Modification of the dispersion of opto-excitons in a magnetic field

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Mixing of long-wave longitudinal and transverse states of opto-excitons in a magnetic field was observed. Using the phenomenon of interference of opto-excitons in thin crystals (V. A. Kiselev *et al.*, Phys. Stat. Sol. (B), **72**, 161 (1975)) we were able to observe and analyze the change of the opto-exciton dispersion.

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Normal waves propagating along the principal directions in a crystal can be divided in some cases into purely transverse and purely longitudinal waves. In the presence of an external magnetic field, such a division, generally speaking, is impossible[2] (if we disregard propagation of the waves along the field). In this case mixing of longitudinal and transverse states takes place. Since the longitudinal states acquire a transverse component of the electric field, they should interact with light.

In the present study we observed the change produced in the dispersion of opto-excitons by the mixing of longitudinal and transverse states under the influence of a magnetic field. These changes were revealed by the appearance of additional singularities in the interference spectra of thin crystals.

We investigated the transmission spectra of CdSe crystals of thickness 0.8–1.5 μm at $T=2$ K using an instrument with dispersion 1.9 Å/mm. To obtain the magnetic field we used a superconducting solenoid with a critical field ~8 T.

In the absence of a magnetic field, in a geometry with **E**⊥**c** and **K**⊥**c**, the transmission spectrum of thin crystals has a narrow minimum $A_L^{\perp}$ (Fig. 1a). Its sharp high-energy edge is due to the fact that opto-excitons of the upper branch 2, whose damping is much smaller than in branch 1, come into play in the energy transport process at frequencies above ω_L (Fig. 1b). Below the minimum $A_L^{\perp}$, an interference structure is observed (the region $A_F^{\perp}$), due to the interaction of the opto-exciton Γ_{5T} of branch 1 with the forbidden exciton Γ_6 of branch 4.[3]

The dispersion curves shown in Fig. 1b for a CdSe crystal, were obtained by a spectrum-interference method developed in[1,3]. These dispersion curves show an unambiguous correspondence, with respect to the interference properties in a wide range of frequencies, with the spectrum of the CdSe crystal of 1.2 μm thickness; a fragment of this spectrum is shown in Fig. 1a.

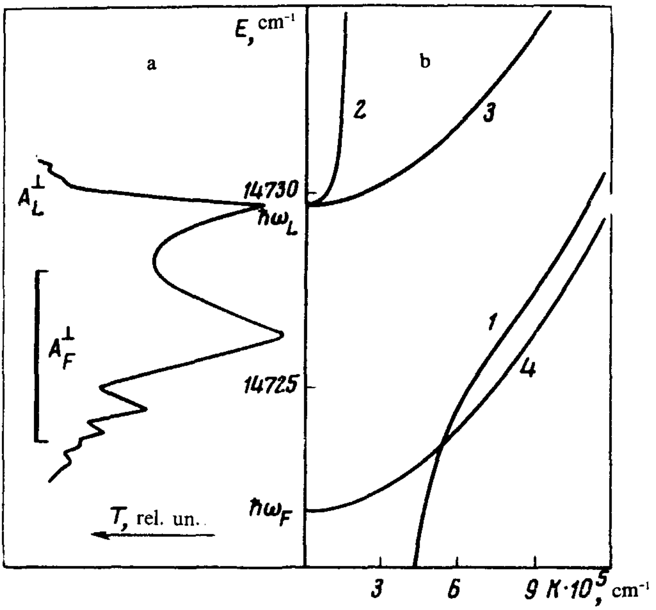

FIG. 1a. Microphotograph of the transmission spectrum of a CdSe crystal 1.2 μm thick, magnetic field $\mathbf{H}=0$; **E**⊥**c**, **K**⊥**c**; b—opto-exciton dispersion plotted in accordance with the interference singularities of the spectrum.

