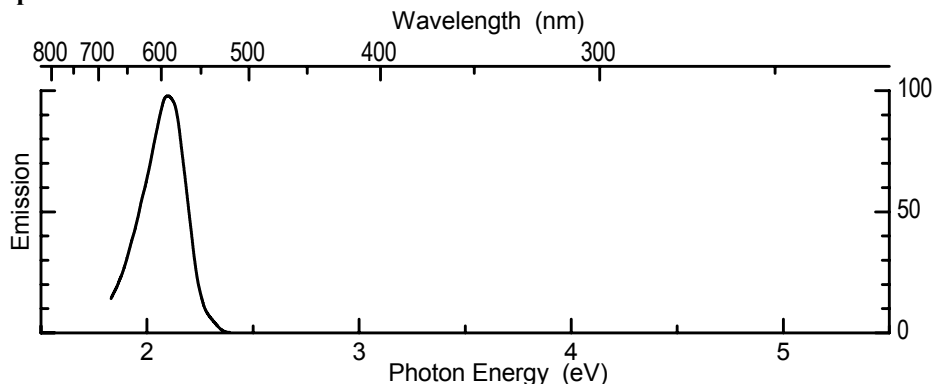
Emission width (FWHM): 0.25 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV).

Excitation efficiency by e-beam: +/-25%

Decay: Exponential, about 200 msec to 1/10

Spectra

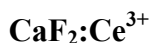


Remark

No sensitizer is known to permit excitation by these UV wavelengths.

References

1. Klasens, H.A., Zalm, P., and Huysman, F.O., The manganese emission in AbF₃ compounds, *Philips Res. Rep.*, 8, 441 (1953).
2. Smith, A.L., New manganese-activated fluoride phosphors, *J. Electrochem. Soc.*, 101, 189 (1954).
3. Williams, F.E., and Eyring, H., The mechanism of the luminescence of solids, *J. Chem. Phys.*, 15, 289 (1947).
4. Bräunlich, P., Hanle, W., and Scharmann, A., Zur thermolumineszenz von MgF₂-Mn, *Z. Naturforsch. Pt. A*, 16, 869 (1961).



Structure: Cubic (fluorite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------------|--------|---------------|
| CaF ₂ | 90 | 70 |
| CeF ₃ | 5 | 9.85 |
| AlF ₃ | 5 | 4.2 |

Preparation

Start with plain CaF₂ and pre-fire it in open quartz boats, air, 1000°C, 1 hour.

Make a slurry of the CaF₂ + CeF₃ + AlF₃ in methanol.

Add ~1–2 ccm HF acid; stir to uniformity. Dry; powderize.

Add ~2–3 g of iodine, mix by dry grinding.

Fire in capped quartz tubes, N₂, 1000°C, 1 hour. Powderize.

Optical Properties

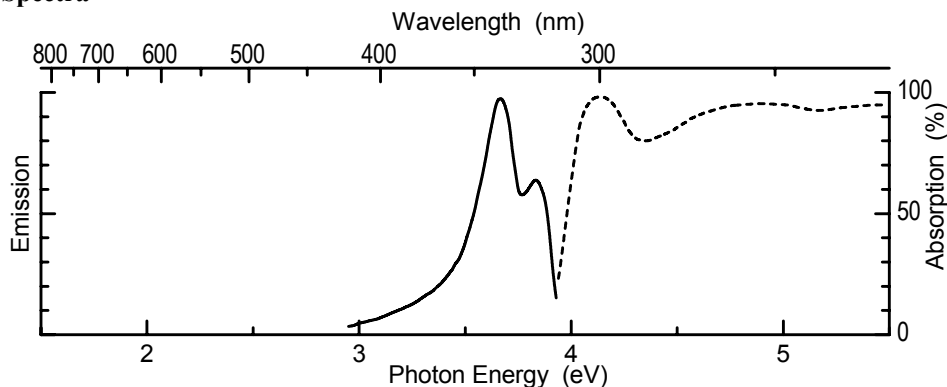
Emission color: UV

Emission peak: 3.68 eV, 3.88 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Kröger, F.A., and Bakker, J., *Physica*, 8, 628 (1941).
2. Ginther, R.J., Luminescence of K₄MnCl₆ and KCl (Pb + Mn), *J. Electrochem. Soc.*, 98, 74 (1951).
3. Loh, E., Ultraviolet absorption spectra of Ce³⁺ in alkaline-earth fluorides, *Phys. Rev.*, 154, 270 (1967).
4. Schlesinger, M., and Whippey, P.W., Investigations of 4f–5d transitions of Ce³⁺ in CaF₂, *Phys. Rev.*, 171, 361 (1968).
5. Leach, R., Energy transfer and sensitization in single crystal phosphors, *J. Electrochem. Soc.*, 105, 27 (1958).

CaF₂:Eu²⁺

Structure: Cubic (fluorite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaF ₂ | 100 | 70 |
| Eu ₂ O ₃ | 0.2 (of Eu) | 0.350 |

Preparation

Mix by slurring in methanol (in a plastic container).

Add ~2 ccm HF acid; stir to uniformity.

Dry; powderize.

Add ~2–3 g of iodine; mix by dry grinding.

Fire in capped quartz tubes, N₂, 800°C, 1 hour.

Powderize.

Optical Properties

Emission color: Violet

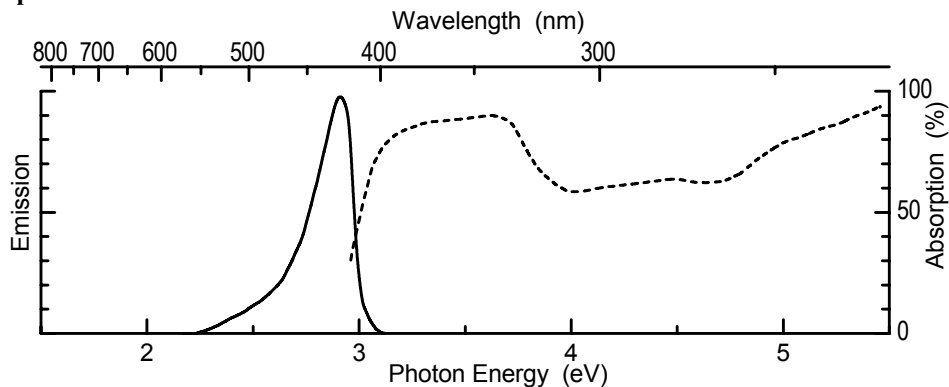
Emission peak: 2.93 eV

Emission width (FWHM): 0.22 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +

Spectra

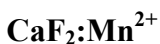


Remark

This material can be sensitized for better UV excitation with 4.88 eV by addition of Ce (see CaF₂:Ce³⁺).

References

1. Amster, R.L., Photosensitization of terbium fluorescence by europium in CaF₂, *J. Electrochem. Soc.*, 117, 791 (1970).
2. Amster, R.L., and Wiggins, C.S., Spectroscopic identification of europium-oxygen complexes in calcium fluoride, *J. Electrochem. Soc.*, 116, 68 (1969).



Structure: Cubic (fluorite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaF ₂ | 99 | 77 |
| MnCO ₃ | 1 | 1.15 |

Preparation

Mix by slurring in methanol (in a plastic container).

Add ~2 ccm HF acid; stir to uniformity.

Dry; powderize.

Add ~2–3 g of iodine; mix by dry grinding.

Fire in capped quartz tubes, N₂, 800°C, 1 hour.

Powderize.

Optical Properties

Emission color: Blue-green

Emission peak: 2.50 eV

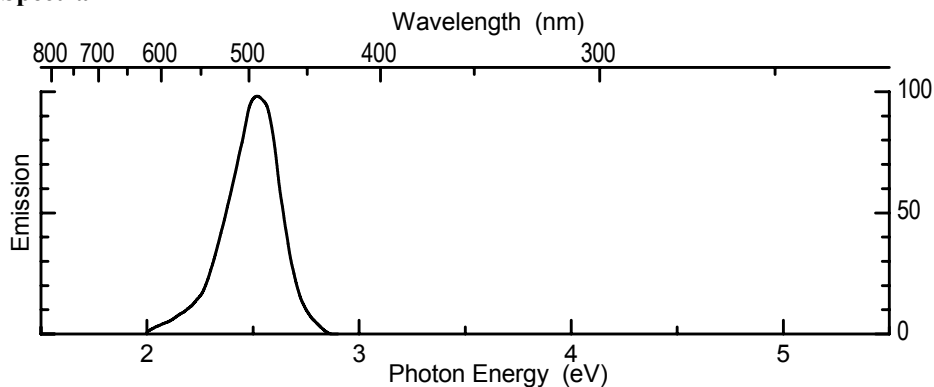
Emission width (FWHM): 0.29 eV

Excitation efficiency by UV: $-(4.88 \text{ eV}), -(3.40 \text{ eV})$

Excitation efficiency by e-beam: $+1.5\%$

Decay: Near-exponential decay, 45 msec to 1/10

Spectra



Remarks

1. This material can be sensitized for better UV excitation by 3.40 eV with addition of Eu (see $\text{CaF}_2:\text{Eu}^{2+}$).
2. The material can be sensitized for better UV excitation by 4.88 eV with addition of Ce (see $\text{CaF}_2:\text{Ce}^{3+}$).
3. The emission shifts to lower energy (= longer wavelength) with increasing Mn concentration.
4. Mn concentrations below 1% give somewhat longer decay times, up to ~ 60 msec to 1/10.

References

1. Klasens, H.A., Zalm, P., and Huysman, F.O., The manganese emission in AbF_3 compounds, *Philips Res. Rep.*, 8, 441 (1953).
2. Smith, A.L., New manganese-activated fluoride phosphors, *J. Electrochem. Soc.*, 101, 189 (1954).
3. Garlick, G.F.J., and Sayer, M., Decay of cathodoluminescence and nonradiative processes in manganese activated phosphors, *J. Electrochem. Soc.*, 109, 678 (1962).
4. Ginther, R.J., and Kirk, R.D., *J. Electrochem. Soc.*, 104, 365 (1967).
5. Schmid, W.F., and Mooney, R.W., The thermoluminescence of $\text{CaF}_2\text{-Mn}$, *J. Electrochem. Soc.* 110, 340 (1963).

CaF₂:Ce³⁺,Mn²⁺

Structure: Cubic (fluorite)

Optical Properties

Emission color: Blue-green

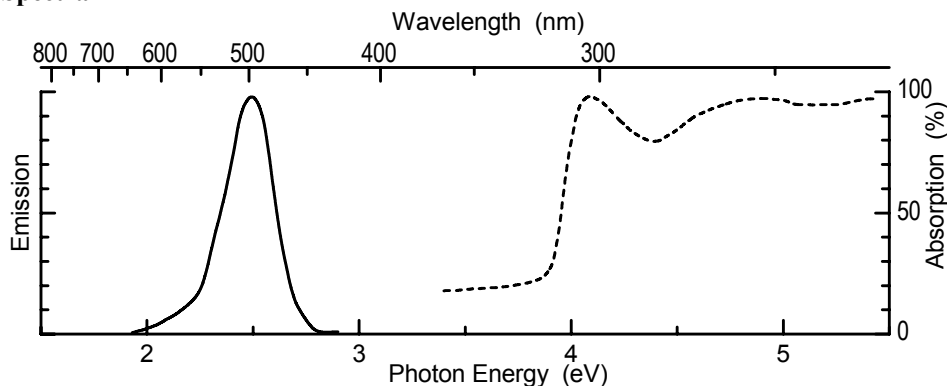
Emission peak: 2.50 eV

Emission width (FWHM): 0.35 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Kröger, F.A., and Bakker, J., *Physica*, 8, 628 (1941).
2. Ginther, R.J., Luminescence of K₄MnCl₆ and KCl (Pb + Mn), *J. Electrochem. Soc.*, 98, 74 (1951).

CaF₂:Ce³⁺,Tb³⁺

Structure: Cubic (fluorite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------------|--------|---------------|
| CaF ₂ | 80 | 62 |
| CeF ₃ | 5 | 9.85 |
| TbF ₃ | 10 | 21.6 |
| AlF ₃ | 5 | 4.2 |

Preparation

Start with plain CaF₂ and pre-fire it in open quartz boats, air, 1000°C, 1 hour.

Make a slurry of all the above ingredients in methanol.

Add ~2 ccm HF acid; stir to uniformity.

Dry; powderize.

Add ~2–3 g of iodine; mix by dry grinding.

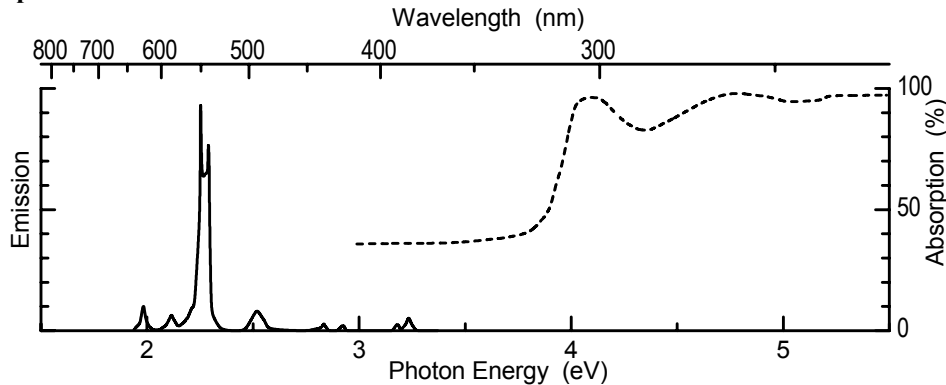
Fire in capped quartz tubes, N₂, 1000°C, 1 hour.

Powderize.

Optical Properties

Emission color: Pale green
Emission peaks: 2.26–2.28 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



Remark

UV excitation is almost exclusively determined by the Ce³⁺ absorption (see CaF₂:Ce³⁺).

Reference

1. Amster, R.L. Photosensitization of terbium fluorescence by europium in CaF₂,
J. Electrochem. Soc., 117, 791 (1970).

CaF₂:U

Structure: Cubic (fluorite)

Composition

| Ingredient | Mole % | By weight (g) |
|--|--------|---------------|
| CaF ₂ | 100 | 78 |
| UO ₂ (NH ₃) ₂ ·6H ₂ O | 0.1 | 0.500 |
| LiF | 1 | 0.260 |

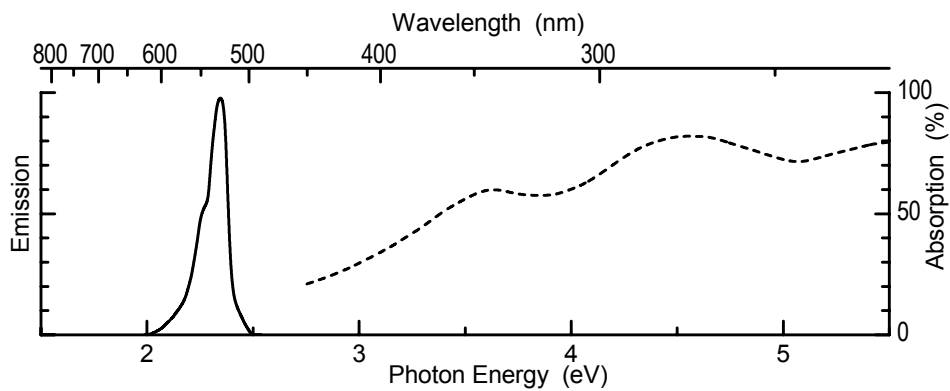
Preparation

Dissolve the uranyl nitrate in a little methanol; add solution to the CaF₂ + LiF mix.
Make a slurry of in methanol; stir to uniformity.
Dry; powderize.
Fire in open alumina crucibles, air, 1000°C, 1 hour.
Powderize.

Optical Properties

Emission color: Green
Emission peak: 2.345 eV
Emission width (FWHM): 0.11 eV
Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: Very poor

Spectra



References

1. Gorlich, P., Karras, H., and Lehmann, R., Über die optischen eigenschaften der erdalkalihalogenide vom flussspat-typ(I), *Phys. Status Solidi.*, 1, 387 (1961).
2. Gorlich, P., Karras, H., and Lehmann, R., Über die optischen eigenschaften der erdalkalihalogenide vom flussspat-typ(II), *Phys. Status Solidi.*, 1, 551 (1961).
3. Nicholas, J.V., Luminescence of hexavalent uranium in CaF₂ and SrF₂ powders, *Phys. Rev.*, 155, 151 (1967).

CaCl₂:Eu²⁺ in SiO₂

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaO | 7.6 | 4.3 |
| Eu ₂ O ₃ | 1 (of Eu) | 1.76 |
| NH ₄ Cl | 17.5 | 9.4 |
| SiO ₂ | 100 | 60 |

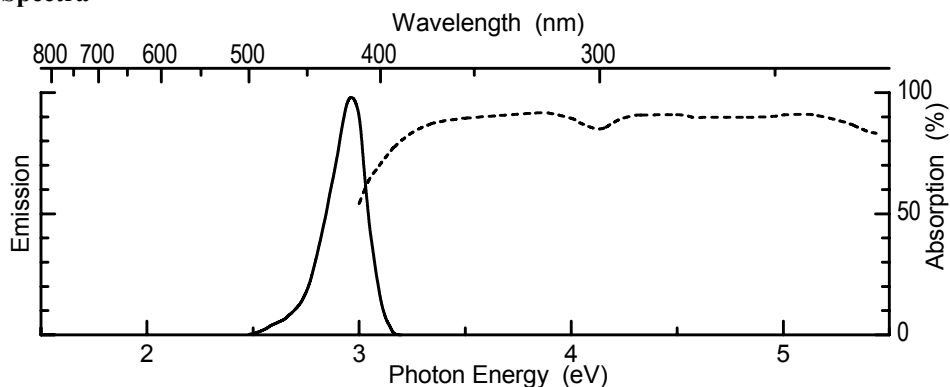
Preparation

- Mix by slurring in methanol, plus a little water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
Add the above amount of NH₄Cl once again; mix by dry grinding.
 2. Fire in capped quartz tubes, CO, 1000°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Blue-violet
Emission peak: 2.97 eV
Emission width (FWHM): 0.195 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: –

Spectra



Reference

1. Lehmann, W., Heterogeneous halide-silica phosphors, *J. Electrochem. Soc.*, 122, 748 (1975).

$\text{CaCl}_2:\text{Eu}^{2+}, \text{Mn}^{2+}$ in SiO_2

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-----------|---------------|
| CaO | 7.5 | 4.2 |
| NH_4Cl | 20 | 10.7 |
| Eu_2O_3 | 1 (of Eu) | 1.76 |
| MnCO_3 | 1 | 1.15 |
| SiO_2 | 100 | 60 |

Preparation

Mix by slurring in methanol, plus a little water.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, N_2 , 900°C, 1 hour. Powderize.
Add the above amount of NH_4Cl once again; mix by dry grinding.
2. Fire in capped quartz tubes, CO, 1000°C, 1 hour. Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: Yellow

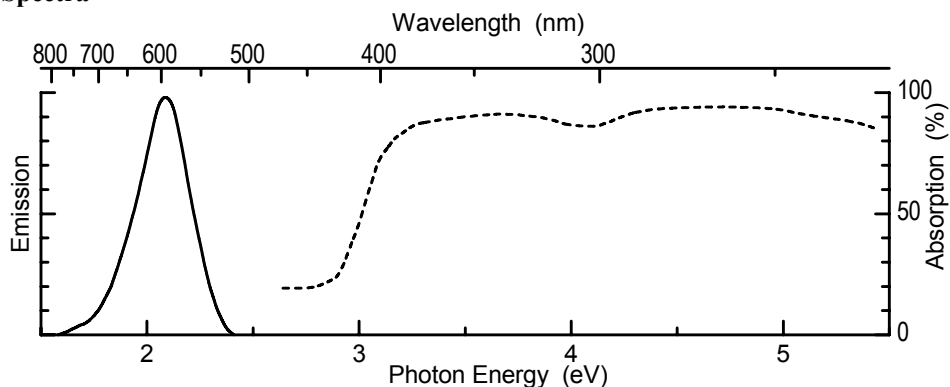
Emission peak: 2.09 eV

Emission width (FWHM): 0.30 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: –

Spectra



Remarks

1. The Cl in this recipe can be replaced by Br.
2. The emissions of $\text{CaCl}_2:\text{Eu}^{2+}, \text{Mn}^{2+}$ and $\text{CaBr}_2:\text{Eu}^{2+}, \text{Mn}^{2+}$ are identical.

Reference

1. Lehmann, W., Heterogeneous halide-silica phosphors, *J. Electrochem. Soc.*, 122, 748 (1975).

$\text{CaBr}_2:\text{Eu}^{2+}$ in SiO_2

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| CaO | 7.6 | 4.3 |
| Eu_2O_3 | 1.2 (of Eu) | 2.1 |
| NH_4Br | 17.5 | 17.2 |
| SiO_2 | 100 | 60 |

Preparation

Mix by slurring in methanol, plus a little water.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, N_2 , 900°C , 1 hour.
Powderize.
Add the above amount of NH_4Br once again; mix by dry grinding.
2. Fire in capped quartz tubes, CO , 1000°C , 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Blue

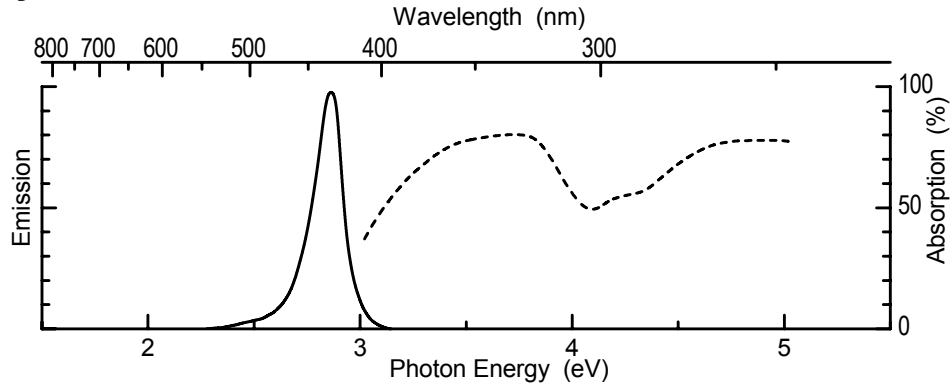
Emission peak: ~ 2.865 eV

Emission width (FWHM): 0.18 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: –

Spectra



Reference

1. Lehmann, W., Heterogeneous halide-silica phosphors, *J. Electrochem. Soc.*, 122, 748 (1975).

CaI₂:Eu²⁺ in SiO₂

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| CaO | 6 | 3.4 |
| CaF ₂ | 3 | 2.34 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| NH ₄ I | 20 | 29 |
| SiO ₂ | 100 | 60 |

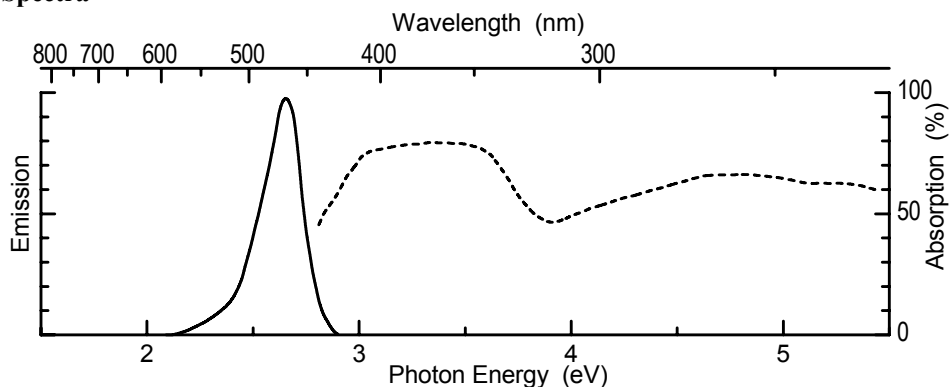
Preparation

- Mix by slurring in methanol, plus a little water.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 900°C, 1 hour. Powderize.
Add the above amount of NH₄I once again; mix by dry grinding.
 2. Fire in capped quartz tubes, CO, 1000°C, 1 hour. Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: Light blue
Emission peak: 2.67 eV
Emission width (FWHM): 0.21 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: –

Spectra



Remark

This phosphor is sensitive to even very small traces of Mn which causes a red emission band (see $\text{CaI}_2:\text{Eu}^{2+}, \text{Mn}^{2+}$).

Reference

1. Lehmann, W., Heterogeneous halide-silica phosphors, *J. Electrochem. Soc.*, 122, 748 (1975).

$\text{CaI}_2:\text{Eu}^{2+}, \text{Mn}^{2+}$ in SiO_2

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| CaO | 7 | 3.9 |
| CaF ₂ | 1 | 0.78 |
| Eu ₂ O ₃ | 0.65 (of Eu) | 1.14 |
| MnCO ₃ | 0.1 | 0.115 |
| NH ₄ I | 15 | 21 |
| SiO ₂ | 100 | 60 |

Preparation

Mix by slurring in methanol, plus a little water.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, N₂, 900°C, 1 hour.

Powderize.

Add the above amount of NH₄I once again; mix by dry grinding.

2. Fire in capped quartz tubes, CO, 1000°C, 1 hour.

Powderize.

Wash in water several times. Dry.

Optical Properties

Emission color: Light red, slightly pinkish hue

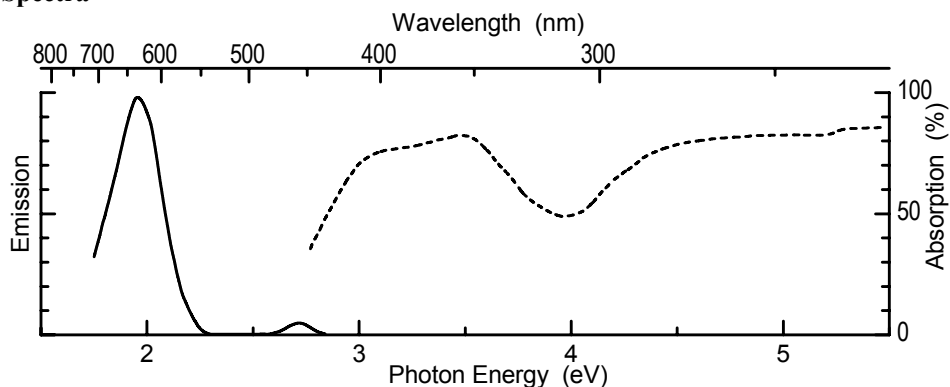
Emission peak: 1.95 eV, additionally a weak Eu^{2+} -emission band at 2.70 eV

Emission width (FWHM): 0.29 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: –

Spectra



Reference

1. Lehmann, W., Heterogeneous halide-silica phosphors, *J. Electrochem. Soc.*, 122, 748 (1975).
-



Structure: Cubic (fluorite)

Optical Properties

Emission color: Violet

Emission peak: 2.95 eV

Emission width (FWHM): 0.30 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +

Reference

1. Chenot., C.F., Can. Pat., 896 453 (1972).
-



Optical Properties

Emission color: Violet

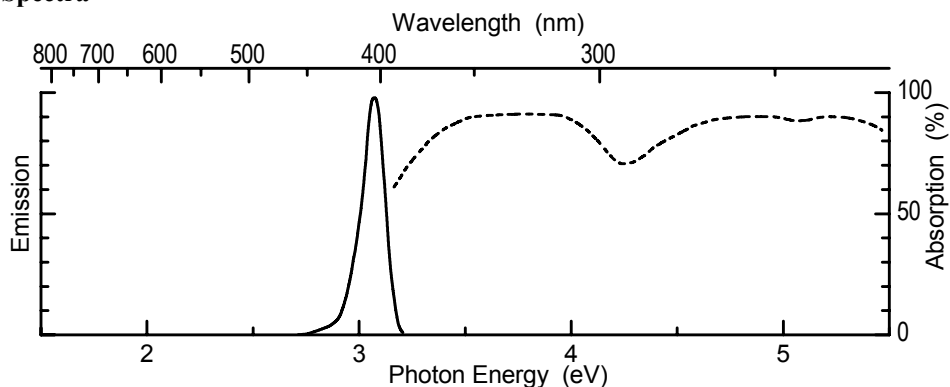
Emission peak: 3.06 eV

Emission width (FWHM): 0.12 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: –

Spectra



Reference

1. Lehmann, W., Heterogeneous halide-silica phosphors, *J. Electrochem. Soc.*, 122, 748 (1975).

$\text{Sr}(\text{Cl}, \text{Br}, \text{I})_2:\text{Eu}^{2+}$ in SiO_2

Structure: Cubic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| SrO | 8 | 8.3 |
| Eu_2O_3 | 1.5 (of Eu) | 2.6 |
| NH_4Cl | 17.5 | 9.4 |
| SiO_2 | 100 | 60 |

Preparation

Mix by slurring in methanol, plus a little water.

