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Improved color rendition in high pressure mercury vapor lamps

Mary V. Hoffman

The addition of $Y_3Al_5O_{12}$:Ce to the group of phosphors suitable for color correcting the mercury discharge lamp provides for improving the color rendering index without a lumen loss. By altering the cerium content in the formulation, the absorption and brightness can be adjusted to its optimum value in the lamp.

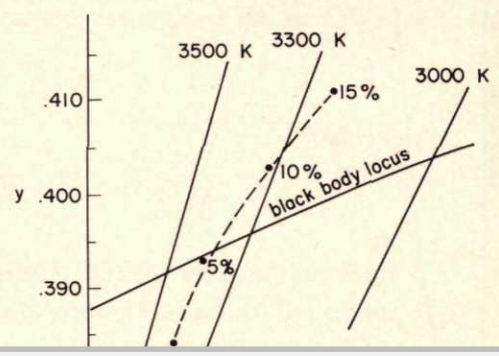
The ideal in color rendition of a high pressure mercury discharge lamp has been the subject of several recent papers, in which simulated spectral distributions have been created by the addition or subtraction of spectral energy.[1,2] This can be done to obtain lamps of selected color temperatures, with various combinations of real and simulated phosphor emissions. The optimization of the luminous efficiency can be calculated in the same manner. One study has shown that the addition of emission at 620 nanometers to the Hg discharge is near the optimum for color rendition, but that for lamps with color temperature of 4000 to 3000 kelvins, it is necessary to remove some of the Hg discharge in the blue. For luminosity, addition of emission near 590 nanometers is needed.[2,3]

Among the existing phosphors meeting the temperature and stability requirements of the mercury discharge lamps, only Y VO_4:Eu and Y(VP)O_4:Eu phosphors (YVP) supply emission at the necessary spectral region, with the main peak at 618 nanometers. They do not provide absorption of the blue Hg lines in sufficient amount or emission in the high luminous region. Filtering of the blue can be obtained by the addition of a pigment or of a phosphor which also acts as a pigment. The phosphor magnesium fluogermanate activated with manganese (MG) is the only suitable red emitter with appreciable absorption of the blue lines, but since the emission is at 650 to 660 nanometers, the luminosity is not enhanced by this substitution. Combinations of these two phosphors can be used, as described by Rokosz, *et al.*[4]

We have found another phosphor, cerium-activated yttrium aluminate garnet (YAG:Ce) which is useful in improving color rendition by absorbing the blue Hg radiation and also adds to the total emission of the lamp by converting this blue radiation into emission centered at 560 nanometers. It can be combined with the Y(VP)O_4:Eu emission, effectively changing the color of the lamp.

Lamps prepared with blends of YAG:Ce and YVP phosphors show the shift in color points from below the black body to, on, or above the locus, depending on the proportions used. Typical color points are shown in Fig. 1 for a warm color corrected lamp. The

Figure 1. Color shifts with increasing YAG:Ce in Y(VP) O_4:Eu.



color shift is due largely to the absorption of the 436 nanometer Hg line, which is filtered by about 40 percent with 15 percent YAG in the blend. The luminosity of the lamps remains about the same for four lamp colors shown. This is due to the efficient conversion of the 436 Hg line into visible emission. These data are summarized in Table I.

The actual color points obtained can be varied by the amount of phosphor used on the lamp as well as the proportion of YAG:Ce in the blend. It can also be varied by using the blend over a pre-coat, as described by Rokosz, *et al.*[4] The pre-coat acts as a reflector for both ultraviolet and the blue radiation, allowing better utilization of the Hg radiation by the phosphors. With the YAG:Ce present, the reflection of the blue radiation increases its effect both as a pigment and as a phosphor.

The YAG:Ce phosphor, which was developed for its emission characteristics under cathode ray excitation[5,6] is strongly absorbing in the blue, as shown

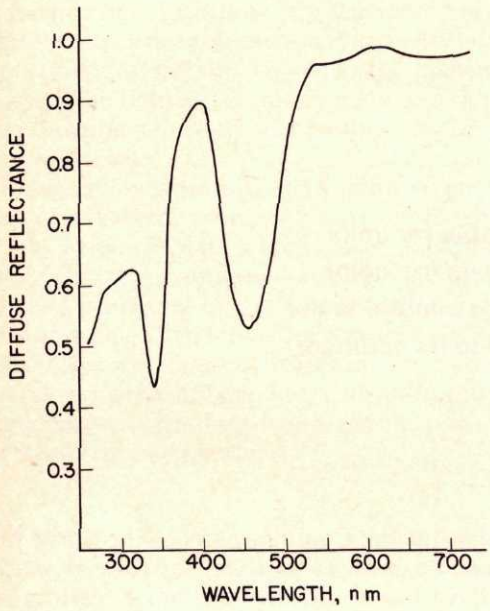


Figure 2. Diffuse Reflectance curve, $(Y_{2.925}\ Ce_{0.075})_3\ Al_5O_{12}$.

