loops of small dimensions, on the order of 30 - 170 Å. On the other hand, it is known [9, 10] that the maximum pinning force is expected under conditions when the dimension of the pinning centers is $\ell \sim \xi$, where ξ is the coherence length.

In our case, obviously, as a result of low-temperature neutron irradiation at a dose 4.5×10^{12} cm^{-2}, the growth of ϕ_c is due to the pinning of the dislocations already present in the sample by the newly produced point defects. The dislocations, in turn, are pinning centers for the vortices.

Storing the sample for 80 hours at T = 100°K (the corresponding values are designated by triangles) does not eliminate the irradiation effect.

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EXCITATION ENERGY TRANSFER BETWEEN TRIVALENT RARE-EARTH IONS, STIMULATED BY A RADIATION FIELD

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We have observed the transfer of excitation energy from Yb^{3+} ions to Tb^{3+} ions in silicate glass; this transfer was stimulated by radiation from a neodymium laser with wavelength 1.06 μ. The energy transfer was effected by the interaction of the Yb^{3+} ion in the excited state, the Tb^{3+} ion in the ground state, and a photon of energy equal to the difference between the excited energy states of the ions Yb^{3+} ($^2F_{5/2}$) and Tb^{3+} ($^5D_4$). In our experiments, the radiation of the neodymium laser not only excited the Tb^{3+} ions, but also produced a photon field at a difference frequency. A theoretical analysis of the transfer of excitation energy between active ions with photon participation is given in [1].

The investigations were performed on silicate-glass samples activated with 8 mol.% Tb^{3+} and 7 mol.% Yb^{3+} (the content of the initial batch). Irradiation of such glass by a neodymium laser operating either in the free-running mode or Q-switched, at T = 300°K, produced luminescence of the Tb^{3+} ions in the region 0.48 - 0.53 μ; this luminescence was connected with transitions from the $^5D_4$ level to the $^7F_{6-0}$ levels. The energy level scheme of the Yb^{3+} and Tb^{3+} ions

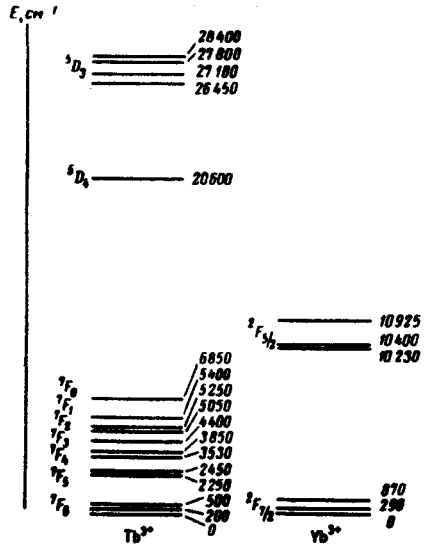

Fig. 1

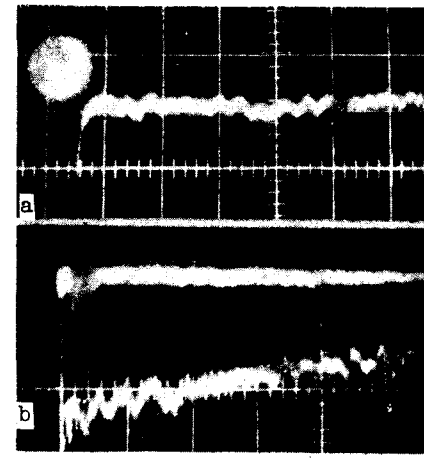

Fig. 2

Fig. 1. Energy level scheme of the ions Tb^{3+} and Yb^{3+}.

Fig. 2. Oscillogram of luminescence of Tb^{3+} ions following excitation of a sample by neodymium-laser radiation with pulse duration 2×10^{-8} sec, at a sweep duration 5 μsec/cm (a) and 50 μsec/cm (b).

is shown in Fig. 1[2]. The laser radiation transfers the Yb^{3+} ions to the $^2F_{5/2}$ state and produces a photon field at a frequency corresponding to the difference between the energy states $^5D_4$ and $^2F_{5/2}$ of Tb^{3+} and Yb^{3+}, respectively. Excitation with ultraviolet radiation at T = 300°K produced in this sample luminescence of the Tb^{3+} ions from the $^5D_4$ level, with a lifetime 500 μsec, and luminescende of Yb^{3+} ions from the $^2F_{3/2}$ level with a lifetime 200 μsec. The emission spectra and the lifetimes of the excited states of the active ions, following laser irradiation, did not differ from those observed after ultraviolet excitation.