Dry in air. Powderize when dry.

1. Fire in capped quartz tubes, N_2 , 900°C, 1 hour. Powderize.
Add the above amount of NH_4I once again; mix by dry grinding.
2. Fire in capped quartz tubes, CO, 1000°C, 1 hour. Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: Violet

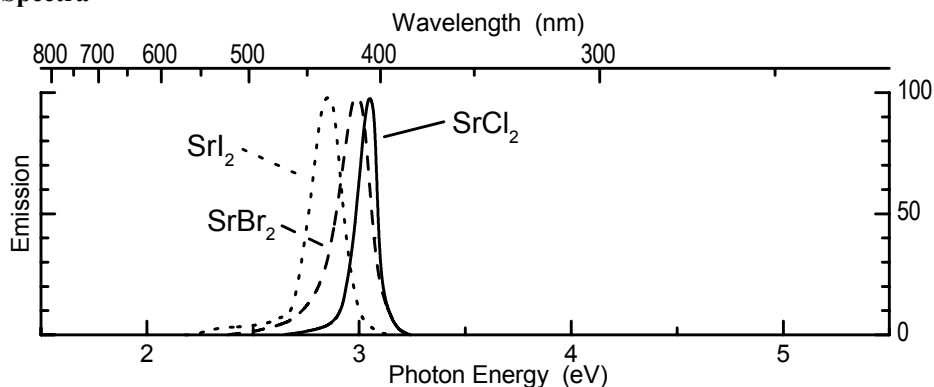
Emission peaks: Peak position depending on the used halide; for SrCl_2 is at ~3.06 eV, for SrBr_2 at ~3.015 eV, and SrI_2 at ~2.865 eV.

Emission width (FWHM): Width also depending on used halide; for SrCl_2 is 0.175 eV, for SrBr_2 is 0.16 eV, and for SrI_2 is 0.12 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: –

Spectra

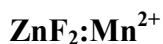


Remark

The Cl in this recipe can be replaced by Br or I.

Reference

1. Lehmann, W., Heterogeneous halide-silica phosphors, *J. Electrochem. Soc.*, 122, 748 (1975).



Structure: Tetragonal

Optical Properties

Emission color: Orange-yellow

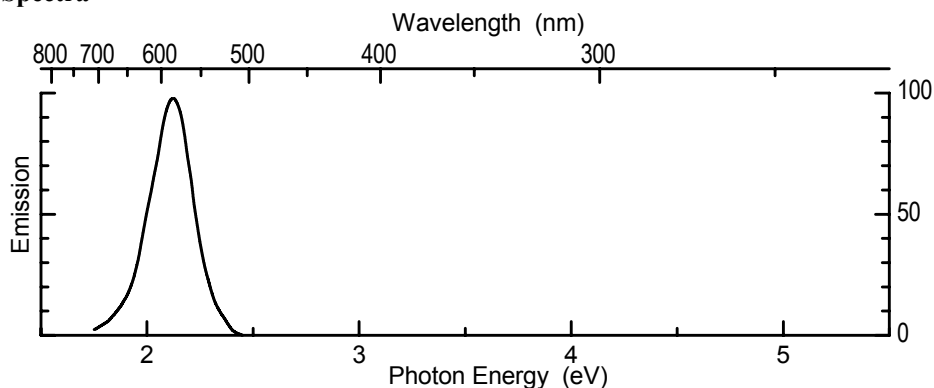
Emission peak: 2.12 eV

Emission width (FWHM): 0.24 eV

Excitation efficiency by UV: - (4.88 eV), - (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).
2. Klasens, H.A., Zalm, P., and Huysman, F.O., The manganese emission in ABF_3 compounds, *Philips Res. Rep.*, 8, 441 (1953).

- Smith, A.L., New manganese-activated fluoride phosphors, *J. Electrochem. Soc.*, 101, 189 (1954).
- Johnson, P.D., and Williams, F.E., Energy levels and rate processes in the thallium activated potassium chloride phosphor, *J. Chem. Phys.*, 20, 124 (1952).
- Johnson, J.S., and Williams, F.E., Thermoluminescence of manganese-activated zinc fluoride phosphors, *J. Opt. Soc. Am.*, 39, 709 (1949).
- Fonda, G.R., and Studer F.J., Optical properties of zinc fluoride phosphors, *J. Opt. Soc. Am.*, 38, 1007 (1948).
- Studer, F.J., and Rosenbaum, J., The phosphorescence decay of halophosphates and other doubly activated phosphors, *J. Opt. Soc. Am.*, 38, 1007 (1948).



Structure: Cubic (fluorite)

Optical Properties

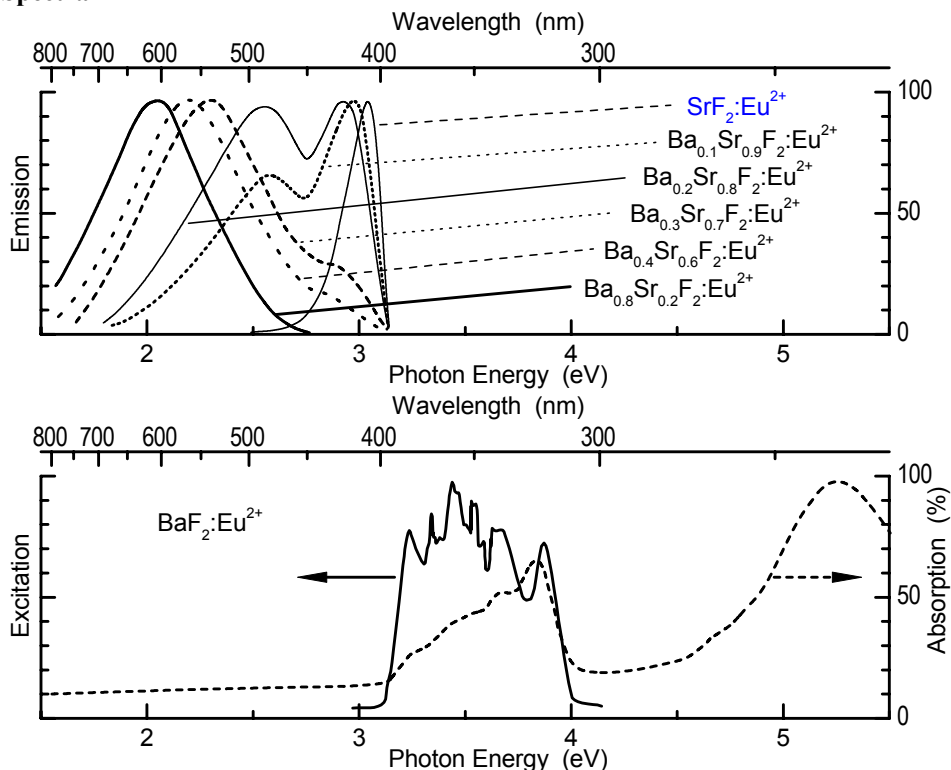
Emission color: varies with composition from yellow to blue

Emission peak: varies with composition from 2.04 to 3.04 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

- Chenot, C.F., Can. Pat. 896 453 (1972).
- Mou, W.F., and McClure, D.S., Photoionization and trapping of electrons in the system $\text{BaF}_2:\text{Eu}:\text{Sm}$, *Phys. Rev. B*, 47 no.17, 11031–11038 (1993).

3. Reut, E.G., Study on characteristics of wideband luminescence of Eu and Yb ions in crystals with fluorite structure, *Opt. Spekr.*, 45, 518 (1978) [*Opt. Spectrosc. (USSR)* 45, 290 (1978)].
4. Reut, E.G., Nature of luminescence of bivalent Eu and Yb ions in fluorite-type crystals, *Opt. Spekr.*, 40, 99 (1976) [*Opt. Spectrosc. (USSR)* 40, 55 (1976)].
5. Kaplyansky, A.A., and Feofilov, P.P., Spectra of divalent rare earth ions in crystals of alkali-earth fluorides. 2. Europium and Ytterbium, *Opt. Spekr.*, 13, 235 (1962) [*Opt. Spectrosc. (USSR)* 13, 129 (1962)].

$\text{YF}_3:\text{Mn}^{2+}$

Structure: Orthorhombic

Optical Properties

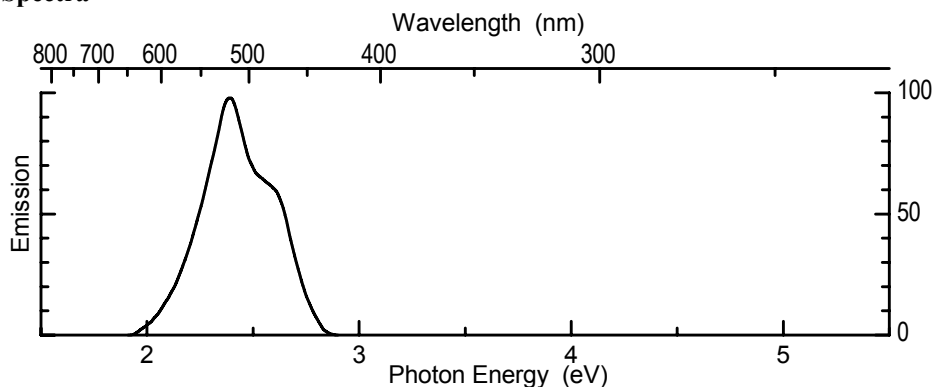
Emission color: Greenish

Emission peaks: 2.38 and 2.60 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



$\text{YF}_3:\text{Mn}^{2+}, \text{Th}^{4+}$

Structure: Orthorhombic

Optical Properties

Emission color: Light blue

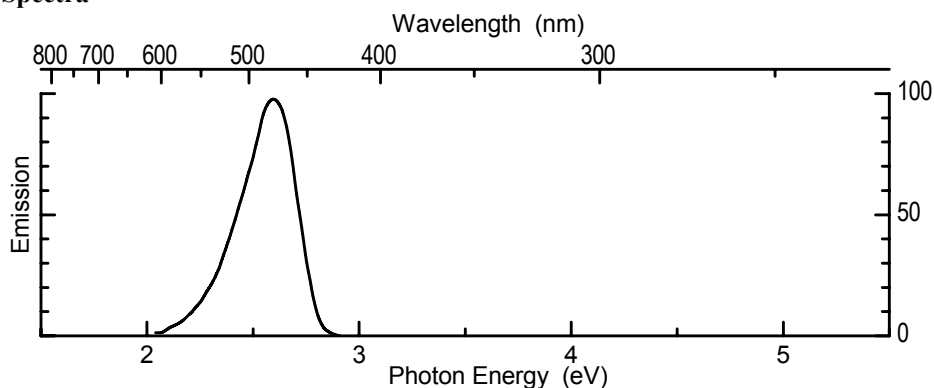
Emission peak: 2.60 eV

Emission width (FWHM): 0.29 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



KMgF₃:Eu²⁺

Structure: Cubic (perovskite)

Optical Properties

Emission color: UV

Emission peak: 3.42 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: –

References

1. Sommerdijk, J.L., and Bril, A., Divalent europium luminescence in perovskite-like alkaline-earth alkaline fluorides, *J. Lumin.*, 11, 363 (1976).
 2. Seo, H.J., Moon, B.K., and Tsuboi, T., Two-photon excitation spectroscopy of 4f⁷ → 4f⁷ transitions of Eu²⁺ ions doped in a KMgF₃ crystal, *Phys. Rev. B*, 62, no. 19, 12688–12695 (2000).
 3. Ellens, A., Meijerink, A., and Blasse, G., ⁶I emission and vibronic transitions of Eu²⁺ in KMgF₃, *J. Lumin.*, 59, 293 (1994).
-

KMgF₃:Mn²⁺

Structure: Cubic (perovskite)

Optical Properties

Emission color: Orange

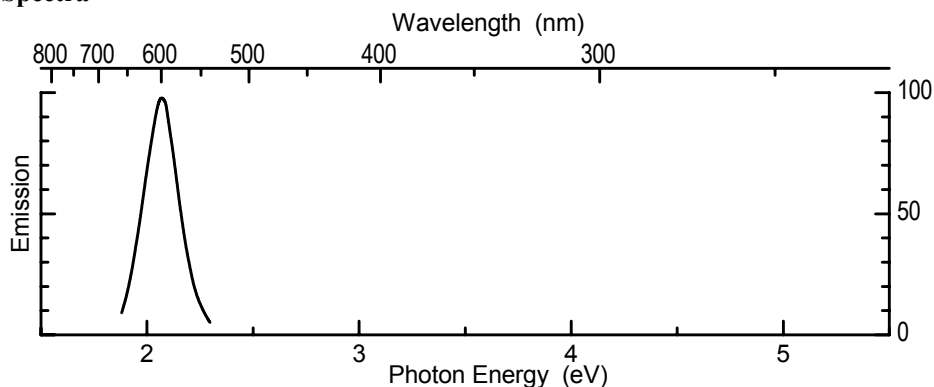
Emission peak: 2.08 eV

Emission width (FWHM): 0.18 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

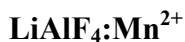
Excitation efficiency by e-beam: +

Spectra



Reference

1. Kurtz, R.J., Cathodoluminescent characteristics of Mn-activated KMgF₃, *J. Electrochem. Soc.*, 109, 18 (1962).



Optical Properties

Emission color: Red

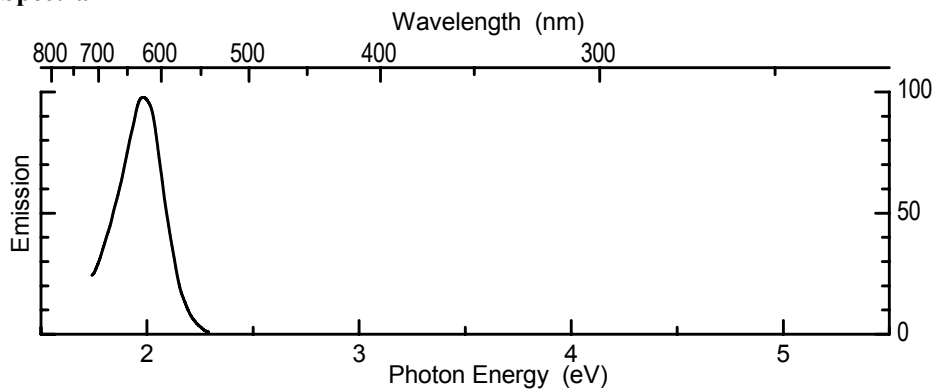
Emission peak: 1.99 eV

Emission width (FWHM): 0.26 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Structure: Cubic

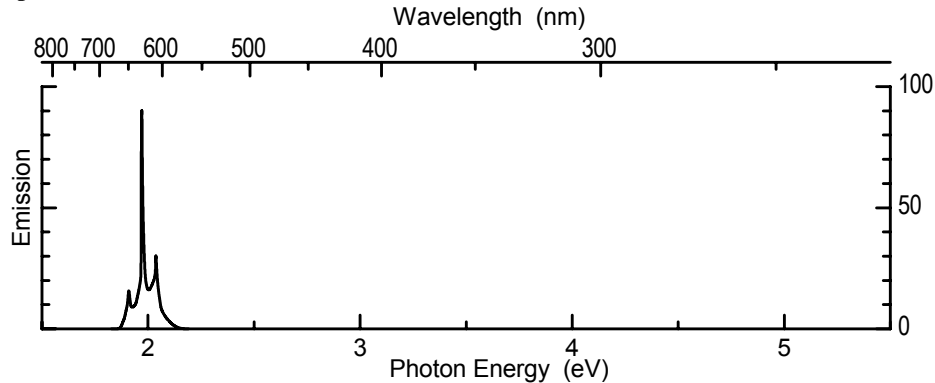
Optical Properties

Emission color: Red

Emission peak: 1.97 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Paulusz, A.G., Efficient Mn(IV) emission in fluorine coordination, *J. Electrochem. Soc.*, 120, 942 (1973).



Structure: Rhombohedral

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| Y ₂ O ₃ | 95 (of Y) | 107.4 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| NH ₄ Br | 110 | 108 |

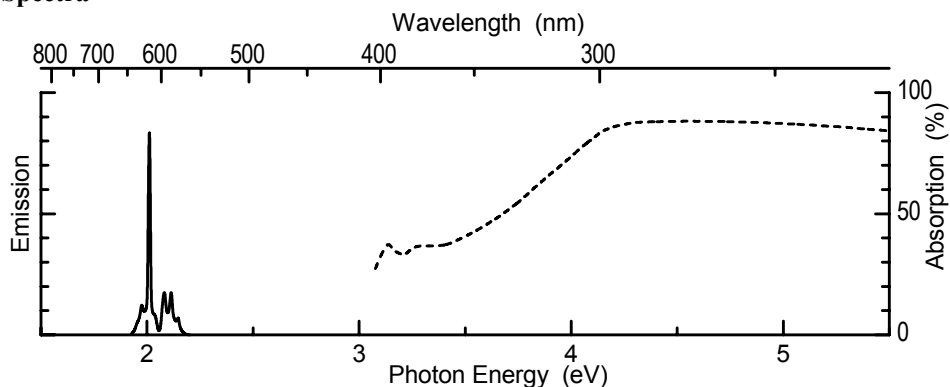
Preparation

- Make a suspension of all ingredients in water.
Boil down to dry (slowly, to let the conversion of Y₂O₃ to YOBBr take place).
Powderize.
1. Fire in capped quartz tubes, N₂, ~500°C, ½ hour.
Powderize.
 2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Red
Emission peaks: 1.967–2.150 eV; main line at 1.996 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Spectra



Remarks

1. This phosphor is hygroscopic. Keep dry.
2. This phosphor is difficult to prepare. It tends either to be partly reduced (forming Eu²⁺, blue emission) or to be partly oxidized (liberating brown bromine).



Structure: Rhombohedral (matlockite)

Optical Properties

Emission color: Violet – UV

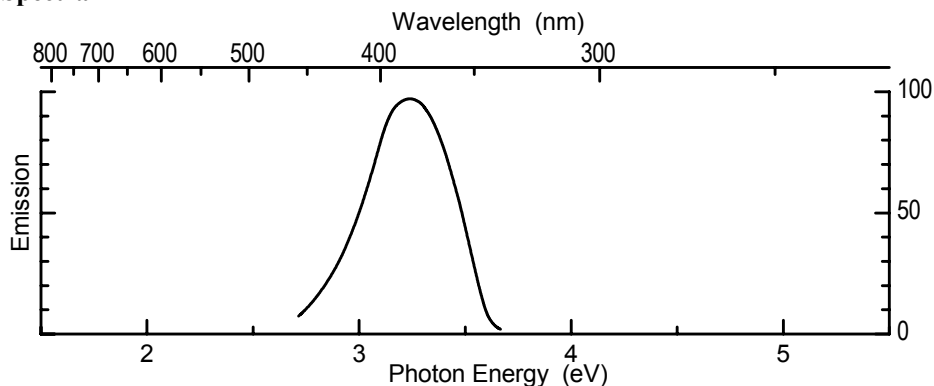
Emission peak: 3.24 eV

Emission width (FWHM): 0.47 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Blasse, G., and Bril, A., and Poorter, J.A.D., Fast-decay phosphors, *J. Electrochem. Soc.*, 117, 346 (1970).
2. Blasse, G., and Bril, A., Photoluminescent efficiency of phosphors with electronic transitions in localized centers, *J. Electrochem. Soc.*, 115, 1067 (1968).
3. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).

YOCl:Eu³⁺

Structure: Rhombohedral (matlockite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| Y ₂ O ₃ | 95 (of Y) | 107.4 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| NH ₄ Cl | 110 | 59 |

Preparation

Make a suspension of all ingredients in water.

Boil down to dry (slowly, to let the conversion of Y₂O₃ to YOCl take place).

Powderize.

1. Fire in capped quartz tubes, N₂, ~500°C, ½ hour.

Powderize.

2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.

Powderize.

Wash in water several times.

Dry.

Optical Properties

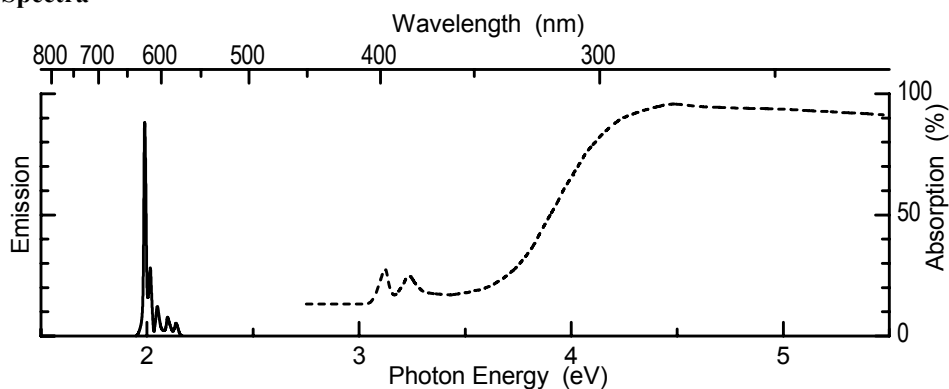
Emission color: Red

Emission peaks: 1.97–2.14 eV; main peak at 2.00 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: –

Spectra



Remark

This phosphor is hygroscopic. Keep dry.

Reference

1. Blasse, G., and Bril, A., Broad band UV excitation of Sm³⁺-activated phosphors, *Phys. Lett.*, 23, 440 (1966).

YOF:Eu³⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| Y ₂ O ₃ | 64 (of Y) | 72.3 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| YF ₃ | 34 | 49.6 |

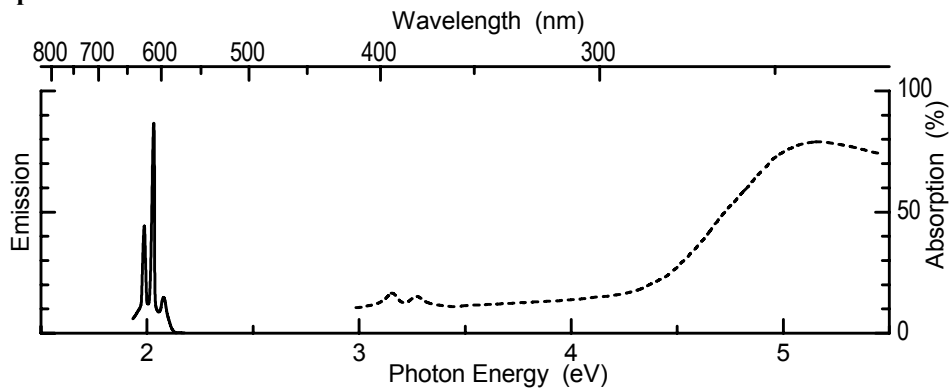
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.

Optical Properties

Emission color: Light red
Emission peaks: 1.977, 2.038, and 2.105 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: –

Spectra



Reference

1. Blasse, G., and Bril, A., Broad band UV excitation of Sm³⁺-activated phosphors, *Phys. Lett.*, 23, 440 (1966).

YOF:Tb³⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-----------|---------------|
| Y ₂ O ₃ | 61 (of Y) | 69 |
| Tb ₄ O ₇ | 5 (of Tb) | 9.4 |
| YF ₃ | 34 | 49.6 |

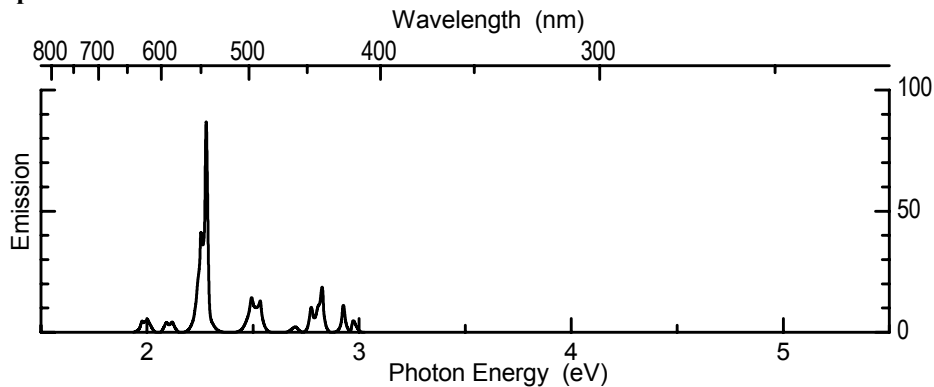
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.

Optical Properties

Emission color: Pale green
Emission peaks: 1.982–2.993 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +/4–5%

Spectra



Remark

UV excitation is very poor (too little absorption) and can probably be improved by addition of Ce³⁺.



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|------------|---------------|
| La ₂ O ₃ | 61 (of La) | 99.4 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| LaF ₃ | 34 | 66.6 |

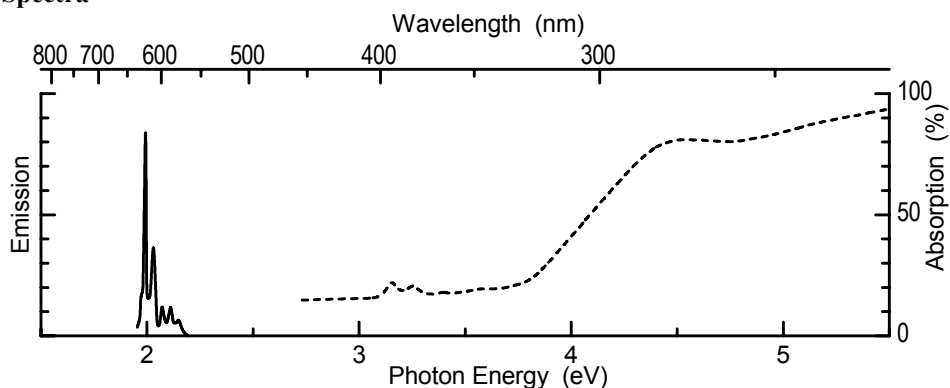
Preparation

- Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.

Optical Properties

Emission color: Red
Emission peak: 1.981–2.145 eV; main line at 1.981 eV
Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Spectra



LaOCl:Bi³⁺

Structure: Rhombohedral (matlockite)

Optical Properties

Emission color: UV

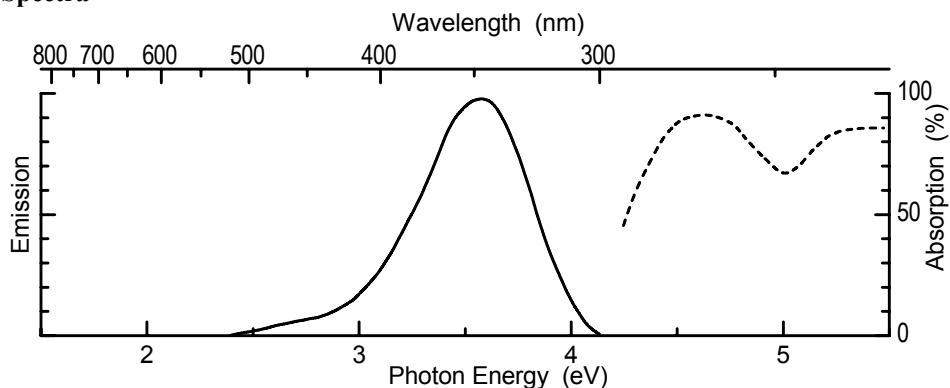
Emission peak: 3.56 eV

Emission width (FWHM): 0.58 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Blasse, G., and Bril, A., Investigations on Bi³⁺-activated phosphors, *J. Chem. Phys.*, 48, 217 (1968).
2. Boulon, G. et al., *Proc. Int. Conf. Phys.*, 48, 217 (1968).
3. Jaquier, B., Photoluminescence processes in LaOCl-Bi and YOCl-Bi, *J. Lumin.*, 10, 95 (1975).

LaOCl:Eu³⁺

Structure: Rhombohedral (matlockite)

Optical Properties

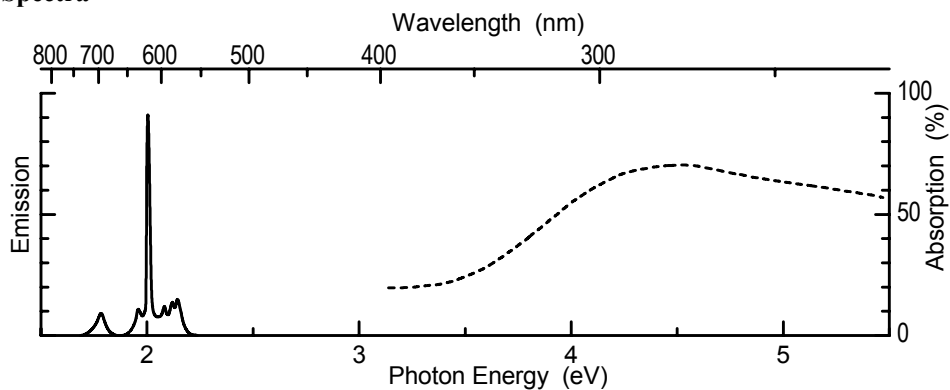
Emission color: Light red

Emission peak: 2.02 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: –

Spectra



Reference

1. Blasse, G., and Bril, A., Characteristic luminescence, 1. The absorption and emission spectra of some important activators, *Philips Tech. Rev.*, 31, 304 (1970).