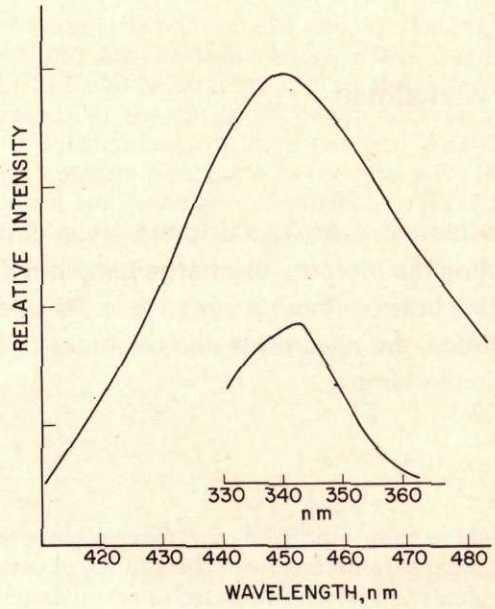


Figure 3. Excitation curve: detected wavelength—511 nanometers.

Figure 4. Emission curve: excitation wavelength—436 nanometers.

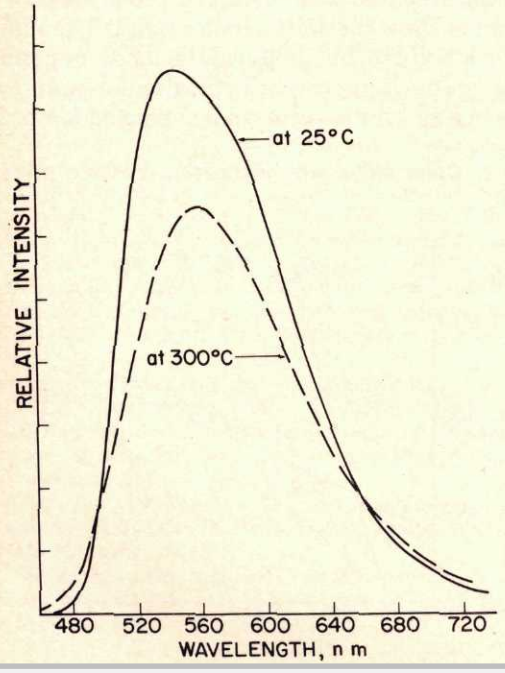


***Figure 5. Emission intensity vs cerium content, measured* at 25° C and 300° C. Excitation wavelength—436 nm.**

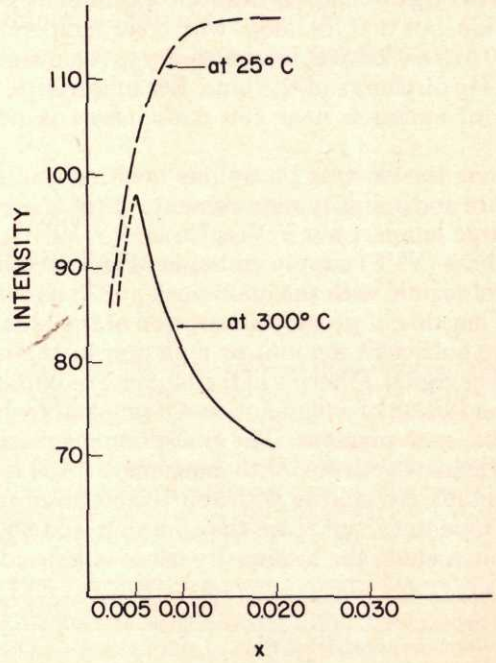


Table I—Lamp data: YAG:Ce with $Y(VP)O_4$:Eu

Percent YAG:Ce	100-hour lm/w	X	Y	CRI
0	51.5	.408	.384	45
5	52.1	.411	.394	—
10	50.7	.420	.403	—
15	51.3	.426	.411	51

by the diffuse reflectance curve (see Fig. 2), and is also excited by this radiation. This absorption is into the 5d state of the cerium, which in this crystal structure, lies in an unusual position. Cerium usually absorbs in the ultraviolet and emits in the near ultraviolet or in the blue. The YAG:Ce phosphor is not excited by 254 nanometers and only weakly by 365 nanometers from the Hg arc. The excitation spectra (See Fig. 3) shows the very strong dependence of the emission intensity on the 436-nm Hg radiation.

