PHOTOCONDUCTIVITY OF RUBY WHEN STRONGLY IRRADIATED BY A RUBY LASER

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We have observed photoconductivity in ruby exposed to strong light from a ruby laser. The photconductivity was observed at an irradiation power ~10^{10} W/cm^2, prior to the onset of damage in the ruby, in a very small range of incident-light intensities. The experimental procedure was as follows. Holes were drilled in a ruby sample (20 x 6 x 6 mm) for electrodes of 2 mm diameter. The distance between the plates of the capacitor made up of the electrodes was 2 mm. Light from a Q-switched ruby laser was focused on the interelectrode space. A voltage of 4 kV was applied to the electrodes. The signal was picked off from a 10 kΩ resistor and fed to one beam of a two-beam oscilloscope (SI-7) through a cathode follower and an amplifier with pass band 20 cps - 30 Mcs. The laser generation signal was applied to the second beam. To eliminate effects connected with surface conductivity, a grounded metal ring was fastened around the electrode from which the signal was picked off.

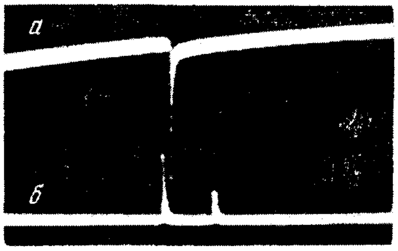

Fig. 1. a -- Photoconductivity pulse, b -- laser pulses spaced 20 μsec apart.

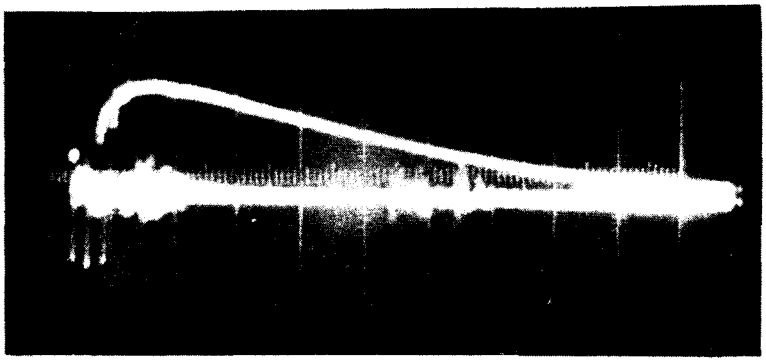

Fig. 2. Pulse of ruby photoconductivity at instant of damage

Figure 1 shows an oscillogram obtained from the two-beam oscilloscope. A conductivity signal was observed only from the first, more powerful generation pulse. This points to the presence of a threshold. What we measured was not the conductivity directly, but the recharging of the capacitor made up by the electrodes, due to the appearance and motion of carriers in the interelectrode space. If the number of carriers is n, then their displacement under the influence of a field E (V/cm) by a distance d produces on the capacitor plates a change of charge

$$Q = \frac{ned}{D},$$

where D is the distance between electrodes and e is the electron charge.

The current due to this change of charge in a time τ (τ = RC of the circuit) produces across the load resistor R a voltage

$$U = \frac{nedR}{D\tau} .$$

The induced dipole moment ned under the influence of a field of intensity E for carriers with mobility μ, is determined by

$$ned = \int_0^\tau En(t)e\nu dt = \frac{U\tau D}{R} .$$

According to our measurements

$$U = 10^{-1}\text{ V};\quad \tau = 5 \times 10^{-8}\text{ sec};\quad D = 2 \times 10^{-1}\text{ cm};\quad R = 10^4 \Omega;\quad E = 5 \times 10^3\text{ V/cm}.$$

Hence

$$\int_0^\tau n(t)e\nu dt = 2 \times 10^{-17}\text{ Coul.cm}^2\text{/V}.$$

The number of carriers n(t) depends on the intensity of the incident light, the ionization probability, and the electron-recombination probability in the conduction band of the corundum. Lack of data on the mobility and the lifetime of the electrons in the band prevent us from estimating accurately the ionization probability of the chromium ions. If we assume, however, $\nu = 5 \times 10^{-2}$ cm^2/V-sec [1], then the average carrier density is $n(t) = 5 \times 10^{15}$ cm^{-3}. The density $w^{(b)}$ of the electrons produced per second in the conduction band of corundum, calculated in accordance with the formula