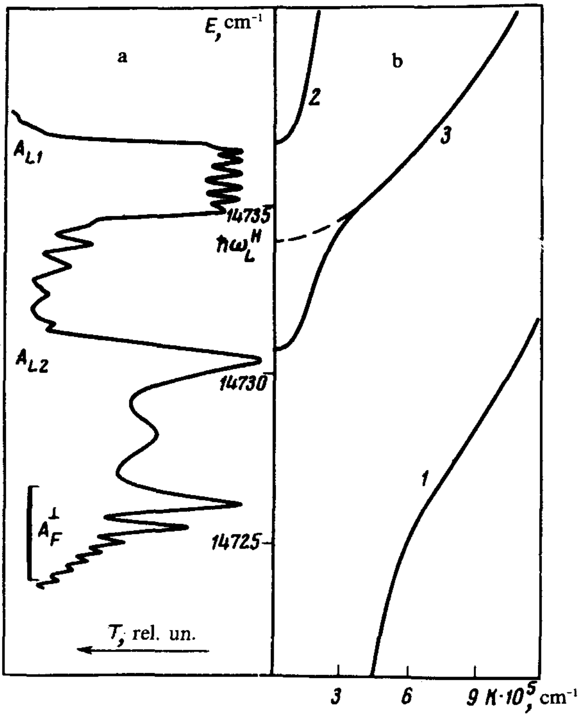

FIG. 2. a) Microphotograph of the transmission spectrum of a CdSe crystal 1.2 μm thick in a magnetic field $H = 7$ T, **E**⊥**c**, **K**⊥**c**, **H**||**c**; b) dispersion of the opto-excitons in a magnetic field $H = 7$ T.

Figure 2 shows the transmission spectrum of the same crystal in the same geometry (**E**⊥**c**, **K**⊥**c**) in an external magnetic field **H**||**c** of intensity 7 T. In the presence of a magnetic field, shift is observed of the entire interference structure in this region, towards higher energies, as well as the appearance of two transmission minima A_{L_1} and A_{L_2}, which are connected with the appearance, near **K**$=0$, of two exciton branches that interfere with the light. This splitting is not connected with the Zeeman effect on the ground state of the exciton 1S, i.e., with the action of the field on the internal motion of the exciton, due to the mixing of the longitudinal waves with the allowed transverse oscillations.$^{1)}$ The splitting increases linearly with increasing magnetic field. In the region between the maxima A_{L_1} and A_{L_2}, a Fabry-Perot mixed interference branch 3 is observed (Fig. 2). As **K** → ∞ this branch corresponds to pure longitudinal states.

To plot the dispersion curves from the interference spectrum we used an equation for the polarization,[4] in which account was taken of the action of the magnetic field

$$B\nabla^2 \mathbf{P}(\mathbf{r}, \omega) - (\omega_0^2 - \omega^2)\, \mathbf{P}(\mathbf{r}, \omega) - \frac{e}{mc}\, [\dot{\mathbf{P}}(\mathbf{r}, \omega) \times \mathbf{H}] = \alpha \mathbf{E}(\mathbf{r}, \omega).$$

The parameters B and α were taken from the known dispersion law at $H=0$.[1] The parameter ω_0 was selected with the aid of a computer such as to obtain the best agreement between the frequencies of the Fabry-Perot singularities determined from the formula $Kl = \pi N$,[5] on the one hand, and the experimental interference singularity of the spectra on the other. The obtained dispersion curves at $H = 7$ T are shown in Fig. 2b. It is seen that a magnetic field hardly changes the shapes of branches 1 and 2.$^{2)}$

Branch 3 becomes substantially restructured near $\mathbf{K}=0$, where it corresponds to the mixed state. At $H=0$ it is transformed into the dispersion curve of the longitudinal exciton. In the region of small $\mathbf{K}(0\leqslant K<3\times10^5\ \mathrm{cm}^{-1})$ the branch 3 interacts with the light, a fact that manifests itself in the large value of the transmission coefficient in the frequency interval 14 735–14 731 cm^{-1} (Fig. 2a).

Thus, we have observed, for the first time ever, a substantial restructuring of the dispersion of opto-excitons in a magnetic field. The possibility of "constructing" in a magnetic field exciton bands near $\mathbf{K}=0$ is of interest for the problem of Bose-Einstein condensation of excitons. Since condensation on branch 1 is impossible,[6] and on branch 2 it is difficult to obtain the required concentration of the quasiparticles, the formation of branch 3 can lead to more favorable conditions for the onset of Bose-Einstein condensation of the excitons.

[1] We have investigated in detail the behavior of the $1S$ state of the exciton in a magnetic field in the geometry $\mathbf{H}\|\mathbf{c}$, $\mathbf{E}\|\mathbf{c}$, when the transverse exciton is dipole-forbidden. In this geometry we did not observe the doublet splitting of the level.

[2] An analysis of weak changes of the dispersion of these branches will be presented in a more detailed paper.

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