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SPONTANEOUS FRANZ-KELDYSH EFFECT IN CdTe

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The study of light absorption edge near the fundamental band of a semiconductor, and particularly the investigation of the origin of the absorption tails in the forbidden band, is of great practical and scientific interest. The model explaining their origin as being due to impurity states is presently universally accepted [1 - 4]. The fact that the absorption has a certain temperature dependence indicates that phonons also take part in the formation of the tails [5].

Subsequently there was developed a point of view according to which the impurities can play a double role. On the one hand, they produce a certain density of states, and on the other their electric field can shift the edge of the absorption band, i.e., a spontaneous Franz-Keldysh effect should arise [6, 7].

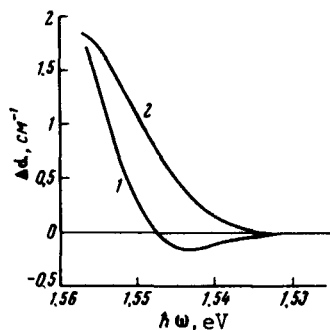


Fig. 1. Change of absorption index $\Delta\alpha$ vs. the light quantum energy $\hbar\omega$ at two harmonics for $E_1 = 10^4$ V/cm: 1 - $\Delta\alpha_1$ with frequency 400 Hz, 2 - $\Delta\alpha_2$ with frequency 800 Hz.

Our investigation of the electroabsorption of cadmium telluride near the edge of the fundamental band has made it possible to observe the presence of internal microfields. The differential method employed by us made it possible to distinguish the absorption due to the oriented part of the microfields from the remaining absorption.

The measurements were performed at liquid-nitrogen temperatures using a previously described setup [8]. A sinusoidal electric field of frequency $\Omega = 400$ Hz was applied to the investigated sample and modulated the transmitted monochromatic light.

The change of the absorption index of light in an alternating electric field should contain

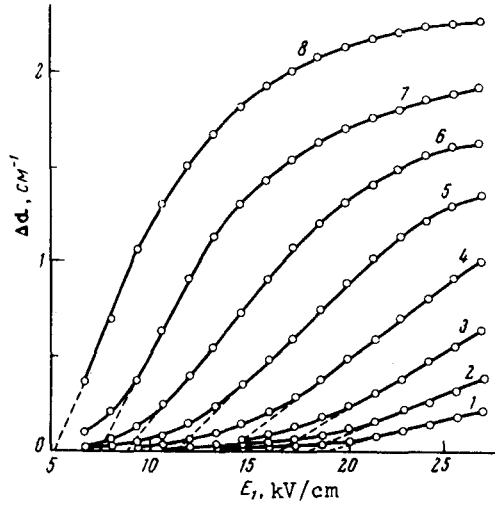


Fig. 2

Fig. 2. Plots of $\Delta\alpha_1$ vs. E_1 for different values of $\hbar\omega$ (in eV): 1 - 1.519, 2 - 1.524, 3 - 1.529, 4 - 1.534, 5 - 1.539, 6 - 1.544, 7 - 1.549, 8 - 1.554.

Fig. 3. Plots of $\Delta\alpha_1$ vs. $\hbar\omega$: 1 - $E_0 = 0$, 2 - $E_0 = 10^3$ V/cm, 3 - $E_0 = 10^3$ V/cm.

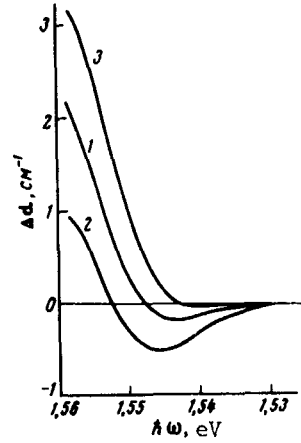


Fig. 3

only even harmonics of the field frequency, if the directions parallel and anti-parallel to the external field are equivalent in the sample.

In our case, however, we observed odd harmonics in addition to the even ones. Figure 1 shows plots of the changes of the absorption indices $\Delta\alpha_1$ and $\Delta\alpha_2$ (frequencies 400 and 800 Hz, respectively) against the light quantum energy $\hbar\omega$ for the first and second harmonics. Harmonics III and IV were also observed.

It is known that to obtain odd harmonics of the transmitted-light modulation it is customary to apply to the sample, in addition to the modulating alternating voltage $E_1 \cos \Omega t$, also an external dc voltage E_0 [9]. $\Delta\alpha_n$ is then given by

$$\Delta\alpha_n = \int_0^\pi f(|E_0 + E_1 \cos \Omega t|) \cos n \Omega t d\Omega t. \quad (1)$$

As seen from (1), $\Delta\alpha$ should contain only even harmonics if $E_0 = 0$.

Since there was no external bias in our experiment, the presence of odd harmonics could be explained by assuming that the optical transitions occur in crystal regions in which there are internal fields. But the presence of an internal microfield alone still does not suffice to explain the appearance of odd harmonics. In fact, if we rewrite $\Delta\alpha_n$ in the form

$$\Delta\alpha_n = \frac{1}{V} \sum_E \Delta V_E \int_0^\pi f(|E + E_1 \cos \Omega t|) \cos n \Omega t d\Omega t, \quad (2)$$

where ΔV_E is that part of the volume V in which the internal field \vec{E} varies in the interval $(\vec{E}, d\vec{E})$, then in order to have $\Delta\alpha_{2k+1} \neq 0$ we must have $\Delta V_E \neq \Delta V_{-E}$, i.e., the contributions made to the absorption by the microfield regions with intensities \vec{E} and $-\vec{E}$ should be different.

