

Section 7: Other Phosphor Data

- 7.1 Oxides
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- 7.4 Aluminates
- 7.5 Halides and Oxyhalides
- 7.6 CaS and ZnS-Type Sulfides
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Section 7

OTHER PHOSPHOR DATA

Information about the following additional phosphors and their properties has been kindly provided (in Lehmann's format) by Edith Bourret-Courchesne, Luis Carlos, Takashi Hase, Dongdong Jia, Weiyi Jia, Willi Lehmann (posthumously), Yoh Mita, Shinji Okamoto, Shozo Oshio, Madis Raukas, Cees Ronda, Yoshitaka Sato, Lauren E. Shea-Rowhler, Masaaki Tamatani, and Hajime Yamamoto.

7.1 Oxides

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

$\text{Bi}_4\text{Ge}_3\text{O}_{12}$
 $\text{CaTiO}_3:\text{Eu}^{3+}$
 $\text{CaTiO}_3:\text{Pr}^{3+}$
 $\text{Gd}_3\text{Ga}_5\text{O}_{12}:\text{Cr}^{3+}$
 $\text{GdNbO}_4:\text{Bi}^{3+}$
 $\text{K}_2\text{La}_2\text{Ti}_3\text{O}_{10}:\text{Eu}$
 $\text{LuTaO}_4:\text{Nb}^{5+}$
 $\text{SrIn}_2\text{O}_4:\text{Pr}^{3+}, \text{Al}^{3+}$
 $\text{SrY}_2\text{O}_4:\text{Eu}^{3+}$
 $\text{SrTiO}_3:\text{Pr}^{3+}, \text{Al}^{3+}$
 $\text{SrTiO}_3:\text{Pr}^{3+}$
 $\text{Y(P,V)O}_4:\text{Eu}$
 $\text{Y}_2\text{O}_3:\text{Ce}$
 $\text{Y}_2\text{O}_3:\text{Eu (YOE)}$
 $\text{Y}_2\text{O}_3:\text{Eu}^{3+}$
 $\text{Y}_2\text{O}_3:\text{Tb}^{3+}$
 $\text{Y}_2\text{O}_3:\text{Ce}^{3+}, \text{Tb}^{3+}$
 $\text{Y}_2\text{O}_2\text{S}:\text{Eu}$
 $(\text{Y,Gd})_2\text{O}_3:\text{Eu}^{3+}$
 YTao_4
 $\text{YTao}_4:\text{Nb}^{5+}$
 $\text{YVO}_4:\text{Dy}^{3+}$
 ZnGa_2O_4
 $\text{ZnGa}_2\text{O}_4:\text{Mn}^{2+}$
 $\text{ZnO}:\text{Bi}^{3+}$
 $\text{ZnO}:\text{Zn}$
 $\text{ZnO}:\text{Ga, Ultrafast}$
 $\text{ZnO-CdO}:\text{Ga, Ultrafast}$
 $\text{Zn}_2\text{SiO}_4:\text{Mn}$

$\text{Bi}_4\text{Ge}_3\text{O}_{12}$

Structure: Cubic

Preparation

Grow the crystals of $\text{Bi}_4\text{Ge}_3\text{O}_{12}$ from stoichiometric melts, using Czochralski method.

Use a platinum crucible, atmospheric environment, and radio frequency induction heating.

The growth atmosphere has to be oxygen; otherwise the Pt crucible will be attacked.

Optical Properties

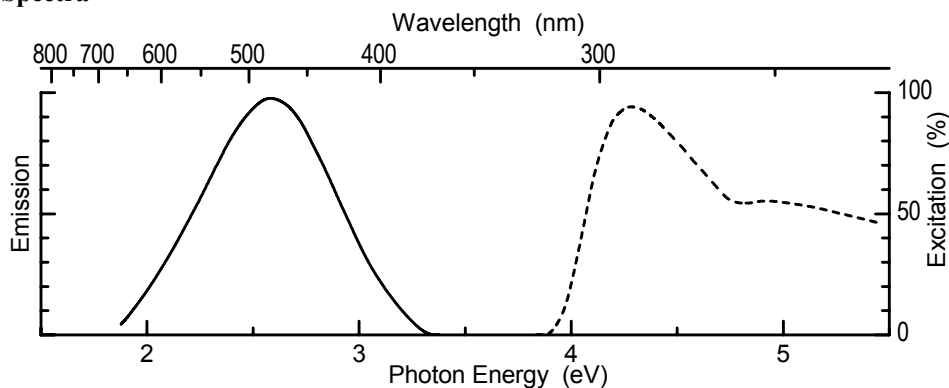
Emission peak: 485 nm

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

Excitation efficiency by e-beam: +

Decay to 1/e: 0.3×10^{-6} s

Spectra



Remarks

1. This contribution is from Hajime Yamamoto.
2. The melting point of the single crystal is 1044°C.
3. The crystals will only be really colorless when the raw materials Bi_2O_3 and GeO_2 have a high purity.
4. The other growth technique of the horizontal Bridgman–Stockbarger method is now popular to prevent growths forming a core.

References

1. Weber, M.J., and Monchamp, R. R., Luminescence of $\text{Bi}_4\text{Ge}_3\text{O}_{12}$: Spectral and decay properties, *J. Appl. Phys.*, 44, 5495 (1973).
2. Blasse, G., and Grabmaier, B.C., *Luminescent Materials*, p. 179, Springer-Verlag, Heidelberg, (1994).
3. Rossner, W., and Grabmaier, B.C., Phosphors for X-ray detectors in computed tomography, *J. Lumin.*, 48, 29 (1991).

CaTiO₃:Eu³⁺

Structure: Orthorhombic

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	100	10.01
TiO ₂	100	7.98
Eu ₂ O ₃	1	0.352
B ₂ O ₃	3	0.209

Preparation

Mix by dry grinding or milling.

Press into pellets.

1. Fire in air, 1000°C, 1 hour.
Powderize.
Grind and press into pellets again.
2. Fire in open quartz boats, air, 1300°C, 3 hours.

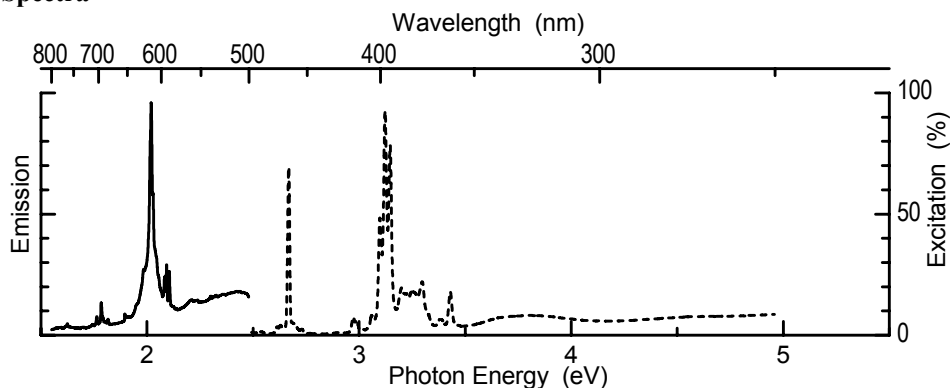
Optical Properties

Emission color: Red

Emission peak: 612 nm

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

Spectra



Remarks

1. This contribution is from Weiyi Jia.
2. This compound is known as calcium titanate.

Reference

1. Rivera, I., Master Degree Thesis, University of Puerto Rico—Mayaguez (2001).

CaTiO₃:Pr³⁺

Structure: Orthorhombic.

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	100	10.01
TiO ₂	100	7.98
Pr(NO ₃) ₃ .6H ₂ O	0.5	0.313
B ₂ O ₃	3	0.209

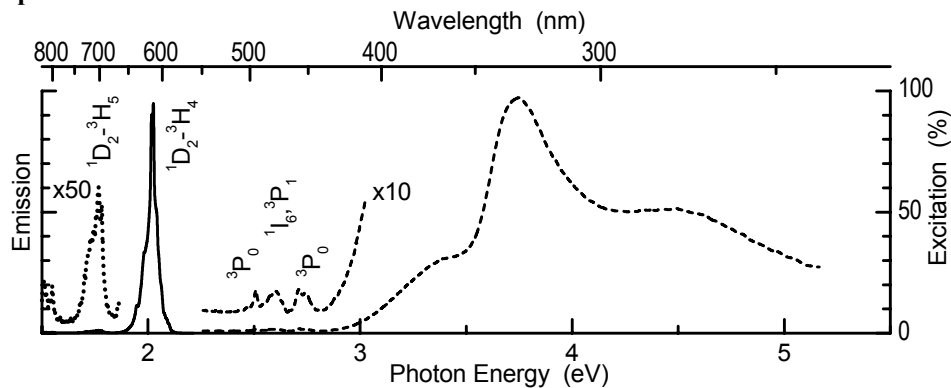
Preparation

- Mix by dry grinding or milling.
Press into pellets.
1. Fire in air, 1000°C, 1 hour.
Powderize.
Grind and press into pellets again.
 2. Fire in open quartz boats, air, 1300°C, 3 hours.

Optical Properties

Emission color: Red
Emission peak: 612 nm
Excitation efficiency by UV: + (3.40 eV), + (4.88 eV)

Spectra



Remarks

1. This contribution is from Weiyi Jia.
2. This compound is also known as calcium titanate.

References

1. Rivera, I. et al., Proceedings of the Second National Student Conference of NASA URC-SC 2000, Nashville, 180 (2000).
2. Jia, W., Xu, W., Rivera, I. et al., Effects of compositional phase transitions on luminescence of Sr_{1-x}Ca_xTiO₃:Pr³⁺, *Solid State Commun.*, 126, 153 (2003).

Gd₃Ga₅O₁₂:Cr³⁺

Structure: Cubic (garnet)

Composition

Ingredient	Mole %	By weight (g)
Gd ₂ O ₃	37.5	100
Ga ₂ O ₃	62.5	86.2
Cr ₂ O ₃	0.5	0.6

Preparation

Combine the proper amounts of the oxides with some nitric acid to form a precipitate. Stir well and add the NH₄OH solution. Wash with water to remove the NH₄Cl by-product and excess NH₄OH. Dry in air.

1. Fire in air, 900°C for an hour or more. Ball-mill the powder with a grinding media and a liquid vehicle, such as water or methanol.
2. Fire in flowing O₂, 1500–1550°C, 2 hours.

Co-doping with a small amount of Ce reduces the afterglow.

Optical Properties

Emission color: Red

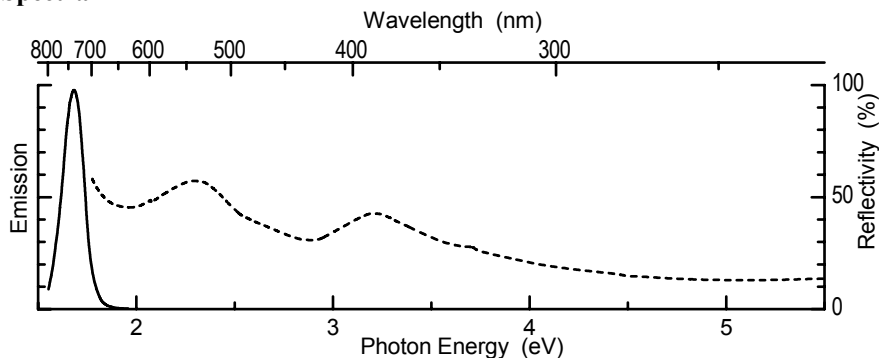
Emission peak: 730 nm

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

Excitation efficiency by e-beam: +

Decay to 1/e: 0.17×10^{-3} sec

Spectra



Remark

This contribution is from Hajime Yamamoto.

References

1. Greskovich, C., and Duclos, S., Ceramic scintillators, *Annu. Rev. Mater. Sci.*, 27, 69 (1997).
2. Rossner, W., Bodinger, H., Leppert, J., and Grabmaier, B.C., The conversion of high energy radiation to visible light by luminescent ceramics, *IEEE Trans. Nucl. Sci.*, 40, 376 (1993).
3. Blasse, G., Grabmaier, B.C., and Ostertag, M., The afterglow mechanism of chromium-doped gadolinium gallium garnet, *J. Alloys Ingredients*, 200, 17 (1993).
4. Petermann, K., and Huber, G., Broad band fluorescence of transition metal doped garnets and tungstates, *J. Lumin.*, 31/32, 71 (1984).

GdNbO₄:Bi³⁺

Structure: Tetragonal (scheelite)

Composition

Ingredient	Mole %	By weight (g)
Gd ₂ (C ₂ O ₄) ₃ ·10H ₂ O	41.51	15.701
Nb ₂ O ₅	56.98	6.646
Bi ₂ O ₃	1.51	0.350

Preparation

Mix by slurring in acetone or by dry blende.

1. Fire in covered crucible, air, 600–800°C, 1 hour.
Dry in air. Powderize when dry.
2. Fire in covered crucible, air, 1350–1650°C, 3 hours.
Store in a well-sealed container.

Optical Properties

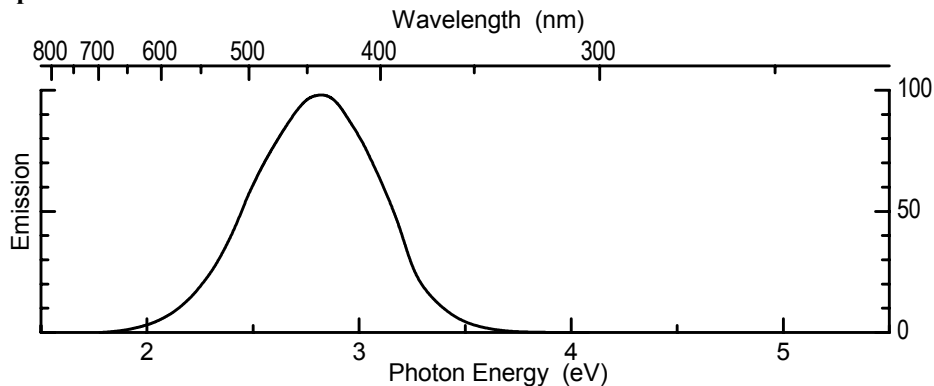
Emission color: Blue

Emission peak: 430 nm

Excitation efficiency by UV: Broad range, suitable for 2537 Å

Excitation efficiency by e-beam: Good

Spectra



Remarks

1. This contribution is from Madis Raukas.
2. This phosphor has a general formula of Gd_{1-x}Bi_xNbO₄ and per above ingredients yields a stoichiometry with x = 0.03.

Reference

1. Grisafe, D.A., and Fritsch, C.W., U.S. Pat., 3 767 589 (1973).

K₂La₂Ti₃O₁₀:Eu

Structure: Layered perovskite

Composition

Ingredient	Mole %	By weight (g)
K ₂ CO ₃	23.06	6.63
TiO ₂	57.72	9.59
La ₂ O ₃	19.03	12.90
Eu ₂ O ₃	0.19	0.141

Preparation

Mix stoichiometric amounts in a paint shaker for 30 minutes with about 20 mol% of excess potassium carbonate to compensate for losses due to volatilization.

Fire in covered alumina crucibles, air, increasing from 700°C to 1100°C, over 3 hours.

Fire in covered alumina crucibles, air, 1100°C, 24 hours.

Fire in covered alumina crucibles, air, 700°C, 2 hours.

Cool to room temperature.

Powderize.

Fire in covered alumina crucibles, air, 1100°C, 24 hours.

Washed in de-ionized water.

Filter, dry at 130°C, and screen through a 325-mesh stainless steel sieve.

Optical Properties

Emission peaks: Lines at 594, 617, and 702 nm.

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

Excitation efficiency by e-beam: Characteristic emission at about 1.1 fL level under focused 15 kV/ 8 μ A excitation

Remarks

1. This contribution is from Madis Raukas.
2. This phosphor in general formulation of K₂La₂Ti₃O₁₀:Eu is another example of materials belonging to intercalation ingredients.
3. The described composition yields a concentration of 0.02 mol Eu per mole of phosphor.
4. Good electroluminescent properties result when this phosphor is intercalated with conductive polymers or metals.

References

1. Qi, R.Y., Karam, R.E., Reddy, V.B., and Cox, J.R., U.S. Pat., 5 567 351 (1996).
2. Qi, R.Y., and Karam, R.E., U.S. Pat., 5 658 495 (1997).
3. Reddy, V.B., Karam, R.E., and Northrop, S.K., U.S. Pat., 5 489 398 (1996).
4. Qi, R.Y., and Karam, R.E., U.S. Pat., 5 531 926 (1996).
5. Reddy, V.B., and Karam, R.E., Northrop, S.K., and Zhang, Y., U.S. Pat., 5 531 928 (1996).

LuTaO₄:Nb⁵⁺

Structure: Monoclinic

Composition

Ingredient	Mole %	By weight (g)
Lu ₂ O ₃	—	—
Ta ₂ O ₅	—	—

Preparation

Mix stoichiometric quantities of the Lu₂O₃ and Ta₂O₅.

1. Fire in alumina containers, air, 1200°C, 8–10 hours.
Ball-mill, using a Freon solvent as grinding medium.
2. Fire in alumina containers, either by itself or in the presence of 50% Li₂SO₄, air, 1250°C, 10–14 hours.
In the cases where flux is used, leach with water.
Wash in methanol.
Dry at 130°C.

Optical Properties

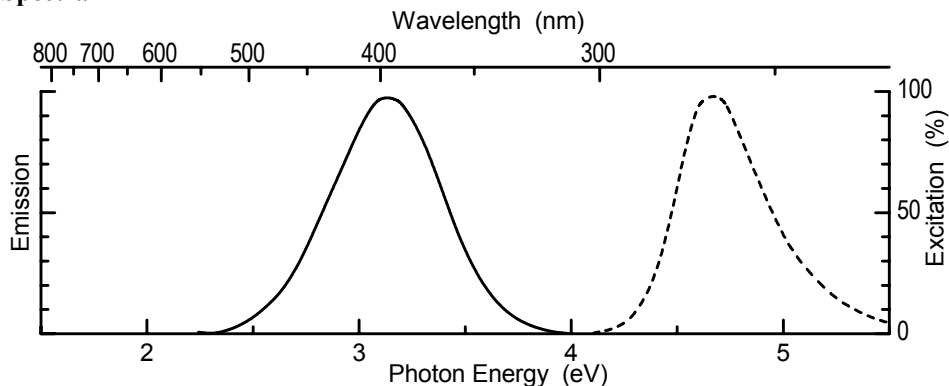
Emission color: Violet

Emission peak: 394 nm

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

Excitation efficiency by e-beam: +

Spectra



Remark

This contribution is from Masaaki Tamatani.

Reference

1. Brixner, L.H., and Chen, H.Y., On the structural and luminescent properties of the M³⁺ LnTaO₄ rare earth tantalates, *J. Electrochem. Soc.*, 130, 2435 (1983).



Structure: Orthorhombic

Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	99.8	147.33
In ₂ O ₃	200 (of In)	277.64
Pr ₆ O ₁₁	0.2 (of Pr)	0.340
Al(OH) ₃	5	3.900

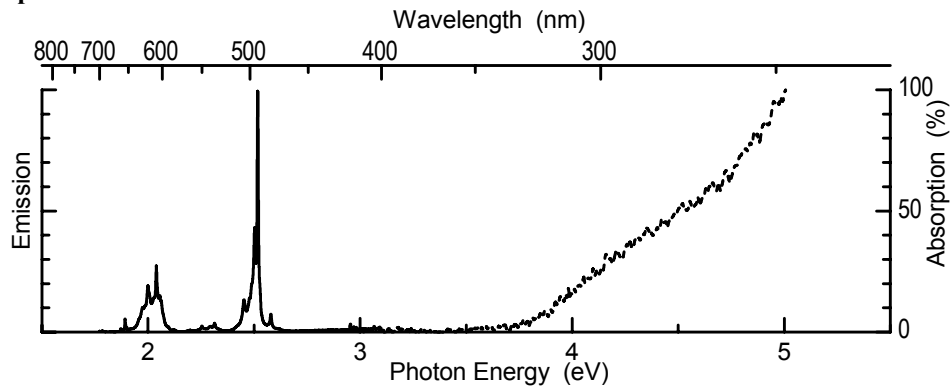
Preparation

Mix by slurring in ethanol.
Dry in air.
Fire in aluminum crucibles, stagnant air, 1250°C, 3 hours.
Powderize.
Store in air.

Optical Properties

Emission peak: 2.517 eV
Emission width (FWHM): 0.007 eV
Excitation efficiency by UV: – (3.40 eV), ++ (4.88 eV)
Excitation efficiency by e-beam: ++ (10eV–1 keV)
Decay to 1/e: ~10 μsec

Spectra



Remark

This contribution is from Shinji Okamoto.

SrY₂O₄:Eu³⁺

Structure: Orthorhombic

Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	100	10
Y ₂ O ₃	100	15.3
Eu ₂ O ₃	1	0.238
H ₃ BO ₃	6	0.251

Preparation

Mix by grinding in a mortar for 30 minutes.

Press into pellets with a hydraulic press machine at 40,000 psi.

1. Fire in air, 1000°C, 2 hours.

Powderize by dry ball-milling.

Press into pellets again.

2. Fire in air, 1350°C, 3 hours.

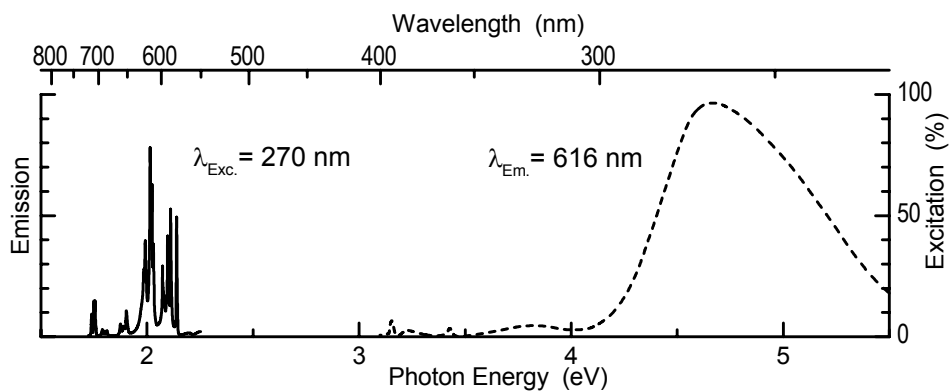
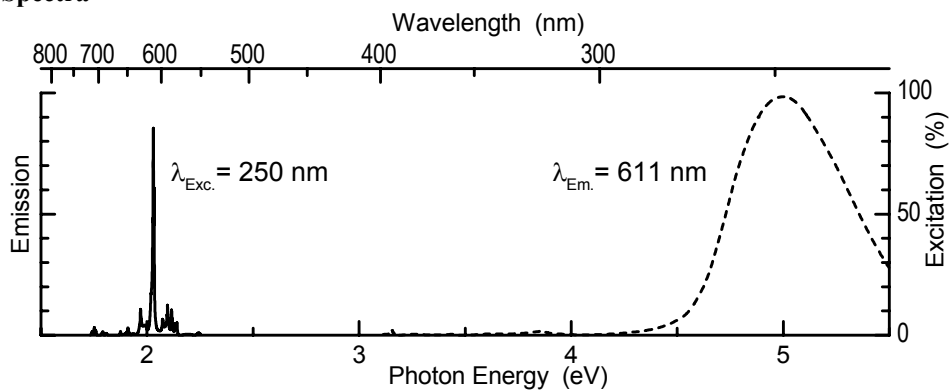
Optical Properties

Emission color: Red

Emission peak: 611 nm

Excitation efficiency by UV: ++ (2.88 eV), ++ (3.40 eV)

Spectra



Remark

This contribution is from Weiyi Jia.

References

1. Videa, M., Xu, W., Geil, B. et al., High Li⁺ self-diffusivity and transport number in novel electrolyte solutions, *J. Electrochem. Soc.*, 148, A1352 (2001).
2. Park, S.J., Park, C.H., Yu, B.Y. et al., Structure and luminescence of SrY₂O₄:Eu, *J. Electrochem. Soc.*, 146, 3903 (1999).



Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	99.8	147.33
TiO ₂	100	79.879
Pr ₆ O ₁₁	0.2 (of Pr)	0.340
Al(OH) ₃	5–30	3.900–23.401

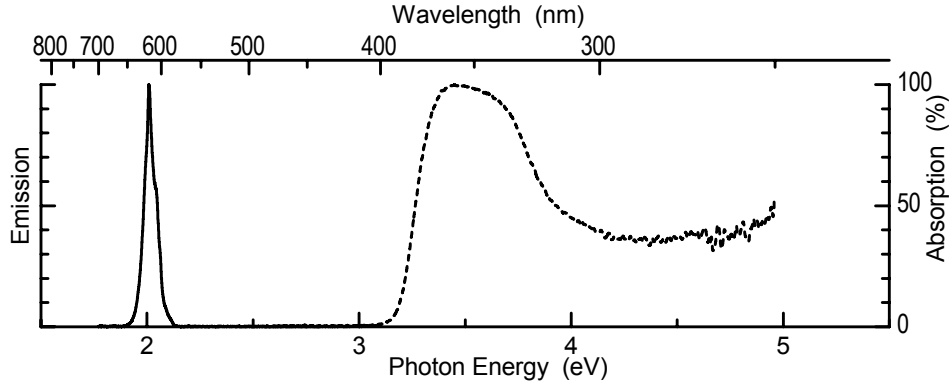
Preparation

Mix by slurring in ethanol.
Dry in air.
Fire in aluminum crucibles, stagnant air, 1300°C, 2 hours.
Powderize.