$$w^{(b)} \simeq 70\ N\ \omega \left(\frac{I_0}{\hbar\omega} \right)^{3/2} \left(\frac{e^2\epsilon^2}{m\omega^2 I_0} \right)^3$$

at irradiation powers ~10^{10} W/cm^2 is equal to $w^{(b)} = 10^{26}$ cm^{-3} sec^{-1}. If we assume that the electron concentration in the band is quasistationary, then the effective lifetime of the electron in the conduction band of the corundum is

$$T = \frac{n}{w^{(b)}} = 5 \times 10^{-11}\text{ sec.}$$

The appearance of electrons in the conduction band of the corundum is due to the many-photon absorption in the chromium ions and to their ionization. The ionization probability increases rapidly as the frequency of the electromagnetic field (or its harmonics) approaches the natural frequencies of the electronic transitions. We have observed that at irradiation powers -10^{11} W/cm^2 the ruby experiences damage accompanied by an intense flash of light [3]. In addition to the bands cited in [3], with maxima at ~620 and ~450 nm, we observed a band with maximum ~360 nm occurring at the instant of breakdown. The electrons in the chromium ions absorb the light of ruby frequency and go over into the metastable level ^2E. From this level they go via two-photon absorption to the level $^2T_2$.

We propose [3] that a noticeable part of the electrons reaching the level $^2T_2$ proceed further to the conduction band. Estimates show that at the employed light intensities the probability of transitions to the lower levels is ~10^{+9} sec^{-1}, and the probability of falling into the conduction band is ~10^{+10} sec^{-1}.

In our estimates we disregard the variation of the real part of the dielectric constant. This variation may be due to heating of the medium in the focal region or to the Stark effect in the light field. Since according to our estimates the local heating prior to the onset of damage in the ruby, at constant volume, does not go beyond 1000°, the signal produced by the change of ϵ is not more than 10^3 V, i.e., smaller than the observed signal by two orders of magnitude.

The Stark effect can be disregarded in our case, since it has no inertia. The kinetics of the conductivity signal observed by us differs from lasing action. Figure 2 shows the conductivity signal taken with a sweep of 100 nsec per division. An increase in the conductivity is observed during the generation time (~50 nsec). The prolonged attenuation is apparently due to the capture of the electrons by the shallow traps near the bottom of the conduction band of the corundum.

Absorption from the excited ^2E level should be manifest in the dependence of the absorption coefficient on the intensity of the incident laser light. Figure 3 shows this dependence (curve 1). Curve 2 in the same figure shows the variation of the absorption coefficient, calculated for a two-level system. This curve lies lower than the experimental one. The difference increases with increasing intensity of the incident light.

It follows therefore that there exists additional absorption, which increases with the intensity of the light. We assume that it is due to two-photon processes from the excited level.

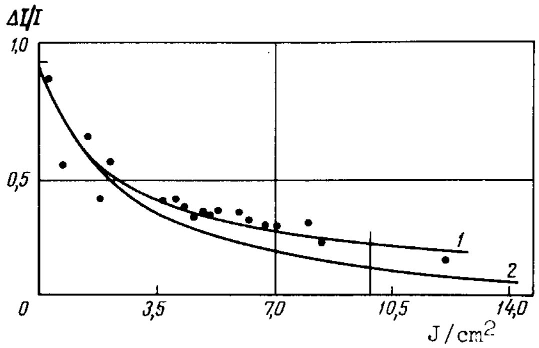

Fig. 3. Ruby absorption coefficient vs. incident light intensity. 1 -- Experimental curve, 2 -- theoretical.

The vertical line in Fig. 3 shows the minimum energy at which the conductivity is observed.

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[2] F. V. Bunkin and A. M. Prokhorov, JETP 48, 1084 (1965), Soviet Phys. JETP 21, 725 (1965).

[3] T. P. Belikova and E. A. Sviridenkov, JETP Letters 1, No. 6, 37 (1965), transl. p. 171.

MAGNETIC MOMENT OF A SUPERCONDUCTING ELLIPSOID IN A MIXED STATE

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It is known that in superconductors of type I, whose interface between the normal and superconducting phases has positive surface energy α_{ns}, the transition from the superconducting into the normal state takes place in all cases (with the exception of an infinitely long cyl-