Figure 2 shows an oscillogram of the luminescence signal of the Tb^{3+} ions following irradiation of the sample with light from a Q-switched neodymium laser with pulse duration 2×10^{-8} sec. The resolution time of the receiving apparatus was 5×10^{-6} sec. From an examination of the radiation kinetics of the Tb^{3+} ions it is seen that the luminescence follows directly the exciting pulse. Besides the above-considered process of excitation-energy transfer stimulated by the radiation field, the appearance of the green luminescence of the Tb^{3+} ions may be due also to cooperative interactions, i.e., the transfer of the energy of two excited Yb^{3+} ions to one Tb^{3+} ion, and two-photon excitation of Tb^{3+} ions. We shall show that in our case these processes cannot explain the appearance of the green glow of the Tb^{3+} ions following laser excitation.

As seen from the energy-level scheme (Fig. 1) the energy of the transition from the $^7F_6$ level to the $^5D_4$ level of the Tb^{3+} ions is 20600 cm^{-1}. The absorption line width corresponding to the transition from the $^7F_6$ to the $^5D_4$ level at T = 300°K amounts, according to our measurements, to ∿360 cm^{-1}. The energy of two quanta of laser emission with wavelength 1.06 μ is ∿18800 cm^{-1}. Thus, even when account is taken of the line width, two quanta of the laser radiation do not suffice to excite the Tb^{3+} ions to the $^5D_4$ level. This is evidence that two-photon excitation is ineffective in this system.

In the case when the appearance of the luminescence is due to cooperative processes [3 - 5], excitation by a neodymium-laser pulse of 2×10^{-8} sec duration should produce a luminescence flare-up of the Tb^{3+} ions, determined by the lifetime of the Yb^{3+} ions. In our experiments we observed no flare-up of the

Tb^{3+} ion luminescence within 5 μsec. The excitation-energy transfer occurred within the time of the laser pulse. The green luminescence of Tb^{3+} is thus due to excitation-energy transfer processes in which photons take part.

We have estimated the probability of such an interaction following excitation of the sample by radiation from either a free-running or a Q-switched neodymium laser. We determined the number of excited Yb^{3+} and Tb^{3+} ions at a given energy of the exciting pulse. The number of excited Yb^{3+} ions was estimated from the absorption of the radiation energy in the investigated sample. The absorption coefficient of the Yb^{3+} ions at the frequency of the laser transition at T = 300°K is 0.24 cm^{-1}. The number of excited Tb^{3+} ions was determined from the amplitude of the luminescence signal on the oscilloscope screen. The receiving apparatus was calibrated in the 0.53 μ region with the aid of the second harmonic of the neodymium laser.

In the case of Q-switched generation with pulse duration (τ_0) 2×10^{-8} sec, energy 0.1 J, and beam diameter 0.2 cm, the total number of excited Yb^{3+} ions (n^*_{Yb}) was $\sim 1 \times 10^{17}$, and the number of excited Tb^{3+} ions (n^*_{Tb}) was $\sim 1 \times 10^{15}$. The transfer probability W_e was determined from the relation $n^*_{Tb} = n^*_{Yb} W_e \tau_p$ and turned out to equal $\sim 10^6$ sec^{-1}. In the case of a free-running laser, at $\tau_p = 2 \times 10^{-4}$ sec and the same energy and beam diameter, W_e turned out to equal $\sim 10^2$ sec^{-1}.

The stimulated excitation-energy transfer process observed by us is effected with absorption of a photon. The probability of such a process is equal to the probability of the transfer of energy from the excited Tb^{3+} ion to the Yb^{3+} ion under the influence of the radiation field at a frequency corresponding to the difference of the energy states $^5D_4$ of the Tb^{3+} ion and $^2F_{5/2}$ of the Yb^{3+} ion. The Tb^{3+} ion goes over here from the excited $^5D_4$ state to the ground $^7F_6$ state, and Yb^{3+} goes from the ground $^2F_{7/2}$ state to the excited $^2F_{5/2}$ state with simultaneous stimulated emission of a photon at the difference frequency. In the absence of the radiation field, the energy transfer is realized with spontaneous emission of a photon.

The luminescence connected with transitions from the level of one active ion (Gd^{3+}) to the level of another (Yb^{3+}) in Yb_2O_3, was observed by Feofilov [6]. The probability of this emission amounts, according to the data of [6], to $\sim 10 - 10^2$ sec^{-1}. The probability of the spontaneous process, calculated by us from the probability of the stimulated interaction, turned out to be $\sim 10^2$ sec^{-1}, in agreement with the data of [6].

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