Optical Properties

Emission peak: 2.009 eV
Emission width (FWHM): 0.064 eV
Excitation efficiency by UV: – (3.40 eV), ++ (4.88 eV)
Excitation efficiency by e-beam: ++ (10 eV–1 keV)
Decay to 1/e: ~100 μsec

Spectra



Remark

This contribution is from Shinji Okamoto.

References

1. Itoh, S., Toki, H., Tamura, K., and Kataoka, F., A new red-emitting phosphor, $\text{SrTiO}_3\text{:Pr}^{3+}$, for low-voltage electron excitation, *Jpn. J. Appl. Phys.*, 38, 6387 (1999).
2. Okamoto, S., and Yamamoto, H., Characteristic enhancement of emission from $\text{SrTiO}_3\text{:Pr}^{3+}$ by addition of group-IIIb ions, *Appl. Phys. Lett.*, 78, 655, (2001).

SrTiO₃:Pr³⁺

Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	100	10.00
TiO ₂	100	5.41
Pr(NO ₃) ₃ .6H ₂ O	0.5	0.212
B ₂ O ₃	3	0.142

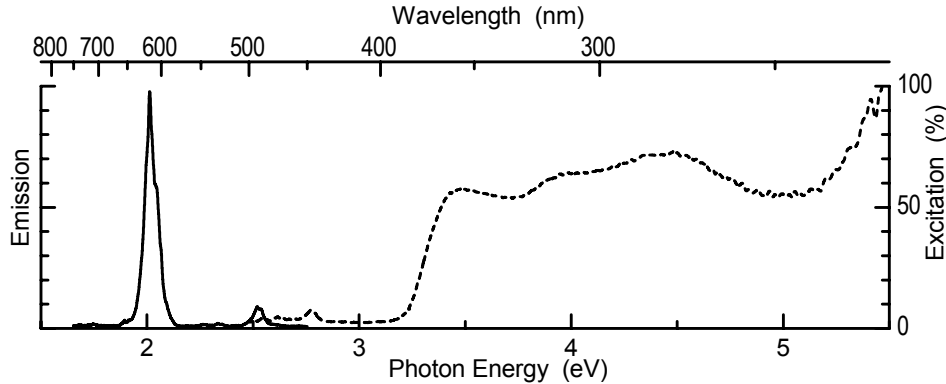
Preparation

- Mix by dry grinding or milling.
Press into pellets.
1. Fire in air, 1000°C, 1 hour.
Powderize.
Grind and press into pellets again.
 2. Fire in open quartz boats, air, 1300°C, 3 hours.

Optical Properties

Emission color: Red
Emission peak: 615 nm
Excitation efficiency by UV: ++ (3.40 eV), ++ (4.88 eV)

Spectra



Remarks

1. This contribution is from Weiyi Jia.
2. This compound is also known as strontium titanate.

Reference

1. Jia, W., Xu, W., Rivera, I. et al., Effects of compositional phase transitions on luminescence of $\text{Sr}_{1-x}\text{Ca}_x\text{TiO}_3\text{:Pr}^{3+}$, *Solid State Commun.*, 126, 153 (2003).

Y(P,V)O₄:Eu

Structure: Xenotime

Composition

Ingredient	Mole %	By weight (g)
Y ₂ O ₃	48	104.8
Eu ₂ O ₃	2	7.0
NH ₄ VO ₃	35	40.9
(NH ₄) ₂ HPO ₄	65	85.8

Preparation

Dry-blend all ingredients and place in a capped quartz or alumina crucible.

1. Fire in 700°C, for 2 hours. Cool and lightly mortar to break aggregates.
2. Fire in 1150°C, for 2 hours. Cool and break up aggregates.
3. Fire in 1150°C, for an additional 2 hours.

Cool and slurry the powder in 2 wt% (NH₄)₂CO₃ solution. Decant with water until neutral. Dry in air, 200°C.

Optical Properties

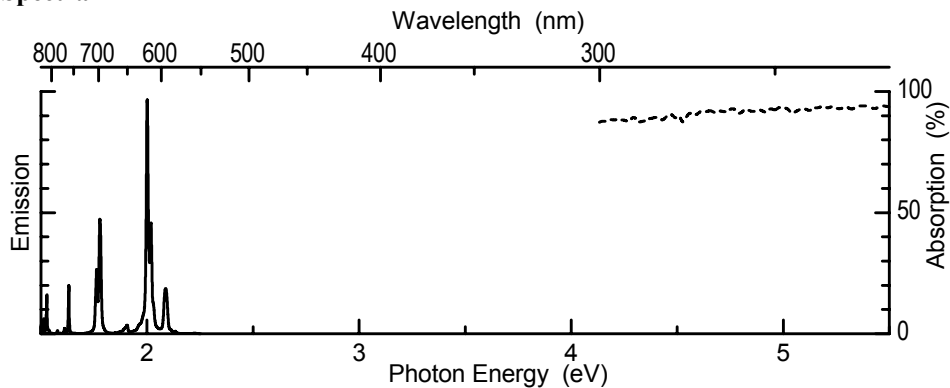
Emission color: Red

Emission peak: 619 nm

Excitation efficiency by UV: ++ (3.40 eV), + (4.88 eV), ++ (8.40 eV)

Excitation efficiency by e-beam: +

Spectra



Remark

This contribution is from Takashi Hase.

References

1. Wanmaker, W.L., and Verlijdsok, J.G., U.S. Pat., 3 417 027 (1968).
2. Japanese Patent Disclosure (Kokai), 50 67782 (1975); 51 114388 (1976).
3. Wanmaker, W.L., Bril, A., Vrugt, J.W.T., and Broos, J., *Proc. Int. Conf. Luminescence*, Budapest, 9-16 (1966).
4. Wanmaker, W.L., Verlijdsok, J.G., and Bres, G.C.M., U.S. Pat., 3 647 708 (1972).

Y₂O₃:Ce

Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
Si(OEt) ₄	100	—
Y(OC ₃ H ₇ i) ₃	7	—
CeCl ₃ (aq.)	1	—
ethanol, water and HCl (pH = 7)	1:2:3	certain amount

Preparation

Stir ingredients.

After 20 minutes, add the CeCl₃ solution dropwise, into a small container such as cuvettes. Cover the cuvette with paraffin film with a pin hole in the center as a outlet of vapor.

Place the wet gel in an oven at 40°C for one or two weeks to obtain transparent dry gels.

Annealing in N₂ + 5% H₂ gas flow at 500–900°C to remove residual water, ethanol, or other organic groups created and entrapped in the gels during gellation process.

Optical Properties

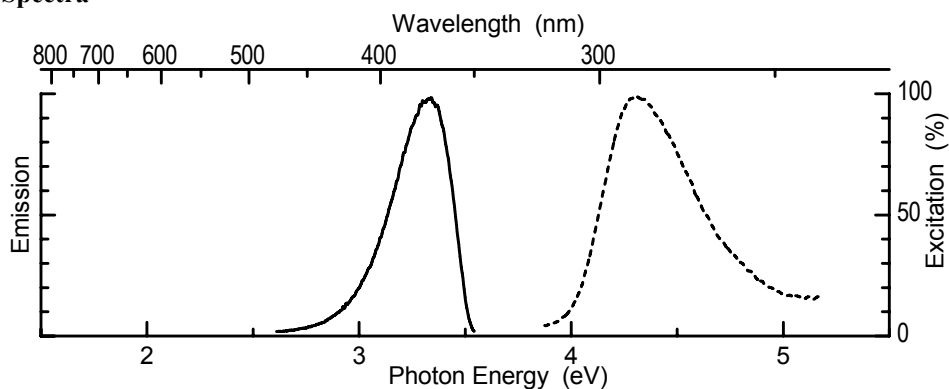
Emission color: Violet (Ce³⁺)

Emission peak: 375 nm

Emission width (FWHM): 30 nm

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

Spectra



Remark

This contribution is from Weiyi Jia.

Nanoclusters embedded in SiO₂ glasses

Reference

1. Jia, W. et al., Photoluminescence of Y₂O₃:Ce³⁺, Tb³⁺ nanoclusters embedded in SiO₂ sol-gel glasses, *Mater. Sci. Eng. C*, 572, 55 (2001).

Y₂O₃:Eu (YOE)

Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
Y ₂ O ₃	94 (Y)	108
Eu ₂ O ₃	6 (Eu)	10.5
CaF ₂	2.5	1.95

Preparation

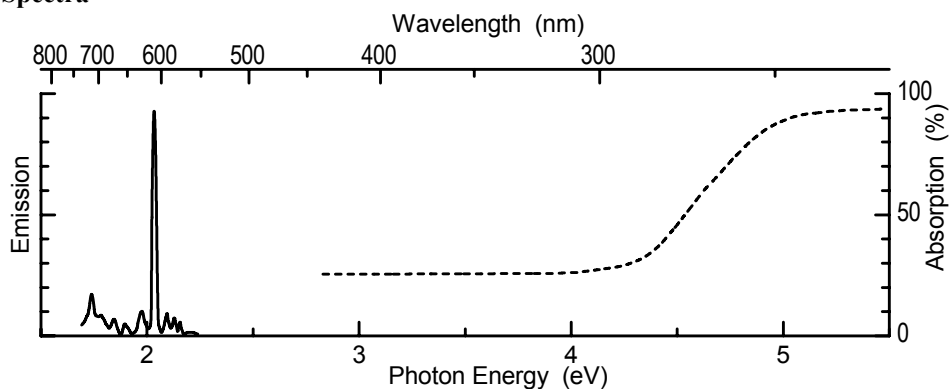
Mix by slurring in water or methanol and dry in air.

Powderize.

Firing should occur in air, at a temperature of about 1300°C for at least 1 hour.

This phosphor is used in fluorescent lamps and also in projection television tubes. It can also be used in plasma display panels. It can be sensitized for excitation at 365 nm using Bi, however, with reduced efficiency at 254 nm.

Spectra



Remark

This contribution is from Cees Ronda.

Y₂O₃:Eu³⁺

Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
Si(OEt) ₄	92.6	100
Y(OC ₃ H ₇ i) ₃	6.5	8.95
EuCl ₃ ·6H ₂ O	0.9	1.58
ethanol, water, and HCl (pH = 2.5) 1:2:3		

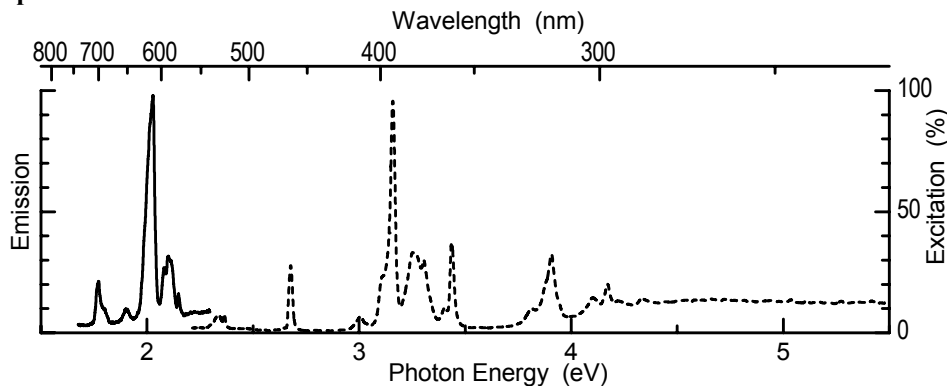
Preparation

Dissolve europium chloride in 2–3 g of distilled water. Blend it into the ethanol/water/HCl mix. Mix the Si and Y solutions and stir for 20 minutes with a magnetic stirring device. Put the EuCl_3 /water/ethanol/HCl solution into the Si/Y mixture dropwise while stirring. Pour the resulting mixture into a small container with a cover, allowing slow evaporating of the excess or resulted water and ethanol. A wet gel will result. The wet gel is dried at low temperatures (45°C) for one or two weeks in an oven, to obtain transparent dry gels. Anneal the dry gel in air at 500–1000°C to remove residual water, ethanol, or other organic radicals.

Optical Properties

Emission color: Red
Emission peak: 612 nm
Emission width (FWHM): 30 nm
Excitation efficiency by UV: Weakly excited at 3.87 eV
Excitation efficiency by e-beam: Weakly excited by cathode rays

Spectra

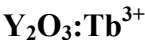


Remark

This contribution is from Weiyi Jia.
 Y_2O_3 nanoclusters embedded in SiO_2 glasses.

References

1. Jia, W., Liu, H., Feofilov, S.P., Meltzer, R., and Jiao, J., Spectroscopic study of Eu^{3+} -doped and $\text{Eu}^{3+}, \text{Y}^{3+}$ codoped SiO_2 sol-gel glasses, *J. Alloys Ingredients*, 11, 311 (2000).
2. Jia, W. et al., Photoluminescence of $\text{Eu}^{3+}:\text{Y}_2\text{O}_3$ nanoclusters embedded in SiO_2 glass, *Mater. Res. Soc. Symp. Proc.*, 271, 519 (1998).



Composition

Ingredient	Mole %	By weight (g)
$\text{Si}(\text{OEt})_4$	92.6	100
$\text{Y}(\text{OC}_3\text{H}_7\text{I})_3$	6.5	8.95
$\text{TbCl}_3 \cdot 6\text{H}_2\text{O}$	0.9	1.8
ethanol, water, and HCl (pH = 7) 1:2:3		certain amount

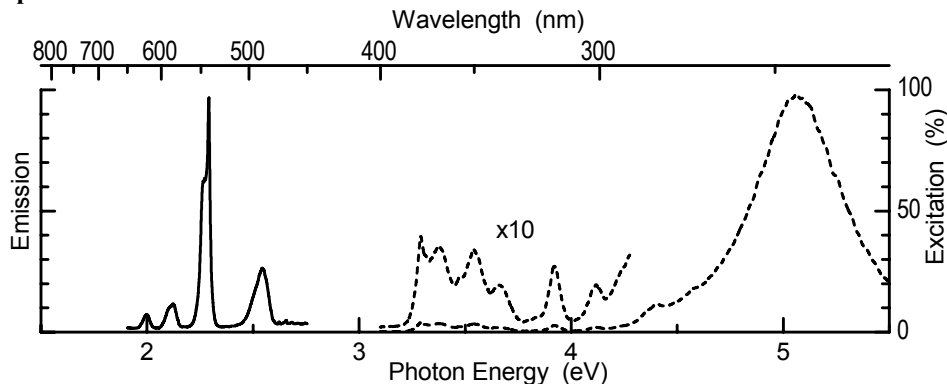
Preparation

Dissolve terbium chloride in 2–3 g of distilled water. Blend it into the ethanol/water/HCl mix. Mix the Si and Y solutions and stir for 20 minutes with a magnetic stirring device. Put the TbCl₃/water/ethanol/HCl solution into the Si/Y mixture dropwise while stirring. Pour the resulting mixture into a small container with a cover, allowing slow evaporating of the excess or resulted water and ethanol. A wet gel will result. The wet gel is dried at low temperatures (45°C) for one or two weeks in an oven, to obtain transparent dry gels. Anneal the dry gel in air at 500–1000°C to remove residual water, ethanol, or other organic radicals.

Optical Properties

Emission color: Green
Emission peak: 543 nm; Minor peaks at 495, 585, and 621 nm
Emission width (FWHM): 30 nm
Excitation efficiency by UV: ++ (3.40 eV), ++ (4.88 eV)

Spectra

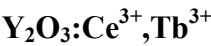


Remark

This contribution is from Weiyi Jia.
Nanoclusters embedded in SiO₂ glasses.

Reference

1. Jia, W. et al., Photoluminescence of Y₂O₃:Ce³⁺, Tb³⁺ nanoclusters embedded in SiO₂ sol-gel glasses, *Mater. Sci. Eng. C*, 572, 55 (2001).



Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
Si(OEt) ₄	91.8	100
Y(OC ₃ H ₇ i) ₃	6.4	8.95
TbCl ₃ ·6H ₂ O	0.9	1.61
CeCl ₃ ·6H ₂ O	0.9	1.53
ethanol, water, and HCl (pH = 7) 1:2:3		

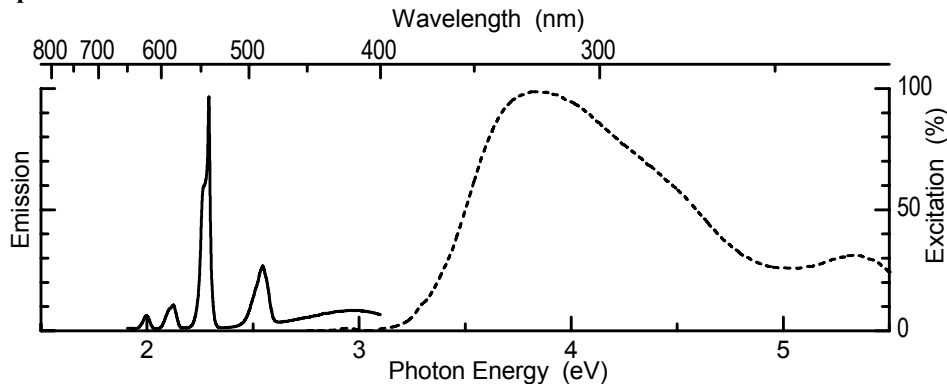
Preparation

Dissolve cerium and terbium chlorides in 2–3 g of distilled water. Blend it into the ethanol/water/HCl mix. Mix the Si and Y solutions and stir for 20 minutes with a magnetic stirring device. Put the Ce-TbCl₃/water/ethanol/HCl solution into the Si/Y mixture dropwise while stirring. Pour the resulting mixture into a small container with a cover, allowing slow evaporating of the excess or resulting water and ethanol. A wet gel will result. The wet gel is dried at low temperatures (45°C) for one or two weeks in an oven, to obtain transparent dry gels. Anneal the dry gel in air at 500–1000°C to remove residual water, ethanol, or other organic radicals.

Optical Properties

Emission color: Violet (Ce³⁺)
Emission peak: 543 nm
Emission width (FWHM): 30 nm
Excitation efficiency by UV: ++ (3.87 eV), ++ (5.39 eV)
Excitation efficiency by e-beam: Weakly excited by cathode rays

Spectra



Remark

This contribution is from Weiyi Jia.
Nanoclusters embedded in SiO₂ glasses.

Reference

1. Jia, W. et al., Photoluminescence of Y₂O₃:Ce³⁺,Tb³⁺ nanoclusters embedded in SiO₂ sol-gel glasses, *Mater. Sci. Eng. C*, 572, 55 (2001).

Y₂O₂S:Eu

Composition

Ingredient	Mole %	By weight (g)
Y ₂ O ₃	94 (Y)	110
Eu ₂ O ₃	3 (Eu)	5.3
Na ₂ CO ₃	100	53
S	300	96

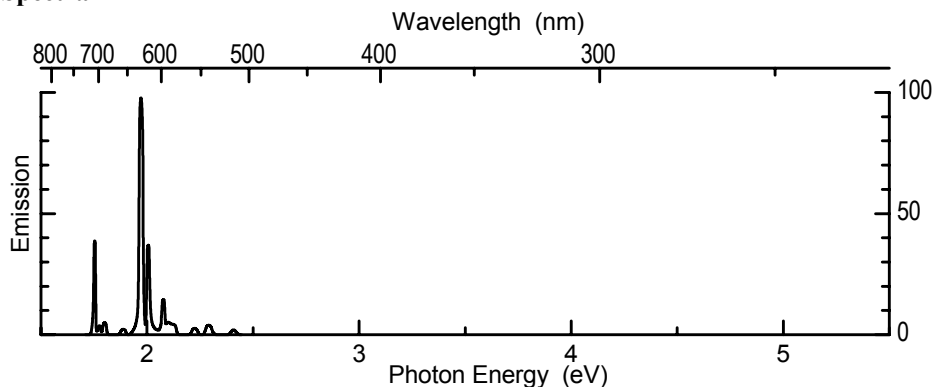
Preparation

Mix the rare-earth oxides by slurring in water or methanol and dry in air. After drying, the mixture should be powdered in mortar. Subsequently, mix the rare earth mixture with Na_2CO_3 and S by dry mixing.

Firing should occur in air in a vessel with a well-closing lid, at a temperature of about 1100°C for a few hours.

After cooling down, the reaction product has to be washed a few times with water to remove residual flux.

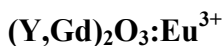
Spectra



Spectrum from the *Phosphor Handbook*, CRC Press, Boca Raton, FL, Fig. 38, p. 478 (1998).

Remark

This contribution is from Cees Ronda.



Structure: Cubic

Preparation

Oxidize the co-precipitated oxalate at about 800°C .

Preferably, if either the sintering or hot-pressing processes are subsequently used to produce the ceramic scintillator, the powder should be de-agglomerated.

Die or isostatically press the powder into powder compacts, using pressures up to about 300 MPa.

The $\text{Y}_{1.34}\text{Gd}_{0.60}\text{Eu}_{0.06}\text{O}_3$ compacts can be densified into transparent ceramics by either vacuum sintering at 1800°C or hydrogen-gas sintering at $1800\text{--}1900^\circ\text{C}$.

Optical Properties

Emission color: Red

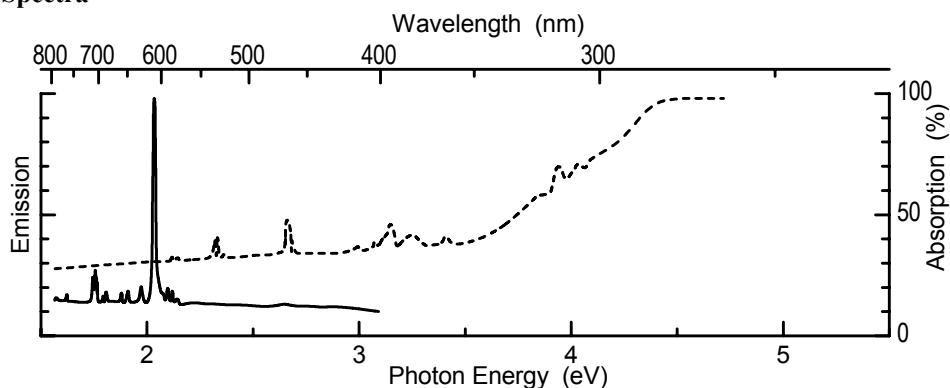
Emission peak: 610 nm

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

Excitation efficiency by e-beam: $+$

Decay to $1/e$: 1×10^{-3} sec

Spectra



Remarks

1. This contribution is from Hajime Yamamoto.
2. Co-doping of a small amount of Pr reduces the afterglow.
3. The sintered samples can be annealed in an oxygen-rich atmosphere to reduce the concentration of point defect/impurity-charge states in the host lattice.

Reference

1. Greskovich, C., and Duclos, S., Ceramic scintillators, *Annu. Rev. Mater. Sci.*, 27, 69 (1997).

YTaO₄

Structure: Monoclinic

Preparation

Stoichiometric quantities are mixed Y₂O₃, Ta₂O₅.

Fire in capped alumina tubes, air, 1200°C, 8–10 hours.

Powderize with a Freon solvent as the grinding medium.

Fire in capped alumina tubes, either by itself or in the presence of 50% Li₂SO₄, 1250°C, 10–14 hours.

In the cases where a flux is used, leach with water and follow by methanol rinsing.

Dry in air, 130°C.

Optical Properties

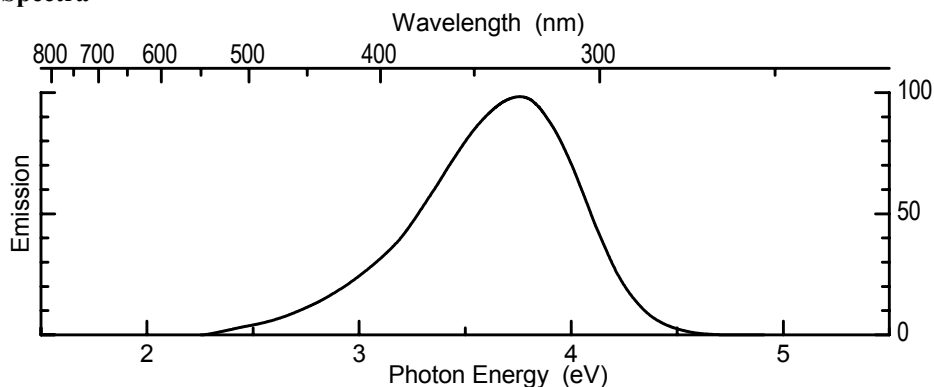
Emission color: UV

Emission peak: 330 nm

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

Excitation efficiency by e-beam: +

Spectra

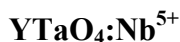


Remarks

1. This contribution is from Masaaki Tamatani.
2. The use of a flux in the synthesis of M'-YTaO₄ not only allows the growth of 4–12 μm single crystals but also assists greatly in the formation of the compound (see Ref. 2).

References

1. Brixner, L.H., and Chen, H.Y., On the structural and luminescent properties of the M' LnTaO₄ rare earth tantalates, *J. Electrochem. Soc.*, 130, 2435 (1983).
2. Issler, S.L., and Torardi, C.C., Solid state chemistry and luminescence of X-ray phosphors, *J. Alloys Ingredients*, 229, 54 (1995).



Structure: Monoclinic

Preparation

Stoichiometric quantities are mixed Y₂O₃, Ta₂O₅, Nb₂O₅.

Fire in capped alumina tubes, air, 1200°C, 8–10 hours.

Powderize with a Freon solvent as the grinding medium.

Fire in capped alumina tubes, either by itself or in the presence of 50% Li₂SO₄, 1250°C, 10–14 hours.

