The Effect of Temperature on the Luminescent Properties of Red-Emitting Y_2O_3:Eu^{3+} Thin Films

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When phosphor materials are exposed to large changes in temperature, the luminescent properties, such as the fluorescent decay time, emission intensity, spectral shape and absorption spectra, change. If these changes are reproducible over successive cycling to high temperatures, the phosphor material can be characterized as a thermographic phosphor (TP). TP's are sometimes the only viable technique for measuring temperatures in hostile and/or inaccessible environments. Typical techniques used are pyrometry, thermocouples, or thermistors, but can only provide a limited amount of reliability, reproducibility and accuracy for determining the temperature in such environments. The primary advantage of using a TP technique is that none of the luminescent properties are dependent on the emissivity or geometry of the coated part whose temperature is to be measured, nor does the phosphor interfere with the normal operation of the coat part [1]. Typical TP's used are phosphor based powdered coatings that are adhered to a part whose temperature is to be measured using a binding agent. This offers a bright emission which can be used to detect the temperature change. Thin phosphor films are a viable alternative. To overcome the decreased emission intensity with thin films, high efficiency thin film phosphors need to be used. In this report, the effect of temperature on the thin film luminescent properties of an efficient red-emitting phosphor, Y_2O_3:Eu^{3+} will be discussed.

Thin films, 100 to 700 nm, of $(Y_{0.96}Eu_{0.04})_2O_3$, were deposited onto either (100) or (111) Si substrates with deposition temperatures ranging from room temperature to 700°C. Films were then annealed at 900°C to achieve their maximum cystallinity and luminescent intensity. Films were then subjected to temperatures from room temperature to 750°C and the luminescent properties measured using a spectrometer with an excitation wavelength of λ_{ex} = 254 nm. A bulk powder sample of Y_2O_3:Eu^{3+} from Nichia was used as a comparison.

Y_2O_3:Eu^{3+} is an ideal material as a thermographic phosphor. Eu^{3+} exhibits sharp spectral lines that arise from forbidden ^5D_J to ^7F_J transitions and are easily detectable against the background radiation. Figure 1 shows the emission spectra at selected temperatures for the $^5D_0$ and $^5D_1$ to ^7F_J transitions.

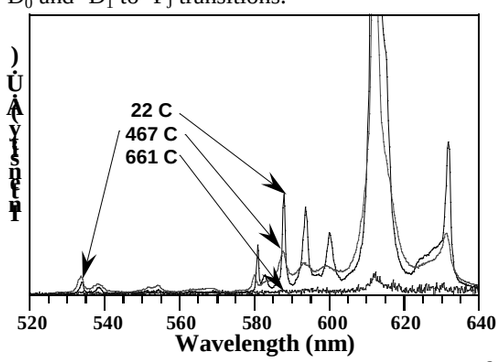

Figure 1. Emission spectra of a thin film of Y_2O_3:Eu^{3+} as a function of temperature.

The emission lines in Figure 1 can be seen to broaden and blue-shift about 1 nm in the temperature range shown. Thus, changes in the spectral line width and peak shifts are not practical for being used to determine the temperature. Figure 2 shows how the intensity of the $^5D_1 \rightarrow {}^7F_J$ 532 and 537 nm and $^5D_0 \rightarrow {}^7F_J$ 611 and 630 nm lines change as a function of temperature from 20 to 660°C. The intensity data has been normalized by dividing the intensity at each temperature by the maximum intensity for that emission line. Between room temperature and ~150°C, the intensity of these lines do not change significantly to accurately determine the temperature in this range. The intensity 523 and 537 nm lines were observed to increase until a maximum intensity of around 420°C. From 150°C to 420°C, the 611 and 630 nm lines were found to decrease linearly. Since the $^5D_1$ level lies above $^5D_0$, as the temperature increases electrons from the charge transfer band that would normally transition to the more favorable emission from the $^5D_0$ are promoted to the $^5D_1$ level instead due to interactions with phonons. This can be observed by determining the slope of the intensity versus temperature. From 150°C to 420°C, the intensity of the $^5D_0 \rightarrow {}^7F_J$ decreases at approximately the same rate at which the $^5D_1 \rightarrow {}^7F_J$ is increasing. At around 420°C, these electrons are further promoted to higher energy levels, $^5D_2$ and $^5D_3$, which do not produce very intense lines, and thus radiative emission was lost around 660°C. From 420°C to 660°C, the intensity of the $^5D_1 \rightarrow {}^7F_J$ lines were found to decrease faster than the $^5D_o \rightarrow {}^7F_J$ lines, which continue to decrease at the same rate as between 150° and 420°C. Therefore, above 150°C, the linearity of the 611 and 630 nm lines can accurately determine the temperature.

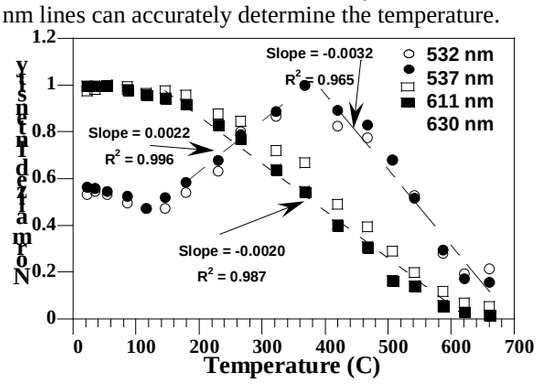

Figure 2. Variation of the 532, 537, 611 and 630 nm lines as a function of temperature. Intensity has been normalized.

For comparison, a Si wafer was coated with a bulk powder of Y_2O_3:Eu^{3+} and the excess particles removed, leaving a uniform coating of individual particles Upon comparison of the emission properties from this bulk powder sample with the thin film sample, very few noticeable differences in the properties were detected. Both the powder and film were found to have the 611 nm line decrease linearly with temperature and at about the same rate, given by the slopes.

References

[1] B.W. Noel, W. Dale Turley, and S.W. Allison, in, Proceedings of the 40th International Instrumentation Symposium, vol., Aerospace Test Measurement, 1994, p. 271-88.