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ANISOTROPY OF POLARIZED-LIGHT ABSORPTION PRODUCED IN GaAs AND CdTe CRYSTALS BY A STRONG ELECTRIC FIELD

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We investigated the light-absorption anisotropy produced by a strong electric field near the intrinsic absorption edge in cubic semiconductors. We shall show that the absorption coefficients $\alpha_{\parallel}$ and $\alpha_{\perp}$ of light polarized parallel and perpendicular to the electric field, respectively, can differ by several times, and that their frequency dependence is also different.

Experimental Results and Discussion

We measured the change of the transmission of polarized light in GaAs and CdTe crystals following application of an alternating electric field. The measured samples were placed in a capacitor so constructed that its electric field was always in a plane perpendicular to the direction of the incident light. After passing through an IKS-12 spectrometer, the light was polarized with a polaroid film. The light polarized either parallel or perpendicular to the electric field was passed through the sample, which was placed in the capacitor. An alternating voltage of 1 kHz frequency was applied to the capacitors. The measurements were made at T = 100°C on high-resistivity ($\rho \sim 10^7 - 10^8$ ohm-cm at 300°K) single-crystal non-oriented GaAs and CdTe samples. We measured directly the change of the intensity ΔI of the transmitted light, due to the shift of the absorption edge in the strong electric field. Simultaneous measurement of the amount of light I_0 passing through the crystal in the absence of the electric field has made it possible to calculate the change $\Delta\alpha$ of the absorption coefficient, using the relation

$$\Delta\alpha \simeq -\frac{1}{L}\ln\left(1 - \frac{\Delta I}{I_0}\right), \quad (1)$$

where L is the crystal thickness.

It should be noted that the values given for the electric field intensity are not exact. The presence of thin air gaps, which were filled with silicone oil in the capacitor, and whose thickness is difficult to measure, may give rise to an error in the estimate of the electric field intensity.

The anisotropy of light absorption and its freqeuncy dependence is best revealed by plotting the ratio of $\Delta\alpha_{\parallel}$ to $\Delta\alpha_{\perp}$ against $\hbar\omega$. Namely, in the case of GaAs (see Fig. 1), $\Delta\alpha_{\parallel}$ may be twice as large as $\Delta\alpha_{\perp}$ for light-quantum energies 0.15 eV away from the edge, and $\Delta\alpha_{\perp}$

can become equal to $\Delta\alpha$ when the absorption edge is approached. With increasing electric field intensity, $\Delta\alpha_{\parallel}/\Delta\alpha_{\perp}$ approaches unity at lower values of $\hbar\omega$. For CdTe (Fig. 2), at a field intensity 12000 V/cm, $\Delta\alpha_{\parallel}/\Delta\alpha_{\perp}$ reaches 2.9 if $E_g - h\omega \sim 0.04$, and at 7500 V/cm even at $E_g - \hbar\omega \sim 0.03$ eV (E_g = width of forbidden band). When $\hbar\omega \to E_g$, the ratio $\Delta\alpha_{\parallel}/\Delta\alpha_{\perp}$ decreases and approaches unity. In the 12000 V/cm field, a region is observed in which this ratio is smaller than unity. To be sure, $\Delta\alpha_{\parallel}$ and $\Delta\alpha_{\perp}$ also decrease in this region, possibly as a result of heating of the crystal. The usual notions concerning the electroabsorption effect [1 - 3], based on a consideration of the optical transitions between one valence band and one conduction band, cannot explain such a strong anisotropy of the effect in the case of cubic crystals in the region of direct transitions at the point Γ where the effective mass is isotropic. In real semiconductors, however, particularly in GaAs and CdTe, the top of the valence band is degenerate, and this can lead to a qualitative change of the picture of electroabsorption. The occurrence of anisotropy under the influence of an electric field in such semiconductors can be easily understood in analogy with the well-investigated influence of uniaxial deformations in the structure of their valence band. By lowering the crystal symmetry, uniaxial deformation lifts, generally speaking, the degeneracy in the top of the valence band. Two new valence bands appear; they are shifted in energy and are strongly anisotropic. The hole states in each of these bands are superpositions of states of heavy and light holes. Such a strong distortion of the spectrum is the consequence of the degeneracy of the hole bands. Since the energies of the heavy and light holes are very close to each other near the point K = 0, even a relatively weak external influence can cause a complete overlap of the energies. Naturally, a strong electric field should cause a noticeable anisotropic distortion near the bottom of the degenerate hole band, and can lead to the appearance of appreciable anisotropy of the light absorption near the intrinsic absorption edge.