In the cases where a flux is used, leach with water and follow by methanol rinsing. Dry in air, 130°C.

Optical Properties

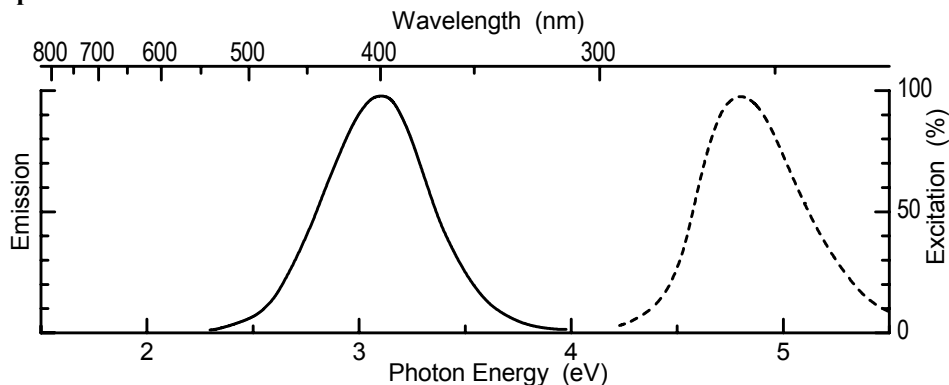
Emission color: Blue

Emission peak: 410 nm (x-ray excitation 2% Nb)

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

Excitation efficiency by e-beam: +

Spectra

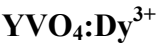


Remarks

This contribution is from Masaaki Tamatani.

Reference

1. Brixner, L.H., and Chen, H.Y., On the structural and luminescent properties of the M' LnTaO₄ rare earth tantalates, *J. Electrochem. Soc.*, 130, 2435 (1983).



Structure: Tetragonal (zircon)

Composition

Ingredient	Mole %	By weight (g)
Y ₂ O ₃	17.15	70.0
NH ₄ VO ₃	82.80	175.0
Dy ₂ O ₃	0.05	0.321

Preparation

Blend the materials thoroughly and fire in an open quartz crucible for 2 hours at 1700°C. Cool slightly and wash with a hot solution of 15 % NaOH. Rinse with de-ionized water until neutral. Dry in air and powderize.

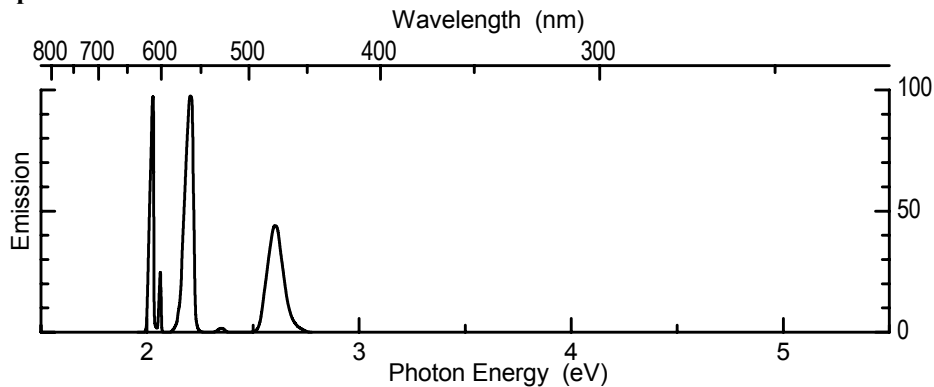
Optical Properties

Emission color: Yellowish-green

Emission peak: Two strong dysprosium peaks at 480 and 570 nm

Excitation efficiency by UV: Suitable for 2537 and 3650 Å

Spectra



Remarks

- 1. This contribution is from Madis Raukas.
- 2. This recipe yields a phosphor containing 0.28 mol% of Dy³⁺, which is optimum for excitation with mercury discharge lamps.
- 3. Other rare-earth elements (Pr, Sm, Eu,, Er, Tm, and alike) can be added up to a half of the activator content. By including such elements or combinations thereof, the emission characteristics can be adjusted.

References

- 1. Faria, S., and Palumbo, D.T., U.S. Pat., 3 555 337 (1968).
- 2. Ballman, A.A., Linares, R.C., and van Uitert, L.G.G., U.S. Pat. 3 152 085 (1964).
- 3. Thompson, G.L., U.S. Pat., 3 322 682 (1967).

ZnGa₂O₄

Structure: Cubic (spinel)

Composition

Ingredient	Mole %	By weight (g)
ZnO	50	8.14
Ga ₂ O ₃	50	18.7
Li ₃ PO ₄ (Flux)	—	—

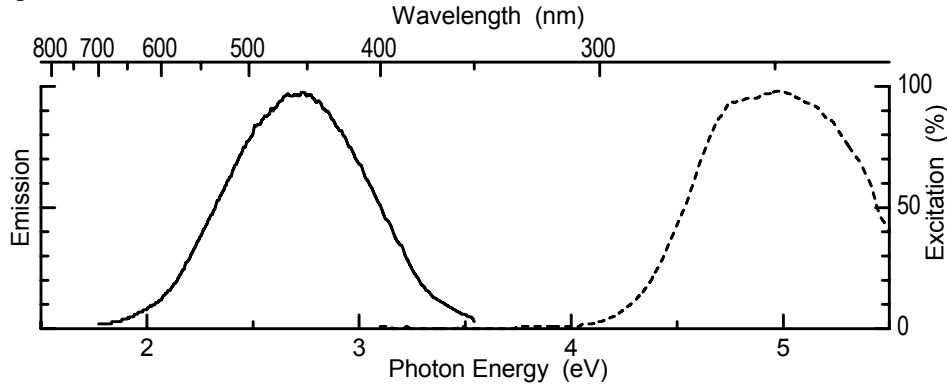
Preparation

Mix by slurring in water or ethanol.
Dry in air. Powderize when dry.
Fire in capped quartz crucibles, stagnant air, 1200°C, 3 hours.
Powderize.
Wash with diluted nitric acid to remove excess flux.
Re-fire in H₂ + N₂ atmosphere, 1100°C, 1 hour.
Powderize.

Optical Properties

Emission color: Blue
Emission peak: 460 nm
Emission width (FWHM): 137 nm
Absorption edge: 270 nm (4.4 eV)
Excitation efficiency by e-beam: 0.7 lm/W or higher at 30 V DC

Spectra

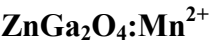


Remark

This contribution is from Sato Yoshitaka.

Reference

1. Itoh, S. et al., The ZnGa₂O₄ phosphor for low-voltage blue cathodoluminescence, *J. Electrochem. Soc.*, 138, 1509 (1991).



Structure: Cubic (spinel)

Composition

Ingredient	Mole %	By weight (g)
ZnO	48	8.14
Ga ₂ O ₃	50	18.7
MnSO ₄	2	0.15
Li ₃ PO ₄ (Flux)		

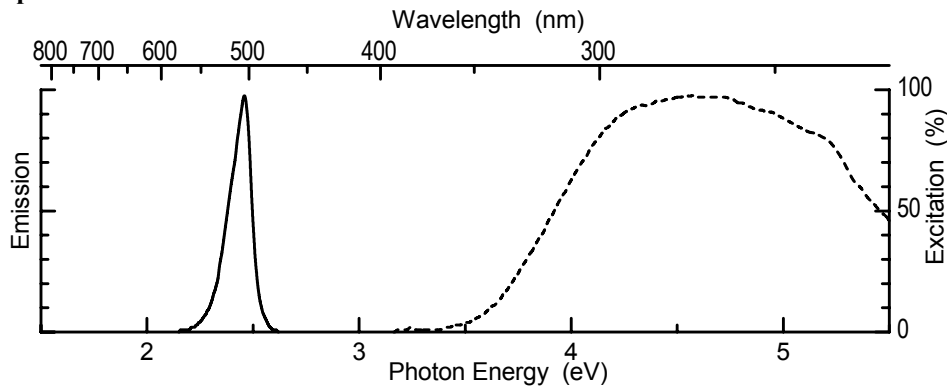
Preparation

Mix by slurring in water or ethanol
Dry in air. Powderize when dry.
Fire in capped quartz crucibles, stagnant air, 1200°C, 3 hours.
Powderize.
Wash with de-ionized water.
Add solution of Mn²⁺ ion, mix, and vaporize moisture by warming.
Re-fire in H₂ + N₂ atmosphere, 1100°C, 1 hour.
Powderize.

Optical Properties

Emission color: Green
Emission peak: 505 nm
Emission width (FWHM): 25 nm
Absorption edge: 270 nm (4.4 eV)
Excitation efficiency by e-beam: 1.0 lm/W or higher at 30 V DC

Spectra



Remark

This contribution is from Yoshitaka Sato.

References

1. Toki, H. et al., *Proceedings of Japan Display'92*, (1992).
2. Toki, H., Kataoka, Y., Morimoto, K., and Itoh, S., ZnGa₂O₄:Mn green catho-
doluminescent phosphors for VFDs, *Tech. Digest Jpn. Display*, 421 (1992).



Structure: Hexagonal (wurtzite)

Composition

Ingredient	Mole %	By weight (g)
ZnO	97.6	10
Bi ₂ O ₃	2.4	1.43

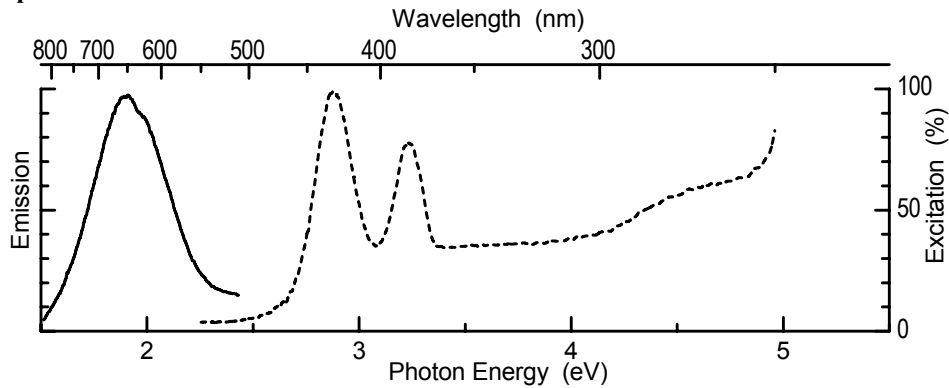
Preparation

- Mix by dry grinding.
1. Fire in air, 800°C, 1 hour.
 2. Fire in capped quartz tubes, stagnant air, 1120°C, 2 hours.
- Store in well-sealed container.

Optical Properties

Emission color: Red
Emission peak: 645 nm
Emission width (FWHM): 3540 cm⁻¹
Excitation efficiency by UV: ++ (3.26 eV), ++ (4.88 eV)

Spectra



Remark

This contribution is from Weiyl Jia.

Reference

1. Mosquera Vargas, E., Master Degree Thesis, University of Puerto Rico—Mayaguez (2003).

ZnO:Zn

Structure: Hexagonal (wurtzite)

Composition

Ingredient	Mole %	By weight (g)
ZnO	100	158

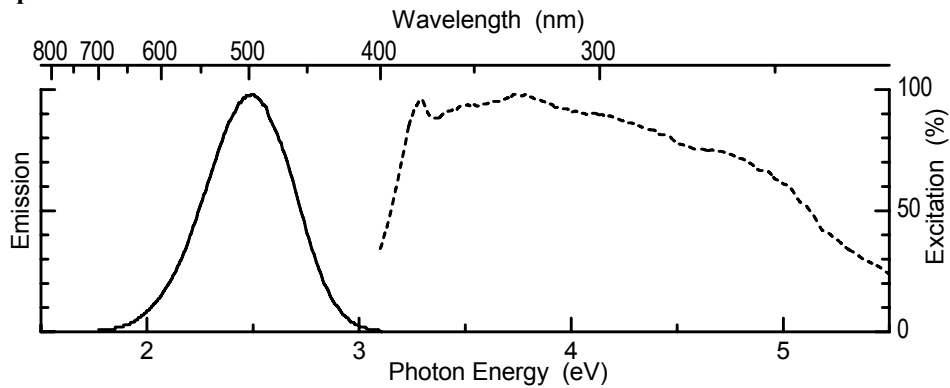
Preparation

Fire in capped quartz crucibles in reduced atmosphere at 1000°C, 1 hour.
Powderize.

Optical Properties

Emission color: Green
Emission peak: 505 nm
Emission width (FWHM): 0.4 eV
Absorption edge: 388 nm (300 K)
Excitation efficiency by e-beam: 16 lm/W or higher

Spectra



Remark

This contribution is from Yoshitaka Sato.

ZnO:Ga, Ultrafast (Type WL-1201)

Composition

Ingredient	Mole %	By weight
ZnO	100	81 g
Ga ₂ O ₃	0.3 (of Ga)	0.280 g
ZnCl ₂	about 1 (not critical)	1.7 g

Preparation

Mix ZnO and Ga₂O₃ porcelain dish, add alcohol to make a uniform slurry. Dissolve the ZnCl₂ in a little water, add solution to above mix, stir to uniformity, and dry at room temperature or at moderate heat (e.g., over night). Then add a little water to make the raw mix slightly moist.

1. Fire in loosely capped quartz glass tubes (about half full, not more), stagnant air, 1100°C, 1 hour. When cool, inspect under UV lamp. Material should be completely dead. Remove suspicious parts and powderize the rest..
2. Fire in open quartz boats, slowly flowing H₂, 800°C, one-half hour. Cool while in H₂ (Important!). Inspect again under UV lamp. The bulk of the material should show deep violet luminescence (just at the limit of visibility). Remove all parts that look different. In case the material does not show the violet luminescence at all, repeat the last firing step at about 100°C higher temperature.

Properties

Body color: Gray

Particles: About in the 5–10 μ m size range

Emission: Narrow band in the near-UV with a tail extending into the visible violet

Peak about 3.195 eV (=388 nm)

Excitation by UV: By all UV shorter than about 380 nm

Excitation by e-beam: Energy— $\eta \approx 1$ –1.2%, decay < 1 nsec

Remarks

1. The ZnCl₂ in the above recipe can be replaced by about 1.1 g of NH₄Cl, or by about 1 ccm of concentrated HCl acid.
2. This phosphor is sensitive to traces of sulfur. Avoid all sulfur like the plague.
3. This phosphor is in a frozen-in semistable state. Do not heat higher than about 300°C except in pure hydrogen.

References

1. Lehmann, W., Edge emission of n-type conducting ZnO and CdS, *Solid State Electron.*, 9, 1107 (1966) and U.S. Patent 3583929 (issued June 1971).
2. Luckey, D., A fast inorganic scintillator, *Nucl. Instr. Meth.*, 62, 119 (1968).
3. Derenzo, S.E., Weber, M.J., Klintonberg, M.K., Temperature dependence of the fast, near-band-edge scintillation from CuI, HgI₂, PbI₂, ZnO:Ga and CdS:In, *Nucl. Instr. Meth.* A 486, 214 (2002).
4. Lehmann, W., Zinc oxide and zinc-cadmium oxide phosphors, *J. Electrochem. Soc.*, 115, 538 (1968).

The above recipe was provided by W. Lehmann during a visit to the Lawrence Livermore National Laboratory in 1987.

ZnO-CdO:Ga, Ultrafast

Composition

Ingredient	Mole %	By weight
ZnO	90	73 g
CdO	10	11.2 g
Ga ₂ O ₃	0.3 (of Ga)	0.280 g
ZnCl ₂	about 1 (not critical)	1.7 g

Preparation

Mix ZnO + CdO + Ga₂O₃ in a porcelain dish, add alcohol to make a uniform slurry. Dissolve the ZnCl₂ in a little water, add solution to above mix, stir to uniformity,

and dry at room temperature or at moderate heat (e.g., over night). Then add a little water to make the raw mix slightly moist.

1. Fire in loosely capped quartz glass tubes (about half full, not more), stagnant air, 1100°C, 1 hour. When cool, inspect under UV lamp. Material should be completely dead. Remove suspicious parts and powderize the rest..
2. Fire in open quartz boats, slowly flowing H₂, 800°C, one-half hour. Cool while in H₂ (Important!). Inspect again under UV lamp. The bulk of the material should be violet luminescent (if it does not, repeat the last firing step at about 100°C higher temperature). (just at the limit of visibility). Remove any parts (if preaent) that look different.

Properties

Body color: Yellowish-gray

Particles: About in the 5–10 μm size range

Emission: Narrow band, peak about 413 nm. Color: violet

Excitation by UV: By all UV shorter than about 400 nm

Excitation by e-beam: Energy—η ≈ 1–1.2%, decay < 1 nsec

Remarks

4. 10% CdO is the limit of solid solubility. Do not add more.
5. The CdO in the above recipe can be replaced by 17.2 g CdCO₃.
6. The ZnCl₂ in the above recipe can be replaced by about 1.1 g of NH₄Cl, or by about 1 ccm of concentrated HCl acid.
7. This phosphor is sensitive to traces of sulfur. Avoid all sulfur like the plague.
8. This phosphor is in a frozen-in semistable state. Do not heat higher than about 300°C except in pure hydrogen.

References

5. Lehmann, W., Edge emission of n-type conducting ZnO and CdS, *Solid State Electron.*, 9, 1107 (1966) and U.S. Patent 3583929 (issued June 1971).
6. Luckey, D., A fast inorganic scintillator, *Nucl. Instr. Meth.*, 62, 119 (1968).
7. Lehmann, W., Zinc oxide and zinc-cadmium oxide phosphors, *J. Electrochem. Soc.*, 115, 538 (1968).

The above recipe was provided by W. Lehmann during a visit to the Lawrence Livermore National Laboratory in 1987.

Zn₂SiO₄:Mn

Composition

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

Preparation

Mix by ball-milling or magnetic stirring in water or an alcohol and dry in air.

Powderize.

Firing should occur in reducing atmosphere at a temperature of about 1150–1250°C for at least an hour.

The efficiency of this material (e-beam and (V)UV excitation) depends on the Mn^{2+} concentration. Higher Mn^{2+} concentrations adjust to a shorter decay time. The quantum efficiency drops less fast than the emission decay time. The emission band shifts to lower energy with increasing Mn^{2+} concentration, due to magnetic interactions lifting the spin selection rule.

This phosphor is used in plasma display panels and fluorescent lamps. It has been used in monochromic computer monitor tubes and projection television tubes (mixed with other green phosphors).

Remark

This contribution is from Cees Ronda.

Reference

1. Ronda, C., and Amrein, T., Evidence for exchange induced luminescence in $\text{Zn}_2\text{SiO}_4\text{:Mn}$, *J. Lumin.* 69, 245 (1996).

7.2 Silicates

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

Ba₂MgSi₂O₇:Eu²⁺
CaMgSi₂O₆:Eu²⁺
Ca₂MgSi₂O₇:Eu²⁺,Mn²⁺
Ca₃MgSi₂O₈:Eu²⁺
Ca₃Al₂Si₃O₁₂:Ce³⁺
Ca₃Al₂Si₃O₁₂:2%Ce³⁺
SrMgSi₂O₆:Eu²⁺
Sr₂MgSi₂O₇:Eu²⁺
Sr₃MgSi₂O₈:Eu²⁺

Ba₂MgSi₂O₇:Eu²⁺

Composition

Ingredient	Mole %	By weight (g)
BaCO ₃	39.84	10.00
MgO	19.92	1.367
SiO ₂	39.84	4.00
Eu ₂ O ₃	0.40	0.120
H ₃ BO ₃	1.6	0.16

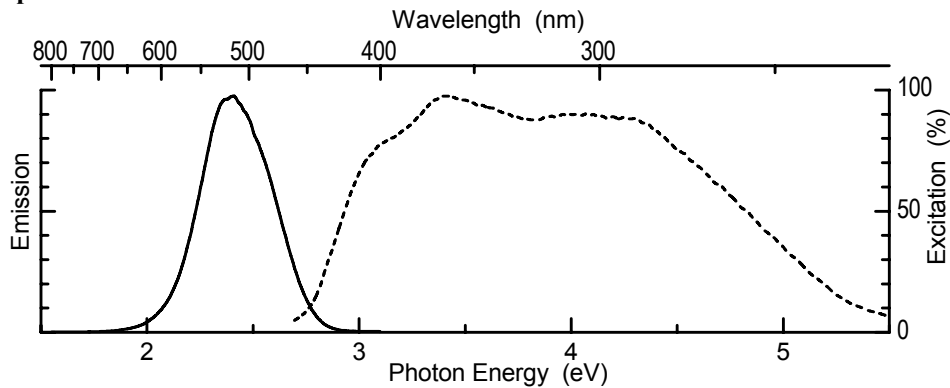
Preparation

Mix and grind. Pre-sinter at 900°C in N₂ for 2 hours. Powderize and grind. Sinter at 1300°C in N₂ + 5% H₂ gas flow for 3 hours. H₃BO₃ serves as flux.

Optical Properties

Emission color: Light blue.
Emission peak: 515 nm
Excitation efficiency by UV: Excited by UV from 240 to 440 nm.

Spectra



Remark

This contribution comes from Weiye Jia.

Reference

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



Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	24.87	10.00
MgO	24.87	4.04
SiO ₂	49.75	12.00
Eu ₂ O ₃	0.51	0.36
H ₃ BO ₃	2	0.48

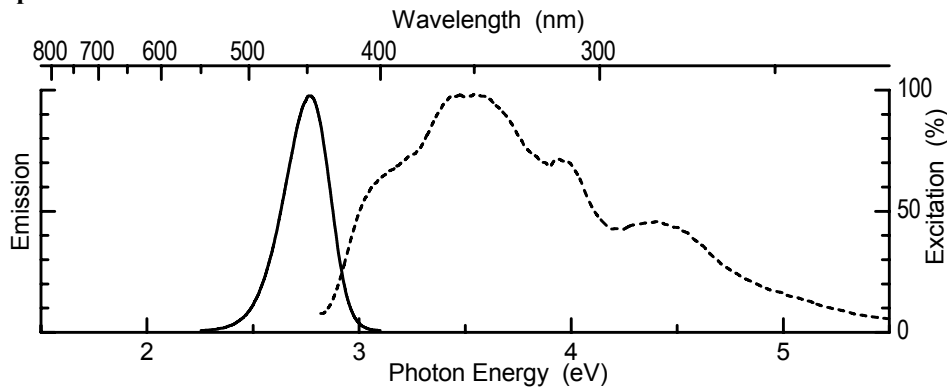
Preparation

Mix and grind. Pre-sinter at 800°C in N₂ for 2 hours. Powderize and grind. Sinter at 1250°C in N₂ + 5% H₂ gas flow for 3 hours. H₃BO₃ serves as flux.

Optical properties

Emission color: Blue
Emission peak: 448 nm
Excitation efficiency by UV: Excited by UV from 250 to 460 nm

Spectra



Remark

This contribution comes from Weiyi Jia.

References

- 1. Jia, W., Unpublished data.
- 2. Smith, A.L., *J. Electrochem. Soc.*, 96, 287 (1949).

Ca₂MgSi₂O₇:Eu²⁺,Mn²⁺

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	39.68	10.00
MgO	19.84	1.367
SiO ₂	39.68	4.00
Eu ₂ O ₃	0.40	0.120
MnO	0.40	0.071
H ₃ BO ₃	1.58	0.16

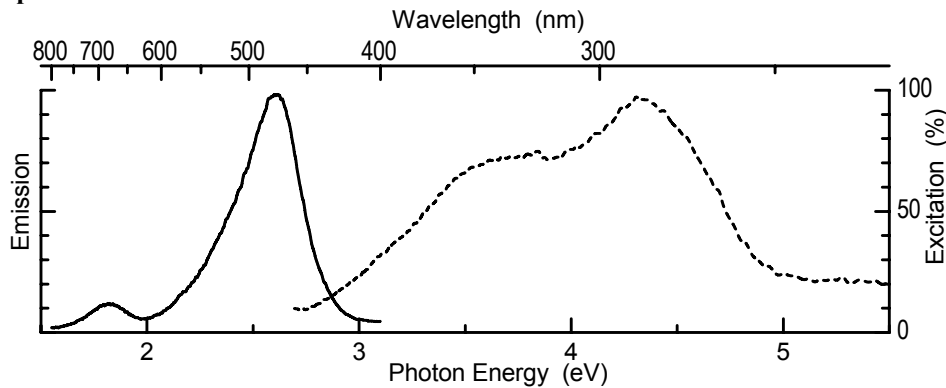
Preparation

Mix and grind. Pre-sinter at 900°C in N₂ for 2 hours. Powderize and grind. Sinter at 1300°C in N₂ + 5% H₂ gas flow for 3 hours. H₃BO₃ serves as flux.

Optical properties

Emission color: Whitish blue-green
Emission peak: Two peaks at 490 and 680 nm, respectively
Excitation efficiency by UV: Excited by UV from 260 to 420 nm

Spectra



Remark

This contribution comes from Weiyl Jia.