4.12 Sulfates

The following host compounds and activators are included in this subsection:

MgSO₄:Eu²⁺
MgSO₄:Pb²⁺
CaSO₄:Eu²⁺,Mn²⁺
CaSO₄:Pb²⁺
CaSO₄:Bi
CaSO₄:Ce³⁺
CaSO₄:Ce³⁺,Mn²⁺
CaSO₄:Eu²⁺
SrSO₄:Bi
SrSO₄:Ce³⁺
SrSO₄:Eu²⁺,Mn²⁺
SrSO₄:Eu²⁺
BaSO₄:Ce³⁺
BaSO₄:Eu²⁺
MgBa(SO₄)₂:Eu²⁺
Mg₂Ca(SO₄)₃:Eu²⁺
Mg₂Ca(SO₄)₃:Eu²⁺,Mn²⁺
Mg₂Sr(SO₄)₃:Eu²⁺

MgSO₄:Eu²⁺

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|---|--------|---------------|
| MgSO ₄ | 97 | 117 |
| Eu ₂ O ₃ | 3 | 5.3 |
| (NH ₄) ₂ SO ₄ | ~10 | 13.2 |
| NH ₄ Cl | 1 | 0.540 |

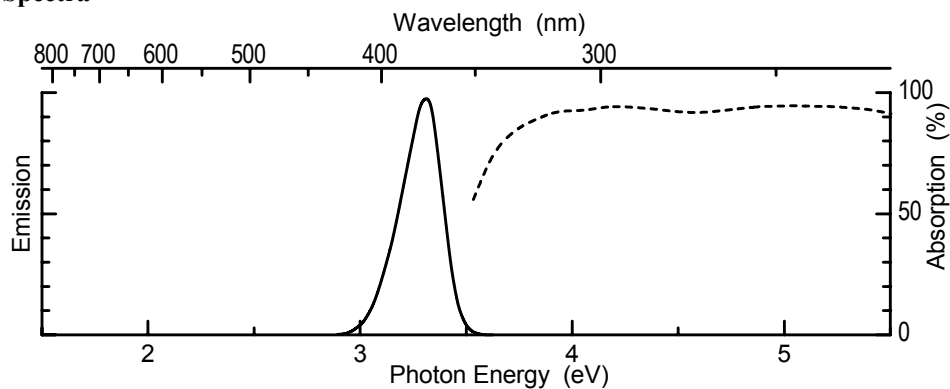
Preparation

Mix by dry grinding or milling.
Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
Store in well-closed containers.

Optical Properties

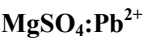
Emission color: UV
Emission peak: 3.31 eV
Emission width (FWHM): 0.24 eV
Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Spectra



Remark

MgSO₄ (epsom salt) is water soluble. Keep dry.



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|---|--------|---------------|
| MgSO ₄ | 97 | 117 |
| PbO | 3 | 56.7 |
| (NH ₄) ₂ SO ₄ | ~10 | 13.2 |
| NH ₄ Cl | 1 | 0.540 |

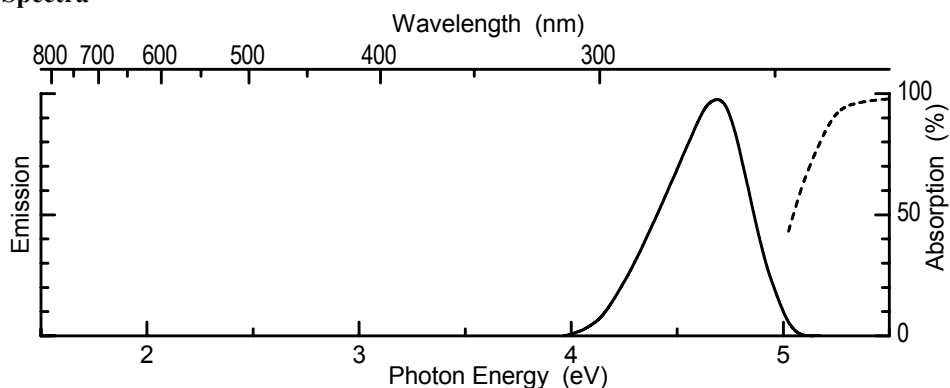
Preparation

Mix by dry grinding or milling.
Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
Store in well-closed containers.

Optical Properties

Emission color: UV
Emission peak: 4.65 eV
Emission width (FWHM): 0.46 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Spectra



Remarks

1. This material is excited only by UV of ~240 nm or shorter and apparently is fairly efficient.
2. MgSO_4 (epsom salt) is water soluble. Keep dry.



Structure: Orthorhombic (anhydrite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------------------------|-----------|---------------|
| CaSO_4 | 90 | 123 |
| Eu_2O_3 | 5 (of Eu) | 8.8 |
| MnCO_3 | 5 | 5.75 |
| $(\text{NH}_4)_2\text{SO}_4$ | ~10 | 13.2 |

Preparation

Mix by dry grinding or milling.

1. Fire in capped quartz tubes, N_2 , 900°C, 1 hour.
Powderize.
Add ~5 g of NH_4Br and ~10 g of $(\text{NH}_4)_2\text{SO}_4$; mix by dry grinding.
2. Fire in capped quartz tubes, N_2 , 800°C, ½ hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: Bluish-green

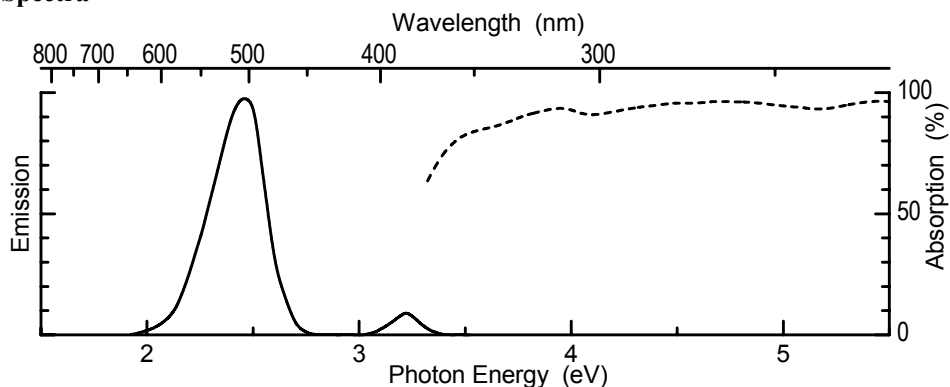
Emission peak: 2.42 eV (Mn^{2+}), 3.20 eV (Eu^{2+})

Emission width (FWHM): 0.30 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +/1%

Spectra



Remark

The spectral positions of the Mn^{2+} -emission band depends on the Mn concentration used, shifting to blue-green for 1% Mn and to yellow-green for 10% Mn.

$\text{CaSO}_4:\text{Pb}^{2+}$

Structure: Orthorhombic (anhydrite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------------------------|--------|---------------|
| CaSO_4 | 98 | 133 |
| CaF_2 | 1 | 0.780 |
| PbO | 1 | 2.23 |
| $(\text{NH}_4)_2\text{SO}_4$ | ~5 | 6.6 |

Preparation

Mix by dry grinding or milling.

1. Fire in capped quartz tubes, N_2 , 950°C , 1 hour.
Add another 6.6 g of $(\text{NH}_4)_2\text{SO}_4$. Mix by dry grinding.
2. Fire in capped quartz tubes, N_2 , 1000°C , 1 hour.
Powderize.
Add 5 g of NH_4Cl . Mix by dry grinding.
3. Fire in capped quartz tubes, N_2 , 1050°C , 1 hour.
Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: UV

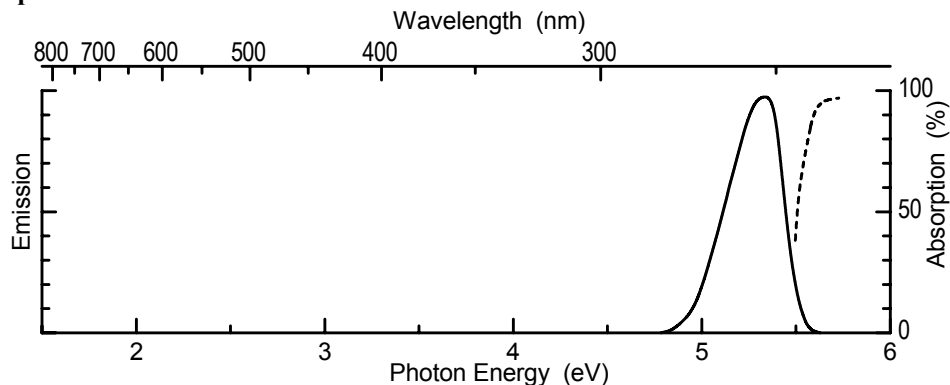
Emission peak: 5.33 eV

Emission width (FWHM): 0.33 eV

Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Remarks

- 1. This phosphor is excited only by UV of ~220 nm or shorter and is fairly efficient.
- 2. It discolors in fluorescent lamps because of (probably) undissolved PbSO₄ dissociation to PbO.

CaSO₄:Bi

Structure: Orthorhombic (anhydrite)

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| CaSO ₄ | 98 | 118 |
| Bi ₂ O ₃ | 1 (of Bi) | 2.3 |
| Na ₂ SO ₄ | 5 (of Na) | 3.5 |
| (NH ₄) ₂ SO ₄ | ~5 | 6.6 |

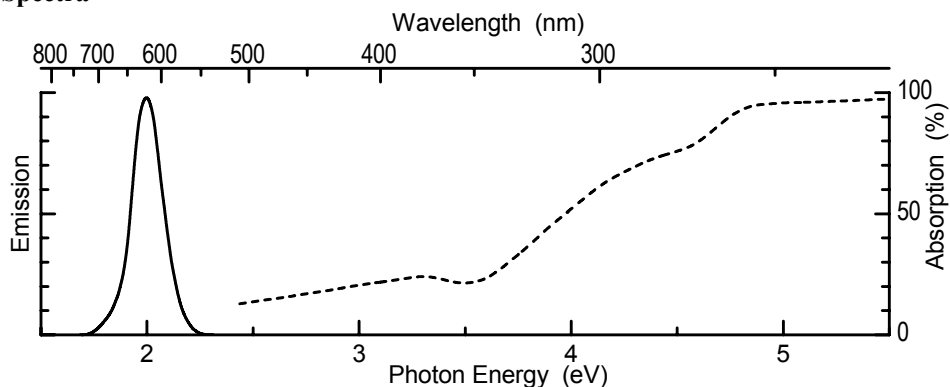
Preparation

- Mix by dry grinding or milling.
- 1. Fire in covered alumina crucibles, N₂, 900°C, 1 hour.
Add another 5–6 g of (NH₄)₂SO₄; mix by dry grinding.
 - 2. Fire in covered alumina crucibles, N₂, 950°C, 1 hour.
Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: Light red
Emission peak: 2.02 eV
Emission width (FWHM): 0.16 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +/-0.7%

Spectra

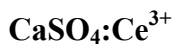


Remark

The nature of this red emission is still unknown: It is not likely to be due to Bi^{3+} but it may possibly be due to Bi^{5+} substituting for S^{6+} .

Reference

1. Kröger, F.A., et al., Bismuth as activator in fluorescent solids, *J. Electrochem. Soc.*, 96, 132 (1949).



Structure: Orthorhombic (anhydrite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------------------------|-----------|---------------|
| CaSO_4 | 94 | 128 |
| CeO_2 | 3 | 5.2 |
| Na_2SO_4 | 5 (of Na) | 3.6 |
| $(\text{NH}_4)_2\text{SO}_4$ | ~10 | 13.2 |

Preparation

Mix by dry grinding or milling.

1. Fire in covered alumina crucibles, N_2 , 900°C, 1 hour.

Powderize.

Add above amounts of Na_2SO_4 and $(\text{NH}_4)_2\text{SO}_4$ once again; mix by dry grinding.

2. Fire in covered alumina crucibles, N_2 , 900°C, 1 hour.

Powderize.

Wash in water several times.

Dry.

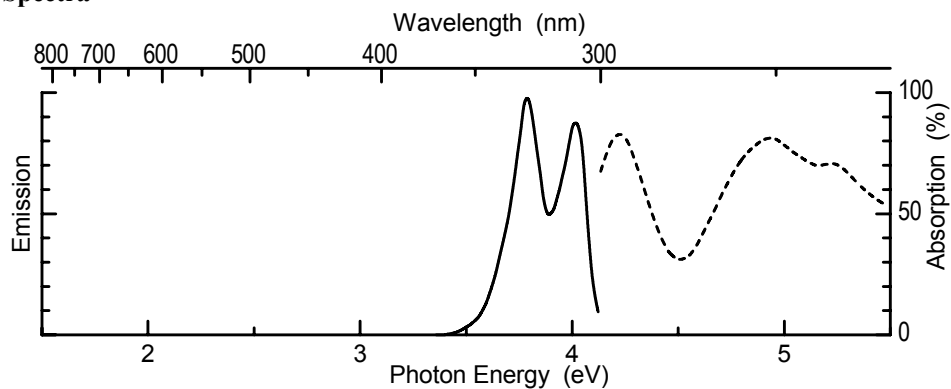
Optical Properties

Emission color: UV

Emission peak: 3.79 eV, 4.01 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Structure: Orthorhombic (anhydrite)

Composition

| Ingredient | Mole % | By weight (g) |
|---|--------|---------------|
| CaSO ₄ | 88.5 | 121 |
| CeO ₂ | 2.5 | 4.3 |
| MnCO ₄ | 6 | 6.9 |
| (NH ₄) ₂ SO ₄ | ~10 | 13.2 |

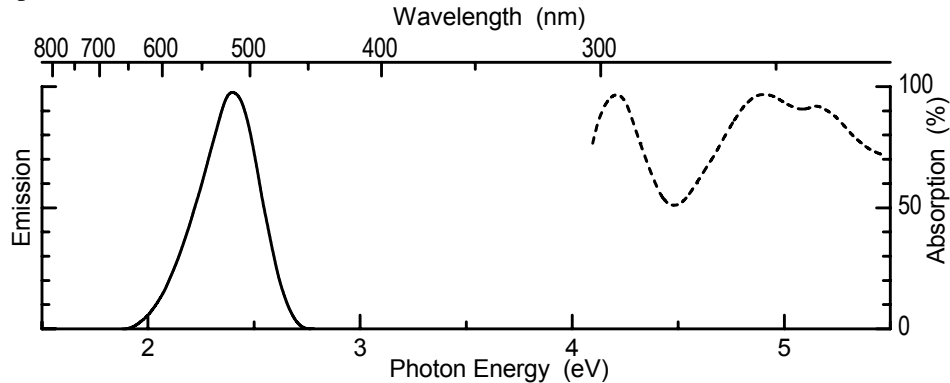
Preparation

- Mix by dry grinding or milling.
1. Fire in capped quartz tubes, N₂, 1000°C, 1 hour.
Powderize.
Add ~10 g of (NH₄)₂SO₄; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 800°C.
Powderize.
Add ~2 g of Li₂SO₄ and ~6 g of (NH₄)₂SO₄; mix by dry grinding.
 3. Fire in capped quartz tubes, N₂, 700°C.
Powderize.
Add ~6 g of (NH₄)₂SO₄; mix by dry grinding.
 4. Fire in capped quartz tubes, N₂, 700°C.
Powderize.
Wash in water several times. Dry.

Optical Properties

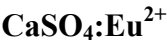
Emission color: Yellow-green
Emission peak: 2.35 eV
Emission width (FWHM): 0.36 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



References

1. Rudolf, J., and Ruffler, H., *Tech. Wiss. Abh. OSRAM Ges.*, 7, 232 (1958).
2. Rabatin, J., *Electrochem. Soc. Meeting*, Washington, DC, Abstr. 157 (May 1976).



Structure: Orthorhombic (anhydrite)

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| CaSO ₄ | 99 | 135 |
| Eu ₂ O ₃ | 1 (of Eu) | 1.76 |
| (NH ₄) ₂ SO ₄ | ~5 | 6.6 |

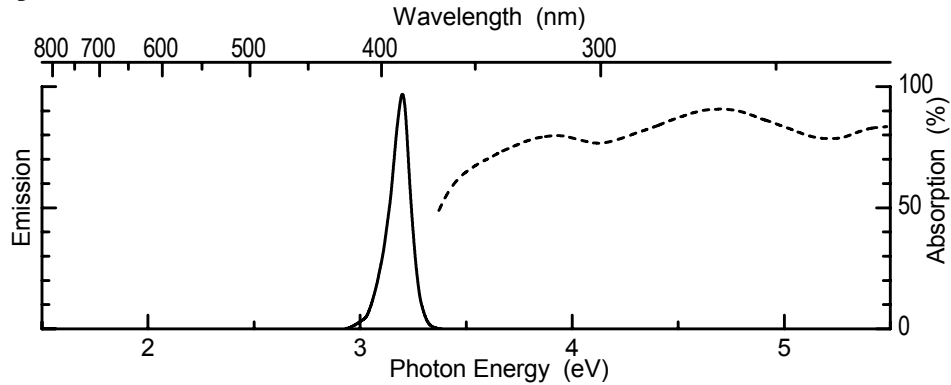
Preparation

- Mix by dry grinding or milling.
1. Fire in capped quartz tubes, N₂, 950°C, 1 hour. Powderize.
Add another 6.6 g of (NH₄)₂SO₄; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 950°C, 1 hour. Powderize.
Add 5 g of NH₄Cl; mix by dry grinding.
 3. Fire in capped quartz tubes, N₂, 1000°C, 1 hour. Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: Very deep violet
Emission peak: 3.20 eV
Emission width (FWHM): 0.12 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: +/-4%
Decay: Near-exponential decay, about 1.1 μsec to 1/10

Spectra



Remark

This CaSO₄ phosphor is stable in water.

References

- 1. Wachtel, A., U.S. Pat., 3 669 897 (1971).
- 2. Dixon, R.L., and Ekstrand, K.E., Thermoluminescence of rare earth activated CdSO₄, SrSO₄ and BaSO₄, *J. Lumin.*, 8, 383 (1974).
- 3. Luckey, D., Germ. Pat., 2 051 240 (1971).

SrSO₄:Bi

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| SrSO ₄ | 98 | 180 |
| Bi ₂ O ₃ | 1 (of Bi) | 2.3 |
| Na ₂ SO ₄ | 5 (of Na) | 3.5 |
| (NH ₄) ₂ SO ₄ | ~5 | 6.6 |

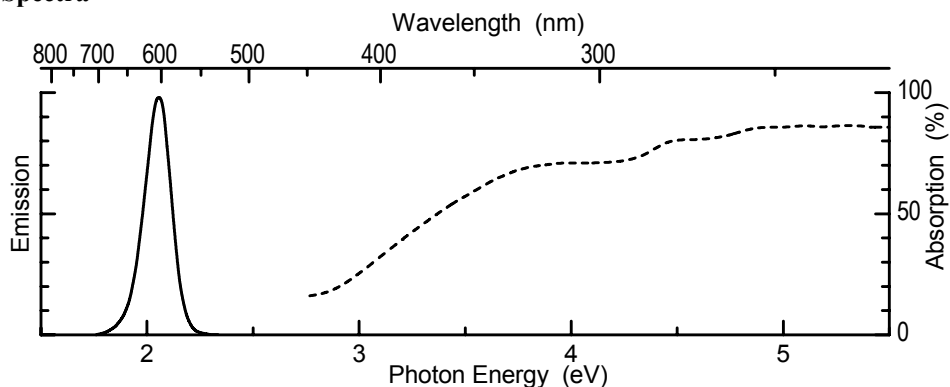
Preparation

- Mix by dry grinding or milling.
- 1. Fire in covered alumina crucibles, N₂, 900°C, 1 hour. Powderize.
Add another 5–6 g of (NH₄)₂SO₄; mix by dry grinding.
 - 2. Fire in covered alumina crucibles, N₂, 950°C, 1 hour. Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: Orange-red
Emission peak: 2.04 eV
Emission width (FWHM): 0.15 eV
Excitation efficiency by UV: – (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +/–1–1.5%

Spectra

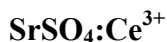


Remark

The nature of this emission is still unknown: It is not likely to be due to Bi^{3+} but it may possibly be due to Bi^{5+} substituting for S^{6+} .

Reference

1. Kröger, F.A. et al., Bismuth as activator in fluorescent solids, *J. Electrochem. Soc.*, 96, 132 (1949).



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|------------------------------|-----------|---------------|
| SrSO_4 | 94 | 173 |
| CeO_2 | 3 | 5.2 |
| Na_2SO_4 | 5 (of Na) | 3.6 |
| $(\text{NH}_4)_2\text{SO}_4$ | ~10 | 13.2 |

Preparation

Mix by dry grinding or milling.

1. Fire in covered alumina crucibles, N_2 , 900°C, 1 hour. Powderize.
Add the above amounts of Na_2SO_4 and $(\text{NH}_4)_2\text{SO}_4$ once again; mix by dry grinding.
2. Fire in covered alumina crucibles, N_2 , 900°C, 1 hour. Powderize.
Wash in water several times. Dry.

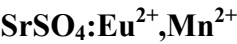
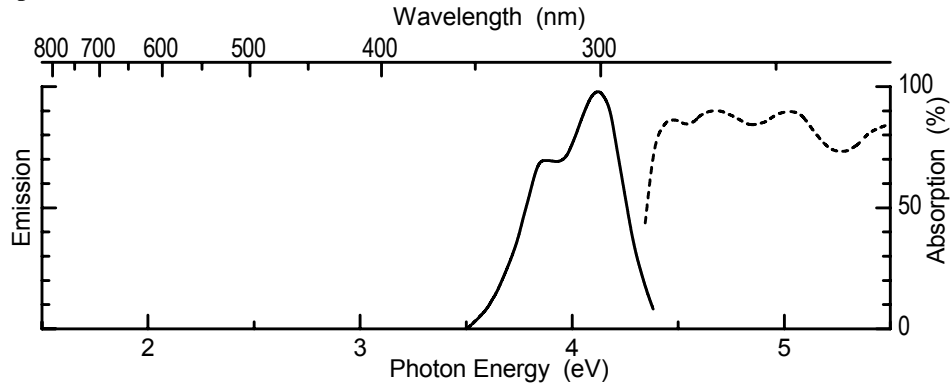
Optical Properties

Emission color: UV

Emission peak: 3.89 and 4.11 eV (Two overlapping bands)

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

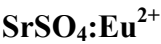
Spectra



Structure: Orthorhombic

Optical Properties

Emission color: Orange
Emission peak: 2.19 eV
Emission width (FWHM): 0.29 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)



Structure: Orthorhombic

Composition

| Ingredient | | | Mole % | | By weight (g) | |
|---|--|--|-----------|--|---------------|--|
| SrSO ₄ | | | 98 | | 180 | |
| Eu ₂ O ₃ | | | 2 (of Eu) | | 3.5 | |
| SrF ₂ | | | 1 | | 1.26 | |
| (NH ₄) ₂ SO ₄ | | | ~5 | | 6.6 | |

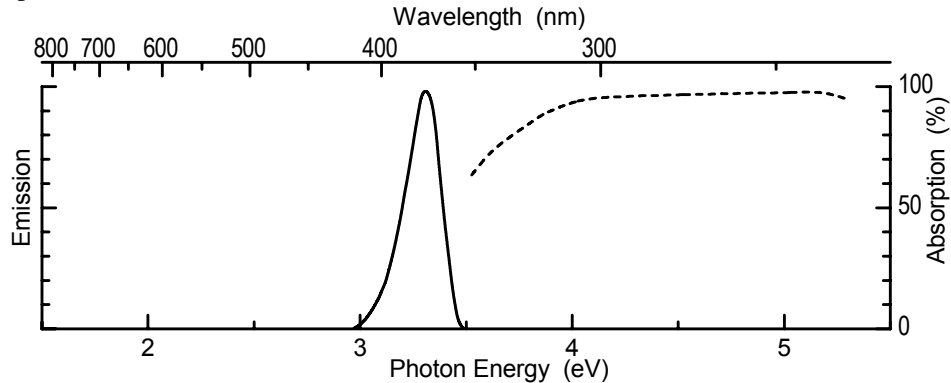
Preparation

- Mix by dry grinding or milling.
1. Fire in capped quartz tubes, N₂, 900°C, 1 hour. Powderize.
Add another 6.6 g of (NH₄)₂SO₄; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 900°C, 1 hour. Powderize.
Add 5 g of NH₄Cl; mix by dry grinding.
 3. Fire in capped quartz tubes, 800°C, 1 hour. Powderize.
Wash in water several times. Dry.

Optical Properties

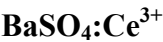
Emission color: UV
Emission peak: 3.30 eV
Emission width (FWHM): 0.24 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: +/-5%
Decay: Near-exponential decay, about 5 μsec to 1/10

Spectra



References

1. Wachtel, A., U.S. Pat., 3 669 897 (1971).
2. Dixon, R.L., and Ekstrand, K.E., Thermoluminescence of rare earth activated CdSO₄, SrSO₄ and BaSO₄, *J. Lumin.*, 8, 383 (1974).
3. Luckey, D., Germ. Pat., 2 051 240 (1971).



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| BaSO ₄ | 94 | 173 |
| CeO ₂ | 3 | 5.2 |
| Na ₂ SO ₄ | 5 (of Na) | 3.6 |
| (NH ₄) ₂ SO ₄ | ~10 | 13.2 |

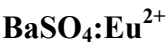
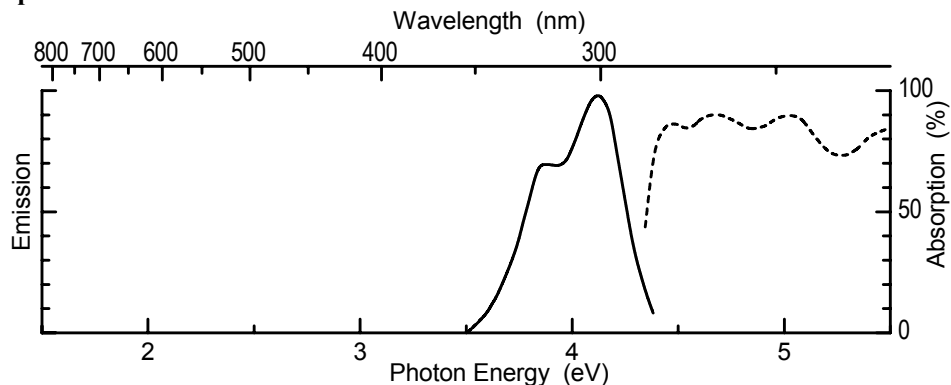
Preparation

- Mix by dry grinding or milling.
1. Fire in covered alumina crucibles, N₂, 900°C, 1 hour.
Powderize.
Add the above amounts of Na₂SO₄ and (NH₄)₂SO₄ once again; mix by dry grinding.
 2. Fire in covered alumina crucibles, N₂, 900°C, 1 hour.
Powderize.
Wash in water several times.
Dry.

Optical Properties

Emission color: UV
Emission peak: 3.89 eV, 4.11 eV (Two overlapping bands)
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| BaSO ₄ | 98 | 180 |
| Eu ₂ O ₃ | 2 (of Eu) | 3.5 |
| SrF ₂ | 1 | 1.26 |
| (NH ₄) ₂ SO ₄ | ~5 | 6.6 |

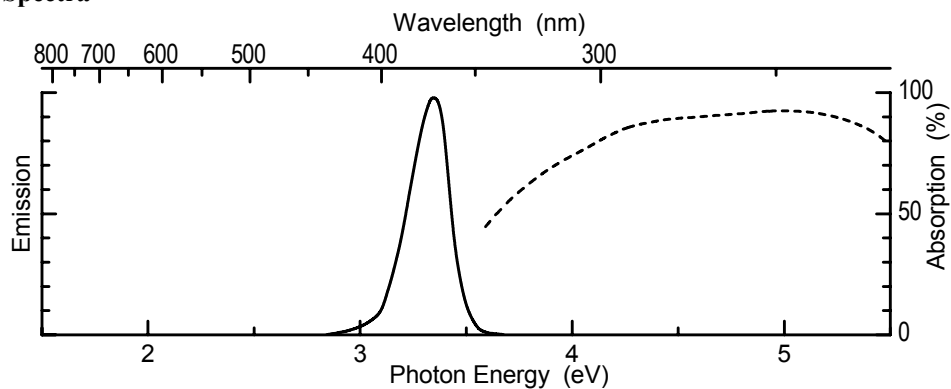
Preparation

- Mix by dry grinding or milling.
1. Fire in capped quartz tubes, N₂, 900°C, 1 hour.
Powderize.
Add another 6.6 g of (NH₄)₂SO₄; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 900°C, 1 hour.
Powderize.
Add 5 g of NH₄Cl; mix by dry grinding.
 3. Fire in capped quartz tubes, 800°C, 1 hour.
Powderize.
Wash in water several times. Dry.