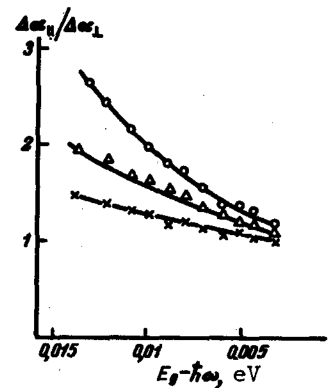

Fig. 1. The ratio $\Delta\alpha_{\parallel}/\Delta\alpha_{\perp}$ vs. the light-quantum energy for GaAs at E = 4600 V/cm (o), 6900 V/cm (Δ), and 9000 V/cm (×).

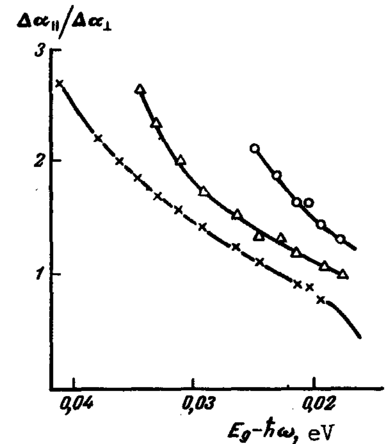

Fig.2. The ratio $\Delta\alpha_{\parallel}/\Delta\alpha_{\perp}$ vs. the light-quantum energy for CdTe at E = 3700 V/cm (o), 7500 V/cm (Δ), and 1200 V/cm (×).

This can be explained, using the simplest model of a triply degenerate valence band, as follows: The effective dipole moment of the transition from the band of the light holes to the conduction band is parallel to the electron quasimomentum, and for the heavy-hole band it is perpendicular [4]. On the other hand, the electrons with smallest $P_{\perp}$, the momentum component perpendicular to the field, tunnel most effectively inside the forbidden band under the influence of the electric field, since the presence of such a component increases the

effective potential barrier for the tunneling, by an amount $P_{\perp}^2/2m^*$ (m^* = reduced mass of electron and hole). It can therefore be assumed that deep in the forbidden band the electron and hole momenta are directed predominantly along the field, and consequently the dipole moments of the transition are oriented along the field for the light holes and perpendicular for the heavy ones, so that in the region of the absorption edge that is shifted by the field, the major contribution to $\alpha_{\parallel}$ is made by the light holes, and that to $\alpha_{\perp}$ is made by the heavy holes. But the light holes, owing to their small mass, tunnel much more effectively than the heavy ones, and there are therefore grounds for assuming that $\Delta\alpha_{\parallel} > \Delta\alpha_{\perp}$ in the frequency region corresponding to the forbidden band in the absence of the field. Calculations made within the framework of the simplest model of the complex band structure described above, i.e., the Kane model [4], without allowance for the spin-orbit splitting and for the influence of the higher bands, confirm these qualitative considerations. Thus, the experimental data [5] confirm the qualitative considerations of theoccurrence of anisotropy of the electroabsorption in the case of degenerate bands. However, no quantitative comparisons of the epxerimental results and the calculations were made, since the employed theoretical model was too idealized, and particularly since it did not take into account the fact that in the absence of an electric field the absorption edge is smeared out.

We did not investigate the connection between the anisotropy effect and the crystal orientation, although a connection between the two is possible.

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EXPERIMENTAL OBSERVATION OF THE CHANGE OF THE SIGN OF THE S-d EXCHANGE INTERACTION

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According to [1 - 4], the scattering of conduction electrons by localized magnetic moments of paramagnetic impurity atoms leads to an additional resistance, and the sign of the temperature-dependent part of this resistance is uniquely determined by the sign of the S-d exchange interaction.

It is shown in [5] that for a one-percent solution of iron in copper at T = 40°K, the R-T curves have a minimum, which results from the addition of two scattering mechanisms: the electron-phonon mechanism and the mechanism of conduction-electron scattering by the localized magnetic moments. As is well known, a positive spin polarization of the matrix is observed for solutions of iron in palladium [6]. Considerable interest attaches to the behavior of the magnetic component of the resistance on going from negative S-d exchange interaction to a positive interaction that leads to the polarization of the matrix.

We investigated the temperature dependence of the electric resistance of 1% solutions of iron in Cu_{1-x}-Pd_x alloys (x = 0.01, 0.02, 0.05, 0.1, 0.2, 0.3, 0.6, 0.8). According to