Photoluminescence characterization of rare-earth garnet crystals for fiber-optic thermometer

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A fiber-optic fluorescence thermometer, using temperature dependence of fluorescence lifetime, is a useful technique for temperature measurement in extraordinary conditions. In the fluorescence thermometer, temperature is measured based on the temperature dependence of the lifetime of fluorescence from the phosphorous sensor head. The sensitivity and the accuracy of the measurement, therefore, depend greatly on the properties of the sensor crystals. Various crystals, such as ruby (Cr doped Al_2O_3), spinel (Cr doped $MgAl_2O_4$), alexandrite (Cr doped $BeAl_2O_4$) and emerald (Cr doped $Be_3Al_2Si_6O_{18}$) have been reported for the sensor head of the fiber-optic thermometer. In these crystals, host crystals effect greatly on the temperature dependence of fluorescence lifetime of Cr ions. Among many sensor materials, oxide crystals composed of rare-earth element and aluminum have many advantages of chemical and thermal stability as the sensor head of thermometer.

In this paper, crystals are grown with rare-earth garnet compositions, $Y_3Al_5O_{12}$ and $Lu_3Al_5O_{12}$, doped with Cr_2O_3 using floating zone technique (FZ). Photoluminescence (PL) from the grown crystals is evaluated for the fluorescence thermometer applications.

Crystals doped with Cr^{3+} ions have been grown from 4N-Al_2O_3, 4N-rare-earth oxides (R_2O_3: R=Y and Lu), and 3N-Cr_2O_3 with nominal compositions of $Y_3(Al_{5-x}Cr_x)O_{12}$ and $Lu_3(Al_{5-x}Cr_x)O_{12}$ using floating zone technique. Emission and excitation spectra from the grown crystals were measured. Temperature dependence of the PL lifetime was also evaluated using a fiber-optic thermometer equipment excited by a pulse-driven light emitting diode (LED).

In Cr doped $Y_3Al_5O_{12}$ garnet crystals, photoluminescence (PL) peaking at around λ=677 and 700 nm is observed with lifetime of τ=1.6 ms at room temperature. PL lifetime decreases from 1.8 ms to 1.0 ms with the temperature from 290 K to 360 K. Temperature coefficient of PL lifetime is 1.1×10^{-2} ms/K. In the crystal grown with a nominal composition of $Lu_3(Al_{4.95}Cr_{0.05})O_{12}$, PL peaking at 680 and 700 nm is also observed as shown in Fig. 1. PL lifetime of crystal, τ=3.6 ms at room temperature, is calculated from decay curve of PL intensity.

From these studies, Cr doped $Y_3Al_5O_{12}$ and Cr doped $Lu_3Al_5O_{12}$ crystals are suggested to be useful as the sensor materials for fluorescence thermometer. Temporal characteristics of PL from Cr doped $Y_3Al_5O_{12}$ and Cr doped $Lu_3Al_5O_{12}$ crystals are quite comparable to that of ruby (Cr doped Al_2O_3) crystal. Cr doped garnet crystals are potentially useful material for the sensor crystals in the fluorescence thermometer.

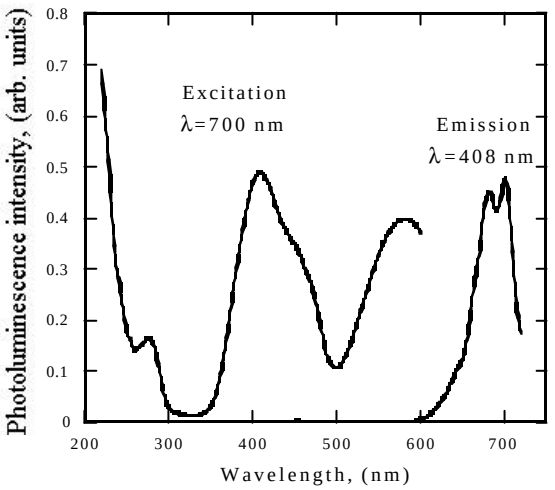

Fig. 1 Emission and excitation spectrum from crystal grown with a nominal composition of $Lu_3(Al_{4.95}Cr_{0.05})O_{12}$ using floating zone (FZ) technique