3-8 Efficient Infrared Upconversion Display Devices

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Combinations of infrared excitable phosphors with efficient infrared emitting GaAs:Si diodes have long been interesting for application to color display devices and so on. However, the low conversion efficiencies at low exciting current have so far hindered them from wider application.

Substantial improvement in conversion efficiency of green-emitting, infrared upconversion display devices was realized by employing BaY_2F_8:Yb,Er single crystal and confining the infrared exciting energy in an optical cavity. The improvement was found partly due to the extension of Yb excited state lifetime due to the reabsorption of infrared energy. Analyses were carried out to investigate the ultimate conversion efficiency of the upconversion devices.

Crystals of $BaY_{1.34}Yb_{0.60}Er_{0.06}F_8$ composition were obtained by the Bridgman method. Absorption and infrared emission spectra of the crystals are shown in Fig. 1 along with emission spectrum of a GaAs:Si diode. A simple display device was fabricated by putting a small crystal platelet onto a GaAs:Si diode and by containing them in an optical cavity (Fig. 2). The side of the cavity was composed of a reflecting ring and the upper side was covered with a dichroic filter that reflects almost all of the infrared light and transmits 90% of the green light. The devices showed approximately 10 times increase in efficiency in comparison to that of devices employing powdered crystals. The lifetime of ytterbium excite state (τ_s), measured in a typical case, was as long as 3.6 msec compared to the value of 1.9 msec obtained for small crystal and without a reflecting cavity.

Several important characteristics of the upconversion devices were shown to be calculated straightforwardly from a simple model. Particularly, τ_s can be given with a relation

$$1/\tau_s = Wr+Wn-Wr \int \frac{\alpha(\lambda)\ \varepsilon(\lambda)}{f+\alpha(\lambda)} d\lambda \text{ ----- (1),}$$

where Wr ($\sim 400s^{-1}$) and Wn ($\sim 100s^{-1}$) are radiative and nonradiative decay rates of ytterbium ions, respectively, $\alpha(\lambda)$ is absorption constant and $\varepsilon(\lambda)$ is normalized emission spectrum ($\int \varepsilon(\lambda)d\lambda=1$) and f ($cm^{-1}$) is spatial loss factor. The value for f can be approximately given with a relation

$$f = \Sigma AiTi/4V \text{ ----- (2),}$$

where Ai's are surface areas for different patches, V is volume of the cavity and Ti is transmissivity of infrared radiation corresponding to i-th patch. Dependence of measured τ_s on f was in qualitative accord with Eq. (1).

The conversion efficiency at given excitation level is dependent on the degree of confinement, which is in inverse relation with f, τ_s and the volume of the crystals. Quantitative estimates show that the conversion efficiency of the upconversion devices will be nearly two orders of magnitude higher than the value previously considered.

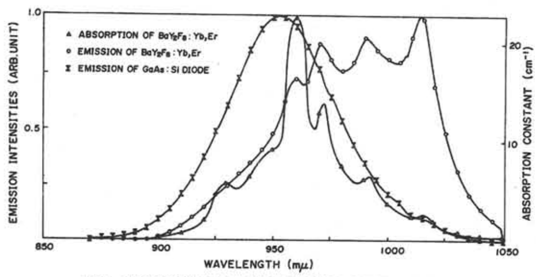

FIG.1 ABSORPTION AND INFRARED EMISSION SPECTRA OF BaY_2F_8:Yb,Er CRYSTAL AND TYPICAL EMISSION SPECTRUM OF GaAs: Si DIODE

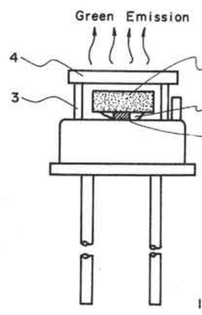

FIG.2