Reference

1. Jia, W., Unpublished data.

Ca₃MgSi₂O₈:Eu²⁺

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	49.83	10.00
MgO	16.61	1.367
SiO ₂	33.22	4.00
Eu ₂ O ₃	0.34	0.120
H ₃ BO ₃	1.33	0.16

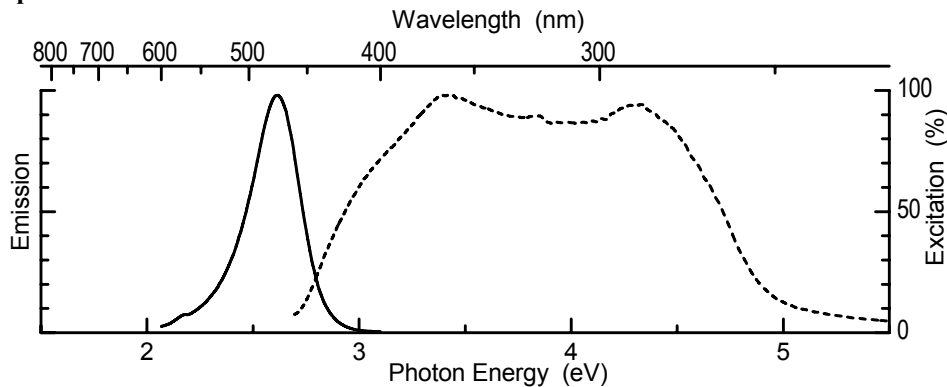
Preparation

Mix and grind. Pre-sinter at 900°C in N₂ for 2 hours. Powderize and grind. Sinter at 1350°C in N₂ + 5% H₂ gas flow for 3 hours. H₃BO₃ serves as flux.

Optical properties

Emission color: Light blue
Emission peak: 480 nm
Excitation efficiency by UV: Excited by UV from 250 to 440nm

Spectra



Remark

This contribution comes from Weiyi Jia.

Reference

1. Jia, W., Unpublished data.



Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	300	10
Al ₂ O ₃	100	3.40
SiO ₂	300	6
Ce ₂ O ₃	1	0.11
H ₃ BO ₃	5	0.103

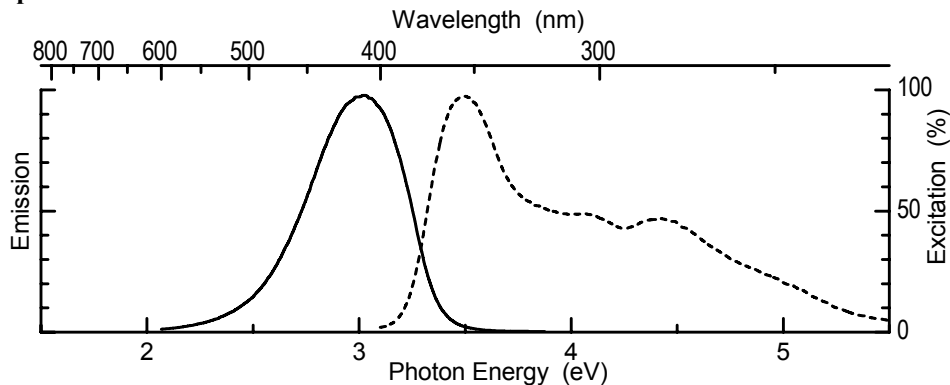
Preparation

- Mix by grinding in a mortar for 30 minutes.
Press into pellets with a hydraulic press machine at 40,000 psi.
1. Fire in air, 900°C, 2 hours.
Powderize by dry ball-milling.
Press into pellets again.
 2. Fire in 95%N₂ + 5% H₂, 1200°C, 3 hours

Optical Properties

Emission color: Violet
Emission peak: 410 nm
Excitation efficiency by UV: ++ (2.88 eV), ++ (3.40eV)

Spectra

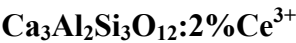


Remark

This contribution is from Weiyi Jia.

Reference

- 1. Jia, W., Unpublished data.



Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	300	10.00
Al ₂ O ₃	100	3.40
SiO ₂	300	6.00
Ce ₂ O ₃	1	0.110
H ₃ BO ₃	5	0.103

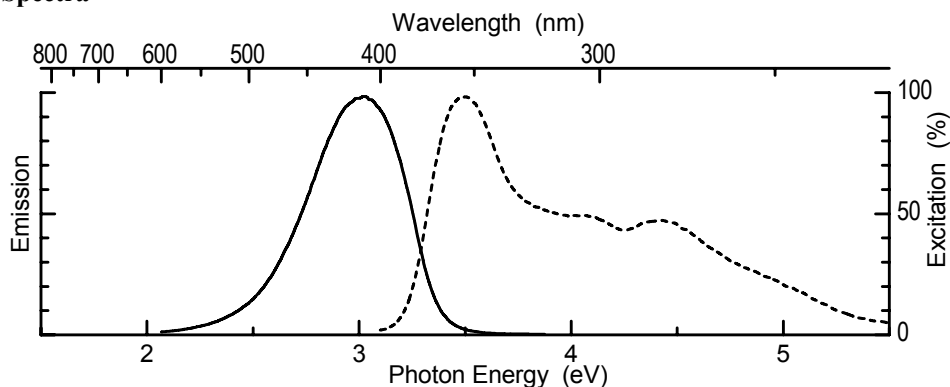
Preparation

- Mix by dry grinding in a mortar for 30 minutes.
Press into pellets with a hydraulic press machine at 40,000 psi.
- 1. Fire in air, 900°C, 2 hours.
Powderize.
Grind and press into pellets again.
 - 2. Fire in 95%N₂ + 5% H₂, 1200°C, 3 hours

Optical Properties

Emission color: Violet
Emission peaks: 280 and 355 nm
Excitation efficiency by UV: ++ (3.40 eV), ++ (4.88 eV)

Spectra



Remarks

- 1. This contribution is from Weiyi Jia.
- 2. This compound is also known as calcium aluminum silicate.

Reference

- 1. Jia, W., Unpublished data.



Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	24.87	10.00
MgO	24.87	2.74
SiO ₂	49.75	8.14
Eu ₂ O ₃	0.51	0.238
H ₃ BO ₃	2	0.325

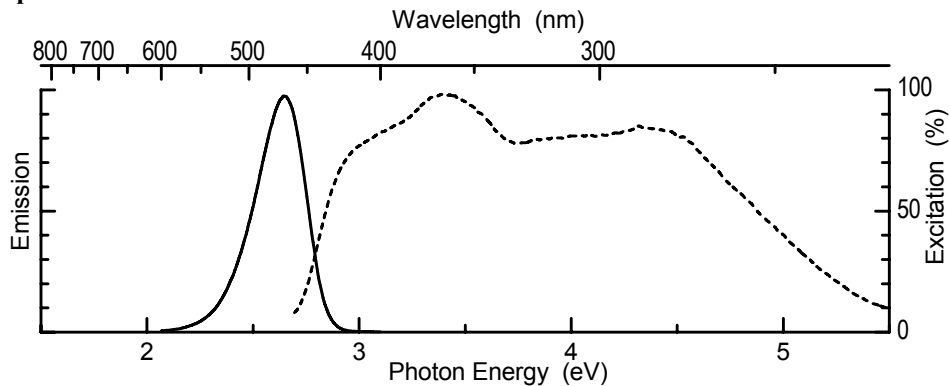
Preparation

Mix and grind. Pre-sinter at 700°C in air for 2 hours. Powderize and grind. Sinter at 1050°C in N₂ + 5% H₂ gas flow for 3 hours. H₃BO₃ serves as flux.

Optical properties

Emission color: Deep blue
Emission peak: 470 nm; Strong afterglow
Excitation by UV: Excited by UV from 240 to 450 nm.

Spectra



Remark

This contribution comes from Weiyi Jia.

Reference

- 1. Jia,W., Unpublished data.



Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	39.84	10.00
MgO	19.92	1.369
SiO ₂	39.84	4.072
Eu ₂ O ₃	0.4	0.119
H ₃ BO ₃	1.6	0.163

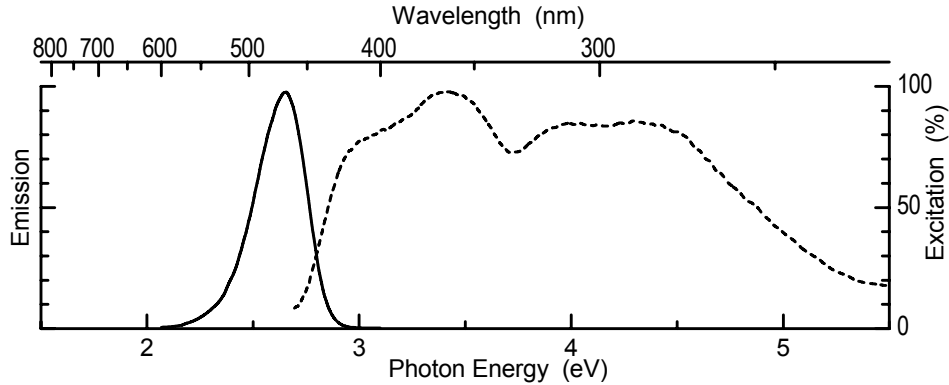
Preparation

Mix and grind. Pre-sinter at 800°C in air for 2 hours. Powderize and grind. Sinter at 1200°C in N₂ + 5% H₂ gas flow for 3 hours. H₃BO₃ (B₂O₃) serves as flux.

Optical properties

Emission color: Blue
Emission peak: 470 nm
Excitation by UV: Excited by UV from 250 to 450 nm

Spectra



Remark

This contribution comes from Weiyi Jia.

References

- 1. Jia,W., Unpublished data.
- 2. Blasse, G., Wanmaker, W.L., terVrugt, J.W., and Bril, A., Fluorescence of Eu²⁺-activated silicates, *Philips Res. Rep*, 23, 189 (1968).

Sr₃MgSi₂O₈:Eu²⁺

Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	49.83	10.00
MgO	16.61	0.912
SiO ₂	33.22	2.715
Eu ₂ O ₃	0.34	0.079
H ₃ BO ₃	1.33	0.108

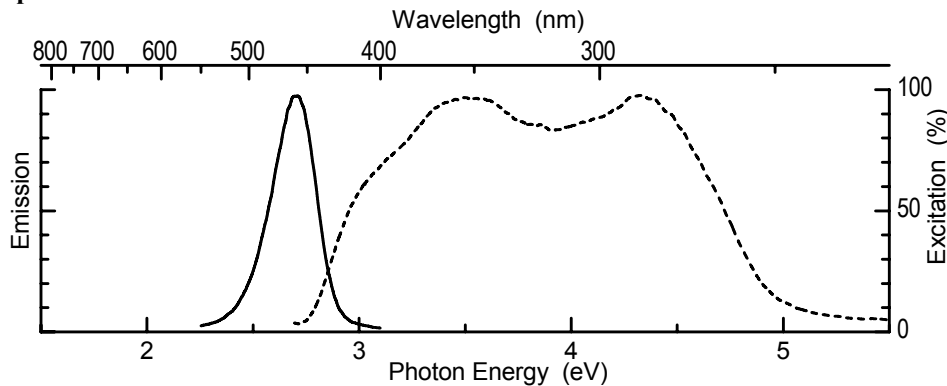
Preparation

Mix and grind. Pre-sinter at 800°C in air for 2 hours. Powderize and grind. Sinter at 1200°C in N₂ + 5% H₂ gas flow for 3 hours. H₃BO₃ (B₂O₃) serves as flux.

Optical properties

Emission color: Light blue
Emission peak: 470 nm
Excitation by UV: Excited by UV from 250 to 450 nm

Spectra



Remark

This contribution comes from Weiyi Jia.

Reference

1. Blasse, G., Wanmaker, W.L., terVrugt, J.W., and Bril, A., 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).

7.3 Phosphates, Halophosphates, and Bo rates

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

(Y,Gd)BO₃:Tb
(Y,Gd)BO₃:Eu
β-Ca₂P₂O₇:Sn,Mn
Sr₂B₅O₉Cl:Eu
Sr_wF_xB₄O_{6.5}:Eu²⁺
Sr_wF_xB_yO_z:Eu²⁺,Sm²⁺

(Y,Gd)BO₃:Tb

Structure: Pseudovaterite

Composition

Ingredient	Mole %	By weight (g)
Y ₂ O ₃	23	51.9
Gd ₂ O ₃	23	83.4
Tb ₄ O ₇	2	15.0
H ₃ BO ₃	139	85.9

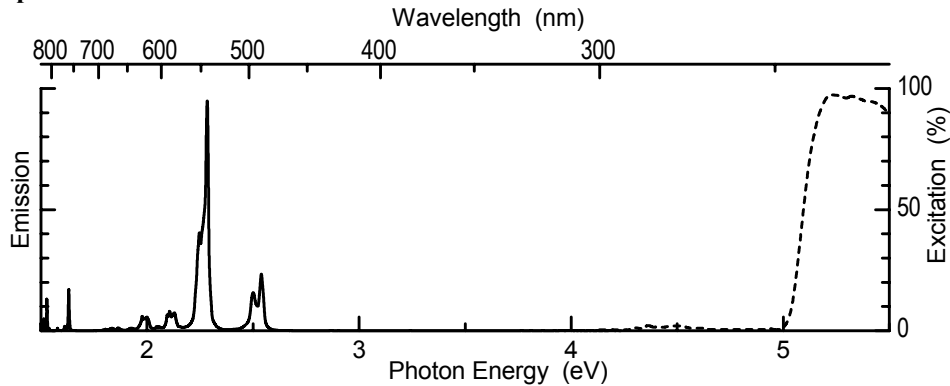
Preparation

- Dry blend ingredients.
1. Fire in capped quartz tubes, air, 400–500°C, 2 hours.
 2. Fire in capped quartz tubes, reducing atmosphere, 1100°C, 2 hours.
- Lightly mortar.
Slurry powder in boiling 10% HCl for 30 minutes.
Decant with boiling water until neutral.
Dry at 110°C.

Optical Properties

Emission color: Green
Emission peak: 544 nm
Excitation efficiency by UV: – (3.40 eV), ++ (4.88 eV), ++ (8.40 eV)

Spectra



Remark

This contribution is from Takashi Hase.

References

1. Japanese Patent Disclosure (Kokai), 52 133 091 (1977).
2. Hoshina, T., Sony Research Center Reports, *Supplement*, 92 (1983).
3. Wyckoff, R.W.G., *Crystal Structure*, 2nd ed., Interscience, New York: (1964).
4. Avella, F.J., Sovers, O.J., and Wiggins, C. S., Rare earth cathodoluminescence in InBO_3 and related orthoborates, *J. Electrochem. Soc.*, 114, 613 (1967).

(Y,Gd)BO₃:Eu

Structure: Pseudovaterite

Composition

Ingredient	Mole %	By weight (g)
Y ₂ O ₃	32	72.2
Gd ₂ O ₃	15	54.4
Eu ₂ O ₃	3	10.6
H ₃ BO ₃	130	80.4

Preparation

Mix by dry blend.

1. Fire in capped quartz tubes or alumina crucibles, air, 400–500°C, 2 hours.
2. Fire in capped quartz tubes or alumina crucibles, air, 1100°C, 2 hours.
Powderize. Slurry in boiling 10% HCl for 30 minutes. Wash by decanting in boiling water until neutral. Dry in air, 110°C.

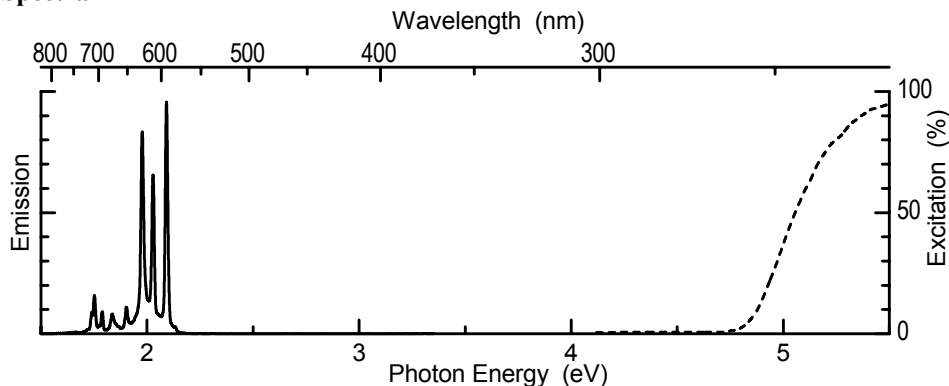
Optical Properties

Emission color: Red

Emission peak: 619 nm

Excitation efficiency by UV: – (3.40 eV), ++ (4.88 eV), ++ (8.40 eV)

Spectra



Remark

This contribution is from Takashi Hase.

References

1. Japanese Patent Disclosure (Kokai), 52 54690 (1977).
2. Koike, J., Okada, K., and Yokozawa, M. *NHK Giken Geppo*, 22, 176 (1979).
3. Wyckoff, R.W.G., *Crystal Structure*, 2nd ed., Interscience, New York (1964).
4. Bril. A., and Wanmaker, W.L., Fluorescent properties of some europium-activated phosphors, *J. Electrochem. Soc.*, 111, 1363 (1964).
5. Avella, F.J., Sovers, O.J., and Wiggins, C.S., Rare earth cathodoluminescence in InBO₃ and related orthoborates, *J. Electrochem. Soc.*, 114, 613 (1967).
6. Chadeyron, G., Arbus, A., Fournier, M.T., and Cousseins, D.Z., Influence of the synthesis method on the luminescent properties of the vaterite-type YBO₃-Eu³⁺, *Cr. Acad. Sci. II.*, 320, 199 (1995).
7. Avella, F.J., U.S. Pat., 3 394 084 (1968).

β-Ca₂P₂O₇:Sn,Mn

Composition

Ingredient	Mole %	By weight (g)
CaHPO ₄	81.04	18.92
SrHPO ₄	8.32	0.73
Sn ₂ P ₂ O ₇	0.28	0.20
MnCO ₃	7.05	1.39
(NH ₄) ₂ HPO ₄	9.31	2.11

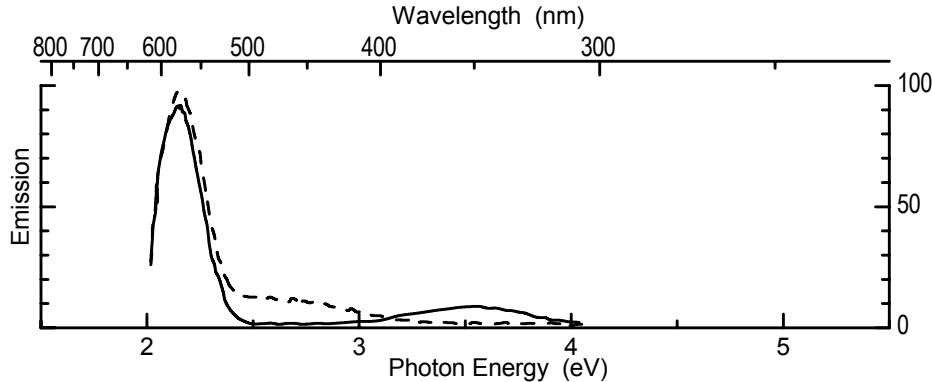
Preparation

- Mix by shaking with six ½ in. nylon balls in a plastic jar on a paint mixer for ½ hour.
Dry in air. Powderize when dry.
1. Fire in alumina trays, 99.5% N₂/0.5%H₂, 625°C, ~½ hour.
Eliminate the H₂
 2. Fire in alumina trays, N₂, 1200°C, 1 hour.
Cool in N₂.

Optical Properties

- Emission color: Orange-red
Emission peaks: 350 and 575 nm
Emission width (FWHM): 72 nm (For the latter peak)
Excitation efficiency by UV: ++ (3.40 eV), + (4.88 eV)
Excitation by e-beam: Weakly excited

Spectra



Remarks

- 1. This contribution is from Madis Raukas.
- 2. Firing temperature should not exceed 1250°C to prevent formation of α-pyrophosphate.
- 3. Exhibits very strong triboluminescence or mechanoluminescence.

References

- 1. Henderson, S.T., *Proc. R. Soc. A*, 173, 323 (1939).
- 2. Ranby, P.W., Mash, D.H., and Henderson, S.T., The investigation of new phosphors, with particular reference to the pyrophosphates, *Brit. J. Appl. Phys.*, S18, 18 (1955).
- 3. Pappalardo, R.G., and Peters, T.E., U.S. Pat., 4 772 417 (1988).



Structure: Tetragonal

Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	26.33	8.85
SrCl ₂	27.42	9.91
Eu ₂ O ₃	0.55	0.44
B ₂ O ₃	45.71	7.25

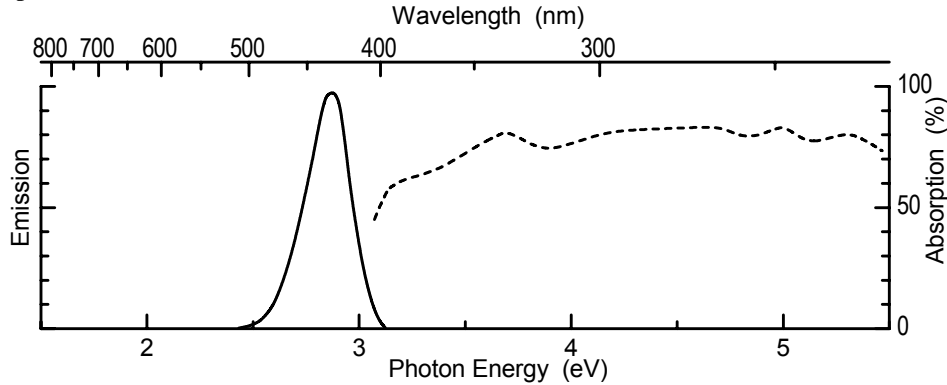
Preparation

Dry blend ingredients.
Fire in molybdenum trays, (99.5 N₂:0.5 H₂), 1025°C, 2 hours.
Cool.
Wash in hot water.
Dry.

Optical Properties

Emission color: Bluish-white body
Emission peak: 425 nm
Emission width (FWHM): 30 nm
Excitation efficiency by UV: ++ (3.40 eV), ++ (4.88 eV)
Excitation efficiency by e-beam: Weakly excited by cathode rays

Spectra

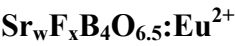


Remark

This contribution is from Madis Raukas.

Reference

1. Peters, T.E., and Baglio, J., Luminescence and structural properties of alkaline earth chloroborates activated with divalent europium, *J. Inorg. Nucl. Chem.*, 32, 1089 (1970).



Composition

Ingredient	Mole %	By weight (g)
Sr(NO ₃) ₂	10.00	63.49
SrF ₂	9.77	61.30
H ₃ BO ₃	80.11	247.36
Eu ₂ O ₃	0.12	2.11

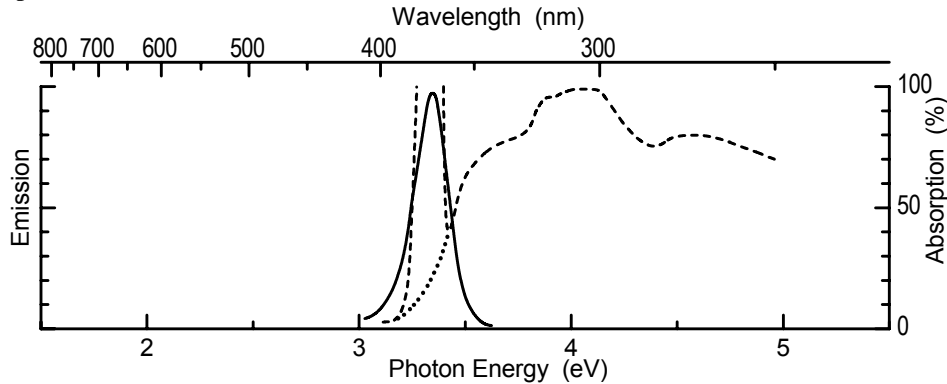
Preparation

Dissolve Eu₂O₃ powder in dilute nitric acid solution and Sr(NO₃)₂ and boric acid in warm water (80°C). Combine these two solutions.
Form a 1:1 solution of acetone and ammonium hydroxide and add to the above solution slowly while stirring vigorously. A fine white precipitate will result and form a slurry.
Cool the slurry to below 20°C, filter, and dry the precipitate in air.
Blend the precipitate with half the SrF₂ and grind.
Place in an open quartz crucible and fire in air at 800°C for 1 hour.
Cool, blend, and grind with the remainder of the SrF₂ into a fine powder. Fire for 2 hours at 890°C in a flow of H₂ in N₂ gas in the same open crucible. Cool and re-grind.

Optical Properties

Emission color: UV
Emission peak: 370 nm
Emission width (FWHM): About 20 nm
Excitation by UV: In a broad range up to about 360 nm
Excitation by e-beam and x-rays: Good excitation by cathode rays

Spectra

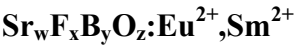


Remarks

- 1. This contribution is from Madis Raukas.
- 2. This is a Eu-sensitized, IR-emitting phosphor, which is used in high- and low-pressure discharge lamps as well as in CRTs. The most efficient version has been determined to be $\text{Sr}_{0.96}\text{F}_{0.62}\text{B}_4\text{O}_{6.5}:\text{Eu}_{0.029}$.

References

- 1. Chenot, C.F., U.S. Pat., 3 649 550 (1972).
- 2. Chenot, C.F., U.S. Pat., 3 448 056 (1969).