If this is so and there exists a certain asymmetry of the internal field, then the contribution of the first harmonic to the absorption should depend on the orientation of \vec{E}_1 relative to the axis of the asymmetry.

To check on this, an external field was applied to the CdTe sample in the (110) plane in different directions, and the absorption was always measured at the same point. The measurements have shown that both $\Delta\alpha_1 \ll \Delta\alpha_2$ and $\Delta\alpha_1 > \Delta\alpha_2$ are possible, i.e., the magnitude of the first harmonic is different in different directions of the crystal.

It follows from (2) that if $E_1 \ll E$ (E can be estimated from the deficit $\Delta\hbar\omega$ [10]), then $\Delta\alpha_1$ should depend linearly on E_1 , and the larger $\Delta\hbar\omega$, the larger the values of E_1 for which the region of linear dependence should exist. Figure 2 shows plots of $\Delta\alpha_1$ against E_1 for different values of $\hbar\omega$. As seen from the figure, linear sections exist but cannot be extrapolated to the point $E_1 = 0$. The intercepts resulting from extrapolation at $\Delta\alpha_1 = 0$ increase with increasing $\Delta\hbar\omega$. This can be understood by recognizing that the signals observed by us come from those microfield regions into which the alternating field E_1 penetrates. The region of penetration of E_1 is bounded by the screening of these fields by the carriers, so that the intercepts should correspond to the critical values of E_1 at which this screening is removed.

If oriented microfields actually exist in the crystal, then by applying to the sample an additional dc field \vec{E}_0 it is possible to change the contribution of the first harmonic to the absorption. Figure 3 shows plots of $\Delta\alpha$ against $\hbar\omega$ in the absence of \vec{E}_0 and at \vec{E}_0 parallel and antiparallel to \vec{E}_1 . As seen from the figure, the sign of the change of $\Delta\alpha_1$ depends on the direction of \vec{E}_0 . The analogous changes of $\Delta\alpha_2$ are of opposite sign. This can be explained by recognizing that the cancellation of the oriented part of the microfield should lead to an increased symmetry of the internal fields, and to a simultaneous increase of the intensities of these fields, at the expense of the volume occupied by the external constant field. In the opposite direction, the volume occupied by the external field does not contribute to the second harmonic, and the field itself decreases the region of the microfield E .

It should be noted that the polarization characters of the electroabsorption of light at the first and second harmonics are analogous. Therefore the polarization properties of the crystals [11] can be investigated by using either harmonic.

It can thus be stated that experiment can yield definite information concerning the existence of oriented microfields in a crystal. From all appearances, the presence of such fields can be expected in crystals without an inversion center (a situation close to that described above was observed by us also for GaAs).

If we adhere to the model described by us, then the cancellation of the first harmonic by a weak external field should make it possible, in principle, to plot the potential curve of the microfield.

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COMPLEX REGGE POLES AND NEW APPROACH TO THE PROBLEM OF ALLOWANCE FOR THE CONTRIBUTIONS OF THE CUTS

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A number of authors have shown recently [1, 2] that the existing models of Regge cuts do not satisfy the limitations that follow from a wide range of experimental data and certain general notions concerning the mechanism of scattering at high energies. In this connection, attempts to improve these models and to find new approaches become particularly important.

We show in this article that a new approach to the problem of accounting for the cut contribution can be formulated on the basis of complex Regge poles (CRP) [3 - 6] and duality. Two circumstances are of importance here: first, unlike the usual models, allowance for the cuts in the form of CRP makes it possible to determine the contribution of the cuts with the aid of sum rules; second, in the CRP model it is easy to satisfy the aforementioned limitations, formulated by Harari [7] in the dual-absorptive scattering picture. We recall that complex cuts result from the influence exerted on the Regge poles by their "accompanying" cuts. Collision with a pole in turn, modifies the cut and the amplitude that takes into account the contributions of both the pole and the cut is effectively described by a complex-conjugate pole pair:

$$T(\nu, t) \sim (\beta_{\text{pole}}(t) + \beta_{\text{cut}}(t)) \nu^{\alpha(t)} + \text{c.c.} \quad (1)$$

Without a special model we cannot separate explicitly the contributions of the pole and of the cut, but this is not compulsory for our purposes. Since both contributions depend in some way on ν , it is possible to find the parameters of the CRP model by using the duality condition written in the form of sum rules [8]. In analogy with the case of real Regge poles, the functions $\alpha(t)$ and $\beta_{\text{eff}}(t) = \beta_{\text{pole}} + \beta_{\text{cut}}$ can be determined directly from experiment [6], so that the amplitude at high energies can be completely constructed. At the same time, the application of sum rules to the ordinary models that take poles and cuts into account encounters fundamental difficulties [1]. The right-hand sides of the sum rules contain in this case convolutions with $\alpha(t)$ and $\beta(t)$ under the integral sign. It is thus impossible to determine these functions of t "directly by points" as in the case of real (and complex) Regge pole. In place of simple connection we obtain a system of equations that include different channels. Finally, a fact of particular importance for the usual models in which the cuts are taken into account, it is not clear which part of the

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