Optical Properties

Emission color: UV
Emission peak: 3.30 eV
Emission width (FWHM): 0.21 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: +/5%
Decay: Near-exponential decay, about 5 μsec to 1/10

Spectra



Reference

1. Luckey, D., Germ. Pat., 2 051 240 (1971).



Structure: KAl (SO₄)₂

Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| MgSO ₄ | 100 | 120 |
| BaSO ₄ | 94 | 219 |
| Eu ₂ O ₃ | 6 (of Eu) | 10.6 |
| (NH ₄) ₂ SO ₄ | ~10 | 13.2 |

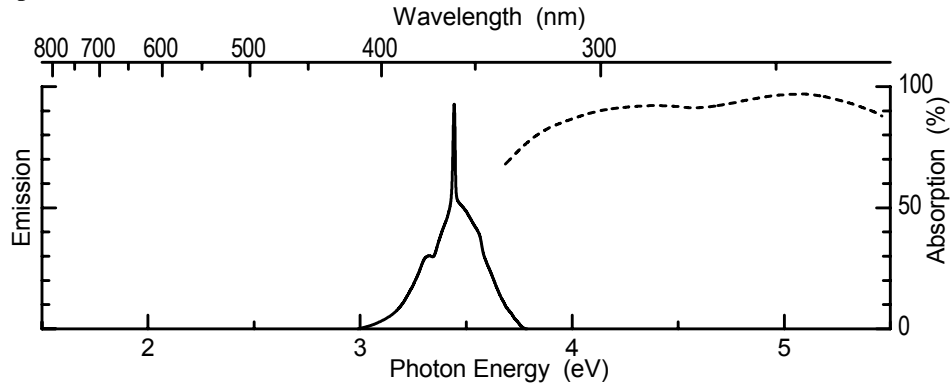
Preparation

- Mix by dry grinding or milling.
1. Fire in capped quartz tubes, N₂, 900°C, 1 hour. Powderize. Add ~10 g of (NH₄)₂SO₄; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour. Powderize. Store in a well-closed container.

Optical Properties

Emission color: UV
Emission peak: Main peak at 3.455 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Remark

This material decomposes in contact with water or in moist air.

References

1. Ryan, F.M. et al., Fine-structure in optical-spectra of divalent europium in alkaline-earth sulfates, *J. Electrochem. Soc.*, 121, 1475 (1974).
2. Blasse, G., VanDenHeuvel, G.P.M., and Stegenga, J., Luminescence of barium magnesium-sulfate, *J. Solid State Chem.*, 17, 439 (1976).
3. Blasse, G., and VanDenHeuvel, G.P.M., Crystal-structure of barium magnesium-sulfate, *J. Inorg. Nucl. Chem.*, 38, 876 (1976).
4. Sakaguchi, M. et al., Thermoluminescence characteristics of binary sulfate phosphors, *J. Electrochem. Soc.*, 124, 1272 (1977).



Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| MgSO ₄ | 200 | 240 |
| CaSO ₄ | 94 | 128 |
| Eu ₂ O ₃ | 6 (of Eu) | 10.6 |
| (NH ₄) ₂ SO ₄ | ~10 | 13.2 |

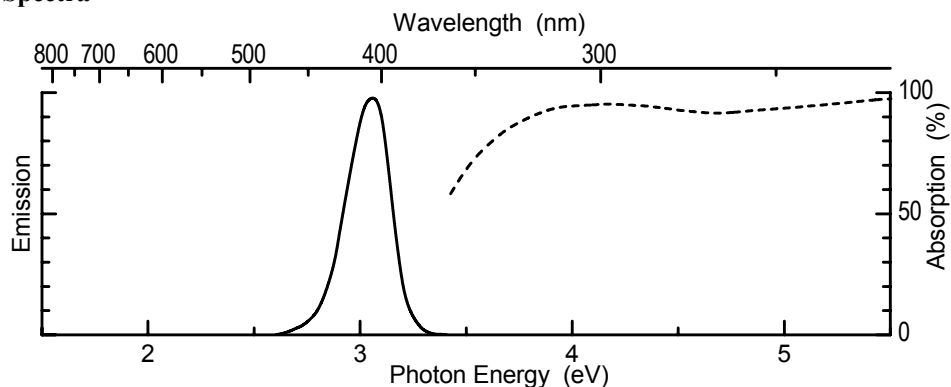
Preparation

- Mix by dry grinding or milling.
- Fire in capped quartz tubes, N₂, 900°C, 1 hour.
Powderize.
Add ~5 g of NH₄Br, and ~10 g of (NH₄)₂SO₄; mix by dry grinding.
 - Fire in capped quartz tubes, N₂, 950°C.

Optical Properties

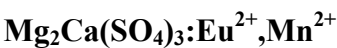
Emission color: Violet
Emission peak: 3.06 eV
Emission width (FWHM): 0.28 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Remark

This material decomposes in contact with water or in moist air. Keep dry.



Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| MgSO ₄ | 200 | 240 |
| CaSO ₄ | 87 | 119 |
| Eu ₂ O ₃ | 5 (of Eu) | 8.8 |
| MnCO ₃ | 8 | 9.2 |
| (NH ₄) ₂ SO ₄ | ~10 | 13.2 |

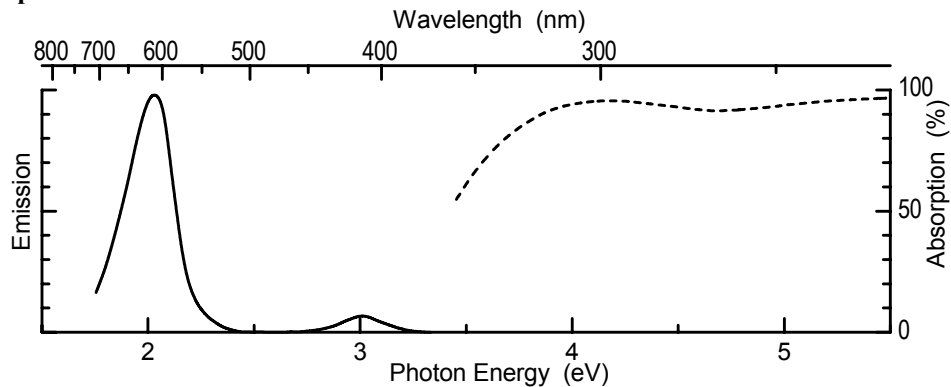
Preparation

- Mix by dry grinding or milling.
- Fire in capped quartz tubes, N₂, 900°C, 1 hour.
Powderize.
Add ~5 g of NH₄Br, and ~10 g of (NH₄)₂SO₄; mix by dry grinding.
 - Fire in capped quartz tubes, N₂, 950°C.

Optical Properties

Emission color: Orange-red
Emission peak: 2.01 eV (Mn²⁺), 3.06 eV (Eu²⁺)
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Remark

This material decomposes in contact with water or in moist air. Keep dry.



Composition

| Ingredient | Mole % | By weight (g) |
|---|-----------|---------------|
| MgO | 200 | 240 |
| SrSO ₄ | 94 | 173 |
| Eu ₂ O ₃ | 6 (of Eu) | 10.6 |
| (NH ₄) ₂ SO ₄ | ~10 | 13.2 |

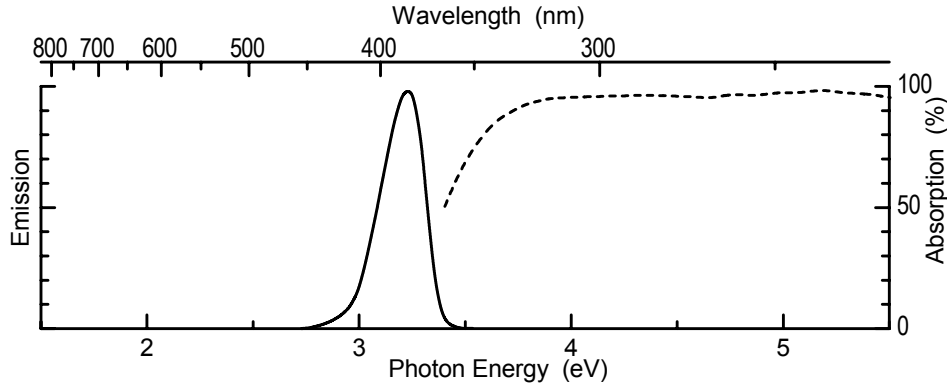
Preparation

- Mix by dry grinding or milling.
1. Fire in capped quartz tubes, N₂, 900°C, 1 hour.
Powderize.
Add 10 g of (NH₄)₂SO₄; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Barely visible deep violet
Emission peak: 3.21 eV
Emission width (FWHM): 0.23 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Spectra



Remark

This material decomposes in contact with water or in moist air.

4.13 ZnS-Type Sulfides

The following host compounds and activators are included in this subsection:

ZnS:Ag⁺,Cl⁻
ZnS:Au,In
ZnS:Cl⁻
ZnS:Cu,Sn
ZnS:Cu⁺,Al³⁺
ZnS:Cu⁺,Cl⁻
ZnS:Eu²⁺
ZnS:Mn²⁺
ZnS:Mn²⁺,Te²⁺
ZnS:P
ZnS:P³⁻,Cl⁻
ZnS:Pb²⁺
ZnS:Pb²⁺,Cl⁻
ZnS:Pb,Cu
ZnS:Sn²⁺
ZnS:Sn,Ag
ZnS:Sn²⁺,Li⁺
ZnSe:Cu⁺,Cl
CdS:Ag⁺,Cl⁻
CdS:In
ZnS-CdS:Cu,I
ZnS-CdS (25-75)
ZnS-CdS (50-50)
ZnS-CdS (75-25)
ZnS-CdS:Ag,Br,Ni
ZnS-CdS:Ag⁺,Cl
ZnS-CdS:Cu,Br long life
ZnS-CdS:Cu,Br high brightness
ZnS-ZnTe:Mn²⁺ 98-2

ZnS:Ag⁺,Cl⁻

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| ZnS | 100 | 98 |
| AgNO ₃ | 0.3 | 0.050 |
| NH ₄ Cl | 5 | 2.5 |

Preparation

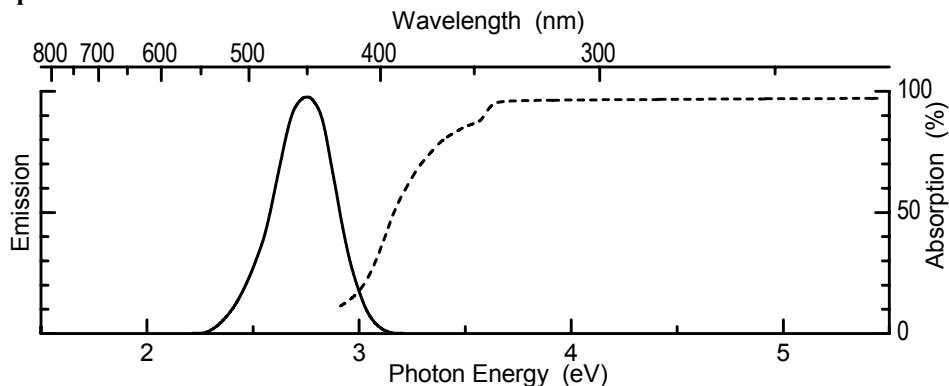
Dissolve the AgNO₃ and the NH₄Cl separately, each in a little water.
Make a slurry of the ZnS in water or methanol.
First add the silver solution, stir, then add the NH₄Cl solution, and stir again.
Dry in air. Powderize when dry.

Add ~2–3 g of sulfur.
Fire in capped quartz tubes, N₂, 1100°C, 1 hour. Powderize.
Wash in water several times (to remove leftover halide). Dry.

Optical Properties

Emission color: Blue
Emission peak: 2.80 eV
Emission width (FWHM): 0.34 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: ++
Decay: Non-exponential decay in the microsecond range

Spectra



Remarks

1. The chlorine in the above recipe may be replaced by bromine.
2. This phosphor corresponds to the commercial P-22B.

References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).
2. Shionoya, S., in *Luminescence of Inorganic Solids*, Goldberg, P., Ed., Academic Press, New York (1966).

ZnS:Au,In

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|---------------|---------------|
| ZnS | 100 | 98 |
| Au metal | 0.005 | 0.010 |
| In ₂ O ₃ | 0.002 (of In) | 0.0023 |
| NH ₄ Cl | 5 | 2.5 |

Preparation

Dissolve the gold in a very little amount of aqua regia.
Add this solution to the ZnS. Make a slurry in methanol. Dry. Powderize.

1. Fire in open quartz boats, H_2S , 900°C , 1 hour.
Powderize.
Add the dry NH_4Cl and about 2–3 g of sulfur; mix by dry grinding.
2. Fire in capped quartz tubes, N_2 , 1200°C , 1 hour.
Powderize. Make a slurry of the phosphor in methanol.
Dissolve the In_2O_3 in a little nitric acid, add the solution to the slurry, stir, dry, and powderize.
Add about 2–3 g of sulfur.
3. Fire in capped quartz tubes, N_2 , 900°C , 1 hour.
4. Fire in open quartz boats, H_2S , 900°C .

Optical Properties

Emission color: Blue-green, long afterglow

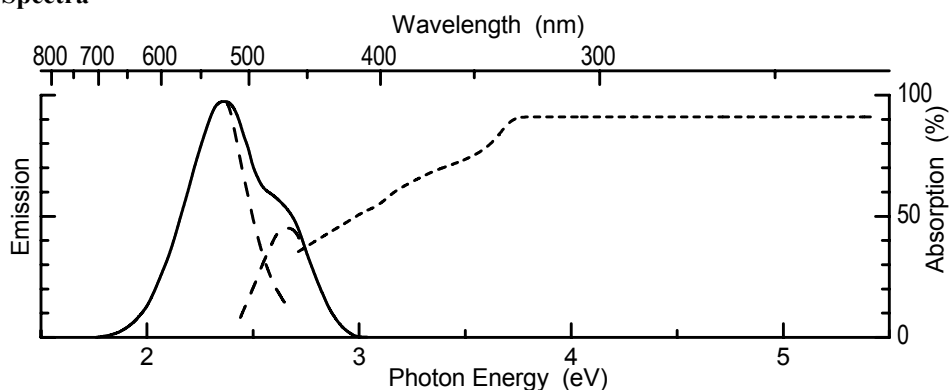
Emission peaks: 2.34 eV, 2.67 eV

Emission width (FWHM): 0.34 eV (First peak)

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Remark

The green phosphorescence of this phosphor after excitation by UV or by e-beam is visible for several hours in the dark.

ZnS:Cl^-

Structure: Cubic, hexagonal (wurtzite)

Optical Properties

Emission color: Blue

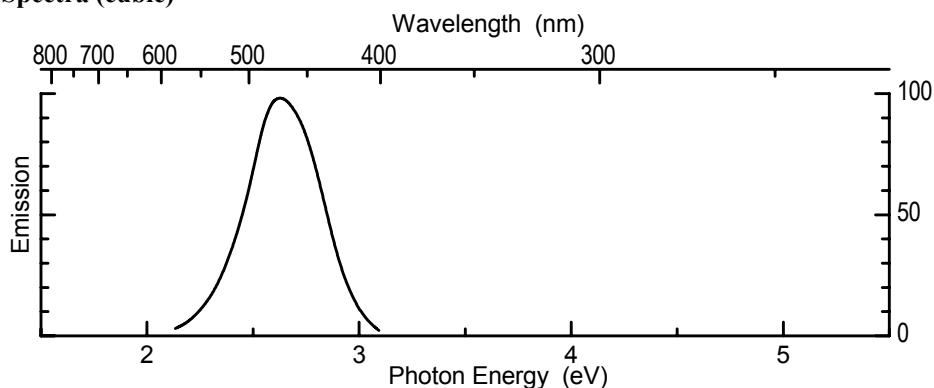
Emission peak: 2.70 eV

Emission width (FWHM): 0.50 eV

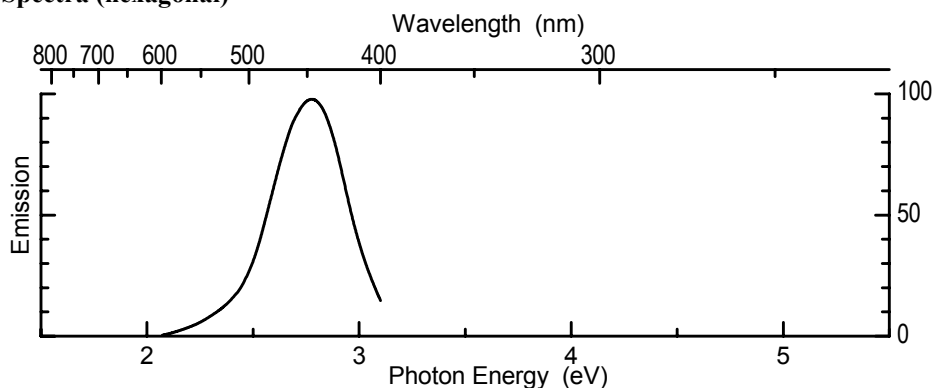
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ++

Spectra (cubic)



Spectra (hexagonal)



References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).
2. Shionoya, S., in *Luminescence of Inorganic Solids*, Goldberg, P., Ed., Academic Press, New York (1966).

ZnS:Cu,Sn

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|---|--------|---------------|
| ZnS | 100 | 98 |
| SnS | 0.1 | 0.150 |
| Cu(C ₂ H ₃ O ₂) ₂ · H ₂ O | 0.001 | 0.002 |

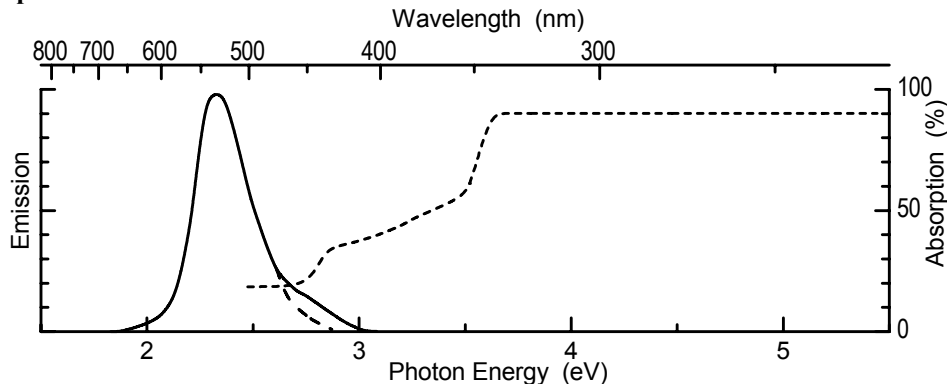
Preparation

Dissolve the copper acetate in a little water; add solution to the ZnS + SnS mix.
Make a slurry in water or methanol.
Dry. Powderize.
Add ~2–3 g of sulfur.
Fire in capped quartz tubes, N₂, 1150°C, 1 hour.

Optical Properties

Emission color: Green
Emission peak: 2.41 eV
Emission width (FWHM): 0.32 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Remarks

- 1. Irradiation of near-IR during excitation by 3.40 eV UV causes strong quenching of the green emission.
- 2. This phosphor is much more sensitive to IR than the fairly well-known ZnS:Cu,Co phosphor.



Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--|--------|---------------|
| ZnS | 100 | 98 |
| Cu(C ₂ H ₃ O ₂) ₂ ·H ₂ O | 0.001 | 0.002 |
| AlCl ₃ | 0.3 | 0.400 |

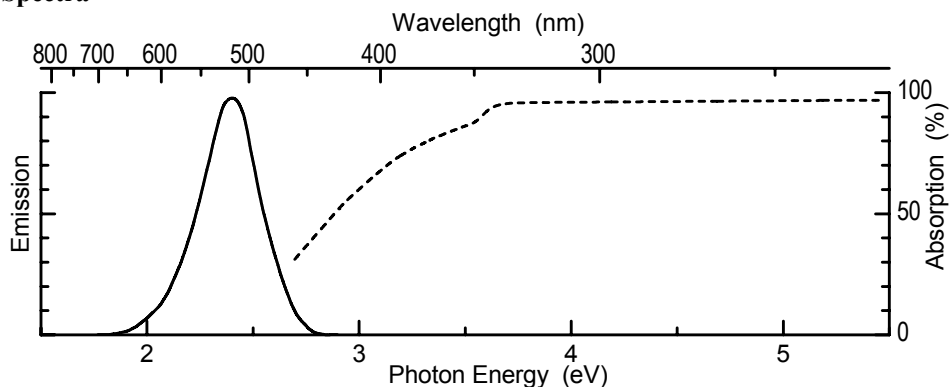
Preparation

Dissolve the copper acetate and the aluminum chloride together in a little water.
Add solution to the ZnS mix.
Add enough water or methanol to make a uniform slurry.
Dry. Powderize.
Add ~2–3 g of sulfur.
Fire in capped quartz tubes, H₂S, 1100°C, 1 hour.
Wash in water several times (stir, let settle) to remove left over chloride. Dry.

Optical Properties

Emission color: Green, long afterglow tail.
Emission peak: 2.38 eV
Emission width (FWHM): 0.32 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: ++
Decay: Non-exponential decay in the microsecond range

Spectra



Remarks

1. The chlorine in the above recipe may be replaced by bromine.
2. This phosphor corresponds to the P-31 cathodoluminescent phosphor.

References

1. Kröger, F.A., *Some Aspects of Luminescence of Solids*, Elsevier, Amsterdam (1948).
2. Gool, W., and Cleiren, A.P., *Philips Res. Rep.*, 15, 238 (1960).



Structure: Cubic (zinc blende)

Optical Properties

Emission color: Blue + green

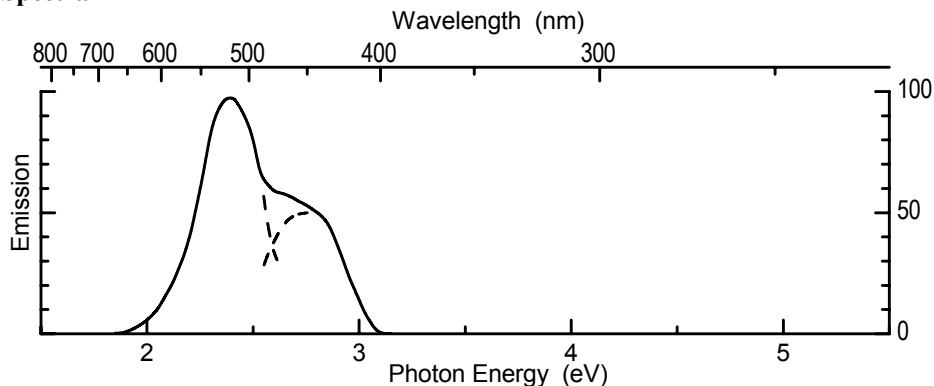
Emission peak: 2.34 eV, 2.79 eV

Emission width (FWHM): 0.33 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ++

Spectra



Reference

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).

ZnS:Eu²⁺

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| ZnS | 100 | 98 |
| Eu ₂ O ₃ | 0.03 (of Eu) | 0.053 |

Preparation

Mix by slurring in water or methanol.

Dry. Powderize.

Add ~2–3 g of sulfur.

1. Fire in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
2. Fire in open quartz boats, H₂S, 1100°C, 1 hour.

Optical Properties

Emission color: Yellow-green

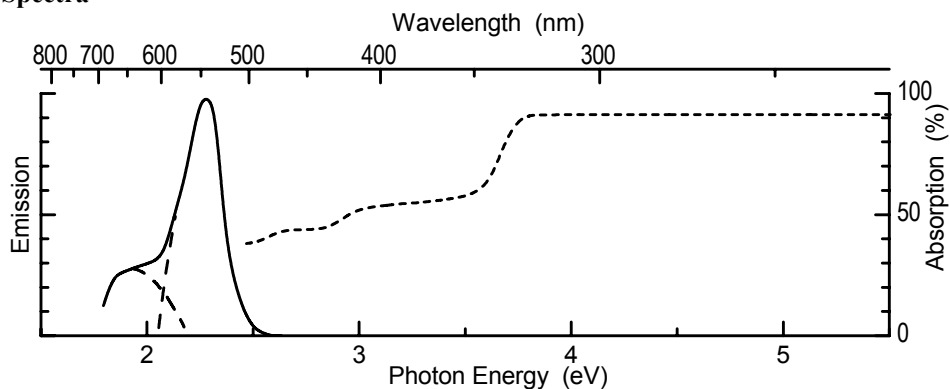
Emission peak: 2.25 eV; Weaker band at 1.95 eV

Emission width (FWHM): 0.24 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: Poor

Spectra



ZnS:Mn²⁺

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| ZnS | 99 | 97 |
| MnCO ₃ | 1 | 1.15 |
| NH ₄ Cl | 1 | 0.540 |

Preparation

Mix by slurring in water or methanol.

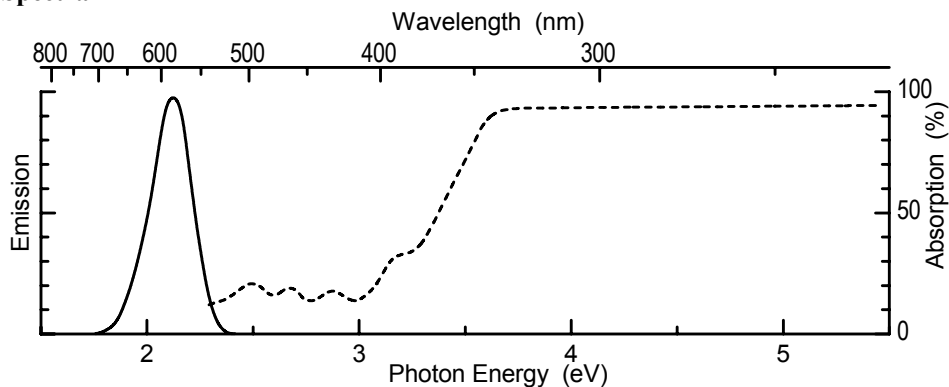
Dry. Powderize.

Add ~2–3 g of sulfur.
Fire in capped quartz tubes, N₂ or H₂S, 1100°C, 1 hour.

Optical Properties

Emission color: Orange-yellow
Emission peak: 2.13 eV
Emission width (FWHM): 0.21 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: +/5%
Decay: Exponential, ~1 msec to 1/10

Spectra



Remarks

1. The emission shifts slightly to lower energy (= longer wavelength) with increasing Mn concentration.
2. This material is remarkable for its strong triboluminescence.

References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).
2. Shionoya, S., in *Luminescence of Inorganic Solids*, Goldberg, P., Ed., Academic Press, New York (1966).



Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| ZnS | 94 | 92 |
| MnCO ₃ | 3 | 3.5 |
| ZnTe | 3 | 5.8 |
| NH ₄ Br | 2 | 2 |

Preparation

First mix only ZnS + MnCO₃ + NH₄Br (not yet the ZnTe).
Make a slurry in water.

Dry in air. Powderize when dry.

Add ~2–3 g of sulfur.

1. Fire in capped quartz tubes, N_2 , $900^\circ C$, 1 hour.
Now admit the $ZnTe$; mix by milling or grinding.
2. Fire in capped quartz tubes, N_2 , $1200^\circ C$, 1 hour. Powderize.
Wash in a solution of a few percentage of Br in methanol and then several times in plain methanol.

Optical Properties

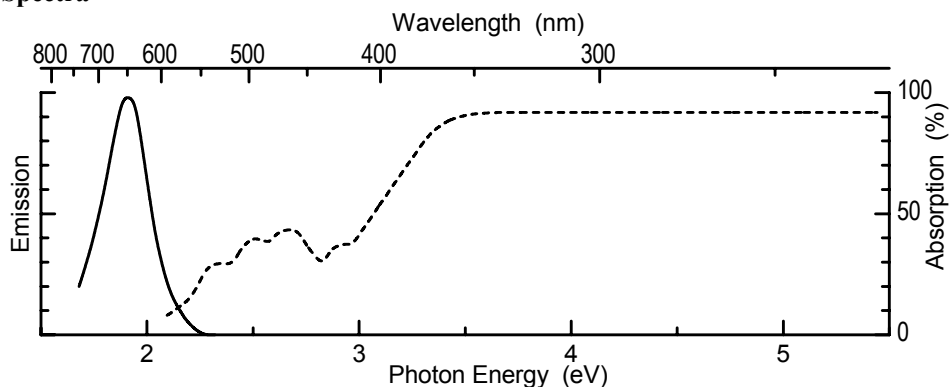
Emission color: Red

Emission peak: 1.92 eV

Emission width (FWHM): 0.24 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Remarks

1. This phosphor has been developed by A. Wachtel.
2. This material is remarkable for its strong triboluminescence (red).