Composition

Ingredient	Mole %	By weight (g)
$\text{Sr}(\text{NO}_3)_2$	10.09	126.98
SrF_2	5.43	40.58 g
H_3BO_3	84.12	309.20
Eu_2O_3	0.25	5.28
Sm_2O_3	0.11	2.09

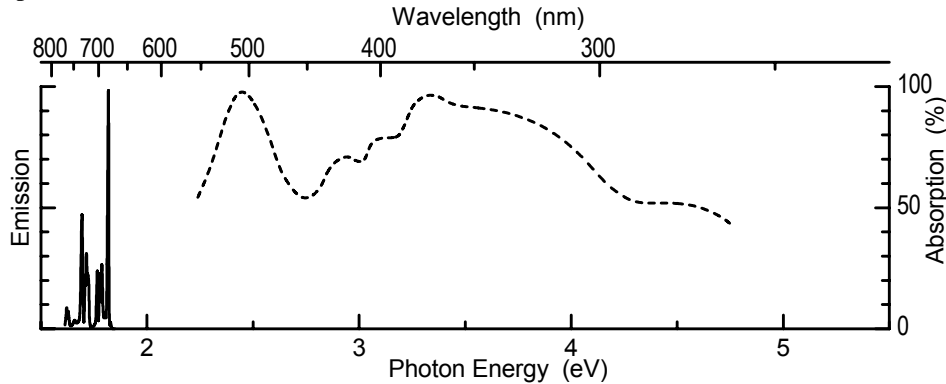
Preparation

Dissolve Eu_2O_3 and Sm_2O_3 powders in dilute nitric acid solution and $\text{Sr}(\text{NO}_3)_2$ and boric acid in warm water (90°C). Combine these two solutions. Form a 1:1 solution of acetone and ammonium hydroxide and rapidly add to the above solution while stirring vigorously. A fine white precipitate will result and form a slurry. The slurry is kept at 80°C for about 2 hours and is cooled to ambient temperature. The resultant is filtered and dried in air. Blend the precipitate with SrF_2 and grind. Place in an open quartz crucible and fire in air at 900°C for 1–2 hours. Cool, blend, and grind into a fine powder. Fire for 2 hours at 900°C in a flow of H_2 in N_2 gas in the same open crucible. Cool and re-grind.

Optical Properties

Emission color: Narrow red and IR
Emission peaks: 684, 693, 697, 703, 723, 725 and 732 nm
Excitation by UV: in broad ranges 250–280, 300–390 nm with additional peaks at 395, 420, and 502 nm due to Sm^{2+}

Spectra



Remarks

1. This contribution is from Madis Raukas.
2. This is a Eu-sensitized, IR-emitting phosphor, which is used in high- and low-pressure discharge lamps as well as CRTs. The most efficient is $\text{Sr}_{0.96}\text{F}_{0.62}\text{B}_4\text{O}_{6.5}:\text{Eu}_{0.029},\text{Sm}_{0.011}$.

References

1. Chenot, C.F., U.S. Pat., 3 649 550 (1972).
2. Chenot, C.F., U.S. Pat., 3 693 006 (1972).
3. Chenot, C.F., U.S. Pat., 3 448 056 (1969).

7.4 Aluminates

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

BaMgAl₁₀O₁₇:Eu,Mn (BAM:Mn)
BaMgAl₁₀O₁₇:Eu (BAM)
CaAl₂O₄:Tb³⁺
CaAl₄O₇:Ce³⁺
CaTi_{0.9}Al_{0.1}O₃:Bi³⁺
CaYAlO₄:Eu³⁺
MgCeAl₁₁O₁₉:Tb³⁺
SrAl₄O₇:Eu³⁺
Sr_xBa_yCl_zAl₂O_{4-z/2}:Mn²⁺,Ce³⁺
Y₃Al₅O₁₂:Ce
Y₃Al₅O₁₂:Ce³⁺
Y₃Al₅O₁₂:Mn⁴⁺
Y₃Al₅O₁₂:Cr³⁺

BaMgAl₁₀O₁₇:Eu,Mn (BAM:Mn)

Composition

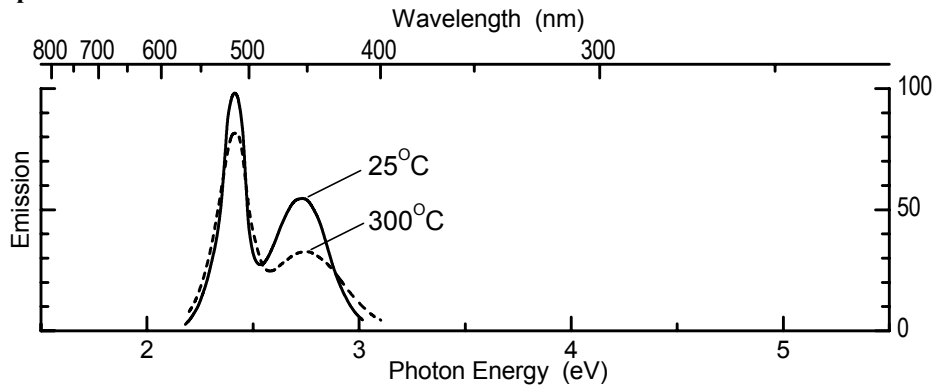
Ingredient	Mole %	By weight (g)
BaCO ₃	80	158
MgO	70	28.2
Al ₂ O ₃	1050 (Al)	536
Eu ₂ O ₃	10 (Eu)	17.6
MnCO ₃	30	34.5
BaF ₂	10	17.5

Preparation

Mix by ball-milling or magnetic stirring in an alcohol and dry in air. Powderize.
Fire in a reducing atmosphere at a temperature of about 1200–1500°C for at least 1 hour. Powderize.

This phosphor can be used in plasma display panels and is in use in fluorescent lamps.
The phosphor remains efficient to high temperatures.

Spectra



Spectra were provided by Madis Raukas.

Remark

This contribution is from Cees Ronda.

BaMgAl₁₀O₁₇:Eu (BAM)

Composition

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

Preparation

Mix by ball-milling or magnetic stirring in an alcohol and dry in air.
Powderize
Fire in reducing atmosphere at a temperature of about 1200–1500°C for at least 1 hour.
This phosphor is used in plasma display panels and in fluorescent lamps. The phosphor remains efficient to high temperatures.

Remark

This contribution is from Cees Ronda.

CaAl₂O₄:Tb³⁺

Structure: Hexagonal

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	100	10
Al ₂ O ₃	100	10.2
Tb ₂ O ₃	1	0.366
B ₂ O ₃	2	0.139

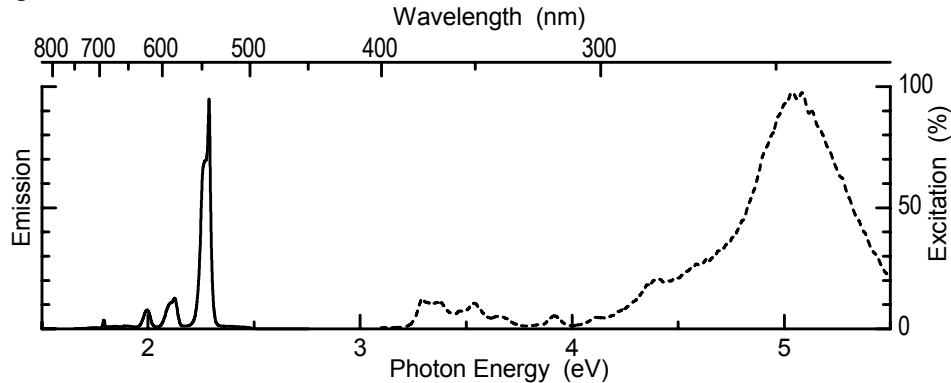
Preparation

- Mix by dry grinding in a mortar for 30 minutes.
Press into pellets with a hydraulic press machine at 40,000 psi.
1. Fire in N₂, 900°C, 2 hours.
Powderize.
Grind and press into pellets again.
 2. Fire in N₂, 1400°C, 3 hours.

Optical Properties

Emission color: Green
Emission peak: 543 nm, with smaller peaks at 590 and 620 nm
Emission width (FWHM): 0.48 eV
Excitation efficiency by UV: ++ (3.40 eV), + (4.88 eV)

Spectra

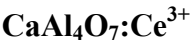


Remarks

- 1. This contribution is from Weiyi Jia.
- 2. This compound is known as calcium aluminate.

References

- 1. Jia, D., Meltzer, R.S., Yen, W.M. et al., Green phosphorescence of $\text{CaAl}_2\text{O}_4:\text{Tb}^{3+},\text{Ce}^{3+}$ through persistence energy transfer, *Appl. Phys. Lett.*, 80, 1535 (2002).
- 2. Jia, D., Wang, X.J., Jia, W., et al., Persistent energy transfer in $\text{CaAl}_2\text{O}_4:\text{Tb}^{3+},\text{Ce}^{3+}$, *J. Appl. Phys.*, 93, 148 (2003).



Structure: Monoclinic

Composition

Ingredient	Mole %	By weight (g)
CaCO_3	100	10
Al_2O_3	200	20.4
$\text{Ce}(\text{NO}_3)_3 \cdot 4\text{H}_2\text{O}$	2	0.366
B_2O_3	2	0.139

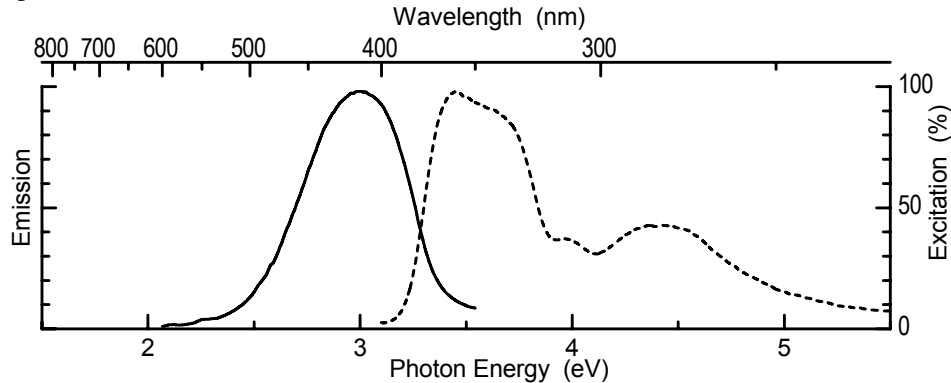
Preparation

- Mix by dry grinding in a mortar for 30 minutes.
Press into pellets with a hydraulic press machine at 40,000 psi
- 1. Fire in N_2 , 900°C, 2 hours.
Powderize.
Grind and press into pellets again.
 - 2. Fire in 95% N_2 + 5% H_2 , 1400°C, 3 hours.

Optical Properties

Emission color: Violet
Emission peak: 407 nm
Emission width (FWHM): 4580 cm^{-1}
Excitation efficiency by UV: ++ (3.40 eV), ++ (4.88 eV)

Spectra



Remarks

- 1. This contribution is from Weiyi Jia.
- 2. This compound is known as calcium tetra-aluminate.

Reference

- 1. Jia, W., Unpublished data.



Structure: Orthorhombic

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	90	9.01
TiO ₂	90	7.18
Bi ₂ O ₃	10	4.66
Al ₂ O ₃	10	1.02

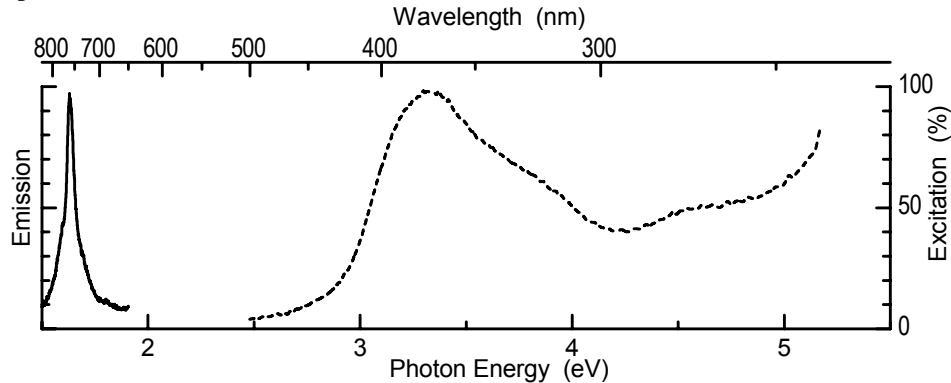
Preparation

- Mix by dry grinding or milling.
Press into pellets.
- 1. Fire in air, 1000°C, 1 hour.
Powderize.
Grind and press into pellets again.
 - 2. Fire in open quartz boats, air, 1300°C, 3 hours.

Optical Properties

Emission color: Deep red
Emission peak: 760 nm
Emission width (FWHM): 440 cm⁻¹
Excitation efficiency by UV: + (3.40 eV), + (4.88 eV)

Spectra



Remarks

- 1. This contribution is from Weiyi Jia.
- 2. This compound is known as calcium titanate.

Reference

- 1. Jia, W., Perez-Andujar, A., and Rivera, I., Energy transfer between Bi³⁺ and Pr³⁺ in doped CaTiO₃, *J. Electrochem. Soc.*, 150, 161 (2003).



Structure: Tetrahedral

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	100	10.01
Y ₂ O ₃	100	22.56
Al ₂ O ₃	100	10.19
Eu ₂ O ₃	1	0.352
B ₂ O ₃	3	0.209

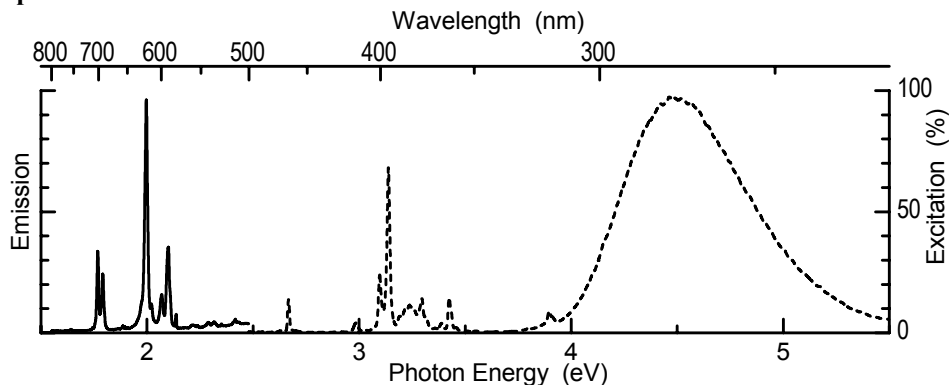
Preparation

- Mix by dry grinding in a mortar for 30 minutes.
Press into pellets with a hydraulic press machine at 40,000 psi.
- 1. Fire in air, 1000°C, 2 hours.
Powderize.
Grind and press into pellets again.
 - 2. Fire in air, 1400°C, 3 hours.

Optical Properties

Emission color: Red
Emission peak: 621 nm, with weaker peaks at 588 and 702 nm
Excitation efficiency by UV: + (3.40 eV), + (4.88 eV)

Spectra



Remarks

- 1. This contribution is from Weiyi Jia.
- 2. This compound is also known as calcium-yttrium aluminate.

Reference

- 1. Jia, W., Unpublished data.



Structure: Hexagonal

Composition

Ingredient	Mole %	By weight (g)
(MgCO ₃) ₄ ·Mg(OH) ₂ ·3H ₂ O·2	9.0	
CeO ₂	6	10.3
Al ₂ O ₃	55	56.1
Tb ₄ O ₇	1	7.5
* Desirable ingredient: (Ce,Tb)O _x (Oxide of coprecipitate as a Ce-Tb ingredient).		

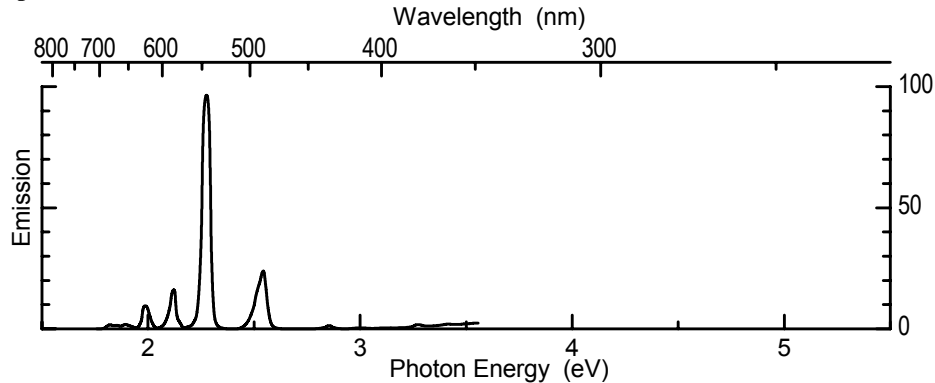
Preparation

Mix by automatic mill.
Fire in alumina crucibles, stagnant air, 1650°C, 2 hours.
Powderize by automatic mill.
Re-fire, in alumina boats, reducing atmosphere (95% N₂/5% H₂), 1600°C, 2 hours.
Powderize.
Store in a well-sealed container.

Optical Properties

Emission peak: 2.28 eV (543 nm)
Emission width (FWHM): 0.048 eV (9.76 nm)
Excitation efficiency by UV: -(3.40eV), +++(4.88eV)

Spectra

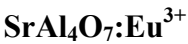


Remark

This contribution is from Shozo Oshio.

Reference

1. Oshio, S., Shigeta, T., and Matsuoka, T., U.S. Pat., 6 290 875 (2001).



Structure: Monoclinic

Composition

Ingredient	Mole %	By weight (g)
SrCO ₃	100	10.01
Al ₂ O ₃	200	7.98
Eu ₂ O ₃	1	0.352
B ₂ O ₃	3	0.209

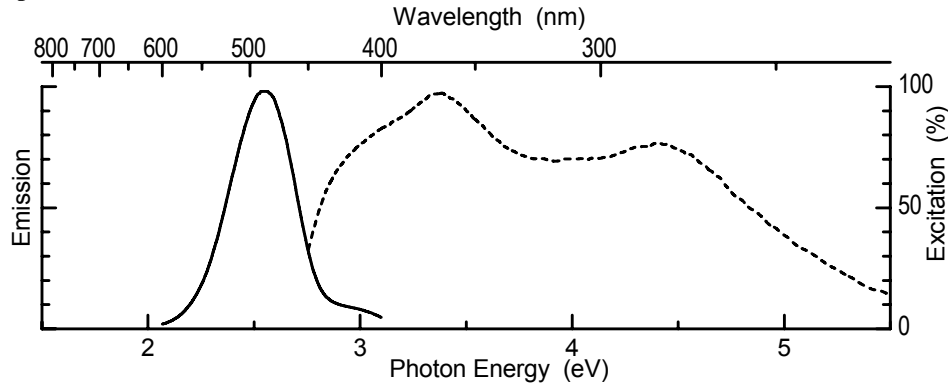
Preparation

- Mix by dry grinding in a mortar for 30 minutes.
Press into pellets with a hydraulic press machine at 40,000 psi.
1. Fire in air, 1000°C, 2 hours.
Powderize.
Grind and press into pellets again.
 2. Fire in air, 1350°C, 3 hours.

Optical Properties

Emission color: Red
Emission peak: 612 nm
Excitation efficiency by UV: + (3.40 eV), + (4.88 eV)

Spectra

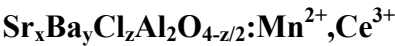


Remarks

- 1. This contribution is from Weiyi Jia.
- 2. This compound is also known as strontium tetra-aluminate.

Reference

- 1. Jia, W., Unpublished data.



Composition

Ingredient	Mole %	By weight (g)
Sr(OH) ₂ ·8H ₂ O	7.80	60.86
Ba(OH) ₂ ·8H ₂ O	4.26	39.43
BaCl ₂	19.17	117.24
Al(OH) ₃	68.10	156.02
Mn(NO ₃) ₂ (52% solution)	0.34	1.79
Ce(NO ₃) ₃ (47.5% solution)	0.34	2.64

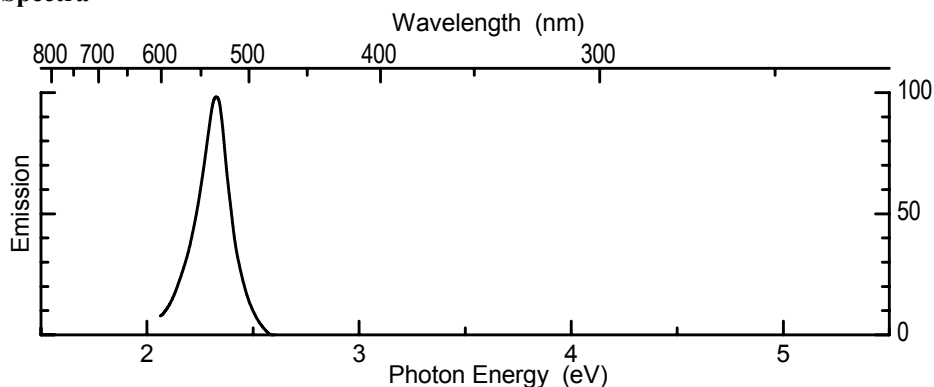
Preparation

Wet blend all components, powders, and standard solutions in acetone for 15 minutes. Dry the admixture in air at 160°C for 5 hours. Re-blend and place in an open container. Fire at a temperature below 400°C for an additional 5 hours. Increase the temperature to 1100–1200°C and fire for 4 hours in a flow of 0.4% H₂ in N₂ gas. Cool to ambient temperature and sieve admixture through 100-mesh stainless screen. Re-fire at 1100–1200°C for about 4 hrs, in a nitrogen atmosphere containing 4% H₂.

Optical Properties

Emission color: Green
Emission peak: 512 nm
Emission width (FWHM): 32 nm
Excitation by UV: In a broad range suitable for mercury discharge
Excitation by e-beam and x-rays: Specified as a phosphor for x-ray intensifiers

Spectra



Remarks

1. This contribution is from Madis Raukas.
2. This is a cerium-sensitized xerographic lamp phosphor.
3. The approximate formula is $\text{Sr}_{0.229}\text{Ba}_{0.688}\text{Cl}_{1.126}\text{Al}_2\text{O}_{0.3437}:\text{Mn}_{0.005},\text{Ce}_{0.005}$.

References

1. Chenot, C.F., U.S. Pat., 3 649 550 (1972).
2. Chenot, C.F., U.S. Pat., 3 693 006 (1972).
3. Chenot, C.F., U.S. Pat., 3 448 056 (1969).

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

Structure: Cubic (garnet)

Composition

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

Preparation

Mix by ball-milling or magnetic stirring in water and dry in air.

Powderize.

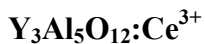
Firing should occur in reducing atmosphere, (e.g. forming gas or CO, at a temperature of about 1300–1500°C for at least 1 hour).

The emission spectrum consists of two bands, due to the spin-orbit split ground state of Ce^{3+} . The material has a pronounced daylight color, as Ce^{3+} absorbs in the blue part of the spectral region and emits yellow light. The spectral position of the emission band of Ce^{3+} can be varied by replacing part of the Al by (e.g., Ga).

This phosphor is used in white LED lamps and also in high-pressure Hg lamps. In LEDs it partially converts blue light into yellow light, resulting in white light. In high-pressure Hg lamps it reduces the color temperature of the light.

Remark

This contribution is from Cees Ronda.



Structure: Cubic (garnet)

Composition

Ingredient	Mole %	By weight (g)
Y ₂ O ₃	100	10
Al ₂ O ₃	200	9.03
Ce(NO ₃) ₃ ·4H ₂ O	2	0.555
B ₂ O ₃	2	0.062

Preparation

Mix by dry grinding in a mortar for 30 minutes.

Press into pellets with a hydraulic press machine at 40,000 psi

Dry in air. Powderize when dry.

1. Fire in N₂, 1000°C, 2 hours.
Powderize.
Press into pellets again.
2. Fire in 95% N₂ + 5% H₂, 1400°C, 3 hours.

Optical Properties

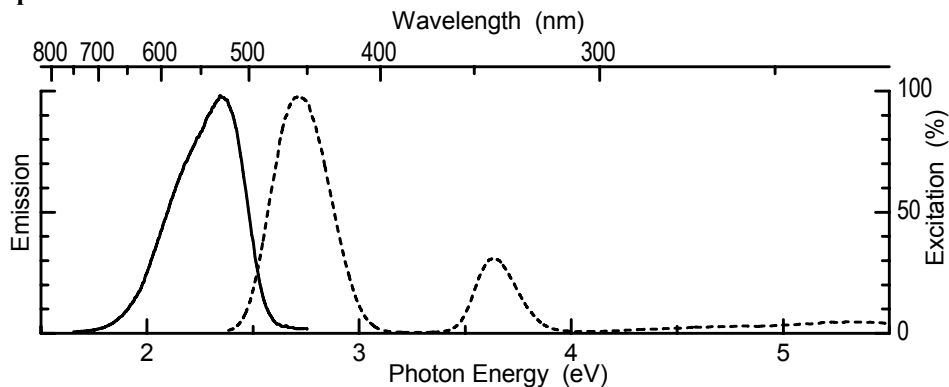
Emission color: Violet

Emission peak: 528 nm

Emission width (FWHM): 4580 cm⁻¹

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

Spectra

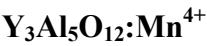


Remark

This contribution is from Weiyi Jia.

