SENSITIZED LUMINESCENCE AND STIMULATED RADIATION FROM YTTRIUM-ALUMINUM GARNET CRYSTALS

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Submitted March 13, 1967

Zh. Eksp. Teor. Fiz. 53, 490–491 (August, 1967)

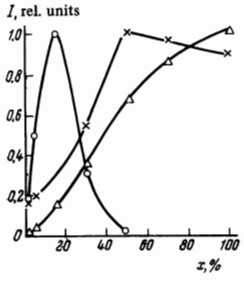
Investigations have been carried out of luminescence of yttrium-aluminum garnet (YAG) crystals containing erbium, thulium, and holmium. It has been shown that at high erbium concentrations the probability for transfer of excitation energy from Er^{3+} ions to Tm^{3+} or Ho^{3+} ions is much greater than that for quenching interactions between the Er^{3+} ions. Continuous generation on the holmium line at a wavelength of 2.0990 μ and a threshold of 45 W over the crystal length has been obtained with YAG crystals containing erbium, thulium, and holmium at 77°K.

IT has been shown in a number of papers that at nitrogen temperatures yttrium-aluminum garnet crystals with a high concentration of active impurities (50% Er, and 2% Ho) are an efficient laser material.[1,2] In the usual systems the concentrations of active ions do not exceed several percent and are restricted by concentration quenching processes which worsen appreciably the generation characteristics of the material.

This communication is devoted to a clarification of the reasons for the high efficiency of YAG containing erbium, thulium, and holmium at 77°K and to an investigation of a laser based on such a system.

Unlike crystals with neodymium impurities, in which concentration quenching sets in at a concentration $\approx$ 1 percent[3], concentration quenching of erbium is observed at concentrations of more than 15 percent (see the figure). This is connected with peculiarities of the level scheme of erbium, in which the pair interaction of ions that leads to quenching is inhibited. In YAG crystals with a concentration of 50% Er the quantum yield of the luminescence in the 1.6-μ band decreases by more than an order of magnitude.

On introducing into the crystals containing erbium a small admixture (1 percent) of thulium or holmium, one observes quenching of the erbium luminescence accompanied by an increase in the emission intensity of these ions. The figure shows the intensity of luminescence of thulium and holmium ions as a function of the erbium concentration. The intensities were compared at the 1.8825 μ line (the $^3H_4 - {}^3H_6$ transition of the thulium ion), and at the 2.0990 μ line (the $^5I_7 - {}^5I_8$ transition of the holmium ion), using crystals of approximately equal dimensions under unchanged conditions of generation and detection. The crystals were grown by spontaneous crystallization from a solution in a melt and by the Czochralski method. The maximum intensity of the holmium emission is obtained at a 50-percent concentration and the thulium emission increases up to a 100-percent erbium concentration. The probability of transfer of excitation energy from Er^{3+} ions to Tm^{3+} or Ho^{3+} ions is thus appreciably larger than the probability of quenching interactions between Er^{3+} ions. For crystals containing holmium a 50-percent erbium concentration is close to optimal. In crystals containing both holmium and thulium ions we observed an increase in the holmium luminescence and quenching of the thulium luminescence.



Dependence of the intensity of Er^{3+}, Tm^{3+}, and Ho^{3+} ions in the crystals: O – [(100 – x)% Y, x% Er] AG, Δ – [(99 – x)% Y, x% Er, 1% Tm] AG, × – [(99 – x) % Y, x% Er, 1% Ho] AG on the concentration of Er at T = 77°K (for all the curves the intensities are normalized to unity).

Laser experiments were carried out on crystals of the following compositions: [48% Y, 50% Er, 2% Ho]AG, and [42% Y, 50% Er, 6% Tm, 2% Ho]AG. Pumping with an IFP-800 lamp at nitrogen temperature, we obtained stimulated emission of two holmium lines with wavelengths of 2.0990 and 2.1285 μ. The thresholds for these lines were 3 and 14 J for a 50-mm long crystal. Continuous generation at 2.0990 μ with a 45-watt threshold over the crystal length was observed when an incandescent lamp was used for excitation. The low threshold for continuous generation is connected with the high transfer efficiency in the YAG system containing erbium, thulium, and holmium and with the comparatively long lifetime of the Ho^{3+} ions (5 millisec in the laser crystal).

We note that a change in the crystal composition allows one to vary within small limits the wavelength of generation. In YAG crystals with 50 percent erbium and 2 percent holmium the 2.0990 μ line is shifted by 10 Å towards longer wavelengths compared with a YAG crystal with 2 percent holmium. Introduction of additional impurities whose ionic radius differs from that of yttrium permits one to increase the tuning band.

[1] L. F. Johnson, L. G. Van Uitert, and G. E. Geusic, Appl. Phys. Letters 7, 127 (1965).

[2] L. F. Johnson, G. E. Geusic, and L. G. Van Uitert, Appl. Phys. Letters 8, 200 (1966).

[3] L. G. Van Uitert and L. F. Johnson, J. Chem. Phys. 44, 3514 (1966).

Translated by Z. Barnea
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