Intensification of exciton reflection in CdS crystals due to the emptying of shallow pockets

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A study has been made of the temperature dependence of the exciton reflection spectra in comparison with curves of the thermally induced current in nominally pure CdS single crystals. An anomalous intensification of the reflection has been discovered in the exciton reflection spectra. This intensification correlates with the emptying of shallow pockets.

Both doped and nominally pure CdS single crystals have shallow pockets, i.e., charge-trapping pockets, which are manifested on the low-temperature curves of the thermally induced current.[1–3] In the present letter we report the observation of an effect of these levels on the exciton reflection spectra of CdS crystals.

Figure 1 shows reflection curves for an *A* exciton in one of the sample wafers, not deliberately doped, versus the temperature. We see that as the sample is heated from liquid-helium temperature to ~30 K, there is a decrease in the reflection at the peak of the exciton reflection spectrum (curves 2 and 3). As the temperature is raised further, over the interval 30–50 K, the reflection at the peak increases, while that at the valley correspondingly decreases. In terms of the peak-to-valley difference, the exciton reflection spectra here (curves 5 and 6) are comparable to that at $T = 4.2$ K (curve 1).

A curve of the thermally induced current is shown at the bottom of Fig. 2, while

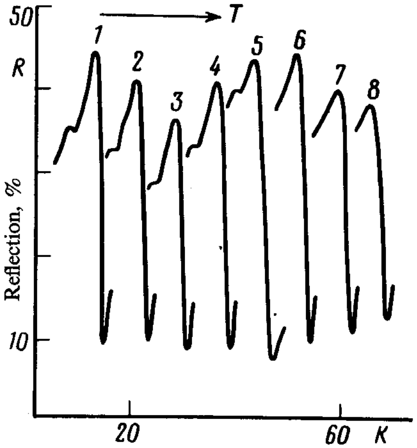

FIG. 1. Changes in the shape of the exciton reflection spectrum of the crystal as it is heated from liquid-helium temperature ($A_{n=1}$, $E \perp C$).

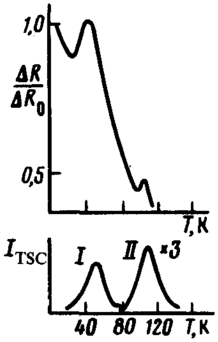

FIG. 2. Temperature dependence of the peak-to-valley difference in the reflection, $\Delta R/\Delta R_0$, and curve of the thermally induced current for a CdS sample ($\Delta R = R_{\max} - R_{\min}$). Peaks I and II correspond to the emptying of shallow pockets (see the text proper).

the top part is the corresponding temperature dependence of the peak-to-valley difference in the reflection for the given sample. We see that in the interval 30–50 K, i.e., in the region of the anomalous increase in reflection, there is a maximum on the curve of the thermally stimulated current. This maximum corresponds to the thermal emptying of a pocket whose energy distance from the bottom of the conduction band can be estimated to be 0.04–0.05 eV (Refs. 1 and 2). A similar nonmonotonic temperature dependence of the exciton reflection spectrum is found in the temperature interval 100–120 K. In this interval, a second maximum appears on the curve of the thermally induced current; this second maximum corresponds to the emptying of a shallower pocket, at 0.08–0.09 eV (Ref. 3).

Our experimental observations show that the anomalies on the temperature dependence of the exciton reflection spectrum are associated with shallow charge-trapping pockets and that the intensification of the exciton reflection is due to the emptying of these pockets. We believe that the observed effect is due to a strong field inhomogeneity (or charge inhomogeneity) near the surface of the crystal (a space-charge region). As the temperature is raised to ~30 K, there is a thermally induced liberation of electrons from traps in the interior, with the result that these electrons become ionized, as in the space-charge region. As the Fermi level shifts with the temperature, the density of ionized pockets increases; the space-charge region spreads out, and the charge inhomogeneity near the surface (with respect to the interior) decreases.

How does the disappearance of the charge inhomogeneity affect the excitation reflection spectrum? We believe that there are two possible reasons that deserve consideration. First, the intensification of the exciton reflection might be interpreted as the result of a decrease in the dissipative damping of excitons due to a decrease in the charge (or the field) near the surface[1)] or a change in the scattering of excitons upon a change in the charge state of the deep pockets. Second, some additional structure is observed on the long-wavelength side of the main reflection peak (curves 1–3 in Fig. 1). This previously observed structure has been attributed to a surface mechanical exciton,[5,6] which may be regarded as an exciton that is localized in a (quantum-mechanical) potential well near the surface as a result of a charge (or field) inhomogeneity. As the sample is heated (curves 4 and 5), this structure shifts toward shorter wavelengths, i.e., toward the main peak. As the temperature is raised even further (curve 6), the structure can no longer be seen clearly. We also see from this figure that an increase in the reflection can be observed in the spectrum, proportional to the spectral shift of the structure. As we mentioned earlier, a temperature increase results in the ionization of shallow pockets and reduces the charge inhomogeneity near the surface. The spreading of the space-charge region leads to a decrease in the depth of the potential well. The levels of excitons localized in the well should shift toward the resonance, i.e., in the short-wavelength direction, as is, in fact, observed experimentally. The increase in the reflection may be interpreted as an increase in the oscillator strength of a localized exciton during the expansion of its localization region; an analogous effect for bound excitons in semiconductors is known as the Rashba effect.[7] Our studies show that potential wells for excitons can also exist at higher temperatures. The additional increase in the reflection at 100–120 K is thus due to the emptying of shallower pockets (Fig. 2).

In summary, shallow pockets play an important role in shaping the exciton spectra. In future, more-detailed papers we will present further evidence for this assertion.

It is our pleasant duty to thank É. I. Rashba for a discussion of these results.

(1)The effect of a surface field on the damping of excitons was first reported in Ref. 4. It should be noted that attempts to analyze the damping in this case run into serious difficulties, since the dissipating damping Γ depends on not only the temperature but also the distance from the surface.

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