Reference

1. Smirnova, R.I., and Pron, G.F., Effect of tellurium on luminescence properties of zinc sulfide luminors, *Opt. Spectrosc.-USSR*, 23, 67 (1967).

ZnS:P

Composition

| Ingredient | Mole % | By weight (g) |
|------------|------------|---------------|
| ZnS | 100 | 98 |
| Zn_3P_2 | 0.4 (of P) | 0.385 |
| NH_4Cl | 0.5 | 0.270 |

Preparation

Mix by dry grinding.

Fire in capped quartz tubes, H_2 , $1100^\circ C$, 1 hour.

Optical Properties

Emission color: Pale yellow

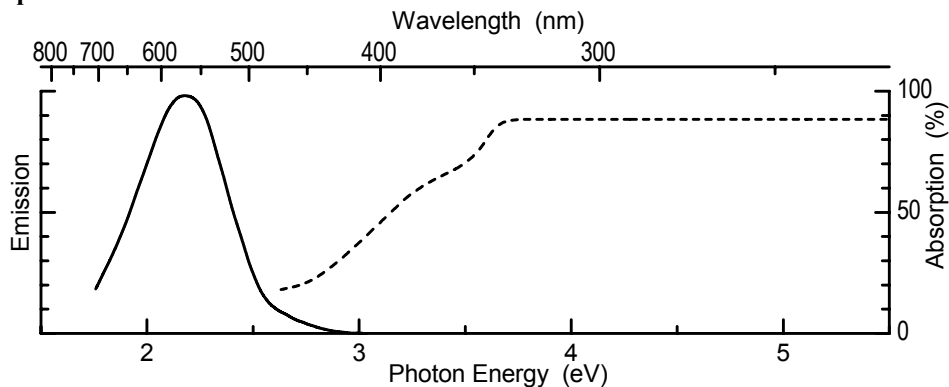
Emission peak: 2.14 eV

Emission width (FWHM): 0.50 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: +/5%; Long afterglow tail

Spectra

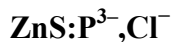


Remarks

1. Spectral positions of the emission band depends on the P concentration. It shifts to a lower energy (= longer wavelengths) with increasing P.
2. Phosphor is poorly reproducible because of high volatility of Zn_3P_2 at firing temperature. The amount of P retained in the phosphor after firing certainly is much lower than the amount added.

Reference

1. McKeag, A.H., and Ranby, P.W., New zinc sulfide phosphors activated by phosphorus, *J. Electrochem. Soc.*, 96, 85 (1949).



Structure: Hexagonal (wurtzite)

Optical Properties

Emission color: Yellowish

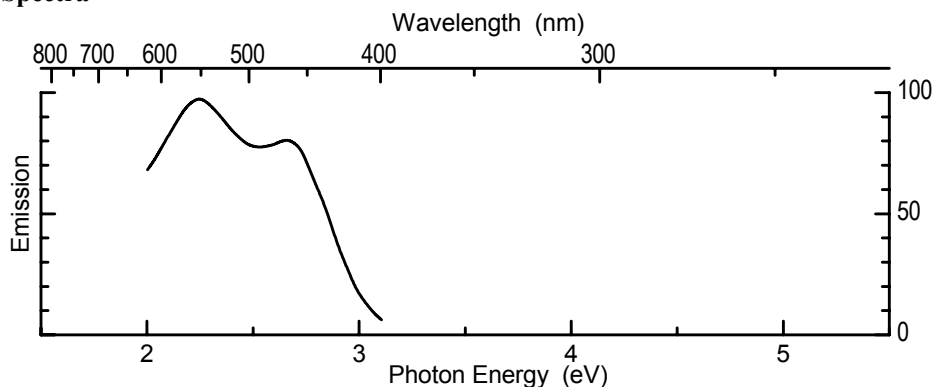
Emission peak: 2.24, 2.66 eV

Emission width (FWHM): 0.50 eV

Excitation efficiency by UV: + (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Reference

1. McKeag, A.H., and Ranby, P.W., New zinc sulfide phosphors activated by phosphorus, *J. Electrochem. Soc.*, 96, 85 (1949).

ZnS:Pb²⁺

Structure: Hexagonal (wurtzite)

Optical Properties

Emission color: Orange

Emission peak: 1.98 eV

Emission width (FWHM): 0.40 eV

Excitation efficiency by UV: – (4.88 eV), + (3.40 eV)

Reference

1. Fonda, G.R., Preparation and characteristics of zinc sulfide phosphors sensitive to infra-red, *J. Opt. Soc. Am.*, 36, 382 (1946).

ZnS:Pb²⁺, Cl[–]

Structure: Hexagonal (wurtzite)

Optical Properties

Emission color: Greenish

Emission peak: 2.54 eV

Emission width (FWHM): 0.40 eV

Excitation efficiency by UV: – (4.88 eV), ++ (3.40 eV)

References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).
2. Fonda, G.R., Preparation and characteristics of zinc sulfide phosphors sensitive to infra-red, *J. Opt. Soc. Am.*, 36, 382 (1946).

ZnS:Pb,Cu

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--|--------|---------------|
| ZnS | 100 | 98 |
| Pb(NO ₃) ₂ | 0.1 | 0.330 |
| Cu(C ₂ H ₃ O ₂) ₂ | 0.001 | 0.002 |

Preparation

Dissolve the lead nitrate and copper acetate together in a little water; add the solution to the ZnS.

Make a uniform slurry with water or methanol. Dry. Powderize.

Add ~2–3 g of sulfur.

Fire in capped quartz tubes, N₂, 1100°C, 1 hour.

Optical Properties

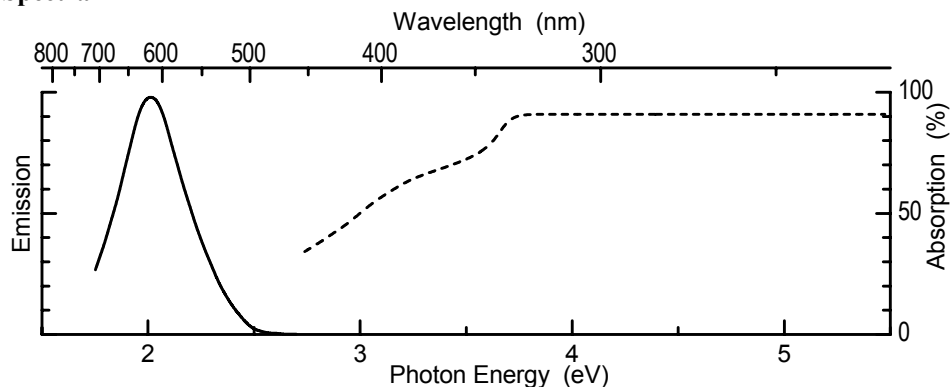
Emission color: Whitish orange during excitation, orange afterglow

Emission peak: 1.99 eV

Emission width (FWHM): 0.40 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Remarks

1. This phosphor is readily excited by UV and shows a long afterglow after excitation.
2. When the afterglow has decreased to a low level, irradiation of near-IR causes a strong orange emission (stimulation).

Reference

1. Fonda, G.R., Preparation and characteristics of zinc sulfide phosphors sensitive to infra-red, *J. Opt. Soc. Am.*, 36, 352 (1946).

ZnS:Sn²⁺

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------|--------|---------------|
| ZnS | 99 | 97 |
| SnS | 1 | 1.5 |
| Sulfur | | ~2–3 |

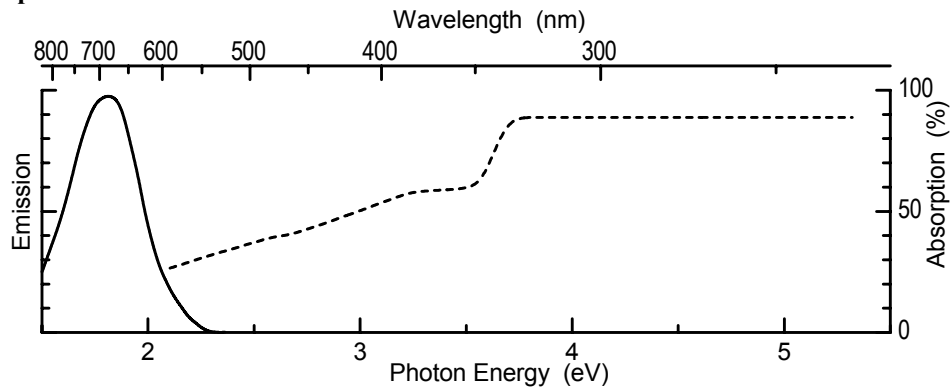
Preparation

Mix by dry grinding.
Fire in capped quartz tubes, N₂, 1150°C, 1 hour.

Optical Properties

Emission color: Red
Emission peak: 1.80 eV
Emission width (FWHM): 0.40 eV
Excitation efficiency by UV: + (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Kulaszewcz, S., *Acta Phys. Polonica A*, 45, 499 (1974).

ZnS:Sn,Ag

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| ZnS | 100 | 98 |
| SnS | 0.1 | 0.150 |
| AgNO ₃ | 0.01 | 0.017 |

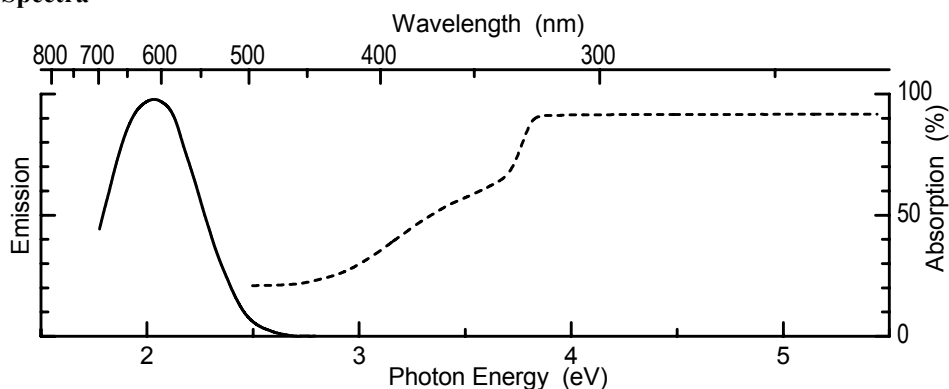
Preparation

Dissolve the AgNO_3 in a little water. Add the solutions to the $\text{ZnS} + \text{SnS}$.
Make a slurry in water or methanol.
Dry in air. Powderize when dry.
Admit $\sim 2\text{--}3$ g of sulfur.
Fire in capped quartz tubes, N_2 , 1150°C , 1 hour.

Optical Properties

Emission color: Pale yellow
Emission peak: 1.99 eV
Emission width (FWHM): 0.50 eV
Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Spectra



Remarks

1. The Ag in the above recipe can be replaced by Li.
2. In contrast to $\text{ZnS}:\text{Cu},\text{Sn}$, this phosphor shows only little response (stimulation) to irradiated IR.

Reference

1. Wachtel, A., ZnS-Sn,Li phosphor, *J. Electrochem. Soc.*, 105, 432 (1958).

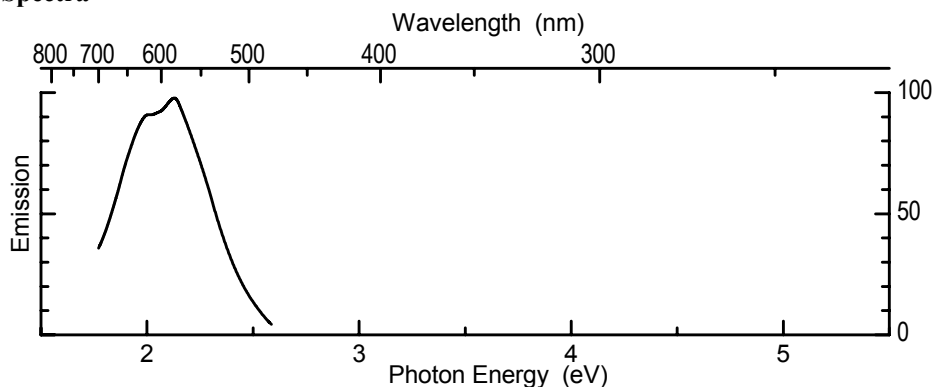


Structure: Hexagonal (wurtzite)

Optical Properties

Emission color: Orange
Emission peak: 1.99, 2.12 eV
Emission width (FWHM): 0.50 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Wachtel, A., ZnS-Sn,Li phosphor, *J. Electrochem. Soc.*, 105, 432 (1958).

ZnSe:Cu⁺,Cl

Structure: Cubic (zinc blende)

Optical Properties

Emission color: Red

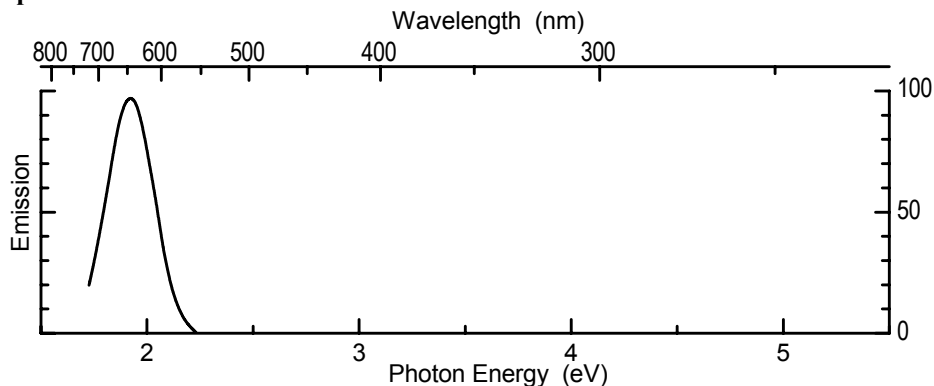
Emission peak: 1.92 eV

Emission width (FWHM): 0.30 eV

Excitation efficiency by UV: - (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: ++

Spectra



References

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949) p. 202.
2. Morehead, F.F., Luminescence in ZnS, Se Cu, Cl, *J. Phys. Chem. Solids*, 24, 37 (1963).

CdS:Ag⁺,Cl⁻

Structure: Hexagonal (wurtzite)

Optical Properties

Emission color: IR

Emission peak: 1.55 eV

Emission width (FWHM): 0.34 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ++

Reference

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).
-

CdS:In

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CdS | 100 | 145 |
| In ₂ O ₃ | 0.1 (of In) | 0.139 |

Preparation

Dissolve the In₂O₃ in a little nitric acid. Add the solutions to the CdS.

Make a slurry in methanol. Dry. Powderize. Add ~2–3 g of sulfur.

1. Fire in capped quartz tubes, H₂S, 900°C, 1 hour.
When cool, inspect under UV lamp. Material should be uniformly red luminescent.
Remove all parts which look different. Powderize.
2. Fire in open quartz boats, H₂, 500°C.
Inspect again under UV lamp. Material should now be uniformly green.

Optical Properties

Emission color: Green

Emission peak: 2.39 eV

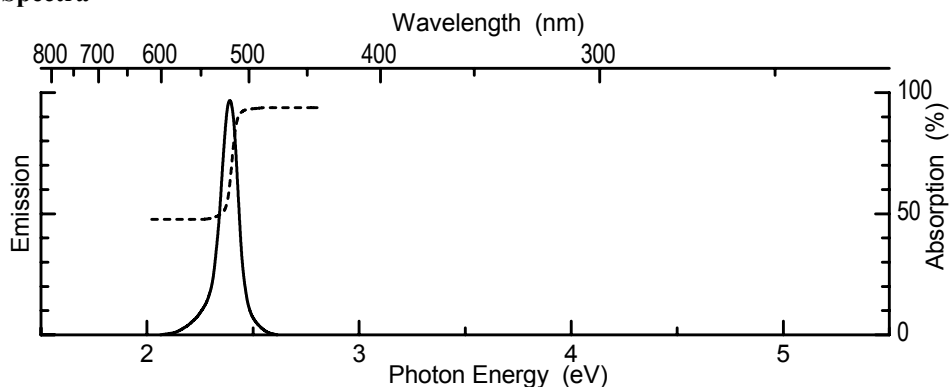
Emission width (FWHM): 0.08 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: +

Decay to 10%: Less than 1 nsec

Spectra



Remarks

1. This phosphor is thermodynamically in an unstable state. Do not heat up (except only in H_2) to more than about $250^\circ C$.
2. Phosphor has limited use in CR tubes for extremely fast display.

Reference

1. Lehmann, W., Edge emission of n-type conducting ZnO and CdS, *Solid State Electron.*, 9, 1107 (1966).

ZnS-CdS:Cu,I

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|------------------------------|--------|---------------|
| ZnS | 98 | 95.4 |
| CdS | 2 | 2.9 |
| $Cu(C_2H_3O_2)_2 \cdot H_2O$ | 0.5 | 2.9 |
| NH_4I | 2 | 2.9 |

Preparation

Dissolve the Cu acetate and the NH_4I separately, each in a little water.

Make a slurry of the ZnS + CdS in methanol.

Add the Cu solution, stir, then add the NH_4I -solution, and stir. Dry. Powderize.

Screen through a medium-fine cloth sieve.

Add ~3–4 g of sulfur. Mix well.

1. Fire in capped quartz tubes, N_2 , $800^\circ C$, 1 hour. Powderize.
2. Fire in open quartz boats, N_2 , $650^\circ C$, 1 hour. After this firing, pull the hot boat with the phosphor out of the furnace into open air and quench rapidly down to room temperature by blowing cold air against it. Powderize.

Boil briefly in a solution of about 10 g NaOH (or KOH) + 10 g NaCN (or KCN) in 1 liter of water.

Wash in plain water several times until neutral.

Dry with methanol in a filter funnel and then in open air.

Screen through 200 mesh or finer.

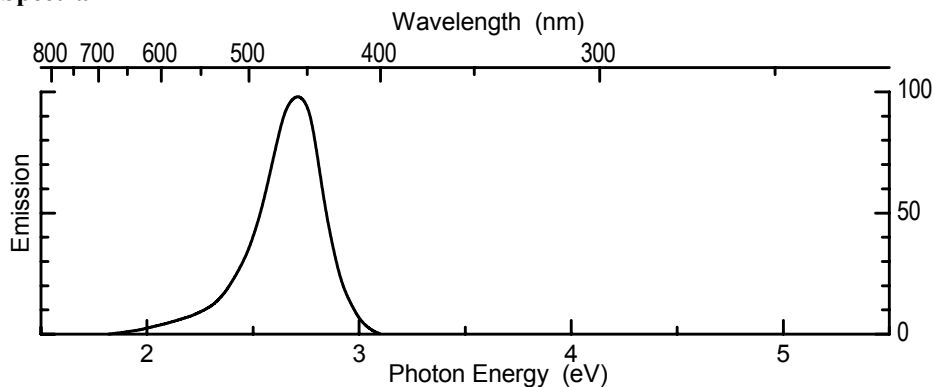
Optical Properties

Emission color: Blue

Emission peak: 2.72 eV

Emission width (FWHM): 0.33 eV

Spectra



Reference

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).

ZnS-CdS (25-75)

Structure: Wurtzite

Optical Properties

Emission color: Deep red

Emission peak: 1.78 eV

Emission width (FWHM): 0.35 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ++

ZnS-CdS (50-50)

Optical Properties

Emission color: Orange

Emission peak: 2.06 eV

Emission width (FWHM): 0.35 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ++

ZnS-CdS (75-25)

Optical Properties

Emission color: Green

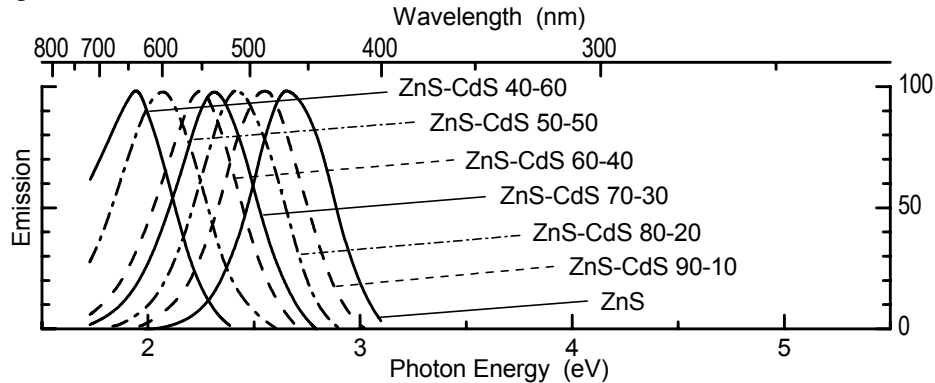
Emission peak: 2.38 eV

Emission width (FWHM): 0.35 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ++

Spectra



Reference

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York (1949).

ZnS-CdS:Ag,Br,Ni

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|---|--------|---------------|
| ZnS | 96 | 93.5 |
| CdS | 4 | 5.8 |
| Cu(C ₂ H ₃ O ₂) ₂ · H ₂ O | 0.8 | 1.6 |
| NH ₄ Br | 0.7 | 0.686 |

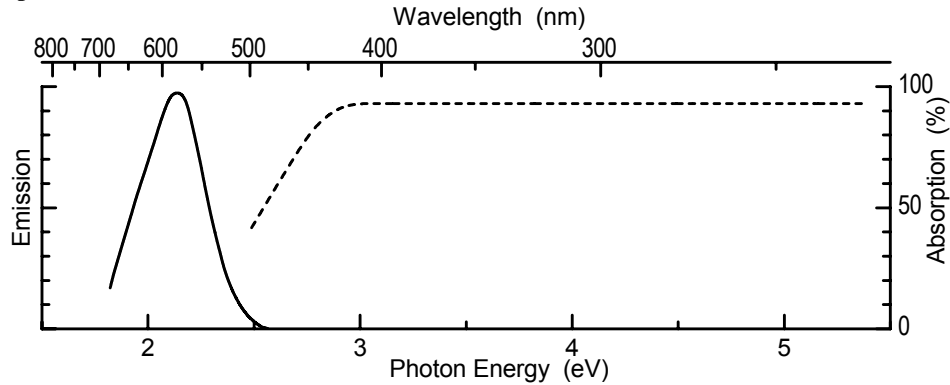
Preparation

- Make a slurry of the ZnS + CdS in methanol.
Dissolve the Cu acetate and the NH₄Br together in a little water. Add the solution to the slurry, stir. Dry. Powderize.
Screen through a medium-fine cloth sieve.
Add ~3–4 g of sulfur. Mix well.
1. Fire in capped quartz tubes, H₂S, 800°C, 45 minutes. Powderize.
 2. Fire in open quartz boats, N₂, 700°C, 1 hour.

Optical Properties

Emission color: Orange-yellow
Emission peak: 2.13 eV
Emission width (FWHM): 0.37 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Remarks

- 1. The emission intensity increases sharply super-linearly with increasing excitation intensity and decreases with increasing temperature: The best obtained temperature response is about 20% per degree Centigrade near room temperature.
- 2. This phosphor is good for thermal imaging.

Reference

- 1. Nail, N.R., Urbach, F., and Pearlman, D., New observations on superlinear luminescence, *J. Opt. Soc. Am.*, 39, 690 (1949).

ZnS-CdS:Ag⁺,Cl

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| ZnS + CdS | 100 | |
| AgNO ₃ | 0.03 | 0.050 |
| NH ₄ Cl | 5 | 2.5 |

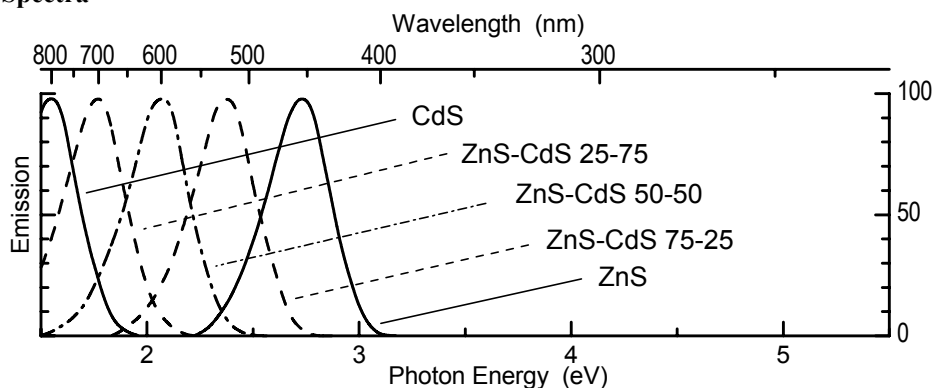
Preparation

Dissolve the AgNO₃ and the NH₄Cl separately, each in a little water.
Make a slurry of the ZnS + CdS of the desired ratio in water or methanol.
First add the silver solution; stir. Then add the NH₄Cl solution; stir again.
Dry. Powderize.
Add ~2–3 g of sulfur. Mix well.
Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Wash in water several times (to remove leftover halide).
Dry.

Optical Properties

Emission peak: Peak position depending on the ZnS/CdS ratio
Emission width (FWHM): ~0.35 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: 20%
Decay to 10%: Non-exponential afterglow in the microsecond range

Spectra



Remarks

1. Chlorine in the above recipe may be replaced by bromine.
2. The phosphor of ZnS/CdS $\approx 72/28$ is commercial P-22G.

Reference

1. Leverenz, H.W., *An Introduction to Luminescence of Solids*, John Wiley & Sons, New York, 1949.

ZnS-CdS:Cu,Br long life

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|--|--------|---------------|
| ZnS | 96 | 93.5 |
| CdS | 4 | 5.8 |
| $\text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2 \cdot \text{H}_2\text{O}$ | 0.8 | 1.6 |
| NH_4Br | 0.7 | 0.686 |

Preparation

Make a slurry of the ZnS + CdS in methanol. Dissolve the Cu acetate and the NH_4Br together in a little water, add the solution to the slurry, and stir. Dry. Powderize. Screen through a medium-fine cloth sieve. Add ~3–4 g of sulfur. Mix well.

1. Fire in capped quartz tubes, H_2S , 800°C , 45 minutes. Powderize.
2. Fire in open quartz boats, N_2 , 700°C , 1 hour. After this firing, pull the hot boat with the phosphor out of the furnace into open air and quench rapidly down to room temperature by blowing cold air against it. Powderize.

Boil briefly in a solution of about 10 g NaOH (or KOH) + 10 g NaCN (or KCN) in 1 liter water. Wash in plain water several times until neutral.

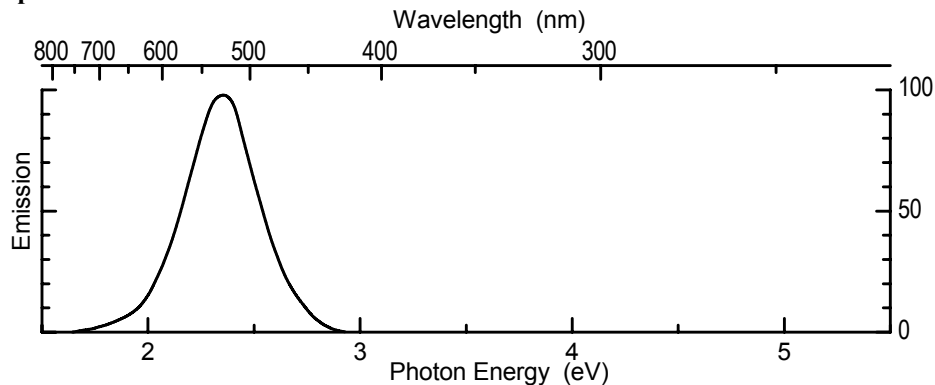
Dry with methanol in a filter funnel and then in open air.

3. Fire the same as 2. Firing includes rapid quenching.
Boil again in cyanide solution as above. Wash in plain water several times until neutral. Dry with methanol in a filter funnel and then in open air.
Screen through 200 mesh or finer.

Optical Properties

Emission color: Green
Emission peak: 2.35 eV
Emission width (FWHM): 0.35 eV

Spectra



Remark

The zero-hour brightness of this phosphor is ~½ of that of the one on the previous page.