Reference

1. Jia, W., and Rivera, E., Unpublished data.



Structure: Cubic (garnet)

Composition

Ingredient	Mole %	By weight (g)
Y ₂ O ₃	33	10
Al ₂ O ₃	66	9.03
MnCO ₃	19	0.051
B ₂ O ₃	2	0.062

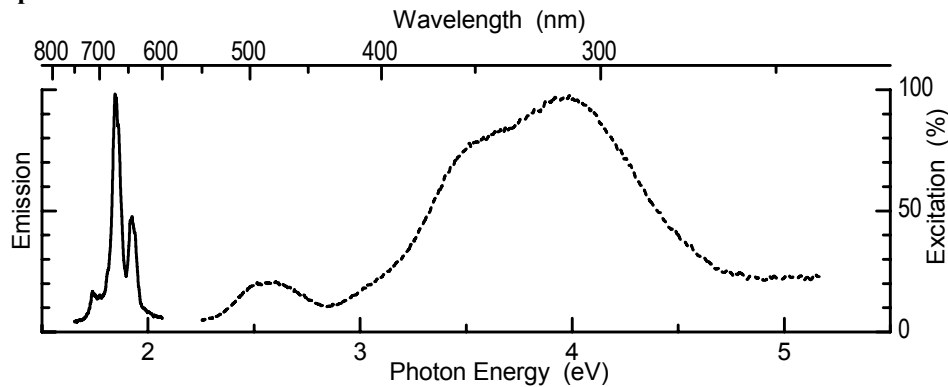
Preparation

- Mix by dry grinding in a mortar for 30 minutes.
1. Fire in N₂, 900°C, 2 hours.
Grind.
 2. Fire in 95% N₂ + 5% H₂, 1400°C, 3 hours.

Optical Properties

Emission color: Deep red
Emission peak: 640 and 667 nm
Emission width (FWHM): 4580 cm⁻¹
Excitation efficiency by UV: ++ (3.40 eV), ++ (4.88 eV)

Spectra

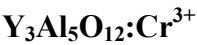


Remark

This contribution is from Weiyi Jia.

Reference

1. Jia, W., and Rivera, E., Unpublished data.



Structure: Cubic (garnet)

Composition

Ingredient	Mole %	By weight (g)
For precursor:		
Y(NO ₃) ₃ ·6H ₂ O	4.04	—
Al(NO ₃) ₃	6.72	—
Cr(NO ₃) ₃ ·9H ₂ O	0.0067	—

Fuels:

$\text{CH}_6\text{N}_4\text{O}$ (carbohydrazide)	1.5 (fuel/oxidizer ratio)
$\text{C}_2\text{H}_5\text{NO}_2$ (glycine)	1.7
$\text{CH}_4\text{N}_2\text{O}$ (urea)	2.5

Preparation

Mix the precursor and the fuel thoroughly in a glass mortar. Place the mixture in an appropriate flameproof dish and dissolve using de-ionized water (~50 ml). Place the dish into a muffle furnace, preheated to 500°C. The solution boils, dehydrates, and ruptures into a flame in 5–10 minutes; the flame lasts for about 15 sec. For carbohydrazide and urea fuels, the result is a foamy powder which can be powdered. When glycine is used, an amorphous ash is produced that needs to be annealed in air at 1000°C for 1 hour. Powders should be placed in well-sealed containers.

Optical Properties

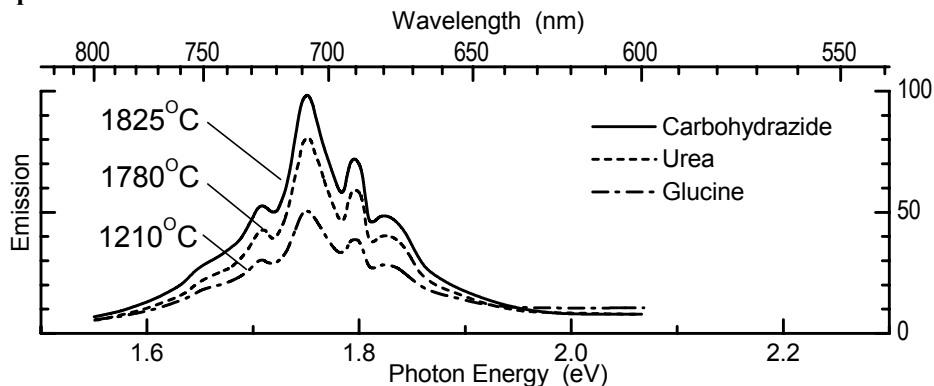
Emission color: Deep red

Emission peaks: 1.8, 1.75, and 1.71 eV; (688, 707, and 725 nm)

Emission width: 0.05 eV at 707 nm

Excitation efficiency by UV: 2.85 eV (435 nm)

Spectra



Remark

1. This contribution is from Lauren E. Shea-Rohwer.
2. The combustion flame temperature is dependent on the fuel used; carbohydrazide produces the highest temperature (1825°C) while glycine produces the lowest (1210°C). The spectra obtained have the same structure but the materials produced by higher temperatures show higher intensities.

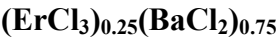
References

1. Sluzky, E. Lemoine, M., and Hesse, K., Phosphor development for alpha-silicon liquid-crystal light valve projection display, *J. Electrochem. Soc.*, 141, 3172 (1994).
2. Hess, N.J. et al., Synthesis and crystallization of yttrium-aluminum-garnet and related-compounds, *J. Mater. Sci.*, 29, 1873 (1994).
3. Shea, L.E. et al., *J. Am. Ceram. Soc.*, 79, 3257 (1996).
Shea Rohwer, L.E., and Walko, R.J., Synthesis and Characterization of Phosphors for Flat Panel Displays, *Handbook of Luminescence, Display Materials, and Devices*, H.S. Nalwa and L.S. Rohwer, Eds., American Scientific Publishers, Stevenson Ranch, CA, (2003).

7.5 Halides and Oxyhalides

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

(ErCl₃)_{0.25}(BaCl₂)_{0.75}
Ba₂Mg₃F₁₀:Eu²⁺
BaFBr:Eu²⁺
BaFCl:Eu²⁺,Pb²⁺
BaFCl:Eu²⁺
BaMg₃F₈:Eu²⁺,Mn²⁺
BaY₂F₈:Er³⁺,Yb³⁺
CsI:Tl
LaOBr:Tb³⁺
LaOBr:Tm³⁺
NaYF₄:Er³⁺,Yb³⁺
YF₃:Er³⁺,Yb³⁺
YF₃:Tm³⁺,Yb³⁺



Composition

Ingredient	Mole %	By weight (g)
ErCl ₃	25	—
BaCl ₂	75	—

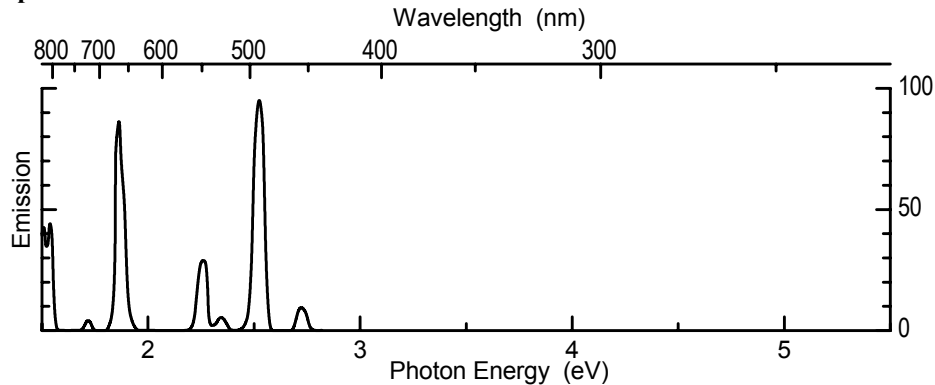
Preparation

Mix thoroughly in dry, inert box.
Heat at 1000°C after eliminating water and O₂ in stream of N₂, Ar, and Cl₂.
Crush after cooling and seal in glass capsule.

Optical Properties

Emission color: Mostly green
Emission peak: 550 nm
Excitation efficiency by IR: Can be excited with 800, 1000, and 1500 nm light

Spectra

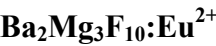


Remarks

- 1. This contribution is from Hajime Yamamoto.
- 2. The phosphor is hygroscopic.

Reference

- 1. Wang, Y., and Ohwaki, J., High-efficiency infrared-to-visible up-conversion of Er³⁺ in BaCl₂, *J. Appl. Phys.*, 74, 1272 (1993).



Composition

Ingredient	Mole %	By weight (g)
BaF ₂	38.80	68.04
MgF ₂	60.00	37.39
EuF ₂	1.20	2.28

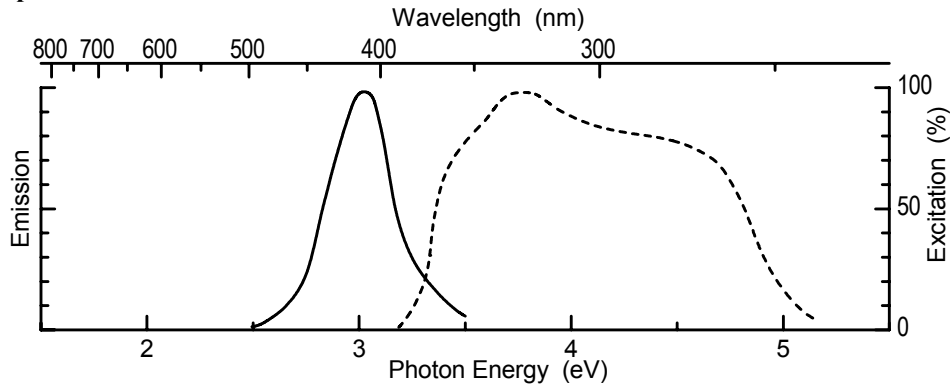
Preparation

Dry mix.
Fire in 5% volume of H₂ in N₂, 830°C, 2 hours.
Powderize.

Optical Properties

Emission color: Deep blue
Emission peak: 415 nm
Excitation efficiency by UV: In a broad range, peaking at around 330 nm
Excitation efficiency by e-beam: Good for x-ray intensifier screens

Spectra



Remarks

- 1. This contribution is from Madis Raukas.
- 2. The firing temperature can be lower (down to 700–750°C) for undoped barium magnesium fluoride; higher temperature is required for activator diffusion. Although not producing as efficiently luminescent material, an inert or even air atmosphere can be used for the reaction.

Reference

- 1. Wolfe, R.W., and Messier, R.F., U.S. Pat., 4 112 328 (1978).

BaFBr:Eu²⁺

Structure: Tetragonal

Preparation

Intimate mixtures of raw materials (BaF₂, BaBr₂, EuF₃) are fired in a H₂/N₂ atmosphere at 600–1000°C (desirably at 700°C). Excess ammonium halide may be used as flux. The phosphors are ground and re-fired. The fired material is ground, washed with cold water or organic liquids, dried, and sieved. Before firing, the materials are dried at 200–300°C. Care is taken to avoid oxygen during firing, and to protect from dissolving in water during washing.

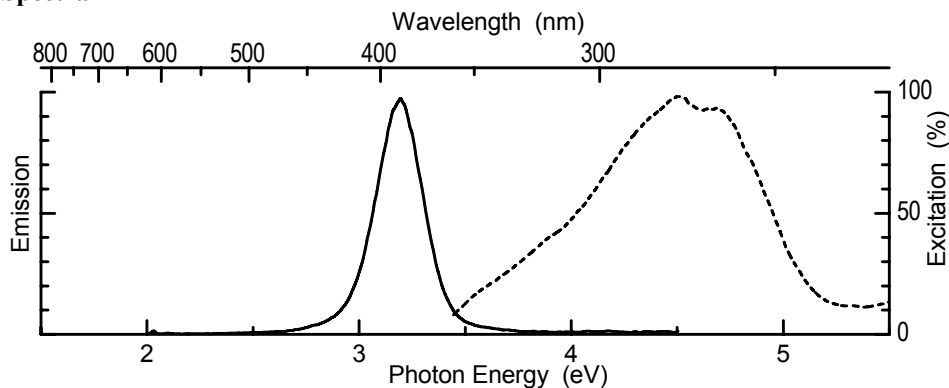
Optical Properties

Emission color: UV/blue

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

Excitation efficiency by e-beam: +

Spectra



Remarks

1. This contribution is from Masaaki Tamatani.
2. This compound is photostimulable and, therefore, useful for radiography.

References

1. Takahashi, K., Phosphors for X-ray and ionizing radiation, *The Phosphor Handbook*, Eds. Shionoya, S., and Yen, W.M., CRC Press, New York (1998).
2. Radzhabov, E., and Kurobori, T., Photoionization processes in barium fluorohalide crystals doped with Eu²⁺, *J. Phys., Condens. Matter*, 13, 1159 (2001).
3. Kotera et al., Japanese Patent Kokai, 55 12143, 55 12144, 55 12145.
4. Kotera et al., U.S. Pat., 439 458 1.

BaFCl:Eu²⁺,Pb²⁺

Composition

Ingredient	Mole %	By weight (g)
BaF ₂	49.52	14.70
BaCl ₂	49.25	17.36
EuCl ₂	1.13	0.428
PbF ₂	0.0096	0.040

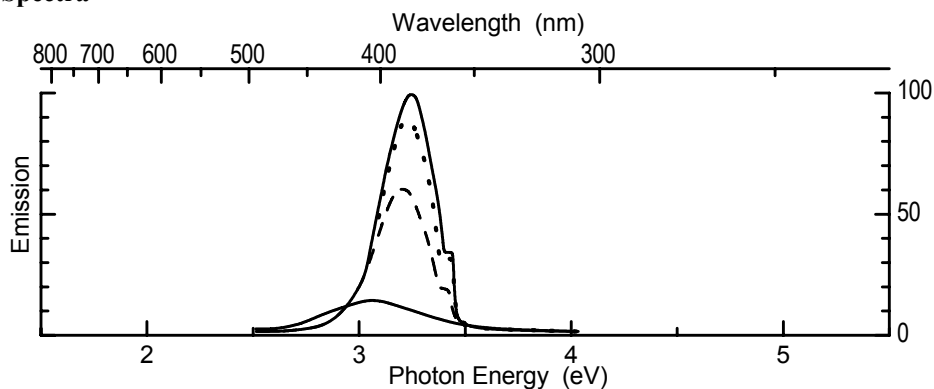
Preparation

Dry blend together.
Fire in N₂, ~ 830°C, 2 hours.
Sieve to -200 +355-mesh size.

Optical Properties

Emission peak: Around 385 nm
Emission width (FWHM): About 35 nm
Excitation by e-beam: Specified as a phosphor for x-ray intensifiers

Spectra



Remarks

1. This contribution is from Madis Raukas.
2. This x-ray phosphor is represented by the formula Ba_{0.9989}Eu_{0.01}Pb_{0.0001}FCl.
3. Lead is an important additive for brightness enhancement and its amount can be varied from about 10 to 1000 molar ppm parts of host, the optimum being at around 100 ppm. For the same purpose, lead can be replaced by aluminum or thallium in slightly different proportions (10–50 ppm Tl, 8,000–15,000 ppm Al).
4. As a further improvement, yttrium or lithium can be used for reducing the persistence (see the second reference).

References

1. Wolfe, R.W., and Messier, R.F., U.S. Pat., 3 951 848 (1976).
2. Wolfe, R.W., and Messier, R.F., U.S. Pat., 4 057 508 (1977).
3. Dietz, H.J., U.S. Pat., 2 303 917 (1942).
4. Uhle, O., U.S. Pat., 2 303 963 (1942).



Structure: Tetragonal

Preparation

Stir the following overnight:
 $(1-2x)\text{BaF}_2(\text{s}) + \text{BaCl}_2(\text{aq}) + 2x \text{EuF}_2(\text{s}) \rightarrow 2 \text{Ba}_{1-x}\text{Eu}_x\text{FCl}(\text{s})$
A stoichiometric excess of aqueous BaCl₂ solution is used.
Separate the precipitate.
Blend with BaCl₂ to serve as a flux.
Fire in a 5% H₂-N₂ mixture at 600–1000°C for 1 hour.
Spray dry the slurry of BaFCl:Eu and aqueous BaCl₂.

Heat the resultant phosphor/flux intermediate at 1000°C.

Wash.

Store in a well-sealed container.

Optical Properties

Emission color: UV/blue

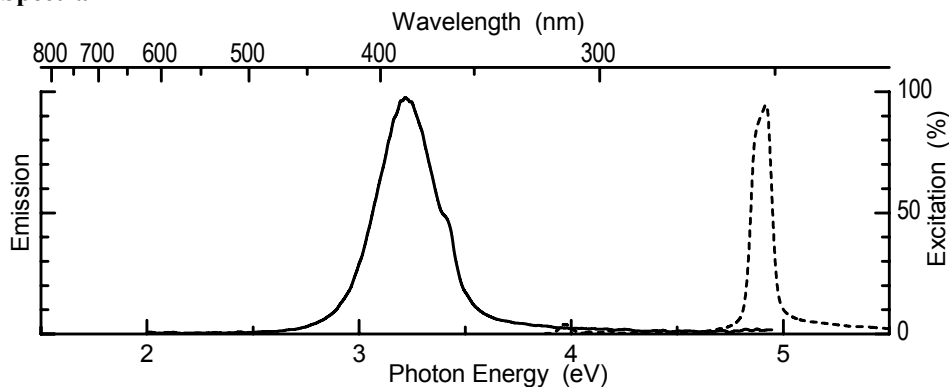
Emission peak: 380 nm

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

Excitation efficiency by e-beam: +

Decay to 1/e: 5.7×10^{-6} sec (UV exc.)

Spectra



Remarks

1. This contribution is from Masaaki Tamatani.
2. This compound is photostimulable.

References

1. Issler, S.L., and Torardi, C.C., Solid state chemistry and luminescence of X-ray phosphors, *J. Alloys Ingredients*, 229, 54 (1995).
2. Ferretti, A., U.S. Pat., 4 524 016 (1985).
3. Radzhabov, E., and Kurobori, T., Photoionization processes in barium fluorohalide crystals doped with Eu^{2+} , *J. Phys. Condens. Matter*, 13, 1159 (2001).



Composition

Ingredient	Mole %	By weight (g)
BaF ₂	23.53	41.26
MgF ₂	70.59	43.99
EuF ₂	1.18	2.23
MnF ₂	4.70	6.07

Preparation

Dry blend together.

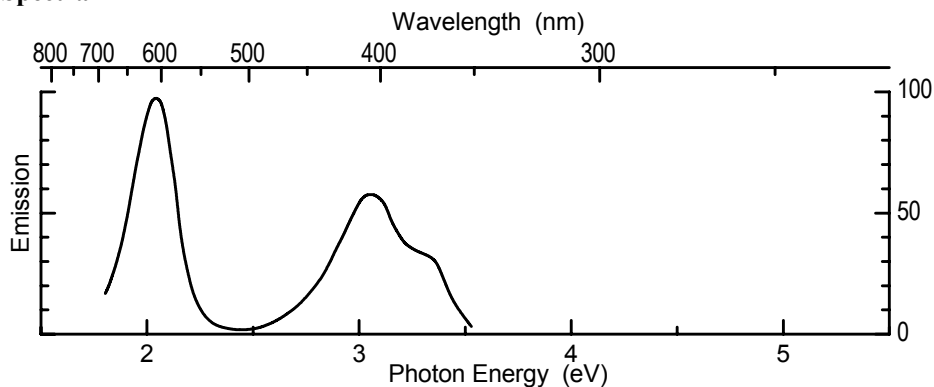
Fire in a flow of 5% H₂ in N₂ at 830°C for 2 hours.

Optical Properties

Emission color: Deep blue (Eu^{2+})

Emission peaks: Two bands. 410 nm (Eu^{2+}) and 610 nm (Mn^{2+})
 Emission width (FWHM): 80 nm (Mn^{2+})
 Excitation efficiency by UV: In a broad range, peaking at around 330 nm
 Excitation by e-beam: Good

Spectra



Remarks

- This contribution is from Madis Raukas.
- The ingredients in the ratio shown above yields the composition of $\text{Ba}_{1.95}\text{Eu}_{0.05}\text{Mg}_{2.80}\text{Mn}_{0.20}\text{F}_{10}$.
- Forming undoped barium magnesium fluoride requires lower firing temperature (700–750°C), higher temperature is required for activator diffusion.

Reference

- Wolfe, R.W., and Messier, R.F., U.S. Pat., 4 112 328 (1978).



Structure: Monoclinic

Composition

Ingredient	Mole %	By weight (g)
YF ₃	78	
YbF ₃	20	
Er F ₃	2	
BaF ₂	100	
ZnF ₂	10	

Preparation

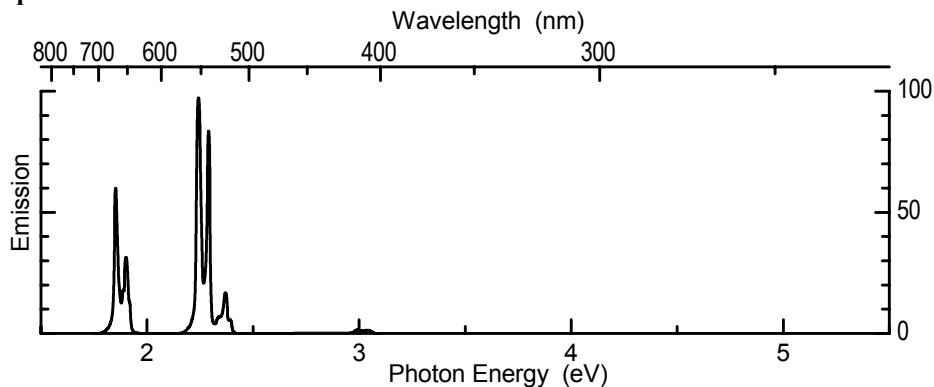
Mix thoroughly in ethanol.
 Fire in a capped alumina crucible in inert or fluorizing atmosphere above 1100°C.
 Wash with water after cooling to remove flux.

Optical Properties

Emission color: Green
 Emission peak: 550 nm

Excitation efficiency by UV: Weak red emission
 Excitation efficiency by e-beam: Weak red emission
 Excitation efficiency by infrared light: Efficient under 970 nm

Spectra



Remarks

1. This contribution is from Hajime Yamamoto.
2. Luminescence characteristics are similar to those of YF₃.

References

1. Mita, Y., Detection of 1.5-μm wavelength laser-light emission by infrared-excitabile phosphors, *Appl. Phys. Lett.*, 39, 587 (1981).
2. Kaminskii, A.A. et al., Spectroscopic and laser properties of Er³⁺-doped monoclinic BaY₂F₈ single-crystals, *Opt. Quant. Electron.*, 22, S95 (1990).

CsI:Tl

Structure: Cubic

Preparation

Single crystals can be grown by several conventional methods:

1. zone melting in a closed vertical crucible after Bridgman–Stockbarger
2. grown from the melt after Czochralski.

Thallium iodide is mixed with CsI before heating, and dissolved in the melt (melting point 623°C).

Optical Properties

Emission color: Green

Emission peak: 550 nm

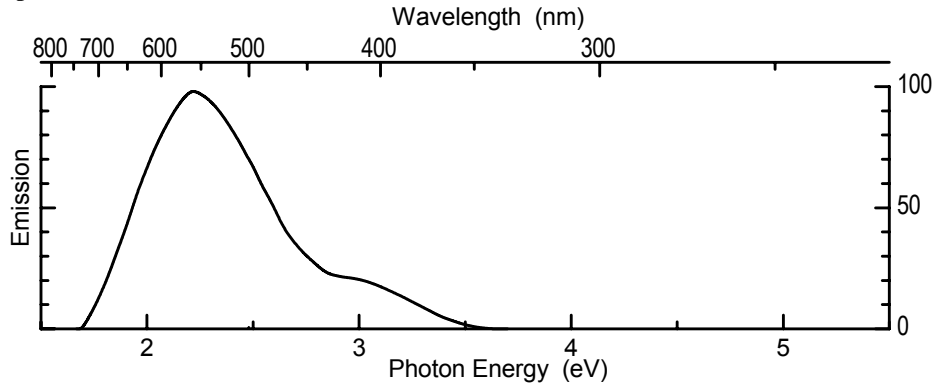
Absorption edge: 4.13 eV (299 nm), 4.61 eV (269 nm), 5.14 eV (241 nm)

Excitation efficiency by UV: + (4.88 eV)

Excitation efficiency by e-beam: ++

Decay to 1/e: 0.98×10^{-6}

Spectra



Spectrum of the emission under x-ray excitation.

Remarks

- 1. This contribution is from Masaaki Tamatani.
- 2. The luminescence intensity is nearly constant for Tl^{+} concentrations between 0.06 and 0.3 mol%.
- 3. During crystal growth, some of the thallium may be lost by evaporation.

References

- 1. Grabmaier, B.C., Crystal scintillators, *IEEE Trans. Nucl. Sci.* NS-31, 372 (1984).
- 2. Blasse, G., and Grabmaier, B.C., *Luminescent Materials*, Springer-Verlag, Heidelberg (1994).
- 3. Birks, J.B., The theory and practice of scintillation counting, Pergamon Press, London (1964).

LaOBr:Tb³⁺

Structure: Tetragonal

Composition

Ingredient	Mole %	By weight (g)
La ₂ O ₃	19.6	100
Tb ₄ O ₇	0.2	2.3
HNO ₃	39.1	38.7
Na ₂ CO ₃	2.0	3.3
NH ₄ Br	39.1	60.1

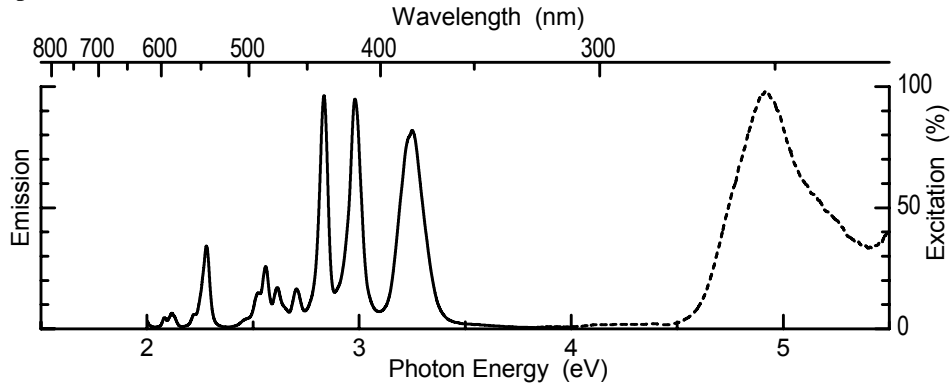
Preparation

- Combine the La₂O₃, Tb₄O₇, and HNO₃. Blend with the Na₂CO₃, and NH₄Br. Ball-mill the powder with a grinding media and a liquid vehicle, such as water.
- 1. Fire in air, 400–500°C, 1 hour. Powderize and reblend powder.
 - 2. Fire in air, 800–1100°C, 1 hour. Powderize, wash, filter, and dry.

