Change of the electron-phonon interaction parameter in CdS by uniaxial compression or by an electric field

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It was observed that uniaxial compression, or else a strong electric field, changes the intensity of the electron-phonon interaction in CdS in optical transitions through a local center.

In polar crystals of II-VI compounds, one observes an edge radiation that consists of a series of equidistant bands separated by the energy of the longitudinal optical phonon. The so-called high-energy series (HES) in CdS is determined by the radiative recombination of the free electrons with bound holes. The relative intensity of the bands in one series is described by the expression $I_n = I_0(\bar{N}^n/n!)$, where I_n is the intensity of the $(n+1)$-st band, produced as a result of the emission of a photon and of n LO phonons, and N is the average number of emitted LO phonons.[1] N characterizes the intensity of the electron-phonon interaction

$$\bar{N} = \left(\frac{e^2}{a}\right)\frac{1}{\hbar\omega_0}\,\frac{1}{\sqrt{2\pi}}\left(\frac{1}{\epsilon_\infty} - \frac{1}{\epsilon_0}\right)$$

a is the effective radius and characterizes the degree of localization of the charge at the center, while ω_0 is the limiting frequency of the LO phonon.

We have ascertained experimentally that uniaxial compression, or else an electric field, can alter the parameter of the electron-phonon interaction in CdS under certain conditions.

The spectra of the HES of the edge emission of pure CdS single crystals were investigated at 77 °K. It turned out that the pressure applied in the direction $\mathbf{P} \perp \mathbf{C}$ ($\mathbf{C}$ is the optical axis of the crystal) leads to a decrease in the relative intensity of the phonon replicas in comparison with the phononless line. The effect becomes most clearly pronounced for radiation polarized along the $\mathbf{C}$ axis ($\vec{\mathcal{E}} \parallel \mathbf{C}$) (Fig. 1c). At a polarization $\vec{\mathcal{E}} \perp \mathbf{C}$ (Fig. 1b), this effect can hardly be noticed. The parameter $\bar{N}$, which is determined in experiment as the ratio I_1/I_0, is equal to approximately 0.95 in the absence of pressure. Uniaxial compression $P = 2.5$ kbar decreases $\bar{N}$ to 0.66.

It is seen from Figs. 1b and 1c that uniaxial compression ($\mathbf{P} \perp \mathbf{C}$) splits the maximum of the series. In the absence of pressure, the energy positions of the maxima for the polarizations $\vec{\mathcal{E}} \perp \mathbf{C}$ and $\vec{\mathcal{E}} \parallel \mathbf{C}$ are identical and correspond, e.g., to Fig. 1a. The splitting of the maximum at $P = 2.5$ kbar reaches 6×10^{-3} eV.

Under uniaxial compression along the $\mathbf{C}$ axis ($\mathbf{P} \parallel \mathbf{C}$), a shift of the entire series is observed towards higher energies. This shift is characterized by a coefficient close to 5×10^{-3} eV/kbar. A change of $\bar{N}$ at this orientation of $\mathbf{P}$ appears only in the case of radiation with $\vec{\mathcal{E}} \parallel \mathbf{C}$, and is smaller by one order of magnitude than in the case $\mathbf{P} \perp \mathbf{C}$ and $\vec{\mathcal{E}} \parallel \mathbf{C}$.

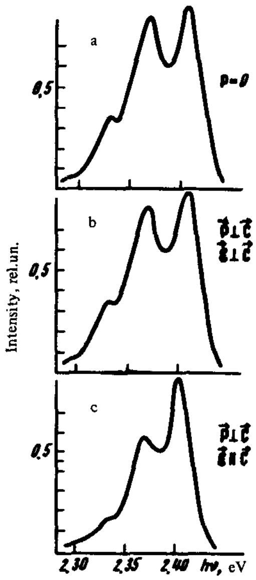

FIG. 1. Spectra of edge emission of CdS under uniaxial compression at various emission polarizations.

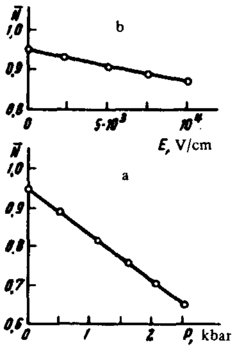

FIG. 2. Dependences of the parameter $\bar{N}$ on the uniaxial compression P and on the electric field E.

It was also observed that an electric field leads to a qualitatively similar effect. In our experiment, the decrease did not exceed 7% for a field $E \approx 10^4$ V/cm ($\mathbf{E} \perp \mathbf{C}$). The dependence of $\overline{N}$ on the pressure and on the field intensity is shown in Fig. 2.

The observed correlation in the action of uniaxial compression and of an electric field on the electron-phonon interaction is obviously piezoelectric, since the CdS crystals are patently piezoelectric. It appears that to explain the observed effect it is necessary to take into account the connection between the structure of the local state and the complicated structure of the valence band of CdS. Uniaxial compression, which lowers the symmetry of the lattice, can affect different subbands differently and can vary their contribution to the impurity state. This interpretation, however, encounters great difficulties, even in a qualitative comparison with experiment, inasmuch as according to[2] an appreciable decrease of the relative positions of the valence subbands occur only at $\mathbf{P} \parallel \mathbf{C}$, i.e., precisely when $\overline{N}$ remains practically unchanged in our experiments.

[1]J. J. Hopfield, J. Phys. Chem. Sol., 10, 110 (1959).
[2]J. E. Rowe, M. Cardona, and F. H. Pollak, Proc. Intern. Conf. A_2B_6 Semicond., New York (1967), p. 112.