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SPECTROSCOPIC INVESTIGATION OF THE Cr TO Tm ENERGY TRANSFER IN  
YTTRIUM ALUMINUM GARNET CRYSTALS

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New and interesting schemes have recently been considered for the efficient operation of solid-state ionic laser systems. Often the available data on these systems were obtained only because they seemed directly related to the laser performance and provide no insight into the physical processes. A more systematic approach is desirable, where more attention is devoted to the elementary basic processes and to the nature of the mechanisms at work. It is with this aim that we have undertaken the present study.

Yttrium Aluminum Garnet ( $Y_3Al_5O_{12}$ ), called YAG, has two desirable properties as host for rare earth impurities: 1) trivalent rare earth ions can replace the yttrium without any charge compensation problem, and 2) YAG crystals have high cutoff energies. The latter property is conducive to the presence of sharp emission spectral lines which lend themselves to laser applications. Several attempts have been made to improve the efficiency of these systems by assisting the rare earth emission by means of energy transfer from a co-dopant  $Cr^{3+}$  ion.

$Cr^{3+}$  has lased in a great number of host lattices, as a three-level monochromatic system in ruby, and as a tunable four-level system in garnets with a low crystal field at the octahedral site that it occupies. In such garnets,  $Cr^{3+}$ , because of its broad band emission, has been used as an efficient sensitizer for  $Nd^{3+}$ .(1) It has also been used as sensitizer for other

ions, such as  $\text{Tm}^{3+}$ , which may be pumped via  $\text{Cr}^{3+}$  with a good quantum efficiency.

In YAG,  $\text{Cr}^{3+}$  resides in a site with a strong crystal field and, consequently, it has sharply defined luminescent levels and an emission confined to a narrower region of the spectrum. However, there is a good spectral overlap between this emission and the  $\text{Tm}^{3+}$  absorption.

With these considerations in mind we have conducted a series of experiments in order to elucidate the nature of the energy transfer process between the  $\text{Cr}^{3+}$  and  $\text{Tm}^{3+}$  ions in YAG. We have obtained spectral data on various samples, single-doped with  $\text{Cr}^{3+}$  and  $\text{Tm}^{3+}$  and co-doped with these two ions, which include absorption, luminescence, excitation and response to pulsed excitation. We have found that the rate of the  $\text{Cr}^{3+}$  to  $\text{Tm}^{3+}$  energy transfer process varies in general with temperature and we have set up a model that explains this temperature dependence. We have studied the time evolution of the Cr emission in the double-doped samples and measured carefully the spectral overlap between this emission and the  $\text{Tm}^{3+}$  absorption in the 77-350K temperature region. From these data we have extracted the relevant parameters that give a measure of the Cr-Tm coupling.

The results of our measurements and calculations indicate that, despite the spectral confinement of the Cr emission, the  $\text{Cr}^{3+}$  ion in YAG can be used to sensitize efficiently the  $\text{Tm}^{3+}$  ion.

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1. G. Armagan and B. Di Bartolo, IEEE J. Quant. Electron. 24, 974 (1988).