Optical Properties

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

Spectra



Remarks

- 1. This contribution is from Masaaki Tamatani.
- 2. Alkali bromide formed by the interaction of alkali carbonate and ammonium bromide serves as a re-crystallizing agent.

References

- 1. Rabatin, J.G., U.S. Pat., 3 617 743 (1971).
- 2. Rabatin, J.G., Tb activated rare earth oxyhalides for x-ray intensifying screen, *Electrochem. Soc. Spring Meeting*, Abstr. 102 (1974).
- 3. Blasse, G., and Brill, A., Investigations of Tb³⁺-activated phosphors, *Philips Res. Rep.*, 22, 481 (1967).
- 4. Holsa, J. et al, Concentration quenching of Tb³⁺ luminescence in LaOBr and Gd₂O₂S phosphors, *Mater. Res. Bull.*, 14, 1403 (1979).



Structure: Tetragonal

Composition

Ingredient	Mole %	By weight (g)
NH ₄ Br	—	—
Tm ₂ O ₃	—	—
La ₂ O ₃	—	—

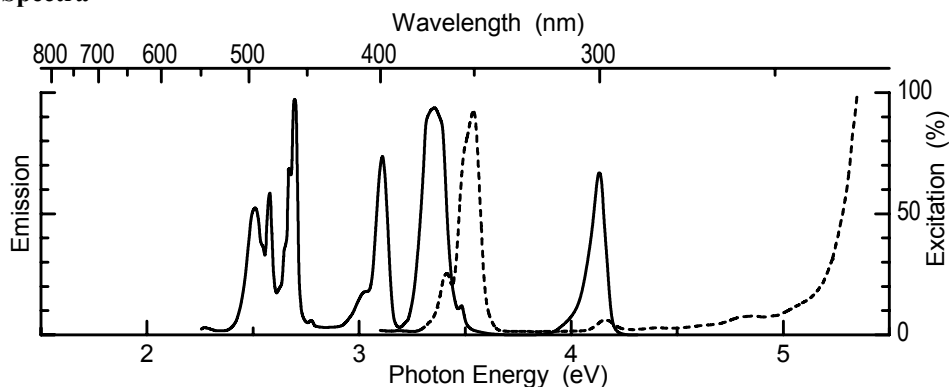
Preparation

(1-x)La₂O₃ + xTm₂O₃ + 2NH₄Br.
Fire in air, 800°C.
Ammonium bromide serves as the brominating agent, while potassium bromide acts as the flux.

Optical Properties

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

Spectra



Remarks

1. This contribution is from Masaaki Tamatani.
2. If water vapor sensitivity is a problem, add some potassium antimony tartrate to the final product.

References

1. Issler, S.L., and Torardi, C.C., Solid state chemistry and luminescence of X-ray phosphors, *J. Alloys Ingredients*, 229, 54 (1995).
2. Rabatin, J.G., U.S. Pat., 3 591 516 (1971).
3. Rabatin, J.G., U.S. Pat., 4 208 470 (1978).



Structure: Trigonal

Composition

Ingredient	Mole %	By weight (g)
YF ₃	57	100
YbF ₃	39	107.9
Er F ₃	4	10.8
Na ₂ SiF ₆	100	226.2

Preparation

Mix Na₂SiF₆ with the proper amount of (Y,Yb,Er)F₃, which has been precipitated from aqueous nitrate solution with HF solution.

Dry.

Fire in capped Pt crucibles, in Ar atmosphere, 630°C, for 2 hours.

NaF produced during decomposition of Na₂SiF₆ acts as flux and forms NaYF₄ lattice.

Optical Properties

Emission color: Green

Emission peak: 550 nm

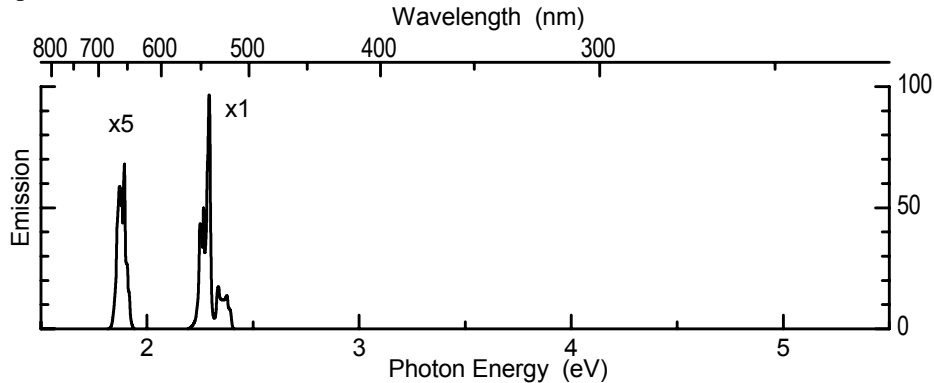
Excitation efficiency by IR: Efficient at 970-nm wavelength

Excitation efficiency by UV: Weak red emission

Excitation efficiency by e-beam: Weak red emission

Excitation by infrared light: Efficient under 970nm

Spectra

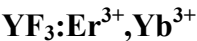


Remarks

- 1. This contribution is from Yoh Mita.
- 2. Luminescence characteristics are similar to those of YF₃ but more intense emission is reported.

Reference

- 1. Kano, T., Yamamoto, H., and Otomo, Y., NaLnF₄-Yb³⁺,Er³⁺ (Ln-Y,Gd,La) — efficient green-emitting infrared-excited phosphors, *J. Electrochem. Soc.*, 119, 1561 (1972).



Structure: Orthorhombic

Composition

Ingredient	Mole %	By weight (g)
YF ₃	78	—
YbF ₃	20	—
ErF ₃	2	—
ZnF ₂	10	—

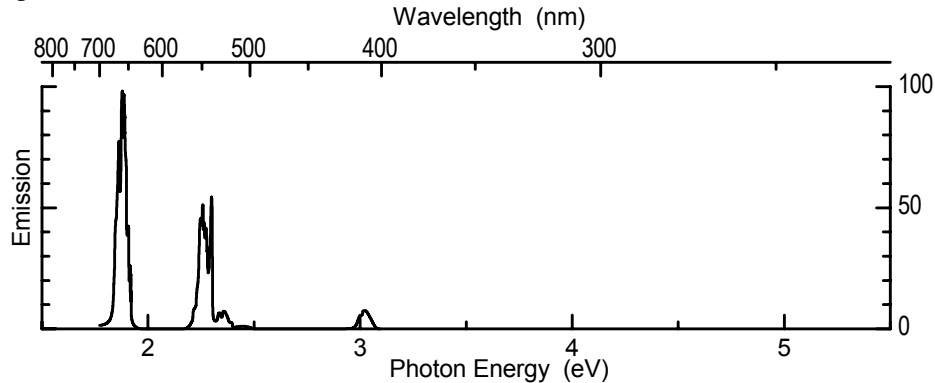
Preparation

Mix thoroughly in ethanol.
Fire in a capped alumina crucible in inert or fluorizing atmosphere above 1100°C.
Wash with water after cooling to remove flux.

Optical Properties

Emission color: Green
Emission peak: 550 nm
Excitation efficiency by UV: Weak
Excitation efficiency by e-beam: Weak
Excitation efficiency by infrared light: Efficient under 970-nm excitation

Spectra

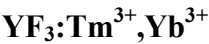


Remarks

- 1. This contribution is from Hajime Yamamoto.
- 2. The green emission is accompanied with red emission, which may be predominant upon higher incorporation of Er³⁺ and Yb³⁺ or partial oxidization. The green emission is observed also under 800 or 1500 nm wavelength light, but higher content of Er dopant is required for obtaining efficient emission.

Reference

- 1. Johnson, L.F. et al., Comments on materials for efficient infrared conversion, *Appl. Phys. Lett.*, 15, 48 (1969).



Structure: Orthorombic

Composition

Ingredient	Mole %	By weight (g)
YF ₃	74	—
YbF ₃	35	—
TmF ₃	0.2	—
ZnF ₂	10	—

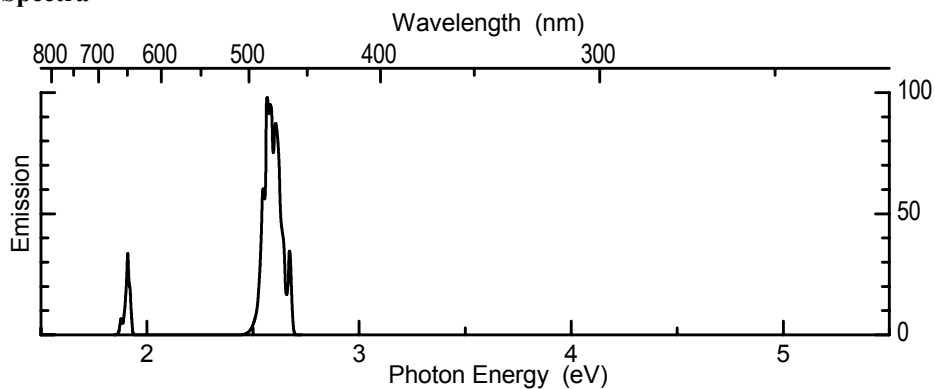
Preparation

Mix thoroughly in ethanol.
Fire in a capped alumina crucible in inert or fluorizing atmosphere above 1100°C.
Wash with water after cooling to remove flux.

Optical Properties

Emission color: Pinkish-blue
Excitation efficiency by IR: Excitable with 970-nm light

Spectra



Remarks

1. This contribution is from Yoh Mita.
2. Blue emission is accompanied by red emission.

Reference

1. Johnson, L.F. et al., Comments on materials for efficient infrared conversion, *Appl. Phys. Lett.*, 15, 48 (1969).

7.6 CaS and ZnS-Type Sulfides

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

CaS:Bi³⁺
CaS:Eu²⁺
CdS:In
CdS:In, Ultrafast
CdS:Te
CdS:In,Te
ZnS:Ag,Cl
ZnS:Cu,Al
ZnS:Te,Mn

CaS:Bi³⁺

Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
CaS	100	10
Bi ₂ O ₃	0.5	0.323
S		0.2

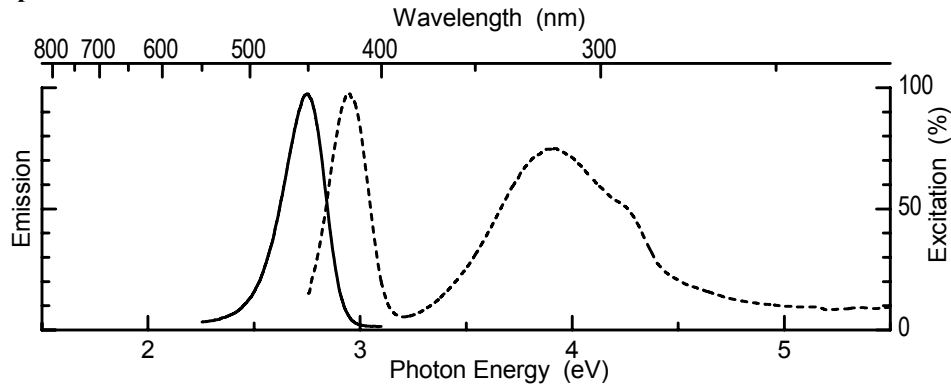
Preparation

Mix by dry grinding or milling.
Fire in N₂, 1200°C, 1 hour.
Powderize.
Store in a well-sealed container.

Optical Properties

Emission color: Deep blue, long blue afterglow
Emission peak: 450 nm
Emission width (FWHM): 1950 cm⁻¹
Excitation efficiency by UV: ++ (3.40 eV), ++ (4.88 eV)

Spectra



Remark

This contribution is from Weiyi Jia.

References

- 1. Jia, W., Unpublished data.
- 2. Lehmann, W., Activators and co-activators in calcium sulfide phosphors, *J. Lumin.*, 5, 87 (1972).



Structure: Cubic

Composition

Ingredient	Mole %	By weight (g)
CaS	100	10
Eu ₂ O ₃	1	0.488
S		0.2

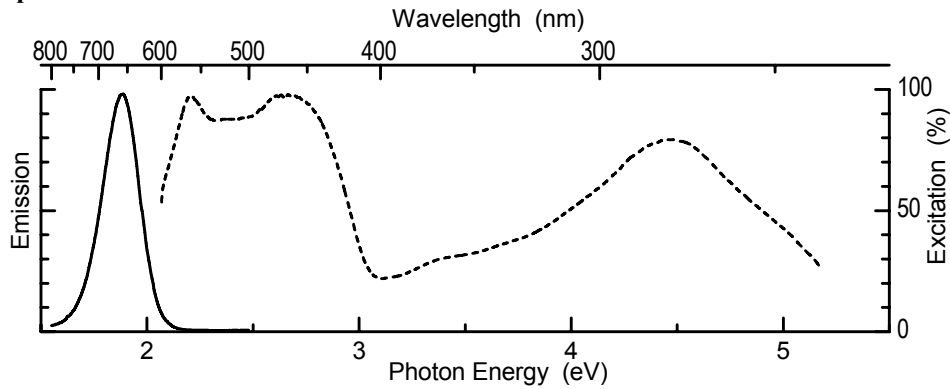
Preparation

Mix by dry grinding or milling.
Fire in 95% N₂ + 5% H₂, 1200°C, 1 hour.
Powderize.
Store in a well-sealed container.

Optical Properties

Emission color: Red, long red afterglow
Emission peak: 655 nm
Emission width (FWHM): 1660 cm⁻¹

Spectra.



Remark

This contribution is from Weiyi Jia.

References

- 1. Jia, D.D., Jia, W.Y., Evans, D.R. et al., Trapping processes in CaS:Eu²⁺, Tm³⁺, *J. Appl. Phys.*, 88, 3402 (2000).
- 2. Lehmann, W., Ryan, F.M., Cathodoluminescence of CaS:Ce³⁺ and CaS:Eu²⁺ Phosphors, *J. Electrochem. Soc.*, 118, 477 (1971).

CdS:In

Structure: hexagonal (wurtzite)

Composition

Ingredient	Mole %	By weight
CdS	99 %	1 g
In ₂ O ₃	1 %	7.95 mg

Preparation

Place the dry CdS and In powders in a quartz ampoule.

Mix vigorously using a Vortex mixer.

Seal the quartz ampoule under vacuum, about 1×10 torr.

Anneal in the sealed quartz ampoule at 900°C for 10 hours.

Break the ampoule open and grind the compound mixture to a fine powder using a mortar and pestle.

Place the compound in a quartz ampoule.

Seal the quartz ampoule under vacuum, about 1×10 torr.

Anneal in the sealed quartz ampoule at 900°C for 10 hours.

Break the ampoule open and grind the compound.

The compound should be a uniform light green color. If it is not uniform it can be treated a third time at 900°C for 10 hours in a vacuum-sealed ampoule.

Optical Properties

Body color: Greenish-yellow

Emission: Peak about 519 nm. Color: green

Excitation by UV: By all UV and by visible blue light

Decay time: <1 nsec; exponential

Remarks

1. This contribution is from Edith Bourret-Courchesne.

References

1. Derenzo, S.E., Weber, M.J., and Klintenberg, M.K., Temperature dependence of the fast, near-band-edge scintillation from CuI, HgI₂, PbI₂, ZnO:Ga and CdS:In, *Nucl. Instr. Meth. A* 486, 214 (2002).
2. Derenzo, S.E., Weber, M.J., Bourret-Courchesne, E., and Klintenberg, M.K., The quest for the ideal scintillator, *Nucl. Instr. Meth. A* 505, 111 (2003).

CdS:In, Ultrafast

Composition

Ingredient	Mole %	By weight
CdS	100 %	145 g
In ₂ O ₃	0.1 %	0.139 g
NH ₄ Cl	about 2 (not critical)	1 g
pure sulfur		about 2 g

Preparation

Make a slurry of the CdS in alcohol. Dissolve the In_2O_3 in a little HNO_3 . Boil till development of brown N_2O_3 vapor ceases (but not to dry). Dissolve the NH_4Cl in a little water. Add both solutions to the CdS slurry, stir to uniformity, and dry at room temperature or at moderate heat (e.g., over night). Then add the sulfur to the dry raw mix.

1. Fire in loosely capped quartz tubes (about half full, not more) slowly flowing H_2S , 900°C , 1 hour. When cool, inspect under UV lamp. Material should be uniformly deep red luminescent. Remove any suspicious parts and powderize the rest.
2. Fire in open quartz boats, slowly flowing H_2 , 600°C , one-quarter hour. Cool while still in H_2 (Important!)

Inspect again under a UV lamp. The material should now be uniformly green luminescent (if it does not, repeat the last firing step at about 100°C higher temperature). Remove any parts (if present) that look different.

Optical Properties

Body color: Grayish-yellow

Particles: About in the 5–10 μm size range

Emission: Narrow band. Peak about 510 nm. Color: green

Excitation by UV: By all UV and by visible blue light

Excitation by e-beam: Energy— $\eta \approx 1$ –1.2%, decay < 1 nsec

Remarks

1. The NH_4Cl in the above recipe can be replaced by about 3.6 g CdCl_2 .
2. The H_2S in the above recipe can be diluted with N_2 (about to 25% H_2S , 75% N_2).
3. This phosphor is in a frozen-in semistable state. Do not heat higher than about 250°C except in pure hydrogen.

References

3. Lehmann, W., Edge emission of n-type conducting ZnO and CdS, *Solid State Electron.*, 9, 1107 (1966).
4. Lehmann, W., U.S. Patent 3 583 929 (issued June 1971).
5. Derenzo, S.E., Weber, M.J., Klintonberg, M.K., Temperature dependence of the fast, near-band-edge scintillation from CuI, HgI_2 , PbI_2 , ZnO:Ga and CdS:In, *Nucl. Instr. Meth. A* 486, 214 (2002).
6. Derenzo, S.E., Weber, M.J., Bourret-Courchesne, E., and Klintonberg, M.K., The quest for the ideal scintillator, *Nucl. Instr. Meth. A* 505, 111 (2003).

The above recipe was provided by W. Lehmann during a visit to the Lawrence Livermore National Laboratory in 1987.

CdS:Te

Structure: hexagonal (wurtzite)

Composition

Ingredient	Mole %	By weight
CdS	99.99 %	10 g
CdTe	0.01 %	1.66mg

Preparation

Place the dry CdS and CdTe powders in a quartz ampoule.

Mix vigorously using a Vortex mixer.

Seal the quartz ampoule under vacuum, about 5×10^{-5} torr.

Anneal in the sealed quartz ampoule at 900°C for 10 hours.

Break the ampoule open and grind the compound mixture to a fine powder using a mortar and pestle.

Place the compound in a quartz ampoule.

Seal the quartz ampoule under vacuum, about 5×10^{-5} torr.

Anneal in the sealed quartz ampoule at 900°C for 10 hours.

Break the ampoule open and grind the compound.

The compound should be a uniform yellow color.

Optical Properties

Body color: yellow

Emission: Peak about ~640 nm. Color: red

Excitation by UV: By all UV and by visible blue light

Decay time: ≈ 270 nsec; nonexponential

Remarks

1. This contribution is from Edith Bourret-Courchesne.

References

1. Cuthbert, J.D. and Thomas, D.G., Optical properties of tellurium as an isoelectronic trap in cadmium sulfide, *J. Appl. Phys.* 39, 1573 (1968).
2. Schotanus, P., Dorenbos, P., and Ryzhikov, V.D., Detection of CdS(Te) and ZnSe(Te) scintillation light with silicon photodiodes, *IEEE Trans. Nucl. Sci.* 39, 546 (1992).
3. Derenzo, S.E., Weber, M.J., and Klintenberg, M.K., Temperature dependence of the fast, near-band-edge scintillation from CuI, HgI₂, PbI₂, ZnO:Ga and CdS:In, *Nucl. Instr. Meth. A* 486, 214 (2002).
4. Derenzo, S.E., Weber, M.J., Bourret-Courchesne, E., and Klintenberg, M.K., The quest for the ideal scintillator, *Nucl. Instr. Meth. A* 505, 111 (2003).

CdS:In,Te

Structure: hexagonal (wurtzite)

Composition

Ingredient	Mole %	By weight
CdS:In*	1% (In) 99%(CdS)	1g
CdS:CdTe*	0.01% (CdTe) 99.99%(CdS)	1g

*see previous pages

Preparation

Place the dry CdS:In and CdS:CdTe powders in a quartz ampoule.
Mix vigorously using a Vortex mixer.
Seal the quartz ampoule under vacuum, about 5×10^{-5} torr.
Anneal in the sealed quartz ampoule at 900°C for 10 hours.
Break the ampoule open and grind the compound mixture to a fine powder using a mortar and pestle.
The compound should be a uniform dark yellow color.

Optical Properties

Body color: dark yellow
Emission: Peak about 618 nm. Color: red.
Excitation by UV: By all UV and by visible blue light.
Decay time:3.5 nsec; exponential.

Remarks

2. This contribution is from Edith Bourret-Courchesne.

References

7. Derenzo, S.E., Weber, M.J., and Klintenberg, M.K., Temperature dependence of the fast, near-band-edge scintillation from CuI, HgI₂, PbI₂, ZnO:Ga and CdS:In, *Nucl. Instr. Meth. A* 486, 214 (2002).
8. Derenzo, S.E., Weber, M.J., Bourret-Courchesne, E., and Klintenberg, M.K., The quest for the ideal scintillator, *Nucl. Instr. Meth. A* 505, 111 (2003).

ZnS:Ag,Cl

Composition

Ingredient	Mole %	By weight (g)
ZnS	100	98
AgNO ₃	0.03	0.050
NH ₄ Cl	5	2.5
S	—	2–3 g

Preparation

AgNO₃ and NH₄Cl are dissolved separately in water. A ZnS slurry is made with water or an alcohol. During stirring, first the AgNO₃ solution is added, followed by adding the NH₄Cl solution.

The mixture is dried in air and powdered. Then sulfur is added. Heating takes place at bout 1100°C in a CO atmosphere. The material can be washed with water to remove any flux residue.

This material is used as blue primary in cathode-ray tubes. It can also be co-doped with Al, instead of Cl. In addition, two modifications can be made (cubic sphalerite and hexagonal wurtzite) with slightly difference spectra. Wurtzite is obtained by heating above about 1020°C and fast cooling.

Remark

This contribution is from Cees Ronda.

ZnS:Cu,Al

Composition

Ingredient	Mole %	By weight (g)
ZnS	100	98
Cu(C ₂ H ₃ O ₂) ₂ H ₂ O	0.03	0.06
AlCl ₃	0.3	0.4
S	—	2–3 g

Preparation

Copper acetate and aluminum chloride are dissolved in water and added to ZnS. Afterwards methanol or water is added to make a uniform slurry which is stirred.

The mixture is dried in air and powdered. Then sulfur is added. Heating takes place at about 1100°C in a CO atmosphere. The material can be washed with water to remove any flux residue.

This material is used as green primary in cathode-ray tubes. It can also be co-doped with Au and Cu, to obtain more green emission.

Remark

This contribution is from Cees Ronda.

ZnS:Te,Mn

Structure: Hexagonal (wurtzite)

Composition

Ingredient	Mole %	By weight (g)
ZnS	94	10.00
ZnTe	3	0.632
MnO	3	0.232
S	10	1.08

Preparation

Mix and grind. Pre-sinter at 800°C in N₂ for 2 hours. Powderize and grind. Sinter at 1200°C in N₂ gas flow for 3 hours.

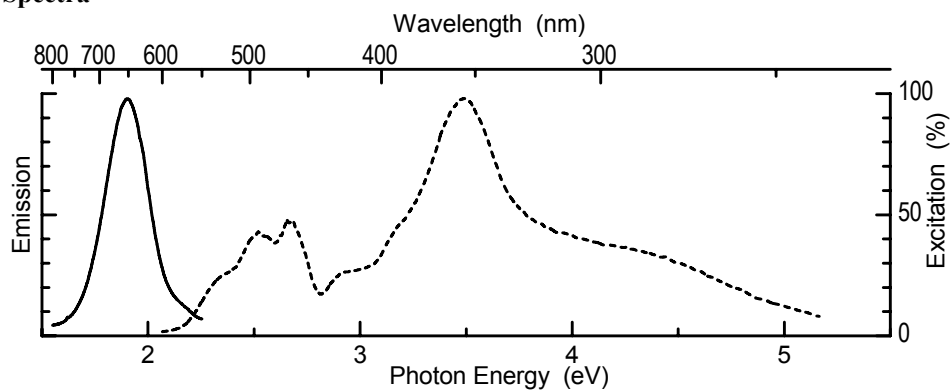
Optical Properties

Emission color: Red

Emission peak: 650 nm

Excitation efficiency by UV: Excited by 280–380 nm and blue green 450–540 nm

Spectra



Remarks

1. This contribution comes from Dongdong Jia.
2. This compound exhibits strong tribo-luminescence.

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).

