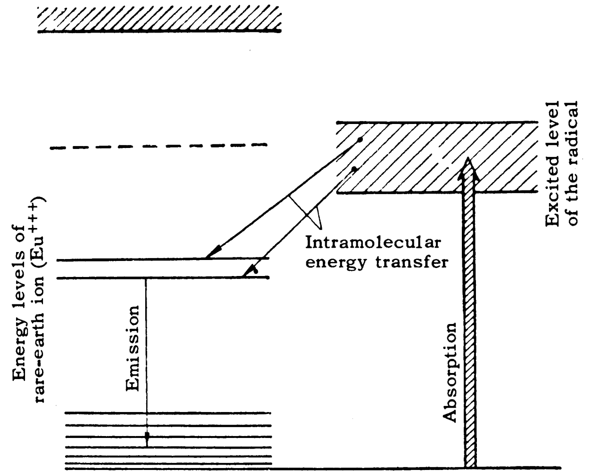

cence yield increases and approaches unity in some cases.

At the present time there are no grounds for assuming that the phenomenon of intramolecular energy transfer is limited to the ions of the rare-earth elements or to organic radicals. Apparently we can choose for any ion capable of luminescence a molecule that has an absorption level in the most suitable place and to which intramolecular energy transfer is possible.

The phenomenon of intramolecular transfer of energy allows us to revise our opinion concerning substances previously regarded as offering little promise for use in lasers. This principle makes feasible lasers more efficient than those with ruby and an extension of the range of generated wavelengths.

I am grateful to Academician P. L. Kapitza for interest in this problem.

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Translated by J. G. Adashko

NONSTATIONARY PHOTOMAGNETIC EFFECT IN GERMANIUM SINGLE CRYSTALS

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THE time behavior of the photomagnetic effect (PME) when the specimen under study is subjected to pulsed illumination remains almost unstudied, if the papers of Bulliard[1] and Lashkarev[2] are disregarded. In these papers very important phenomena accompanying the nonstationary PME remained unnoticed.

The results are given below of a study we have undertaken of the nonstationary PME under pulsed illumination. The photomagnetic emf was measured as usual in the direction perpendicular both to the magnetic field and the direction of the light flux. The specimen was placed in a magnetic field which could attain 30,000 Oe. The illuminating pulse was provided with the aid of a Kerr cell, through which was transmitted the light from a 750 W incandescent lamp. Individual rectangular voltage pulses ($\approx$ 7 kV) were applied to the Kerr cell. The pulse length could be changed from 5 to 2,000 μsec; the time constants of initial rise and decay were equal, and did not exceed 1.5 μsec. The maximum light flux proceeding through the Kerr cell was approximately 10^{17} quanta/sec. According to our measurements the modulation depth of the visible light was 98%. The Kerr cell left the infrared region of the spectrum almost unmodulated, and the resulting modulation depth of the light (determined with a thermopile) was, therefore, 40% when a water filter 5 cm thick was placed in the light path in front of the Kerr cell. The measured PME emf and the voltage pulse on the Kerr cell were recorded simultaneously by an OK-17M double-beam oscilloscope synchronized by the voltage pulse generator.

Single crystal specimens of n type (30 ohm-cm) and p type (60 ohm-cm) germanium cut in the shape of discs approximately 30 mm in diameter were studied. The specimen surfaces were treated by standard methods. The reliability and stability of the apparatus was verified by comparing the anisotropy of the PME curves taken on the pulse apparatus with curves taken in steady-state conditions.[3-6]

The photographs of oscilloscope traces in Fig. 1 show the variation of the odd PME emf with time

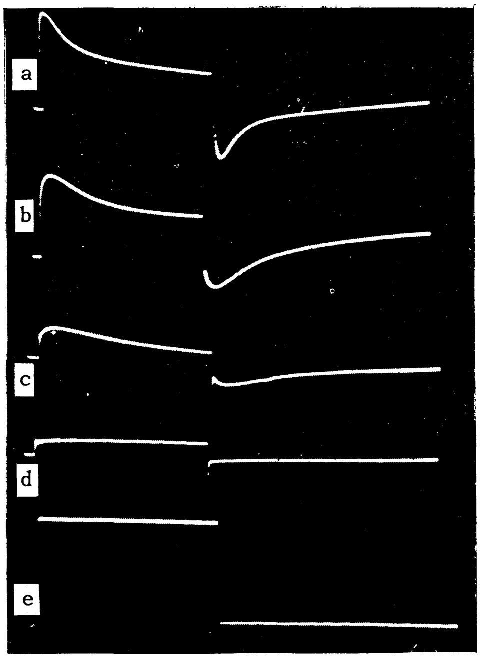

FIG. 1. The variation of the odd PME e.m.f. on specimen thickness: a – l = 1 mm; b – l = 2 mm; c – l = 3.5 mm; d – l = 11 mm; e is the voltage pulse on the Kerr cell (H = 25000 oe).