ZnS-CdS:Cu,Br high brightness

Structure: Hexagonal (wurtzite)

Composition

| Ingredient | Mole % | By weight (g) |
|---|--------|---------------|
| ZnS | 96 | 93.5 |
| CdS | 4 | 5.8 |
| Cu(C ₂ H ₃ O ₂) ₂ · H ₂ O | 0.3 | 0.600 |
| NH ₄ Br | 0.7 | 0.686 |

Preparation

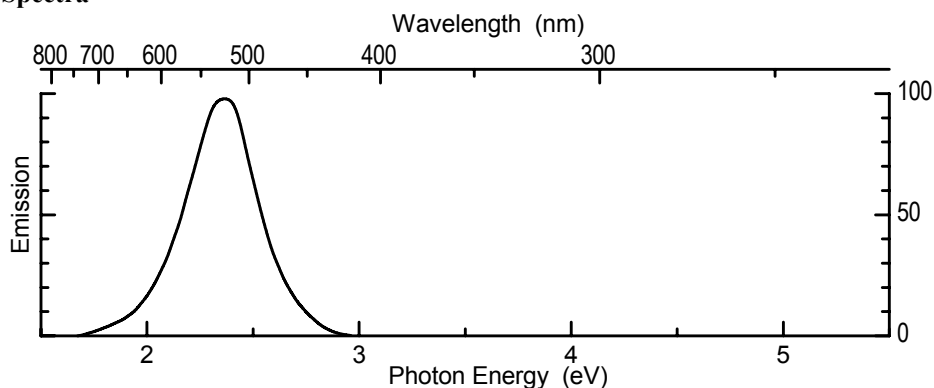
Make a slurry of the ZnS + CdS in methanol. Dissolve the Cu acetate and the NH₄Br together in a little water, add the solution to the slurry, and stir. Dry. Powderize. Screen through a medium-fine cloth sieve. Add ~3–4 g of sulfur. Mix well.

1. Fire in capped quartz tubes, H₂S, 800°C, 45 minutes. Powderize.
2. Fire in open quartz boats, N₂, 650°C, 1 hour. After this firing, pull the hot boat with the phosphor out of the furnace into open air and quench rapidly down to room temperature by blowing cold air against it. Powderize. Boil briefly in a solution of about 10 g NaOH (or KOH) + 10 g NaCN (or KCN) in 1 liter of water. Wash in plain water several times until neutral. Wash in about 2 liters of 10% H₂O₂ solution at room temperature for about 2 hours while stirring. Wash in plain water. Dry with methanol in a filter funnel and then in open air. Screen through 200 mesh or finer.

Optical Properties

Emission color: Green
Emission peak: 2.35 eV
Emission width (FWHM): 0.38 eV

Spectra



Remarks

1. This phosphor has been developed for high zero-hour brightness; its half-life under steady 5 kHz excitation is much shorter than that of the phosphor on the next page.
 2. The H₂O₂ wash is an idea by Wachtel, A., U.S. Pat., 3 165 476 (1965).
-

ZnS-ZnTe:Mn²⁺ 98-2

Structure: Hexagonal (wurtzite)

Optical Properties

Emission color: Red

Emission peak: 1.92 eV

Emission width (FWHM): 0.24 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Reference

1. Smirnova, R.I., and Pron, G.F., Effect of tellurium on luminescence properties of zinc sulfide luminors, *Opt. Spectrosc.-USSR*, 23, 67 (1967).

4.14 CaS-Type Sulfides

The following host compounds and activators are included in this subsection:

MgS:Eu²⁺
CaS:Bi³⁺
CaS:Bi³⁺,Na
CaS:Ce³⁺
CaS:Cu⁺,Na⁺
CaS:Eu²⁺
CaS:Mn²⁺
CaS:La³⁺
CaS:Pb²⁺,Cl
CaS:Pb²⁺
CaS:Pb²⁺,Mn²⁺
CaS:Pr³⁺,Pb²⁺,Cl
CaS:Sb³⁺
CaS:Sb³⁺,Na
CaS:Sm³⁺
CaS:Sn²⁺
CaS:Sn²⁺,F
CaS:Tb³⁺
CaS:Tb³⁺,Cl
CaS:Y³⁺
CaS:Yb²⁺
CaS:Yb²⁺,Cl
SrS:Ce³⁺
SrS:Cu⁺,Na
SrS:Eu²⁺
SrS:Mn²⁺
BaS:Au,K

MgS:Eu²⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| MgO | 100 | 0.040 |
| Eu ₂ O ₃ | 0.1 (of Eu) | 0.176 |
| NH ₄ Cl | 2 | 1 |

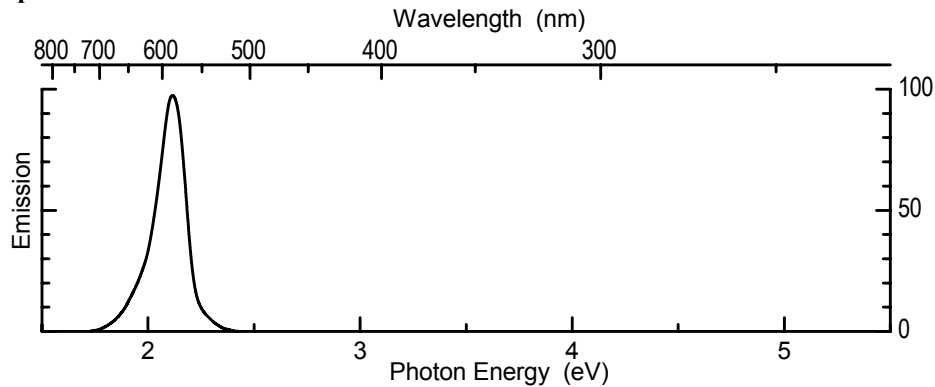
Preparation

- First mix only the MgO and Eu₂O₃.
1. Fire in open quartz boats, N₂ loaded with CS₂, 800°C, 1 hour.
Powderize.
Admit above amount of NH₄Cl and also 2–3 g of sulfur; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
Store in a well-closed container. Keep dry.

Optical Properties

Emission color: Orange-yellow
Emission peak: 2.11 eV
Emission width (FWHM): 0.15 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: +/-8%

Spectra



Reference

1. Kasano, H., Megumi, K., and Yamamoto, H., Cathodoluminescence of $\text{Ca}_{1-x}\text{Mg}_x\text{S-Eu}$, $\text{Ca}_{1-x}\text{Mg}_x\text{S-Ce}$, *J. Electrochem. Soc.*, 131 (1953).

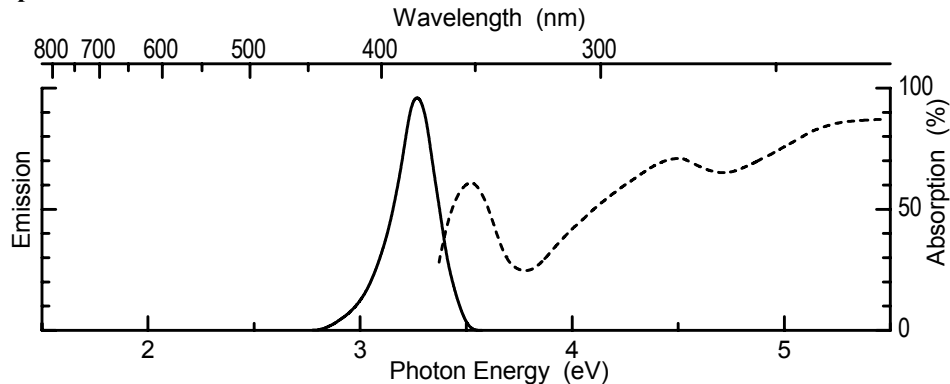
CaS:Bi³⁺

Structure: Cubic (NaCl)

Optical Properties

Emission color: Near UV
Emission peak: 3.27eV
Emission width (FWHM):0.21 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).
2. Lehmann, W., and Ryan, F.M., Fast cathodoluminescent calcium sulfide phosphors, *J. Electrochem. Soc.*, 119, 275 (1972).
3. Ellervee, A.F., Luminescence of Pb²⁺ and Bi³⁺ centers in alkali-earth sulfides and oxides, *Phys. Status Solidi B*, 82, 91 (1977).
4. Garlick, G.F.J., and Mason, D.E., Electron traps and infrared stimulation of phosphors, *J. Electrochem. Soc.*, 96, 90 (1949).
5. Yamashita, N., and Asano, S., Luminescence-centers of Ca(S,Se):Bi³⁺ and **CaO:Bi³⁺** phosphors, *J. Phys. Soc. Jpn.*, 40, 144 (1976).

CaS:Bi³⁺,Na

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| CaCO ₃ | 100 | 100 |
| Bi ₂ O ₃ | 0.03 (of Bi) | 0.70 |
| NaHCO ₃ | 0.5 | 0.420 |

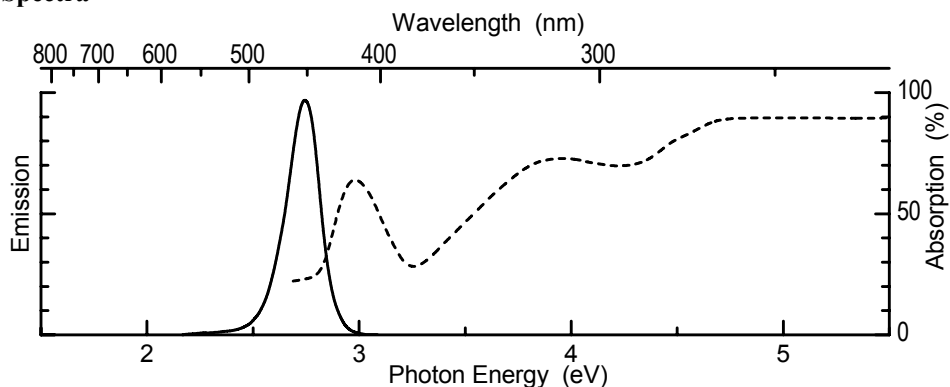
Preparation

- Start from purest CaCO₃. Convert it to CaS by one of the following methods:
1. Fire in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Add the above amounts of Bi and Na, and also ~ 2–3 g of sulfur; mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
 3. Fire in capped quartz tubes, stagnant air, 1200°C, 1 hour.
Store in a well-closed container.

Optical Properties

Emission color: Blue
Emission peak: 2.77 eV
Emission width (FWHM): 0.18 eV
Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: 4–5%
Decay: Non-exponential decay in the microsecond range; long afterglow tail extending into seconds

Spectra



Remarks

1. Preparation required purest starting materials. Luminescent-grade CaCO_3 is not pure enough. Contamination by Mn as low as 1 ppm will cause appearance of the yellow Mn^{2+} emission.
2. Na in above recipe can be replaced by Li but Na seems to have a slight edge over it.

References

1. Garlick, G.F.J., and Mason, D.E., Electron traps and infrared stimulation of phosphors, *J. Electrochem. Soc.*, 96, 90 (1949).
2. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).
3. Lehmann, W., and Ryan, F.M., Fast cathodoluminescent calcium sulfide phosphors, *J. Electrochem. Soc.*, 119, 275 (1972).
4. Yamashita, N., and Asano, S., Luminescence-centers of $\text{Ca}(\text{S}+\text{Se}):\text{Bi}^{3+}$ and $\text{CaO}:\text{Bi}^{3+}$ phosphors, *J. Phys. Soc. Jpn.*, 40, 144 (1976).
5. Ellervee, A.F., Luminescence of Pb^{2+} and Bi^{3+} centers in alkali-earth sulfides and oxides, *Phys. Status Solidi B*, 82, 91 (1977).



Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|-----------------|--------|---------------|
| CaCO_3 | 100 | 100 |
| CeO_2 | 0.05 | 0.086 |

Preparation

Mix well.

1. Fire in open quartz boats, 1100°C , first 1 hour in N_2 and then 1 hour in H_2S . Powderize.
Add about 2–3 g of sulfur.
Admit about 1–2 g of NH_4Cl by dry grinding or milling.
2. Fire in capped quartz tubes, N_2 , 1200°C , 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Green

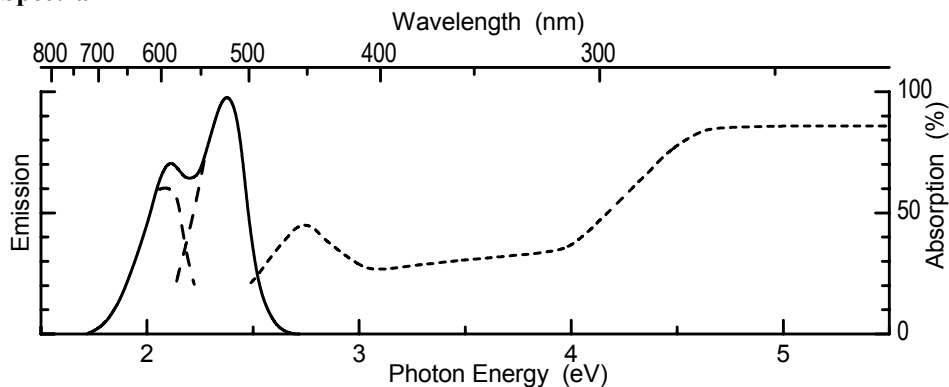
Emission peak: 2.13 eV, 2.38 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: ++/20%

Decay to 10%: Non-exponential decay in the microsecond range; phosphor showing no color change and little saturation up to the highest current densities

Spectra



Remarks

1. Phosphor can be sensitized for efficient excitation by 3.40 eV by addition of Pb (see [CaS:Pb²⁺](#)).
2. Decay time after excitation by an e-beam pulse can be reduced to ~200 nsec (1/10 of original) by addition of Co.
3. Phosphor has a slightly greenish body color due to the combined action of the blue absorption band and the green emission.
4. Cl in the above recipe can be replaced by F, Br, or I.
5. The distance between the two emission bands (in eV) cannot be changed but the exact positions of the bands depend slightly on the used Ce concentration.
6. This phosphor is efficiently luminescent up to ~300°C.
7. This phosphor or modifications of it have found applications in CR tubes and for correction in arc lamps.

References

1. Lehmann, W., Optimum efficiency of cathodoluminescence of inorganic phosphors, *J. Electrochem. Soc.*, 118, 1164 (1971).
2. Lehmann, W., and Ryan, F.M., Fast cathodoluminescent calcium sulfide phosphors, *J. Electrochem. Soc.*, 119, 275 (1972).
3. Lehmann, W., and Ryan, F.M., Cathodoluminescence of CaS-Ce³⁺ and CaS-Eu²⁺ phosphors *J. Electrochem. Soc.*, 118, 477 (1971).
4. Okamoto, F., and Kato, K., Preparation and cathodoluminescence of CaS-Ce and Ca_{1-x}Sr_xS-Ce phosphors, *J. Electrochem. Soc.*, 130, 432 (1983).

CaS:Cu⁺,Na⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--|--------|---------------|
| CaCO ₃ | 100 | 100 |
| Cu(C ₂ H ₃ O ₂) ₂ ·H ₂ O | 0.15 | 0.300 |
| NaHCO ₃ | 1.5 | 1.25 |

Preparation

Dissolve the copper acetate in a little water; add solution to the CaCO₃.
Make a uniform slurry in water or methanol. Dry. Powderize.

1. Fire in open quartz boats, H₂S, 1100°C, 1 hour. Powderize.
Add 800 mg of NaHCO₃ plus ~ 2–3 g of sulfur. Mix by dry grinding.
2. Fire in covered alumina crucibles, H₂, 1000°C, 1 hour.
Powderize. Store in a well-closed container.

Optical Properties

Emission color: Light blue

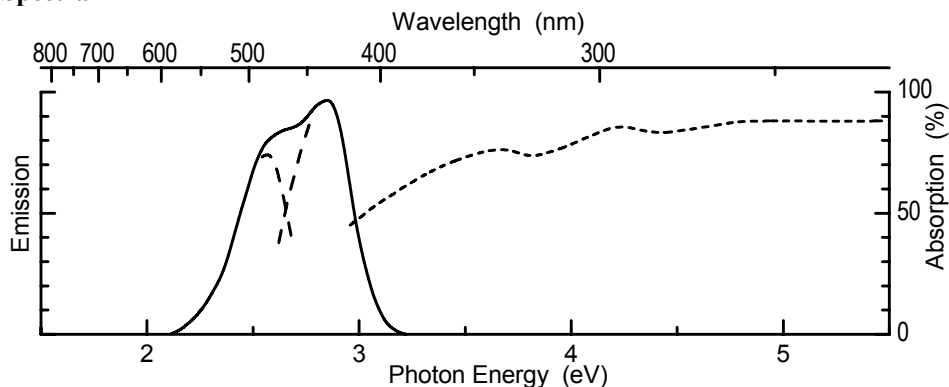
Emission peak: 2.55 eV, 2.83 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ++/16%

Decay: Non-exponential decay, 100 sec to 1/10; phosphor showing much less saturation at the high beam current than P-11

Spectra



Remarks

1. Halides are not co-activators in CaS:Cu (in contrast to ZnS:Cu).
2. The relative heights of the two emission bands depend on the preparation conditions.
3. Na in the above recipe can be omitted or be replaced by Li or K. The peak positions of the two emission bands depend on the alkali used (if any).

References

1. Wachtel, A., CaS-Cu,Eu electroluminescent phosphors, *J. Electrochem. Soc.*, 107, 199 (1960).
2. Lehmann, W., Alkaline earth sulfide phosphors activated by copper, silver, and gold, *J. Electrochem. Soc.*, 117, 1389 (1970).

CaS:Eu²⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| CaCO ₃ | 100 | 100 |
| Eu ₂ O ₃ | 0.05 (of Eu) | 0.088 |
| NH ₄ Cl | ~2 | ~1 |

Preparation

Mix the CaCO₃ and the Eu₂O₃.

1. Fire in open quartz boats, 1100°C, first 1 hour in N₂ and then 1 hour in H₂S. Powderize.
Add the above amount of NH₄Cl, also ~ 2–3 g of sulfur.
Mix by dry grinding.
2. Fire in capped quartz tubes, H₂, 1200°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Red

Emission peak: 1.91 eV

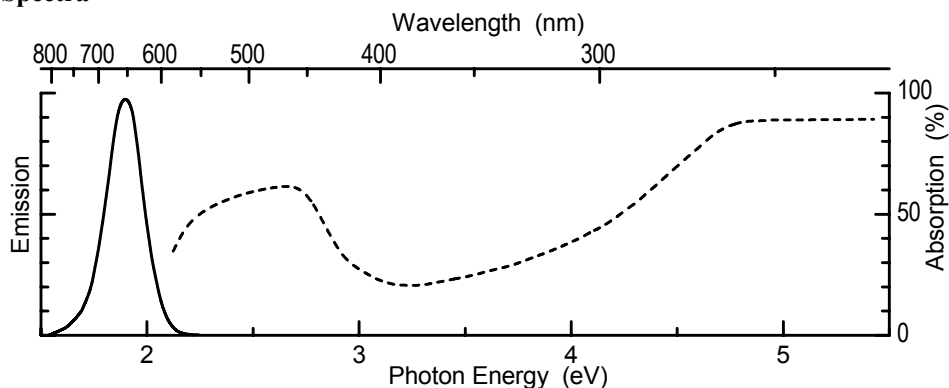
Emission width (FWHM): 0.20 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: ++/10% (can be improved to ~16% by the addition of Ce, see CaS:Ce³⁺, Cl).

Decay: Non-exponential decay in the microsecond range

Spectra



Remarks

1. Phosphor can be sensitized for excitation by 3.40 eV by addition of Sn (see CaS:Sn,F) or by Pb (see CaS:Pb).
2. Decay time after excitation by an e-beam pulse can be reduced to ~300 nsec by addition of Co.
3. This phosphor has a very characteristic pink body color due to the combined actions of the broad blue to yellow absorption band and the red fluorescence.
4. Cl in the above recipe can be replaced by F, Br, or I.

5. The emission peak position depends slightly upon the used Eu concentration.
6. Partial or complete replacement of the Ca by Sr causes the emission to shift to higher energy (= shorter wavelength).
7. This phosphor is efficiently luminescent up to ~300°C.
8. This phosphor or modifications of it have found applications in CR tubes and for correction in arc lamps.

References

1. Lehmann, W., Optimum efficiency of cathodoluminescence of inorganic phosphors, *J. Electrochem. Soc.*, 118, 1164 (1971).
2. Lehmann, W., and Ryan, F.M., Cathodoluminescence of CaS-Ce³⁺ and CaS-Eu²⁺ phosphors *J. Electrochem. Soc.*, 118, 477 (1971).
3. Brauer, P. Z. *Naturforsch. Pt. A*, 6, 561 (1951), and Über eu-ionen in erdalkalioxyden und erdalkali-sulfiden, *Z. Naturforsch Pt A*, 12, 233 (1957).
4. Jaffe, P.M., and Banks, E., Oxidation states of europium in the alkaline earth oxide and sulfide phosphors, *J. Electrochem. Soc.*, 102, 518 (1955).
5. Lehmann, W., and Ryan, F.M., Fast cathodoluminescent calcium sulfide phosphors, *J. Electrochem. Soc.*, 119, 275 (1972).
6. Wachtel, A., CaS-Cu,Eu electroluminescent phosphors, *J. Electrochem. Soc.*, 107, 199 (1960).

CaS:Mn²⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| MnCO ₃ | 0.1 | 0.115 |
| NH ₄ Cl | ~2 | ~1 |

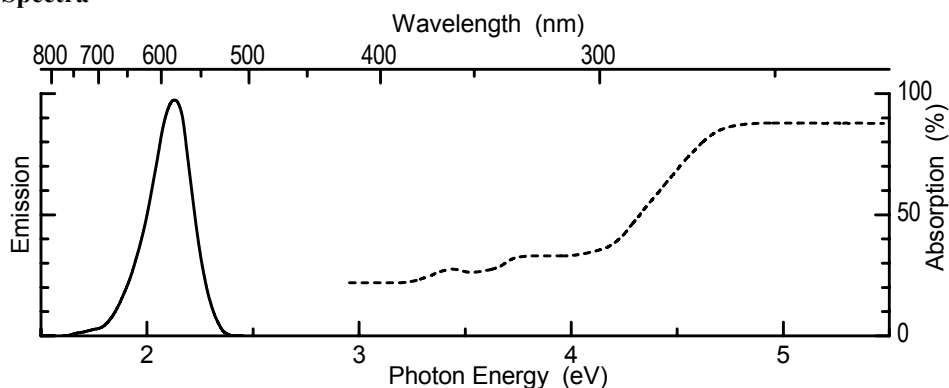
Preparation

- Mix the CaCO₃ and the MnCO₃.
1. Fire in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Add the above amount of NH₄Cl, and ~ 2–3 g of sulfur.
Mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
 3. Fire in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Yellow
 Emission peak: 2.11 eV
 Emission width (FWHM): 0.24 eV
 Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
 Excitation efficiency by e-beam: ++/16%
 Decay: Near-exponential decay with ~8 msec to 1/10

Spectra



Remarks

1. The Cl in the above recipe is not a co-activator. It serves only as a flux and can be replaced by F, Br, or I.
2. The Mn concentration is not critical, the Mn²⁺ emission is fairly strong between about 1 ppm and 5% of Mn/Ca.
3. The emission peak position depends slightly on the Mn concentration used.
4. Partial (up to 10%) replacement of the Ca by Mg shifts the emission from yellow to orange-red. Partial or complete replacement of Ca by Sr shifts it towards green (see [SrS:Mn²⁺](#)).

References

1. Shionoya, S., and Era, K., Sensitization by bismuth of the luminescence of manganese and samarium in calcium sulfide phosphors, *B. Chem. Soc. Jpn.*, 30, 518 (1957).
2. Levshin, V.L., and Mikhaylin, V.V., Paper 111, *Intern Conf. Lumin.*, Budapest (1966).
3. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).
4. Lehmann, W., Optimum efficiency of cathodoluminescence of inorganic phosphors, *J. Electrochem. Soc.*, 118, 1164 (1971).



Structure: Cubic (NaCl)

Optical Properties

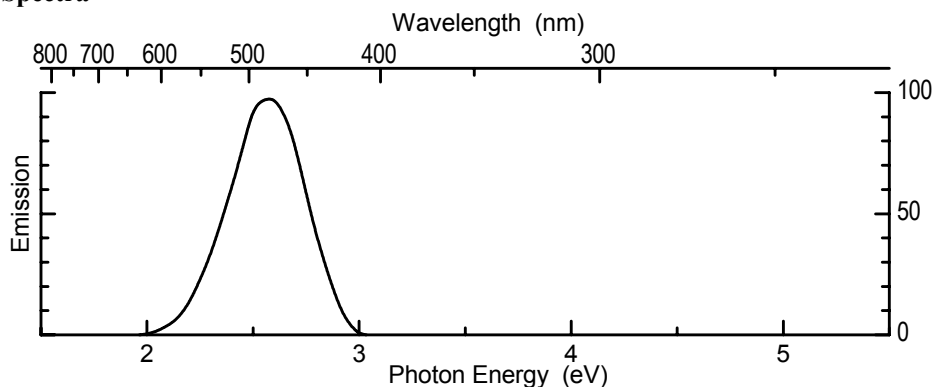
Emission color: Blue-greenish

Emission peak: 2.55 eV

Emission width (FWHM): 0.42 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).

CaS:Pb²⁺,Cl

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| PbO | 0.02 | 0.045 |
| NH ₄ Cl | 3 | 1.5 |

Preparation

Start from purest CaCO₃. Convert to CaS by one of the following methods

1. Fire in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Add ~1g of NH₄Cl, and ~ 2–3 g of sulfur.
Mix by dry grinding.
2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
Add the above amount of PbO, another 2 g of NH₄Cl, and ~ 2–3 g of sulfur.
Mix by dry grinding.
3. Fire in capped quartz tubes, N₂, 1200°C.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Near-UV

Emission peak: 3.39 eV

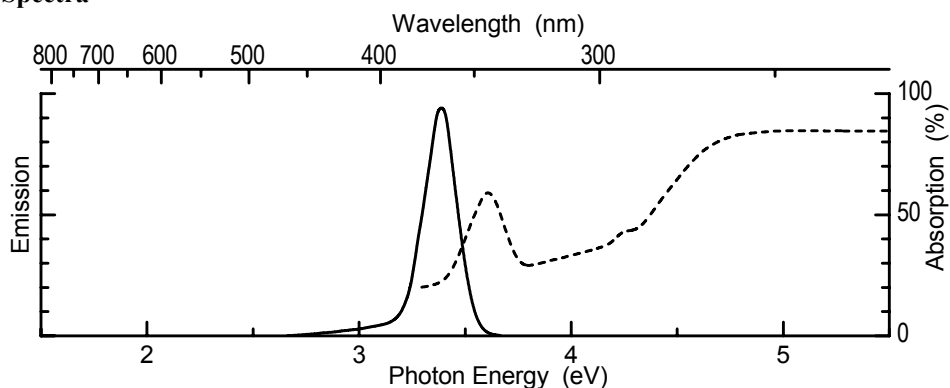
Emission width (FWHM): 0.22 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: 15–17%

Decay: Non-exponential decay in the microsecond range; decay to be shortened to about 250 nsec (to 1/10) by addition of a trace of cobalt

Spectra



Remarks

1. Preparation requires purest starting materials. Normal luminescent-grade CaCO_3 is not pure enough. Contamination by Mn as low as 1 ppm will cause appearance of the yellow Mn^{2+} emission.
2. The NH_4Cl in the above recipe can be replaced by NH_4Br . Fluoride is much less effective.
3. This phosphor has limited application as UV emitter in CR tubes.

References

1. Lehmann, W., Optimum efficiency of cathodoluminescence of inorganic phosphors, *J. Electrochem. Soc.*, 118, 1164 (1971); and Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).
2. Lehmann, W., and Ryan, F.M., Fast cathodoluminescent calcium sulfide phosphors, *J. Electrochem. Soc.*, 119, 275 (1972).
3. Ellervee, A.F., Luminescence of Pb^{2+} and Bi^{3+} centers in alkali-earth sulfides and oxides, *Phys. Status Solidi B*, 82, 91 (1977).

CaS:Pb^{2+}

Structure: Cubic (NaCl)

Optical Properties

Emission color: UV

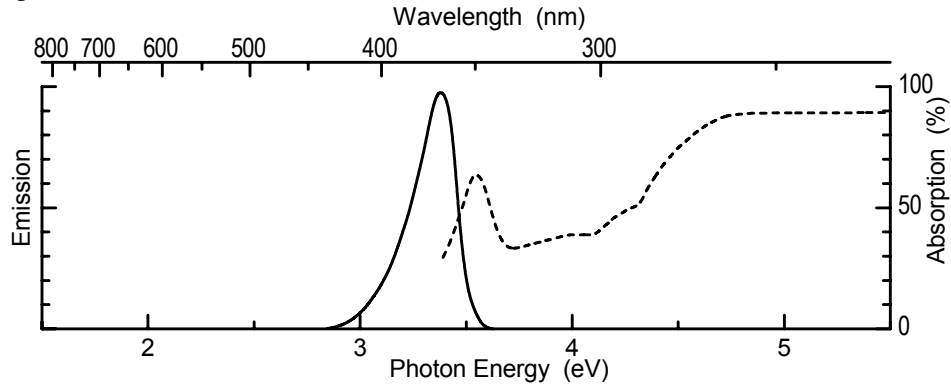
Emission peak: 3.39 eV

Emission width (FWHM): 0.22 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

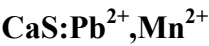
Excitation efficiency by e-beam: ++

Spectra



References

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).
2. Lehmann, W., Optimum efficiency of cathodoluminescence of inorganic phosphors, *J. Electrochem. Soc.*, 118, 1164 (1971).
3. Lehmann, W., and Ryan, F.M., Fast cathodoluminescent calcium sulfide phosphors, *J. Electrochem. Soc.*, 119, 275 (1972).
4. Ellervee, A.F., Luminescence of Pb²⁺ and Bi³⁺ centers in alkali-earth sulfides and oxides, *Phys. Status Solidi B*, 82, 91, (1977).



Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| MnCO ₃ | 0.5 | 0.575 |
| PbO | 0.3 | 0.670 |
| NH ₄ Cl | 2 | ~1 |

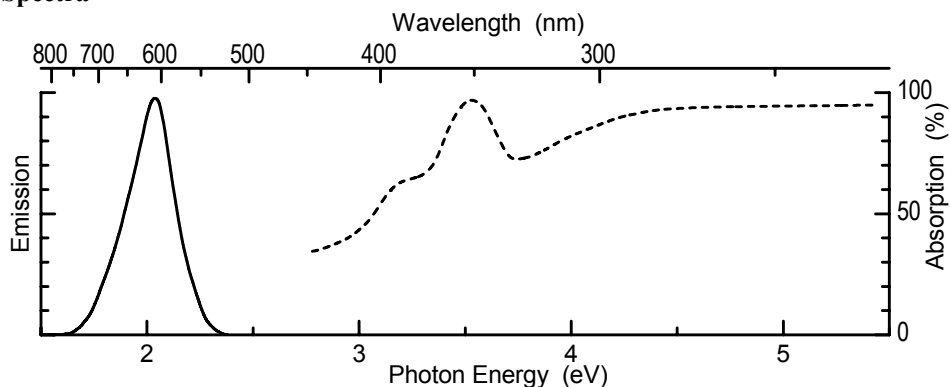
Preparation

- First mix only the CaCO₃ and MnCO₃.
1. Fire in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Add the above amounts of PbO and NH₄Cl, and also ~ 2–3 g of sulfur.
Mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Red-orange (not the yellow of [CaS:Mn²⁺](#) without Pb)
Emission peak: 2.04 eV
Emission width (FWHM): 0.28 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Spectra



Remark

The Mn^{2+} emission shifts to lower energy (+ longer wave lengths) with increasing Pb concentration.

$\text{CaS}:\text{Pr}^{3+}, \text{Pb}^{2+}, \text{Cl}$

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|--------|---------------|
| CaCO_3 | 100 | 100 |
| Pr_2O_3 | 0.1 | 0.165 |
| PbO | 0.02 | 0.045 |
| NH_4Cl | ~2 | ~1 |

Preparation

- First mix only the CaCO_3 and MnCO_3 .
1. Fire in open quartz boats, H_2S , 1100°C , 1 hour. Powderize.
Add the above amount of NH_4Cl and also ~ 2–3 g of sulfur.
Mix by dry grinding.
 2. Fire in capped quartz tubes, N_2 , 1200°C , 1 hour.
Add the above amount of PbO and also ~ 2–3 g of sulfur. Mix by dry grinding.
 3. Fire in capped quartz tubes, H_2 , 1100°C , 1 hour. Powderize.
Store in a well-closed container.

Optical Properties

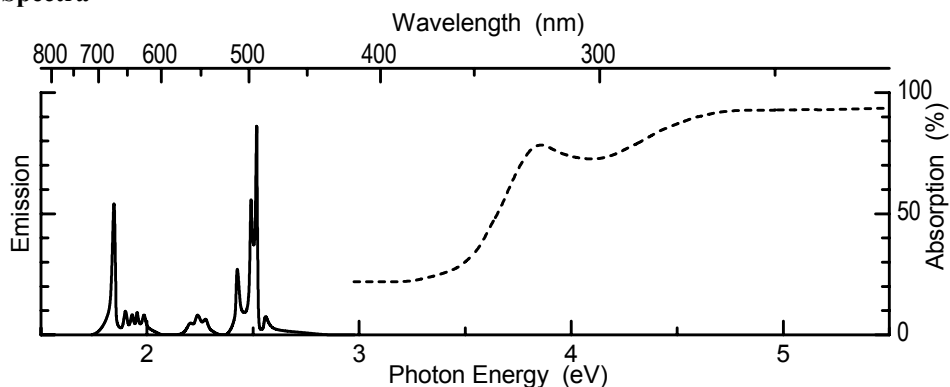
Emission color: Pale greenish-pink

Emission peak: 1.85 eV, 2.50 eV; mainly two line groups in the blue-green and in the red, respectively; also present (not shown in figure below) a strong line at 1.05 eV in the IR

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Decay: Exponential decay, about 0.5 msec to 1/10

Spectra



Remark

The intensity ratio of the two visible line groups is very sensitive to the details of the preparation and excitation.

Reference

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).



Structure: Cubic (NaCl)

Optical Properties

Emission color: Yellow-green

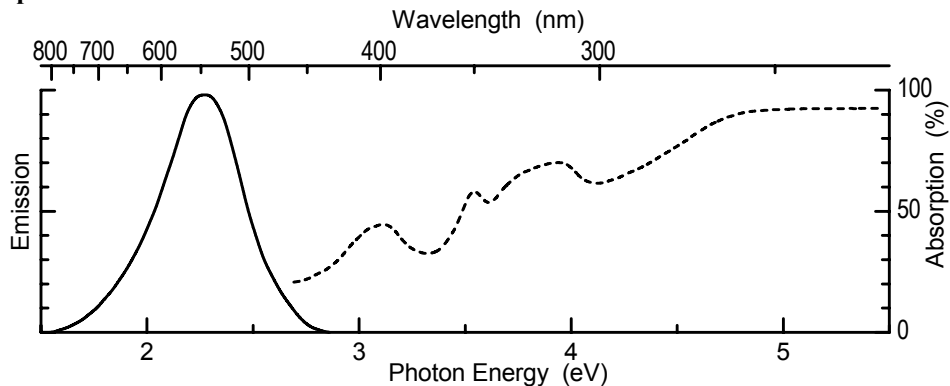
Emission peak: 2.27 eV

Emission width (FWHM): 0.44 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: ++

Spectra



References

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).

2. Lehmann, W., Optimum efficiency of cathodoluminescence of inorganic phosphors, *J. Electrochem. Soc.*, 118, 1164 (1971).
3. Yamashita, N., Luminescence centers of Ca(S-Se) phosphors activated with impurity ions having s-2 configuration. 1. Ca(S-Se)-Sb³⁺ phosphors, *J. Phys. Soc. Jpn.*, 35, 1089 (1973).

CaS:Sb³⁺,Na

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 100 | 100 |
| Sb ₂ O ₃ | 0.1 (of Sb) | 0.145 |
| NaHCO ₃ | 1 | 0.840 |

Preparation

1. Fire (purest CaCO₃ only) in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Add the above amount of Sb₂O₃ + NaHCO₃, and also ~2–3 g of sulfur.
Mix by dry grinding.
2. Fire in covered alumina crucibles, N₂, 1300°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Yellow-green

Emission peak: 2.27 eV

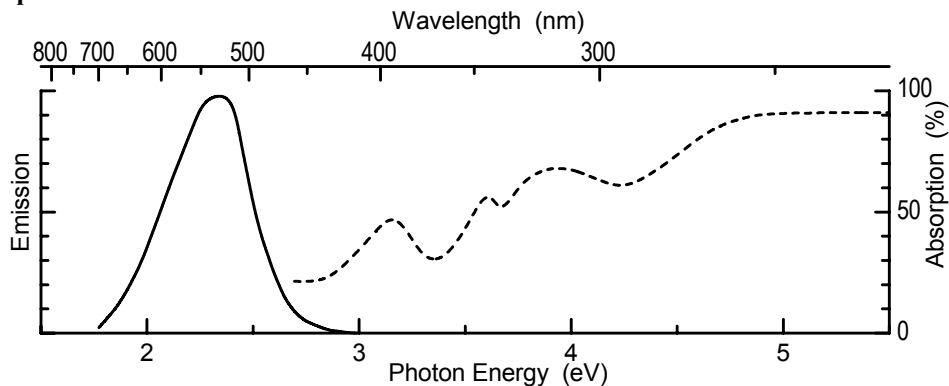
Emission width (FWHM): 0.44 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: 18%

Decay: Exponential decay (~1.5 μsec to 1/10) followed by a long but weak phosphorescence tail

Spectra



References

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).
2. Lehmann, W., Optimum efficiency of cathodoluminescence of inorganic phosphors, *J. Electrochem. Soc.*, 118, 1164 (1971).
3. Yamashita, N., Luminescence centers of Ca (S-Se) phosphors activated with impurity ions having s-2 configuration. 1. Ca(S-Se)-Sb³⁺ phosphors, *J. Phys. Soc. Jpn.*, 35, 1089 (1973).



Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|--------------|---------------|
| CaCO ₃ | 100 | 100 |
| Sm ₂ O ₃ | 0.01 (of Sm) | 0.0175 |
| Na ₄ Cl | ~2 | ~1 |

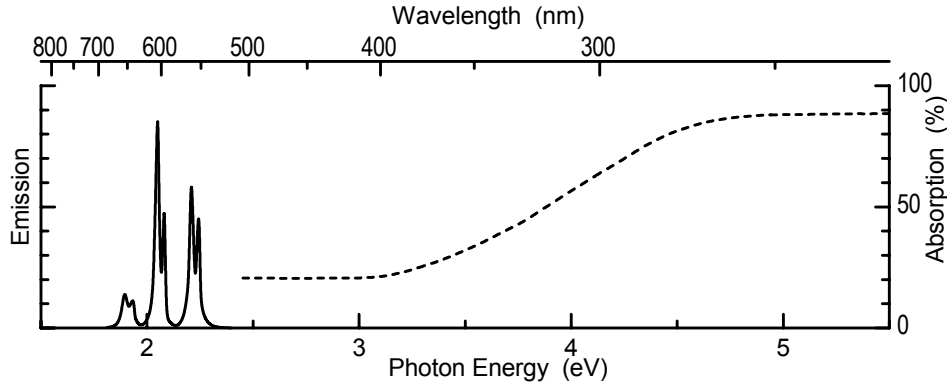
Preparation

- First mix only the CaCO₃ and Sm₂O₃.
1. Fire in open quartz boats, 1100°C, first in N₂, ~ 1 hour and then in H₂S for 1 hour. Powderize.
Add the above amount of Na₄Cl and also ~ 2–3 g of sulfur.
Mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour. Powderize.
 3. Fire in open quartz boats, H₂S, 1100°C, 1 hour. Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Orange-yellow
Emission peak: Strongest lines at 2.04, 2.07, 2.20, and 2.23 eV; also present (not shown in figure below) two strong lines at 1.34 and 1.38 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Decay: Exponential decay, ~10 msec to 1/10

Spectra



Remark

Phosphor can be sensitized for excitation by 3.40 eV UV by addition of Sn (see [CaS:Sn²⁺](#)).

Reference

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).

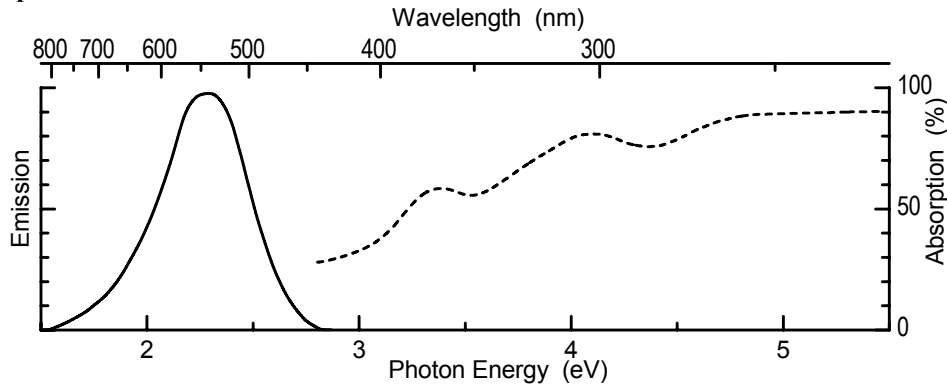


Structure: Cubic (NaCl)

Optical Properties

Emission color: Yellow-greenish
Emission peak: 2.30 eV
Emission width (FWHM): 0.50 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).
2. Yamashita, N., and Asano, S., ESR of 2s ½-state centers in CaS:Sn³⁺, CaSe:Sn³⁺ and CaSe:Pb³⁺, *J. Phys. C Solid State*, 9, L65 (1976).
3. Yamashita, N., and Asano, S., Luminescence-centers of Ca(S:Se):Sn²⁺ phosphors, *J. Phys. Soc. Jpn.*, 41, 536 (1976).



Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| CaCO ₃ | 100 | 100 |
| SnS | 0.1 | 0.135 |
| CaF ₂ | 0.5 | 0.390 |

Preparation

1. Fire in plain CaCO_3 in open quartz boats, H_2S , 1100°C , 1 hour.
Powderize.
Add the above amount of SnS and CaF_2 and about 2–3 g of sulfur.
Mix by dry grinding.
2. Fire in capped quartz tubes, N_2 , 1200°C , 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Pale yellow-green

Emission peak: 2.30 eV

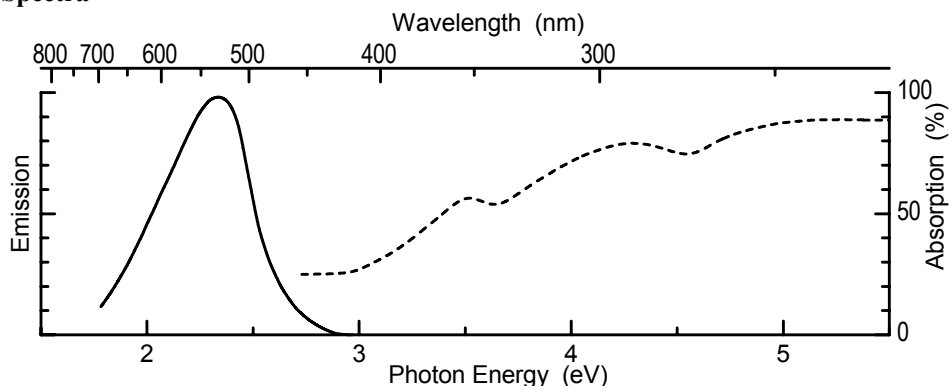
Emission width (FWHM): 0.50 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ~4%

Decay: Non-exponential decay of about 1 msec to 1/10

Spectra



References

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).
2. Yamashita, N., and Asano, S., ESR of $2s\ 1/2$ -state centers in CaS:Sn^{3+} , CaSe:Sn^{3+} and CaSe:Pb^{3+} , *J. Phys. C Solid State*, 9, L65 (1976).
3. Yamashita, N., and Asano, S., Luminescence-centers of Ca(S,Se):Sn^{2+} phosphors, *J. Phys. Soc. Jpn.*, 41, 536 (1976).

CaS:Tb^{3+}

Structure: Cubic (NaCl)

Optical Properties

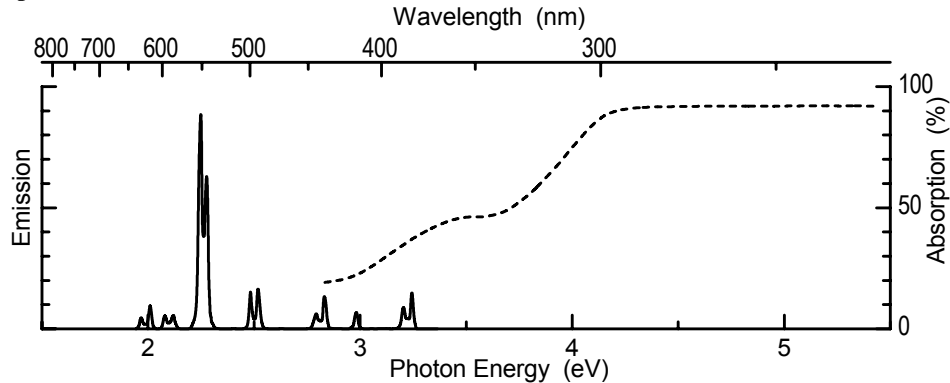
Emission color: Green

Emission peak: 2.26–2.29 eV

Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Reference

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).

CaS:Tb³⁺,Cl

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 100 | 100 |
| Tb ₄ O ₇ | 0.1 (of Tb) | 0.187 |
| NH ₄ Cl | ~2 | ~1 |

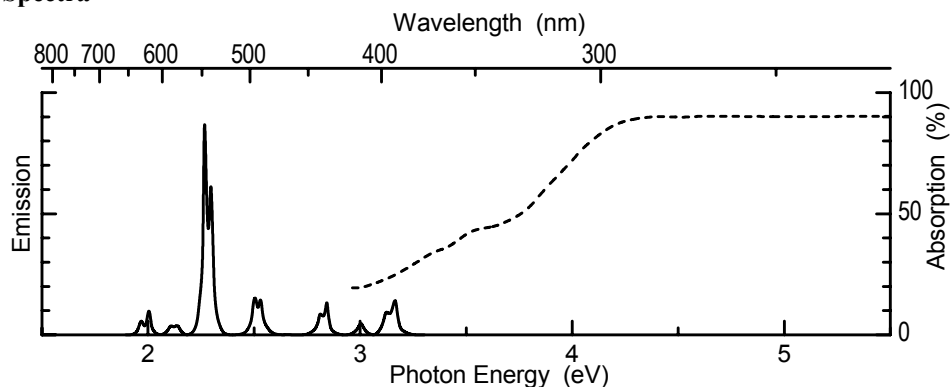
Preparation

- Mix the CaCO₃ and the Tb₄O₇.
1. Fire in plain CaCO₃ in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Add the above amount of NH₄Cl, also ~ 2–3 g of sulfur.
Mix by dry grinding.
 2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
 3. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Pale green
Emission peak: Strongest lines a doublet at 2.26 and 2.29 eV.
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)
Excitation efficiency by e-beam: Relatively poor
Decay: Exponential decay, ~ 3.6 msec to 1/10

Spectra



Reference

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).

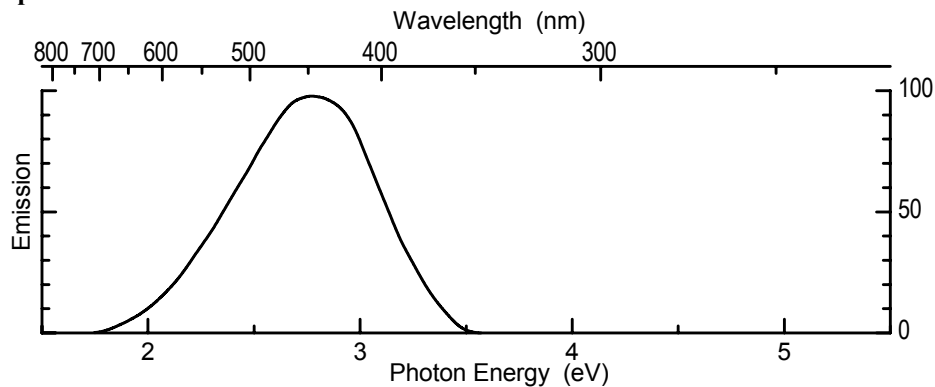


Structure: Cubic (NaCl)

Optical Properties

Emission color: Bluish
Emission peak: 2.80 eV
Emission width (FWHM): 0.78 eV
Excitation efficiency by UV: ++ (4.88 eV), – (3.40 eV)

Spectra



Reference

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).

CaS:Yb²⁺

Structure: Cubic (NaCl)

Optical Properties

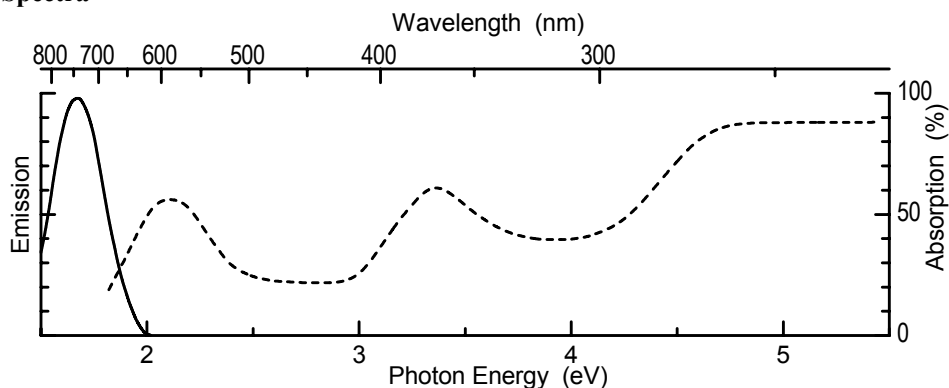
Emission color: IR

Emission peak: 1.66 eV

Emission width (FWHM): 0.30 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Spectra



Reference

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).

CaS:Yb²⁺,Cl

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 100 | 100 |
| Yb ₂ O ₃ | 0.1 (of Yb) | 0.197 |
| NH ₄ Cl | ~ 2 | ~ 1 |

Preparation

Mix the CaCO₃ and the Tb₄O₇.

1. Fire in plain CaCO₃ in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Add the above amount of NH₄Cl and also ~ 2–3 g of sulfur.
Mix by dry grinding.
2. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
3. Fire in capped quartz tubes, N₂, 1200°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Very deep red

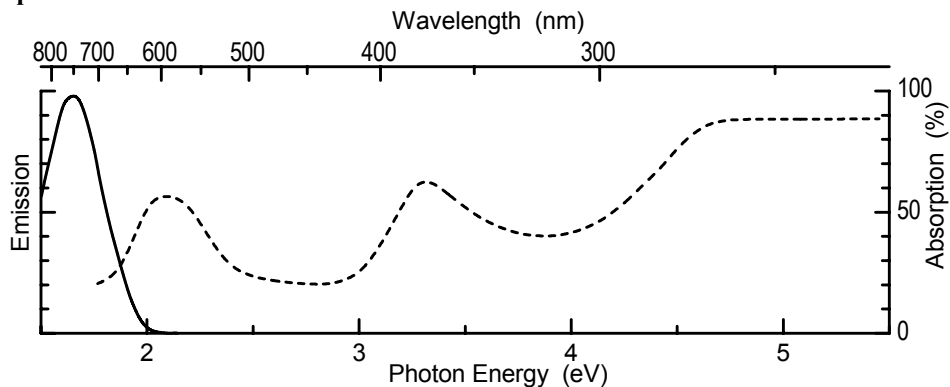
Emission peak: 1.66 eV

Emission width (FWHM): 0.30 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Decay: Non-exponential decay in the 20–50 μsec range

Spectra



Reference

1. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).



Structure: Cubic (NaCl)

Optical Properties

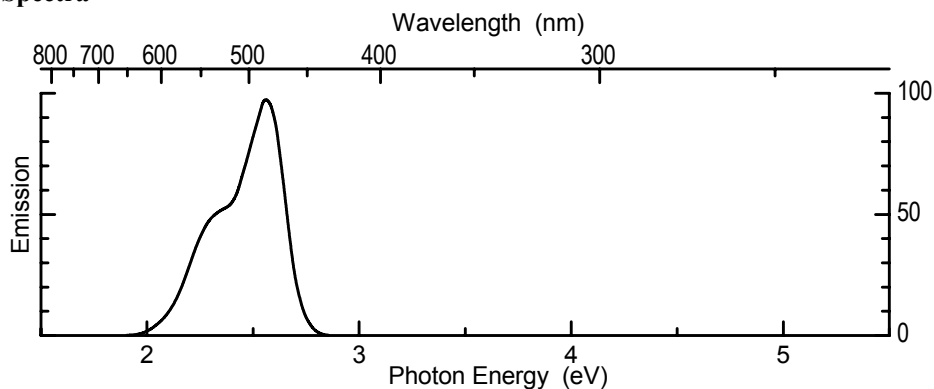
Emission color: Blue-green

Emission peak: 2.20 eV, 2.47 eV – or 2.3 eV, 2.56 eV in cathodoluminescence

Excitation efficiency by UV: + (4.88 eV)

Excitation efficiency by e-beam: +

Spectra



Reference

1. Okamoto, F., and Kato, K., Preparation and cathodoluminescence of CaS-Ce and Ca_{1-x}Sr_xS-Ce phosphors, *J. Electrochem. Soc.*, 130, 432 (1983).

SrS:Cu⁺,Na

Structure Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|---------------------------------------|--------|---------------|
| SrCO ₃ | 100 | 148 |
| CuSO ₄ ·5 H ₂ O | 0.1 | 0.250 |
| NaHCO ₃ | 2 | 1.68 |

Preparation

Dissolve the copper sulfate and the NaHCO₃ together in a little water; add this solution to the SrCO₃.

Make a uniform slurry in water or methanol. Dry; powderize.

Fire in open alumina boats, H₂S, 1200°C, 1 hour. Powderize.

Store in a well-closed container.

Optical Properties

Emission color: Green

Emission peak: 2.33 eV

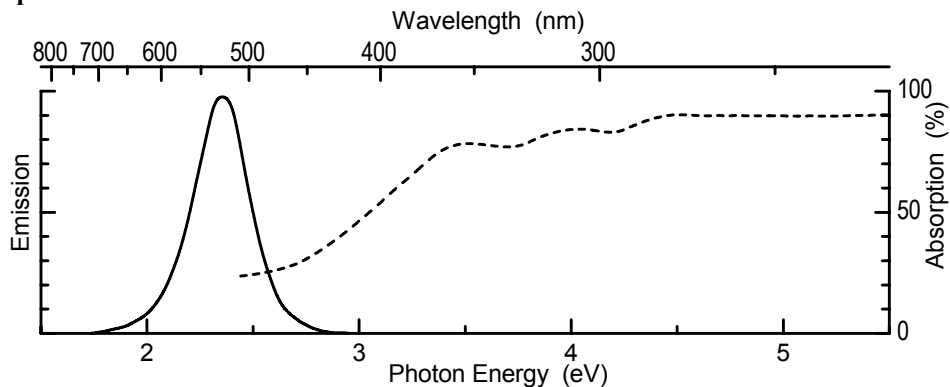
Emission width (FWHM): 0.31 eV

Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)

Excitation efficiency by e-beam: ++/ Very efficient

Decay: Non-exponential decay in the 10 μsec range followed by long phosphorescence

Spectra



Remarks

1. Na in the above recipe cannot be replaced by other alkalies.
2. This phosphor shows exceptionally long and strong phosphorescence after excitation by UV.

Reference

1. Lehmann, W., Alkaline earth sulfide phosphors activated by copper, silver, and gold, *J. Electrochem. Soc.*, 117, 1389 (1970).

SrS:Eu²⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| SrCO ₃ | 100 | 148 |
| Eu ₂ O ₃ | 0.1 (of Eu) | 0.176 |
| NH ₄ Cl | 2 | 1 |

Preparation

First mix only the SrCO₃ + Eu₂O₃.

1. Fire in open quartz boats, H₂S, 1100°C, 1 hour. Powderize.
Add the above amount of NH₄Cl, also ~ 2–3 g of sulfur.
Mix by dry grinding.
2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour. Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Orange-red

Emission peak: 2.00 eV

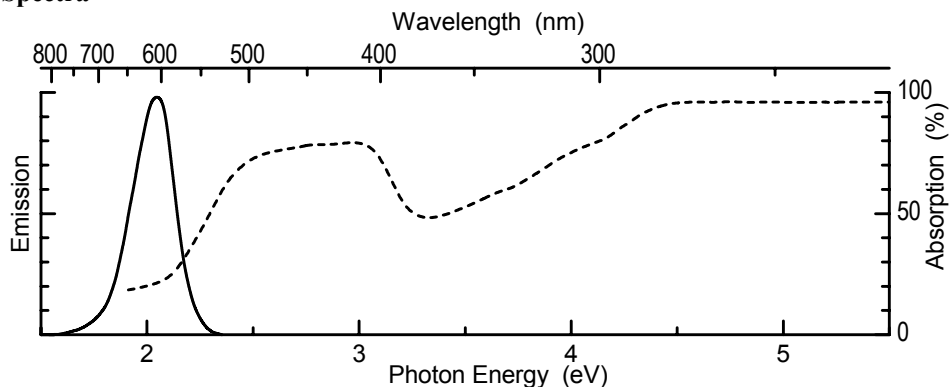
Emission width (FWHM): 0.26 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: +

Decay: Decay in the microsecond range

Spectra



Remarks

1. The Cl in the above recipe may be replaced by F, Br, or I.
2. The characteristic orange body color of this phosphor is caused by the blue to green absorption band and by the orange-red emission excited by ambient light.
3. This phosphor can be sensitized for efficient 3.40 eV excitation by addition of ~0.03 mol% of Pb.