The emission of the phosphor is in a band peaking at about 540 nanometers at 25 ° C shifting to about 560 nanometers at 300° C (See Fig. 4). This is at the maximum eye sensitivity and close to the calculated peak of 590 nm for good lumen output in the system.

As with most phosphors, the specific conditions of the lamp determine its applicability, and the composition can often be altered according to its use. In the YAG:Ce phosphor, the cerium concentration is the critical factor. Both the absorption at 436 nanometers and the emission intensity increase with the cerium concentration with the brightness reaching a maximum at about one- to two-atom percent and the absorption at about three-atom percent when measured at 25° C. At the temperature of operation of the lamp, the phosphor is less efficient, and brightness measurements made at 300° C show that lower cerium concentrations are desirable. As shown in Fig. 5, a rather narrow range of cerium content must be maintained for the best conversion of 436 radiation to emission at 560 nm in the lamp.

References

1. J. J. Opstelten, D. Radielović and W. L. Wanmaker, "The choice and evaluation of phosphors for application to lamps with improved color rendition," *Journal of the Electrochemical Society*, Vol. 120, No. 10, October 1973, p. 1400.
2. T. F. Soules and M. A. Maier, "Optimized spectral power distributions for mercury vapor lamps," *Journal of the Electrochemical Society*, Vol. 121, No. 3, March 1974, p. 407.
3. H. Ivey, "Color and efficiency of fluorescent and fluorescent-mercury lamps," *Journal of the Optical Society of America*, Vol. 62, 1972, p. 814.
4. F. Rokosz, J. W. Sausville, and J. Van Broekhoven, "Incandescent lamp color with high-intensity discharge lamps," JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY, Vol. 3, No. 1, October 1973, p. 95.
5. G. Blasse and A. Bril, "A new phosphor for flying-spot cathode-ray tubes for color television: yellow-emitting $Y_3Al_5O_{12}$:Ce," *Applied Physics Letters*, Vol. II, No. 2, July 15, 1967, p. 53.
6. W. W. Holloway, Jr. and M. Kestigian, "Optical properties of cerium-activated garnet crystals," *Journal of the Optical Society of America*, Vol. 59, No. 1, January 1969, p. 60.

DISCUSSION

W. A. THORNTON:* The high pressure mercury vapor lamp is in need of all the kindly attention it can get. This welcome paper brings better lamp performance closer. It performs a service by bringing another useful phosphor into the very limited line-up of luminescent materials that can endure the operating conditions in this lamp. The new phosphor has the useful property of converting undesired blue-violet arc emission to desired green light, which tends to improve both color rendering and output. Does the increase in Color Rendering Index (CRI), as 15 percent of the new phosphor is added, represent a real visual improvement in color rendering of real objects and scenes? As to the proposed addition of yellow wavelengths near 590 nanoeters "for good lumen output in the lamp system," we believe that such addition would harm color rendering more than it would improve lumen output. The usefulness of the new YAG:Ce phosphor is, we believe, due to the fact (see Fig. 4) that it contributes green light and red light; that it also contributes yellow light is a disadvantage. The Soules and Maier study (see Reference 2) makes clear that peak lumen output by use of yellow light is accompanied by color rendering index of −20. Reference 1 ascribes poor color rendering to yellow emitting phosphors. Has the author any prospect of an efficient phosphor emitting a narrow band near 490 nanometers, which, according to the same references, can help raise CRI further?

AUTHOR:† The true test of improved color rendition always rests on a subjective visual evaluation, especially in a system such as this one, with about ten percent calculated change in CRI. No systematic evaluation of this lamp system has been made, but the general appearances have been favorable.

The emission contribution of YAG:Ce (if present as the only phosphor) would definitely result in a lower CRI. The Soules and Maier paper points to a system that closely approximates a pure YAG:Ce lamp. It has a CRI of 23. The usefulness of the YAG:Ce lies in its ability to absorb the 436-nm Hg line to the extent sufficient to improve the CRI, and supply enough emission to contribute to the lumen level, at a relatively low weight percent.

The Soules and Maier paper ascribes the CRI of −20 to a system containing a narrow band emission at 580 nanometers, when combined with bluer line emission, but shows that when Eu^{+3} emission is present the CRI cannot fall that low.

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