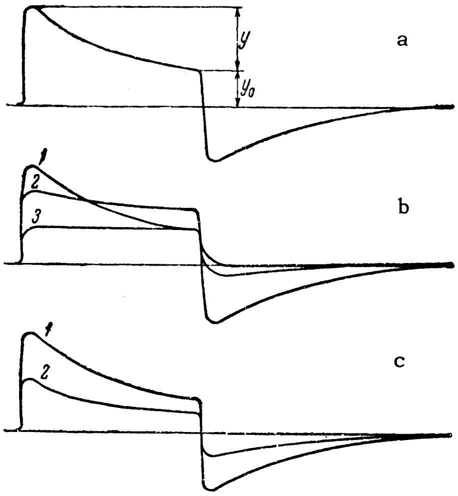

FIG. 2. The effect of background illumination on the shape of the odd PME e.m.f. signal when the specimen is illuminated by rectangular light pulses one millisec long: a and 1b – without background illumination; 2b and 3b – background illumination from the side opposite that illuminated by the pulse; 3b – intensity of background illumination equal to the pulse intensity; 2b – a factor of 2 smaller; 2c – background illumination from the same side as the light pulse and of equal intensity; H = 31000 oe.

when the illuminating pulse had a total length of 1 millisec. The different curves refer to specimens of different thicknesses l cut from the same bar (the diffusion length was L = 2 mm). The symmetry of the curves at the start and end of the light pulse is notable, where the signs of the emf's at the start and end of the light pulse are opposite. In Bulliard's experiments only the characteristic maximum on switching on the light was established. It is seen from Fig. 2 that, as the specimen thickness increases, the extrema level off and disappear completely for specimen thicknesses sufficiently large compared with L. If the illumination is shut off at the instant when the PME emf is going through the maximum, the emf diminishes to zero without changing sign, and the time constants of the rising and falling parts of the curve are equal. Below it is shown that the behavior with time of the PME emf depends greatly on the presence or absence of a constant specimen illumination (background illumination) on which the pulsed illumination is superposed.

The effect of background illumination on the shape of the signal is shown in Fig. 2. The various curves refer to various conditions of background illumination. We shall describe the curves obtained by the quantity $\gamma = y/y_0$, which defines the "sharpness" of the extrema. It is seen from the figures that background illumination of the specimen on the side opposite to that illuminated by the pulse diminishes γ sharply, and, for sufficiently strong background illumination, $\gamma \rightarrow 0$. The same background illumination in the direction coinciding with the direction of the pulsed illumination decreases the PME emf, while leaving γ practically unchanged.

Measurements showed that the form of the time variation of the PME depends greatly on the surface recombination velocity S, which we altered by lightly grinding the etched specimen. It was found that increasing the surface recombination velocity on the illuminated surface increased γ greatly, until the steady-state part of the PME practically disappears. If the surface recombination velocity of the illuminated surface is smaller than for the unilluminated, the steady-state PME emf increases and γ falls sharply.

The photoconductivity was measured as well as the PME emf. The behavior with time of the photoconductivity did not differ qualitatively from data obtained by other authors.

The phenomena described above can, apparently, be explained qualitatively as follows. The PME emf is proportional to the difference in concentration of minority carriers on the illuminated and unilluminated surfaces of the specimen, and is inversely proportional to the conductivity.

$$U_{\mathrm{PME}} \sim [n(0) - n(l)]/(\sigma_0 + \sigma_l),$$

where n(0) is the concentration on the illuminated surface, $n(l)$ is the concentration on the unilluminated surface, σ_0 is the dark conductivity, and σ_I is the photoconductivity. The change in the sign of the PME emf can be explained by the fact that, after the light is switched off, the carrier concentration $n(l)$ becomes greater than $n(0)$ for some short time. This can happen if the surface recombination velocity for the illuminated surface is greater than for the unilluminated. In fact, experiments showed that with an inverse ratio of the surface recombination velocities, the PME emf does not change sign on switching off the light.

The fact that the change in sign of the PME emf on switching off the light is observed on specimens with equal surfaces can, it seems, be explained if it is assumed that there is a variation of surface recombination velocity with illuminating intensity which can, in the first approximation, be written as $S = S_0 + \alpha I$, where I is the illuminating intensity. In this way the results of the experiments on the effect of background illumination on the specimen can also be explained. Thus, for example, when the surface of the specimen not illuminated by the pulsed light is subjected to background illumination, the surface recombination velocities, which were previously different, become equal, and, as a consequence, the change of sign in the PME emf is not observed.

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400

THE MECHANISM OF PARAMAGNETIC SPIN-LATTICE RELAXATION IN IONIC CRYSTALS AT LOW TEMPERATURES

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RECENTLY, in order to eliminate the difficulties which beset the Kronig-Van Vleck theory [1,2] at low temperatures, it has been suggested that the most effective mechanism for paramagnetic spin-lattice relaxation consists of exchange pairs,[3,4] the existence and strong spin-phonon coupling of which has been demonstrated experimentally.[5,6] The hypothesis of relaxation by means of exchange pairs easily explains two basic experimental facts that clearly contradict the Kronig-Van Vleck theory: the strong dependence of the relaxation time T_1 on the concentration of paramagnetic particles C and the weak dependence of T_1 on the magnitude of the applied magnetic field H. The anomalous dependence of T_1 on the temperature T that is sometimes observed also receives a simple interpretation.

It seems to us that relaxation by means of exchange pairs is effective only in crystals with a sufficiently large concentration of paramagnetic particles and that the width of the resonance line is comparable to the least interval separating the resonance peaks of the individual particles from the peaks belonging to pairs. At smaller concentrations the spin-spin interactions are not able to provide a transfer of energy from the individual particles to the pairs, because their energy spectra are usually completely different. Actually, the existence of two different spin-lattice relaxation mechanisms, leading to different temperature dependence of T_1, has been established experimentally in ruby.[6,7] The anomalies of the temperature dependence are observed in crystals with concentrations of paramagnetic ions exceeding 0.2%.

Our calculations have shown that in crystals having a medium concentration of paramagnetic ions the most effective mechanism for relaxation turns out to be the following. Let S and S′ be the spins of the interacting particles and $J(r)$ the exchange integral, a function of the distance r between the particles. Because of indirect exchange the isotropic interaction $\mathcal{H} = J\mathbf{S}\cdot\mathbf{S}'$ is effective at rather large distances. Let 2D be the initial