7.7 Other Compounds

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

CaWO₄:Pb²⁺
GaN:Zn
Gd₂O₂S:Pr³⁺
Gd₂O₂S:Tb
Na(Mg_{2-x}Mn_x)LiSi₄O₁₀F₂:Mn
Na_{1.23}K_{0.42}Eu_{0.12}TiSi₅O₁₃·xH₂O:Eu³⁺
Na_{1.23}K_{0.42}Eu_{0.12}TiSi₄O₁₁:Eu³⁺
Na_{1.29}K_{0.46}Er_{0.08}TiSi₄O₁₁:Eu³⁺
Na₂Mg₃Al₂Si₂O₁₀F₂:Tb

CaWO₄:Pb²⁺

Structure: Tetragonal

Composition

Ingredient	Mole %	By weight (g)
CaCO ₃	48.5	231.7
WO ₃	49.5	100
PbO	1	4.5

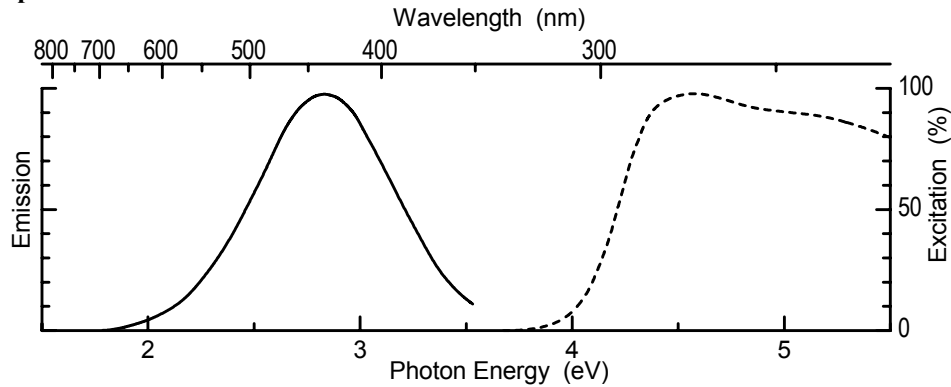
Preparation

Mix ingredients.
Fire in air, 1100°C, several hours.
Powderize, and then wash with 3% HCl (to remove the excess CaO).

Optical Properties

Emission color: Blue
Emission peak: 435 nm
Excitation efficiency by UV: – (3.40 eV), ++ (4.88 eV)
Excitation efficiency by e-beam: +
Decay to 1/e: 10⁻⁵sec

Spectra



Remarks

- 1. This contribution is from Masaaki Tamatani.
- 2. Excess Ca in the material blend gives favorable results.
- 3. NBS1026 is used for lamps, CRTs.

References

- 1. Kamiya, S., and Mizuno, H., Phosphors for lamps, in *Phosphor Handbook*, Ed. Shionoya, S., and Yen, W.M., CRC Press, New York, pp. 422–423 (1998).
- 2. Kojima, T., Phosphors for plasma display, in *Phosphor Handbook*, Ed. Shionoya, S., and Yen, W. M., CRC Press, New York, pp. 629–630 (1998).
- 3. Bril, A., and Hoekstra, W., Efficiencies of phosphors for short-wave ultra-violet excitation, *Philips Res. Rep.* 16, 356–370 (1961).
- 4. Bril, A., and Hoekstra, W., Properties of the fluorescence of some N.B.S. standard phosphors, *Philips Res. Rep.* 19, 296–306 (1964).

GaN:Zn

Structure: Hexagonal (wurtzite)

Composition

Ingredient	Mole %	By weight (g)
ZnS	—	—
Ga ₂ S ₃	—	—

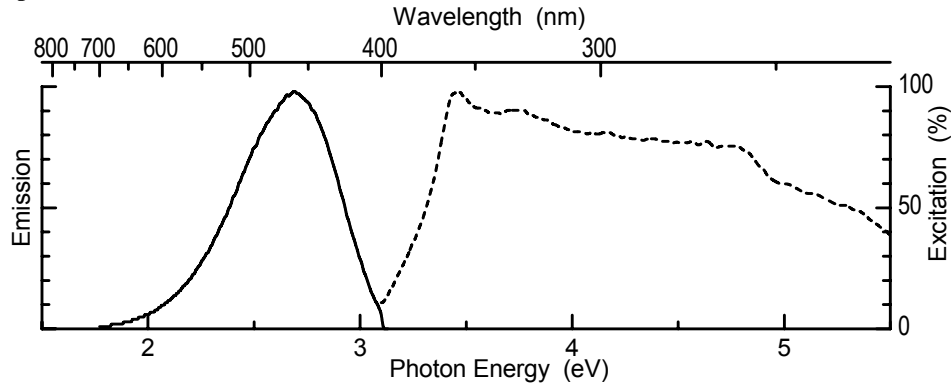
Preparation

Mix by slurring in water or methanol.
Dry in air. Powderize when dry.
Fire in quartz tubes, NH₃, 1100°C, 2 hours.
Powderize. Wash with de-ionized water.
Add solution of Mn²⁺ and vaporize water by warming.
Re-fire in H₂+N₂ atmosphere, 1100°C, 1 hour.
Powderize.

Optical Properties

Emission color: Blue
Emission peak: 460 nm
Emission width (FWHM): 100 nm
Absorption edge: 354 nm (3.5 eV)
Luminance by cr: 650 cd/m² at 50 V DC

Spectra



Remark

This contribution is from Yoshitaka Sato.

References

1. Sato, Y. et al., *Proceeding of IDW'02* (2002).
2. Sato, Y., Takahashi, H., Tamaki, H., and Kameshima, M., Luminescence Properties of a Blue Phosphor, GaN:Zn for VFDs, *Proceedings of the 9th International Display Workshops*, Dec. 4–6 (2002).



Structure: Hexagonal

Composition

Ingredient	Mole %	By weight (g)
Gd ₂ O ₃	100	100
Pr ₆ O ₁₁	0.2	0.56
HNO ₃	some	some
S ₂	some	3
Na ₂ CO ₃	10	2.92

Preparation

- Combine Gd₂O₃ and Pr₆O₁₁ powders with some nitric acid to form a precipitate.
1. Fire in air, 1000°C.
Take the oxide, and combine with sulfur and NaCO₃.
 2. Fire in air, 1100°C.
Rinse well in water.
Co-doping with a small amount of Ce reduces the afterglow.

Optical Properties

Emission color: Green
Emission peak: 510 nm
Excitation efficiency by UV: – (3.40 eV), ++ (4.88 eV)
Excitation efficiency by e-beam: +
Decay to 1/e: 3 × 10^{–6}s

Remarks

- 1. This contribution is from Masaaki Tamatani.
- 2. Three groups have proposed different processes for fabricating the oxysulfide ceramics. Toshiba proposed a high-temperature, hot-isostatic-pressing process using a phosphor powder prepared by the conventional method for CRT phosphors. Hitachi is able to lower the sintering temperature during HIP by adding a sintering aid using a powder having large particle size. Siemens proposed to apply a uni-axial hot pressing process instead of HIP, using powders with very small particle size.

References

- 1. Matsuda, N., Yokota, K., and Tamatani, M., Praseodimium-doped gadolinium oxysulfide ceramics prepared by the hot isostatic pressing process, *Electrochem. Soc. Fall Meeting*, Honolulu, Abstr. No. 1870RNP (1987).
- 2. Yamada, H., Suzuki, A., Uchida, Y., Yoshida, M., and Yamamoto, H., A scintillator Gd₂O₂S:Pr,Ce,F for X-ray computed tomography, *J. Electrochem. Soc.*, 136, 2713 (1989).
- 3. Rossner, W., and Ostertag, M., Properties and application of gadolinium oxysulfide based ceramic scintillators, *Electrochem. Soc. Fall Meeting*, Boston, Abstr. No. 879 (1998).

Gd₂O₂S:Tb

Composition

Ingredient	Mole %	By weight (g)
Gd ₂ O ₃	94 (Y)	170.4
Tb ₄ O ₇	6 (Tb)	11.3
Na ₂ CO ₃	100	53
S	300	96

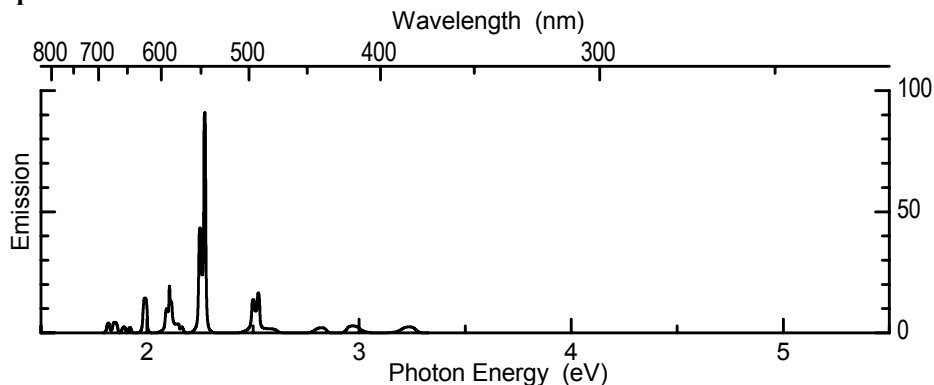
Preparation

Mix the rare-earth oxides by slurring in water or methanol and dry in air. After drying, mixture should be powdered in mortar. Subsequently, mix the rare-earth mixture with Na₂CO₃ and S by dry mixing.

Firing should occur in air in a vessel with a well-closing lid, at a temperature of about 1100°C for a few hours.

After cooling, the reaction product has to be washed a few times with water to remove residual flux.

Spectra



Remarks

- 1. This contribution is from Cees Ronda.
- 2. This material is used in X-ray intensifying screens and in oscilloscope CRTs.



Structure: Lamellar intercalation

Composition

Ingredient	Mole %	By weight (g)
Na ₂ CO ₃	2.50	1.82
MgO	28.80	7.96
Li ₂ CO ₃	7.50	3.80
Na ₂ SiF ₆	5.00	6.45
SiO ₂	55.00	22.66
MnCO ₃	1.20	0.946

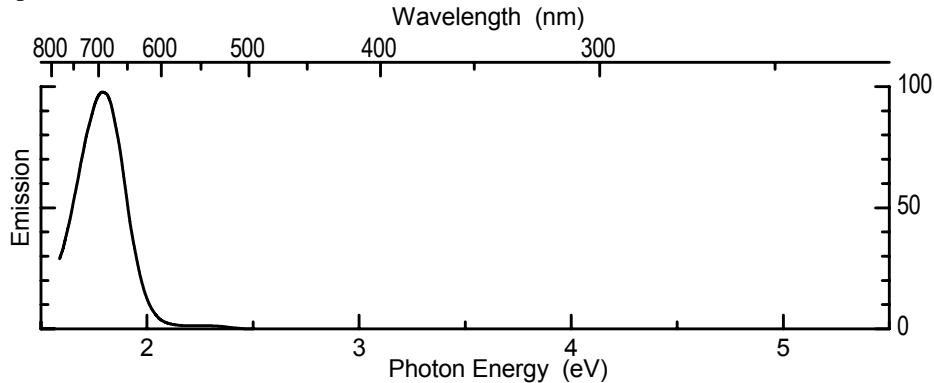
Preparation

Mix stoichiometric amounts in a paint shaker for 30 minutes with about 20 mol% of excess potassium carbonate to compensate for losses due to volatilization.
Fire in covered alumina crucibles, air, 915°C, 36 hours.
Grind.
Fire in covered alumina crucibles, 4% H₂ /N₂, 850°C.
Cool to room temperature.
Powderize.
Screen through a 325-mesh stainless steel sieve.

Optical Properties

Emission color: Redish-pink
Emission peak: 695 nm
Excitation efficiency by UV: + (3.40 eV), + (4.88 eV)
Excitation efficiency by e-beam: Characteristic emission at about 1.4 fL level under focused 15 kV/8 μA excitation

Spectra



Remarks

- 1. This contribution is from Madis Raukas.
- 2. This phosphor in formulation of Na(Mg_{2-x}Mn_x)LiSi₄O₁₀F₂ is an example of a broad family of intercalation ingredient that, besides micas and fluoromicas, includes vermiculites and zeolites.
- 3. Described composition yields a concentration of 0.08 mol Mn per mole of phosphor.
- 4. Good electroluminescent properties when intercalated with conductive polymers or metals.

References

- 1. Qi, R.Y., Karam, R.E., Reddy, V.B., and Cox, J.R., U.S. Pat., 5 567 351 (1996).
- 2. Qi, R.Y., and Karam, R.E., U.S. Pat., 5 658 495 (1997).
- 3. Reddy, V.B., Karam, R.E., and Northrop, S.K., U.S. Pat., 5 489 398 (1996).
- 4. Qi, R.Y., and Karam, R.E., U.S. Pat., 5 531 926 (1996).
- 5. Reddy, V.B., and Karam, R.E., Northrop, S.K., and Zhang, Y., U.S. Pat., 5 531 928 (1996).



Structure: Tetragonal

Composition

Ingredient	Mole %	By weight (g)
Sodium silicate solution (8% Na ₂ O; 27% SiO ₂ ; 65% H ₂ O)	30.7 (of Si)	20.0
TiO ₂ (anatase)	5.6 (of Ti)	1.30
NaCl	58.1 (of Na)	6.90
KCl	5.6 (of K)	1.30
Eu(NO ₃) ₃ ·5H ₂ O	0.12 (of Eu)	0.15

Preparation

- 1. To prepare ETS-10:
Mix 20 g of water to the sodium silicate solution and add the NaCl and KCl.
Stir and add anatase.
Autoclave the gel under autogeneous pressure for 24 hours at 230°C.
The resulting powder is filtered and washed with distilled water at room temperature and then allowed to dry at 110°C.

- To prepare Eu^{3+} -doped ETS-10:
Dissolve 0.07 g of $\text{Eu}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ in 250 ml of water and add 3.94 g of the already prepared ETS-10.
The solution is stirred for 24 hours at 60°C .
The precipitate is filtered and dried in air at 110°C .

*The next two materials also use this as their basic recipe.

Optical Properties

Emission color: Red

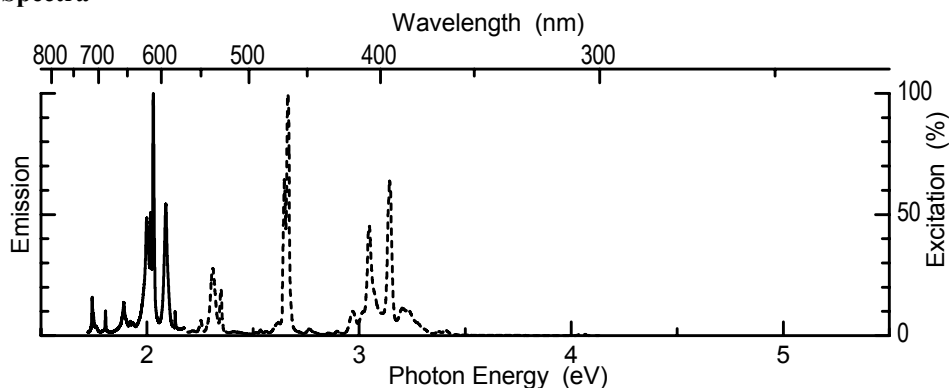
Emission peak: 2.00 eV

Emission width (FWHM): 0.044 eV

Excitation efficiency by UV: The maximum excitation efficiency at 394 nm ($^7\text{F}_0 \rightarrow ^5\text{L}_6$) and 465 nm ($^7\text{F}_0 \rightarrow ^5\text{D}_2$)

Decay to 10% (or $1/e$, as given): To $1/e \approx 3.63 \pm 0.04$ and 1.11 ± 0.02 msec

Spectra

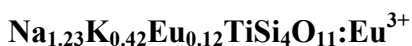


Remarks

- This contribution is from Luis Carlos.
- ETS-10 is also known as microporous sodium potassium titanosilicate.
- ETS-10 is doped through an ion exchange between Na^+ and K^+ with Eu^{3+} .

Reference

- Rainho, J.P., Carlos, L.D., and Rocha, J., New phosphors based on Eu^{3+} -doped microporous titanosilicates, *J. Lumin.*, 87, 1083 (2000).



Structure: Tetragonal

Composition

Ingredient	Mole %	By weight (g)
Sodium silicate solution (8% Na_2O ; 27% SiO_2 ; 65% H_2O)	30.7 (of Si)	20.0
TiO_2 (anatase)	5.6 (of Ti)	1.30
NaCl	58.1 (of Na)	6.90
KCl	5.6 (of K)	1.30
$\text{Eu}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$	0.12 (of Eu)	0.15

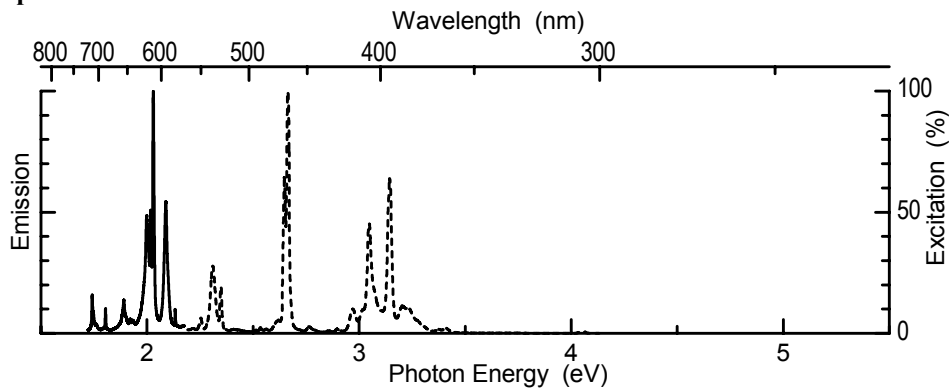
Preparation

- 1. ETS-10 and ETS-10 doped with Eu³⁺ are prepared as in the case of the microporous titanosilicate compound described on the previous page.
- 2. To obtain Eu³⁺ doped narsarsukite:
Eu³⁺-doped ETS-10 is calcined in air from room temperature to 800°C at a heating rate of 5°C per minute.
The material is maintained at 800°C for 3 hours.
Cool in air.

Optical Properties

Emission color: Red
Emission peak: 2.03 eV
Emission width (FWHM): 0.003 eV
Excitation efficiency by UV: The maximum excitation efficiency at 394 nm (⁷F₀→⁵L₆) and 465 nm (⁷F₀→⁵D₂)
Decay to 10%: To 1/e ≈ 3.63 ± 0.04 and 1.11 ± 0.02 msec

Spectra

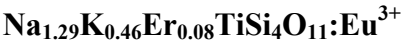


Remarks

- 1. This contribution is from Luis Carlos.
- 2. This material is known as synthetic narsarsukite doped with Eu³⁺.
- 3. The end product is contaminated with quartz and cristobalite impurities.

References

- 1. Rainho, J.P., Carlos, L.D., and Rocha, J., New phosphors based on Eu³⁺-doped microporous titanosilicates, *J. Lumin.*, 87, 1083 (2000).
- 2. Rainho, J.P. et al., Synthesis and luminescence of Eu³⁺-doped narsarsukite prepared by the sol-gel process, *J. Sol-Gel Sci. Tecnol.*, 26, 1005 (2003).



Structure: Tetragonal

Composition

Ingredient	Mole %	By weight (g)
sodium silicate solution (8% Na ₂ O; 27% SiO ₂ ; 65% H ₂ O)	30.7 (of Si)	20.0
TiO ₂ (anatase)	5.6 (of Ti)	1.30

NaCl	58.1 (of Na)	6.90
KCl	5.6 (of K)	1.30
Eu(NO ₃) ₃ ·5H ₂ O	0.12 (of Eu)	0.15

Preparation

1. ETS-10 is prepared as in the case of the microporous titanasilicate compound described in the previous pages.
2. To prepare Eu³⁺-doped ETS-10:
Dissolve 0.07 g of Eu(NO₃)₃·5H₂O in 250 ml of water and add 3.94 g of the already prepared ETS-10.
The suspension is stirred for 24 hours at 60°C.
The precipitate is filtered and dried in air at 110°C.
3. To obtain Er³⁺ doped narsarsukite:
Eu³⁺ doped ETS-10 is calcined in air from room temperature to 800°C at a heating rate of 5°C per minute.
The material is maintained at 800°C for 3 hours.

Optical Properties

Emission color: IR

Emission peak: 0.80 eV

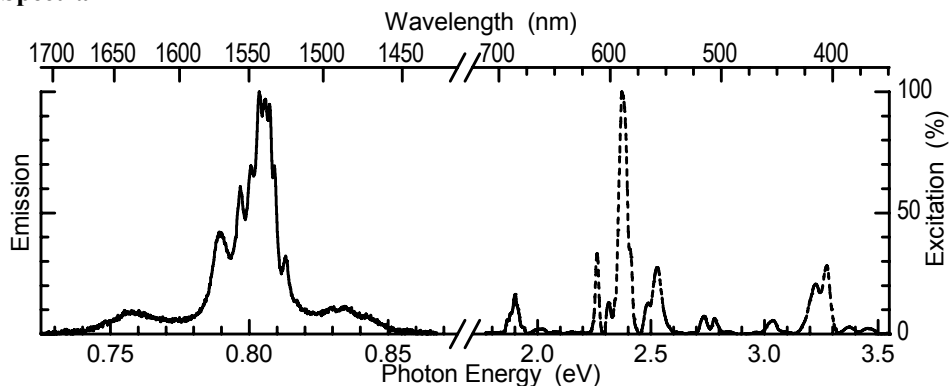
Emission width (FWHM): 0.014 eV

Excitation efficiency by UV: Maximum excitation efficiency at 520 nm

(⁴I_{15/2}→²H_{11/2}) and 488 nm (⁴I_{15/2}→⁴F_{7/2})

Decay to 10%: To 1/e ≈ 7.8 ± 0.2 msec

Spectra



Remarks

1. This contribution is from Luis Carlos.
2. ETS-10 is doped through an ion exchange between Na⁺ and K⁺ with Eu³⁺.
3. This material is known as synthetic narsarsukite.
4. The end product is contaminated with quartz and cristobalite impurities.

References

1. Rocha, J. et al., New phosphors based on Eu³⁺-doped microporous titanosilicates, *J. Mater. Chem.*, 10, 1371 (2000).
2. Rainho, J.P. et al., Er(III) environment in luminescent titanosilicates prepared from microporous precursors, *J. Mater. Chem.*, 12, 1162 (2002).

Na₂Mg₃Al₂Si₂O₁₀F₂:Tb

Structure: Lamellar intercalation

Composition

Ingredient	Mole %	By weight (g)
Na ₂ CO ₃	14.23	12.26
MgO	42.66	13.98
Al ₂ O ₃	13.94	11.56
(NH ₄) ₂ SiF ₆	4.74	6.87
SiO ₂	23.74	11.60
TbF ₃	0.69	1.21

Preparation

Mix all the ingredients thoroughly for 20–30 minutes, preferably in a paint shaker or similar device.

Fire in a covered alumina crucible, with graphite pellets added, 1100°C, 12–24 hours.

Cool to ambient temperature, powderize, and wash in de-ionized water.

Optical Properties

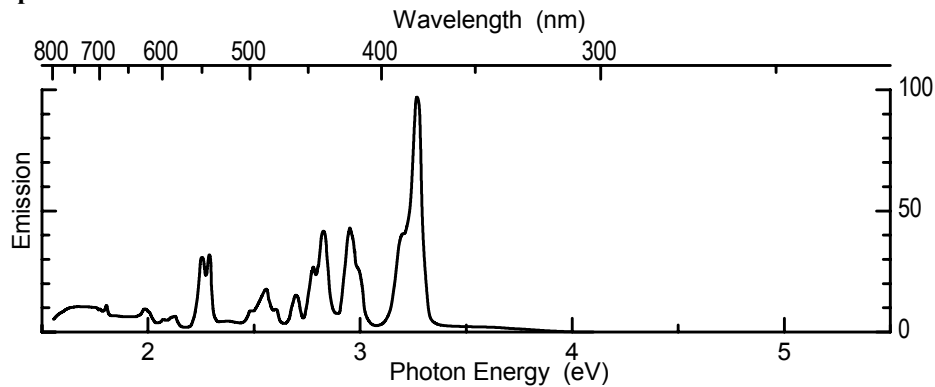
Emission Color: Bluish-green

Emission peaks: 380, 415, 440, and 540 nm

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

Excitation efficiency by e-beam: About 1 fL level under focused 15 kV/8 μA excitation

Spectra



Remarks

1. This contribution is from Madis Raukas.
2. The described procedure yields a concentration of 0.04 mol% Tb. The formula of the compound is Na₂(Mg_{3-x}Tb_x)Al₂Si₂O₁₀F₂.
3. This phosphor is an example of a broad family of intercalation compounds that includes mica, fluoromica, vermiculite, and zeolite.
4. Phosphor has good electroluminescent properties if intercalated with polymers or metals.

References

1. Cox, J.R., and Karam, R.E., U.S. Pat., 5 656 199 (1997).
2. Reddy, V.B., Karam, R.E., and Northrup, S.K., U.S. Pat., 5 489 398 (1996).
3. Oi, R.Y., and Karam, R.E., U.S. Pat., 5 531 926 (1996).
4. Karam, R.E., Reddy, V.B., Northrup, S.K., and Zhang, Y., U.S. Pat., 5 531 928 (1996).
5. Oi, R.Y., and Karam, R.E., and Cox, J.R., U.S. Pat., 5 567 351 (1996).