SrS:Mn²⁺

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------|--------|---------------|
| SrCO ₃ | 100 | 148 |
| MnCO ₃ | 0.1 | 0.115 |
| NH ₄ Cl | 1 | 0.540 |

Preparation

First mix only the SrCO₃ + MnCO₃.

1. Fire in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.
Add the above amount of NH₄Cl and also ~2–3 g of sulfur.
Mix by dry grinding.
2. Fire in capped quartz tubes, N₂, 1100°C, 1 hour.
Powderize.
3. Fire in open quartz boats, H₂S, 1000°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Yellow-green

Emission peak: 2.28 eV

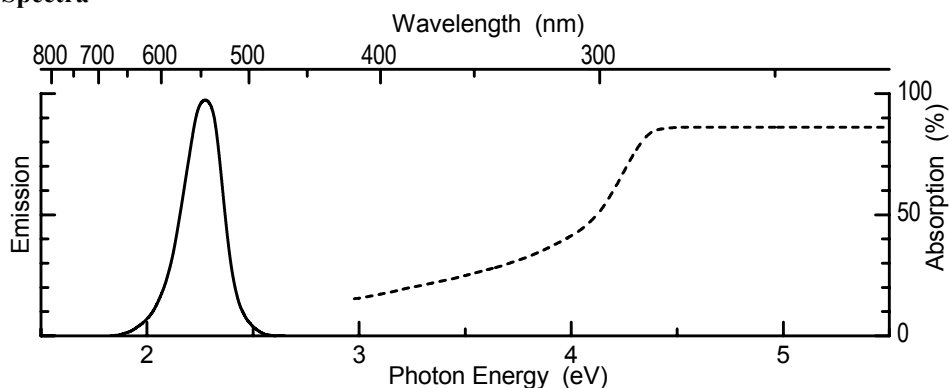
Emission width (FWHM): 0.23 eV

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: +/Fairly efficient

Decay: Exponential decay requiring ~4 msec to 1/10

Spectra



Remark

Phosphor can be sensitized for efficient 3.40 eV excitation by addition of ~0.03 mol% of Pb. This also shifts the emission band peak to ~2.245 eV.

Reference

1. Sorge, O., Thesis, Technical University of Berlin (1959).

BaS:Au,K

Structure: Cubic (NaCl)

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|----------|---------------|
| BaSO ₄ | 100 | 233 |
| Au-metal | 0.1 | 0.197 |
| K ₂ CO ₃ | 1 (of K) | 0.690 |

Preparation

Dissolve the Au in a little (as little as possible) aqua regia and the K₂CO₃ in a little water. Make a slurry of the BaSO₄ in water or methanol.

Add both solutions; stir to uniformity; dry and powderize.

1. Fire in open alumina boats, H₂S, 900°C, 1 hour. Powderize.
2. Fire in open alumina boats, H₂, 700°C, 1 hour. Powderize.

Store in a well-closed container.

Optical Properties

Emission color: Orange-red

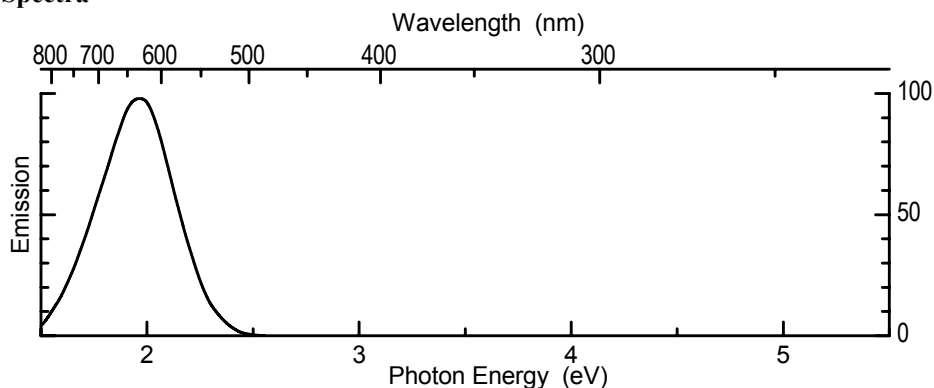
Emission peak: 1.93 eV

Emission width (FWHM): 0.38 eV

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



Remarks

1. This material is very hygroscopic. Do not, under any circumstances, let it come into contact with water.
2. Replacement of K in the above recipe by Li, Rb, Cs, F, or P gives slightly different emission spectra. Replacement of K by Na gives near-dead material.

Reference

1. Lehmann, W., Alkaline earth sulfide phosphors activated by copper, silver, and gold, *J. Electrochem. Soc.*, 117, 1389 (1970).

4.15 Double Sulfides

The following host compounds and activators are included in this subsection:

CaGa₂S₄:Ce³⁺
CaGa₂S₄:Eu²⁺
CaGa₂S₄:Mn²⁺
CaGa₂S₄:Pb²⁺
ZnGa₂S₄:Mn²⁺
ZnBa₂S₃:Mn²⁺

CaGa₂S₄:Ce³⁺

Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 98 | 98 |
| Ga ₂ O ₃ | 200 (of Ga) | 187 |
| CeO ₂ | 1 | 1.7 |
| NaHCO ₃ | 1 | 0.840 |

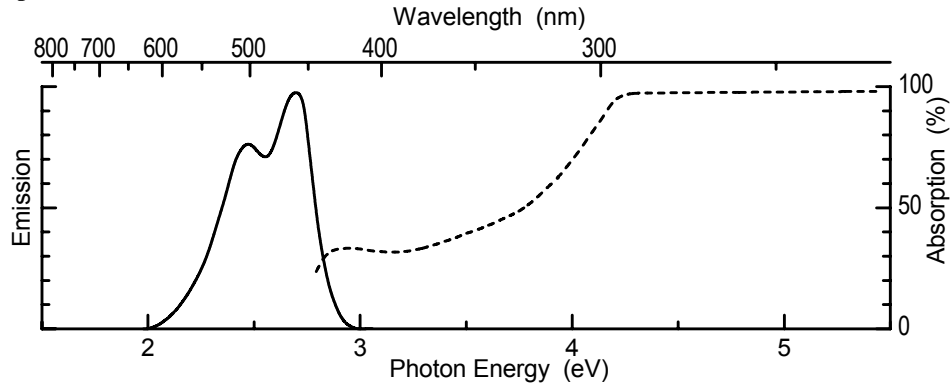
Preparation

- First mix only CaCO₃ + Ga₂O₃ + CeO₂.
1. Fire in open quartz boats, H₂S, 800°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, N₂, 800°C, 1 hour.
Powderize.
Add the above amount of NaHCO₃ and also ~2–3 g of sulfur.
Mix by dry grinding.
 3. Fire in covered alumina crucibles, N₂, 800°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Bluish
Emission peaks: Two overlapping bands ~2.42 and 2.68 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: 4.5%

Spectra

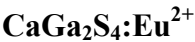


Remark

This phosphor is slightly unstable in water.

Reference

1. Peters, T.E., and Baglio, J.A., Luminescence and structural properties of thiogallate phosphors Ce^{+3} and Eu^{+2} -activated phosphors, *J. Electrochem. Soc.*, 119, 230 (1972).



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------------|-------------|---------------|
| CaCO_3 | 99 | 99 |
| Ga_2O_3 | 200 (of Ga) | 187 |
| Eu_2O_3 | 1 (of Eu) | 1.76 |

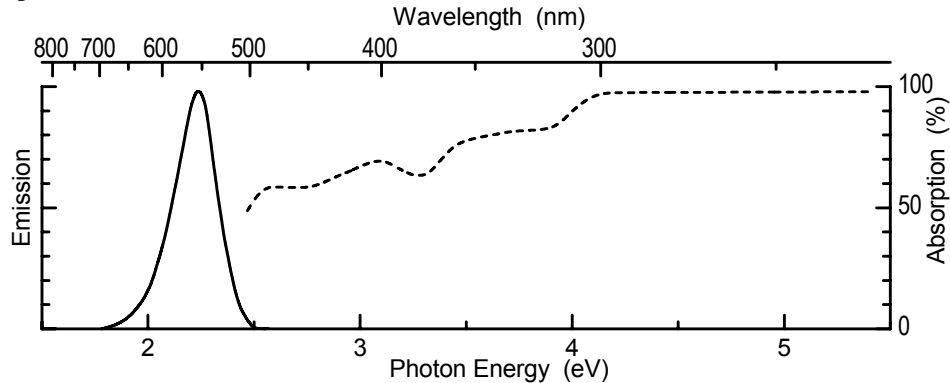
Preparation

- Mix by slurring in water, dry, and powderize.
1. Fire in open quartz boats, H_2S , 800°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, N_2 bubbling through CS_2 , 800°C, 1 hour.
Powderize.
- Store in a well-closed container.

Optical Properties

Emission color: Yellow-green
Emission peak: 2.22 eV
Emission width (FWHM): 0.24 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: 7%

Spectra

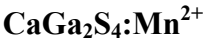


Remark

This phosphor is slightly unstable in water.

References

1. Peters, T.E., and Baglio, J.A., Luminescence and structural properties of thiogallate phosphors Ce^{+3} and Eu^{+2} -activated phosphors, *J. Electrochem. Soc.*, 119, 230 (1972).
2. Donohue, P.C., and Hanlon, J.E., Synthesis and photoluminescence of $\text{MIM2III}(\text{S,Se})_4$, *J. Electrochem. Soc.*, 121, 137 (1974).



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 98 | 98 |
| Ga ₂ O ₃ | 200 (of Ga) | 187 |
| MnCO ₃ | 2 | 2.3 |

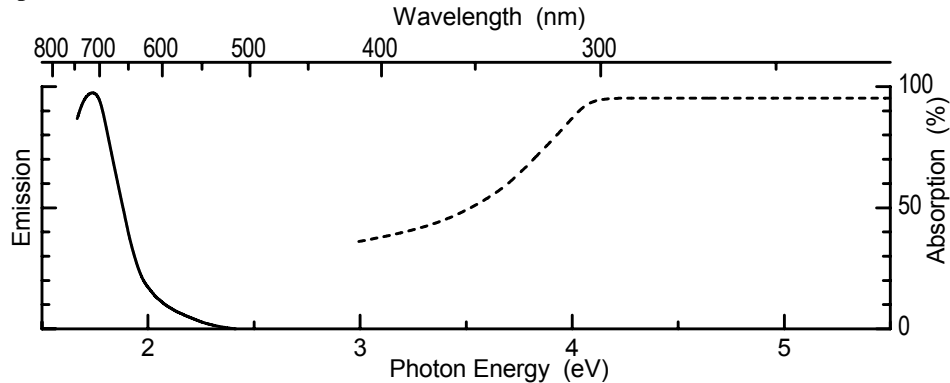
Preparation

- Mix by slurring in water.
Dry in air. Powderize when dry.
- Fire in open quartz boats, H_2S , 900°C, 2 hours.
Powderize.
 - Fire in open quartz boats, N_2 loaded with CS_2 , 800°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

Emission color: Deep red
Emission peak: 1.74 eV
Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



Remark

This phosphor is slightly unstable in water.



Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| CaCO ₃ | 99 | 99 |
| Ga ₂ O ₃ | 200 (of Ga) | 187 |
| PbO | 1 | 2.2 |

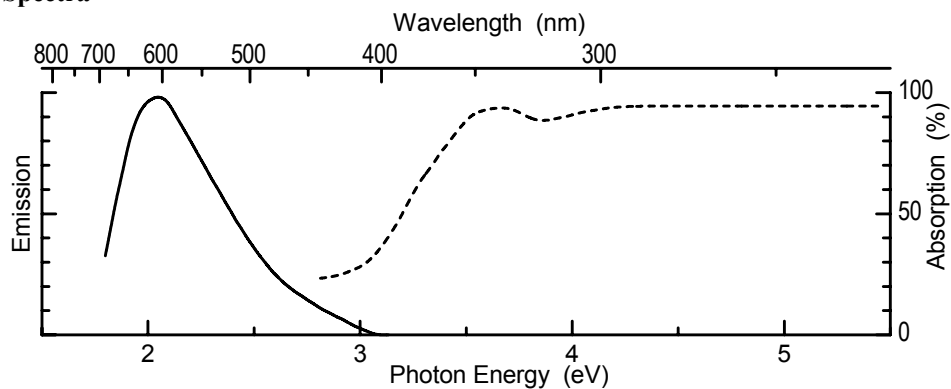
Preparation

- First mix only CaCO₃ + Ga₂O₃.
1. Fire in open quartz boats, H₂S, 800°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, N₂ bubbling through CS₂, 800°C, 1 hour.
Add the above amount of PbO and also ~2–3 g of sulfur.
Mix by dry grinding.
 3. Fire in capped quartz tubes, N₂, 800°C, 1 hour.
Powderize.
Store in a well-closed container.

Optical Properties

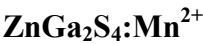
Emission color: Pale whitish-yellow
Emission peak: 2.03 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: 3.5%

Spectra



Remark

This phosphor is slightly unstable in water.



Structure: Tetragonal

Composition

| Ingredient | Mole % | By weight (g) |
|--------------------------------|-------------|---------------|
| ZnS | 98 | 96 |
| Ga ₂ O ₃ | 200 (of Ga) | 187 |
| MnCO ₃ | 2 | 2.3 |

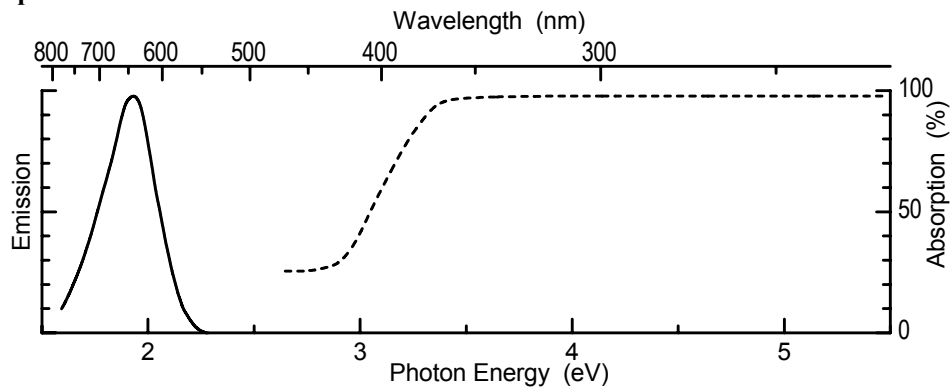
Preparation

- Mix by slurring in water, dry, and powderize.
1. Fire in open quartz boats, H₂S, 1000°C, 1 hour.
Powderize.
 2. Fire in open quartz boats, N₂ bubbling through CS₂, 800°C, 1 hour.
Powderize.
 3. Fire in open quartz boats, H₂S, 1100°C, 1 hour.
Powderize.

Optical Properties

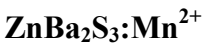
Emission color: Red
Emission peak: 1.92 eV
Emission width (FWHM): 0.30 eV
Excitation efficiency by UV: ++ (4.88 eV), ++ (3.40 eV)
Excitation efficiency by e-beam: 4%
Decay: Exponential decay, about 18–20 msec to 1/10

Spectra



Reference

1. Bird, G., Vecht, A., and Smith, P.J.F., *Electrochem. Soc. Meeting*, San Francisco, Abstr. 92 (May 1974).



Structure: Orthorhombic

Composition

| Ingredient | Mole % | By weight (g) |
|-------------------|--------|---------------|
| ZnS | 98 | 96 |
| BaCO ₃ | 200 | 275 |
| MnCO ₃ | 2 | 2.3 |

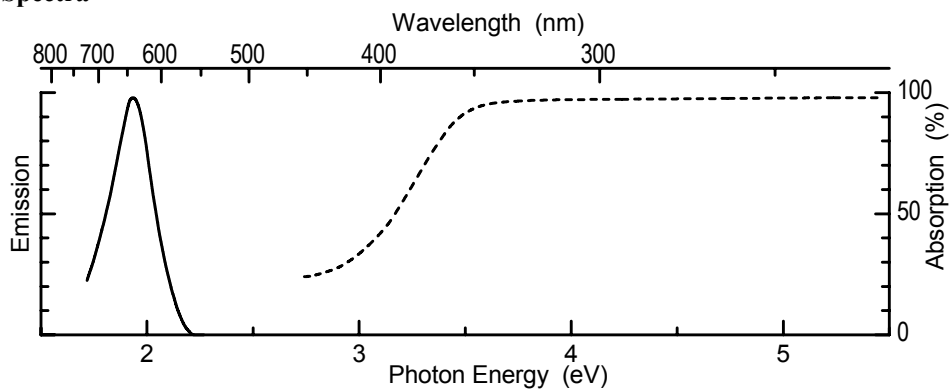
Preparation

- Mix by slurring in water, dry, and powderize.
1. Fire in open quartz boats, H₂S, 800°C, 1 hour. Powderize.
 2. Fire in open quartz boats, H₂, 700°C, 1 hour. Powderize.

Optical Properties

Emission color: Red
Emission peak: 1.935 eV
Emission width (FWHM): 0.24 eV
Excitation efficiency by UV: ++ (3.40 eV)
Excitation efficiency be e-beam: +

Spectra



Remark

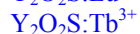
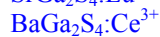
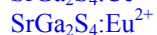
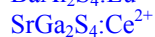
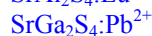
This phosphor has been used for DC-EL by A. Vecht.

References

1. Vecht, A., Electroluminescent displays, *J. Vac. Sci. Technol.*, 10, 789 (1973).
2. Vecht, A. et al., *Electrochem. Soc. Meeting*, San Francisco, Abstr. 93 (May 1974).

4.16 Miscellaneous Sulfides and Oxysulfides

The following host compounds and activators are included in this subsection:



Optical Properties

Emission color: Blue-green

Emission peak: 2.50 eV

Emission width (FWHM): 0.21 eV

Excitation efficiency by UV: + (4.88 eV)

Excitation efficiency by e-beam: +

Reference

1. Donohue, P.C., and Hanlon, J.E., Synthesis and photoluminescence of $\text{MIIM}_2\text{III}(\text{S},\text{Se})_4$, *J. Electrochem. Soc.*, 121, 137 (1974).



Optical Properties

Emission color: Orange

Emission peak: 2.04 eV

Emission width (FWHM): 0.51 eV

Excitation efficiency by e-beam: +

Reference

1. Peters, T.E., Luminescence properties of thiogallate phosphors. 3. Red and white emitting phosphors for flying spot scanner applications, *J. Electrochem. Soc.*, 122, 98 (1975).



Optical Properties

Emission color: Light blue

Emission peak: 2.61 eV

Emission width (FWHM): 0.31 eV

Excitation efficiency by UV: + (3.40 eV)

Excitation efficiency by e-beam: +

Reference

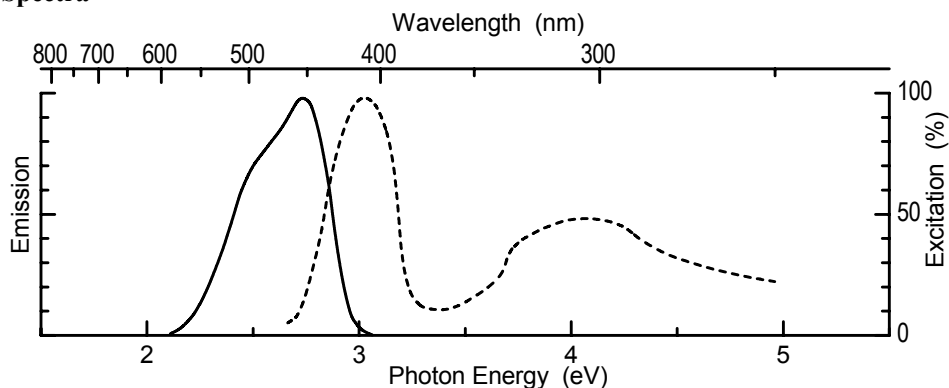
1. Donohue, P.C., and Hanlon, J.E., Synthesis and photoluminescence of MIIM2III(S,Se)_4 , *J. Electrochem. Soc.*, 121, 137 (1974).
-

$\text{SrGa}_2\text{S}_4:\text{Ce}^{3+}$

Optical Properties

Emission color: Blue-green
Emission peak: 2.53 eV, 2.73 eV
Excitation efficiency by UV: + (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



References

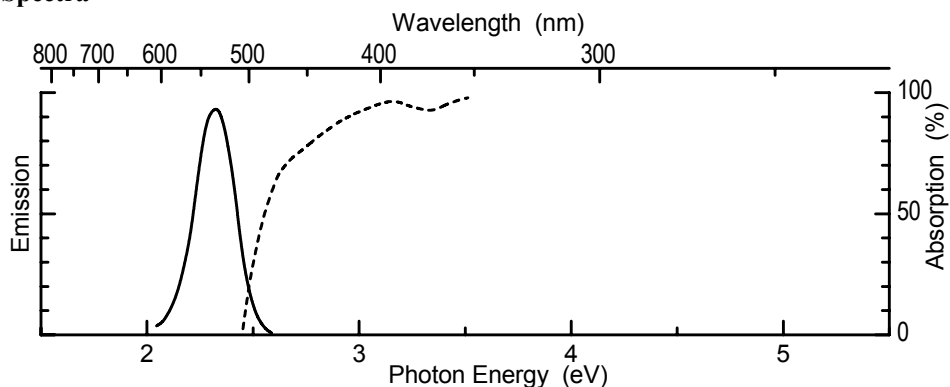
1. Peters, T.E., and Baglio, J.A., Luminescence and structural properties of thiogallate phosphors Ce^{+3} and Eu^{+2} -activated phosphors, *J. Electrochem. Soc.*, 119, 230 (1972).
 2. Peters, T.E., Luminescence properties of thiogallate phosphors. 3. Red and white emitting phosphors for flying spot scanner applications, *J. Electrochem. Soc.*, 122, 98 (1975).
-

$\text{SrGa}_2\text{S}_4:\text{Eu}^{2+}$

Optical Properties

Emission color: Green
Emission peak: 2.31 eV
Emission width (FWHM): 0.20 eV
Excitation efficiency by UV: ++ (3.40 eV)
Excitation efficiency by e-beam: +

Spectra



Reference

1. Peters, T.E., and Baglio, J.A., Luminescence and structural properties of thiogallate phosphors Ce⁺³ and Eu⁺²-activated phosphors, *J. Electrochem. Soc.*, 119, 230 (1972).
2. Donohue, P.C., and Hanlon, J.E., Synthesis and photoluminescence of MIIM2III(S,Se)₄, *J. Electrochem. Soc.*, 121, 137 (1974).

BaGa₂S₄:Ce³⁺

Optical Properties

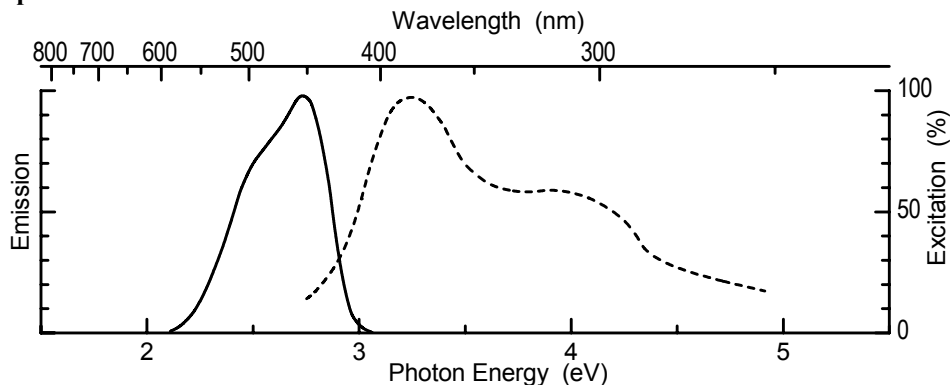
Emission color: Blue-green

Emission peak: 2.53 eV, 2.73 eV

Excitation efficiency by UV: + (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Peters, T.E., and Baglio, J.A., Luminescence and structural properties of thiogallate phosphors Ce⁺³ and Eu⁺²-activated phosphors, *J. Electrochem. Soc.*, 119, 230 (1972).
2. Donohue, P.C., and Hanlon, J.E., Synthesis and photoluminescence of MIIM2III(S,Se)₄, *J. Electrochem. Soc.*, 121, 137 (1974).

BaGa₂S₄:Eu²⁺

Optical Properties

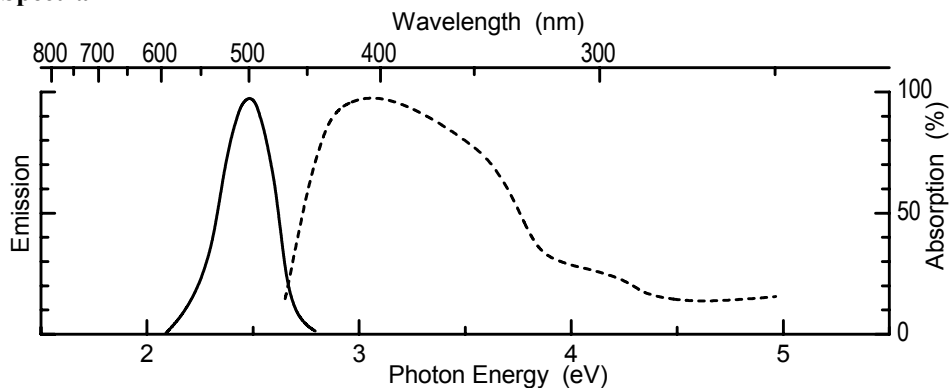
Emission color: Blue-green

Emission peak: 2.52 eV

Excitation efficiency by UV: ++ (3.40 eV)

Excitation efficiency by e-beam: +

Spectra



References

1. Peters, T.E., and Baglio, J.A., Luminescence and structural properties of thiogallate phosphors Ce⁺³ and Eu⁺²-activated phosphors, *J. Electrochem. Soc.*, 119, 230 (1972).
2. Donohue, P.C., and Hanlon, J.E., Synthesis and photoluminescence of MIIM2III(S,Se)₄, *J. Electrochem. Soc.*, 121, 137 (1974).

Y₂O₂S:Eu³⁺

Structure: Trigonal

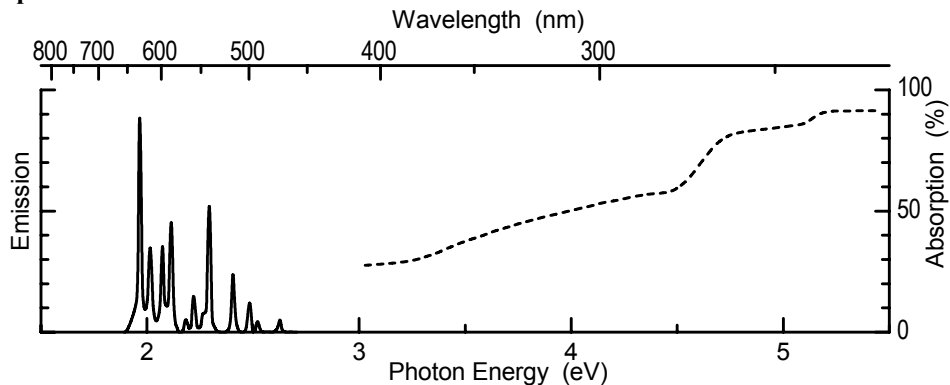
Optical Properties

Emission color: Orange to red (lines)

Excitation efficiency by UV: ++ (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: ++

Spectra



References

1. Royce, M.R., U.S. Pat., 3 418 246 (1968).
 2. Ozawa, L., Preparation of $\text{Y}_2\text{O}_2\text{S}:\text{Eu}$ phosphor particles of different sizes by a flux method, *J. Electrochem. Soc.*, 124, 413 (1977).
 3. Fonger, W.H., and Struck, C.W., Energy loss and energy storage from the Eu^{3+} charge-transfer states in Y and La oxysulfides, *J. Electrochem. Soc.*, 117, 118 (1970).
-

$\text{Y}_2\text{O}_2\text{S}:\text{Tb}^{3+}$

Optical Properties

Emission color: Blue-green

Excitation efficiency by UV: + (4.88 eV), + (3.40 eV)

Excitation efficiency by e-beam: ++

$\text{Gd}_2\text{O}_2\text{S}:\text{Tb}^{3+}$

Optical Properties

Emission color: Green

Emission peak: 2.26–2.29 eV

Excitation efficiency by UV: + (4.88 eV), – (3.40 eV)

Excitation efficiency by e-beam: ++