Self-induced transparency of excitons

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We report observation of self-induced transparency of excitons in $CdS_{0.75}Se_{0.25}$ single crystals ($T = 90\,^{\circ}K$) in resonant interaction between the semiconductor and an ultrashort pulse of the second harmonic of a mode-locked neodymium laser ($\lambda = 0.53\ \mu$, $\tau \approx 5 \times 10^{-12}$ sec).

Self-induced transparency (SIT) of semiconductors in interband transitions is the subject of many theoretical and experimental papers.[1–6] The authors of theoretical papers[7,8] have recently shown that SIT can be observed in the interaction between photons and excitons. A powerful light pulse, of duration shorter than the relaxation times connected with the exciton motion, can propagate with anomalously small losses as a result of induced reradiation of the medium.

The present communication is devoted to an investigation of SIT in a semiconductor following resonant excitation of excitons, and to the measurement of the times T_1 and T_2 of the longitudinal and transverse exciton relaxation, respectively, by the method proposed in[9] for sounding semiconductors.

The experimental setup is described in[4]. The semiconducting single-crystal $CdS_{0.75}Se_{0.25}$ was cooled to 90°K. The sample was exposed to a train of second-harmonic USP from a mode-locked neodymium laser ($\tau \approx 5\times10^{-12}$ sec, $\lambda = 0.53\ \mu$, $\Delta\lambda \approx 5$ Å). The chosen composition of the mixed crystal and the chosen sample temperature have made it possible to obtain resonant excitation of the excitons by radiation of 0.53 μ wavelength. We measured the transmission of the sample (W/W_0, where W_0 and W are the energies of the incident and transmitted radiation) with calorimeters (sensitivity not worse than 10^{-6} J) and a coaxial photocell matched to an I2-7 oscilloscope. The transmission of the sample to continuous radiation ($\lambda = 0.53\ \mu$) was $W/W_0 < 10^{-3}$.

Typical oscillograms of a pulse train entering and leaving the sample, and also the dependence of W/W_0 on the excitation level for a single pulse, are shown in Figs. 1 and 2. The following circumstances should be noted: the selectivity of the semiconductor sample (the most powerful and shortest pulses are separated[10]), the appearance of additional pulses past the sample when the pump level is increased (it appears that the condition for SIT excitation begins to be satisfied for these pulses) without a change in the maximum pulse

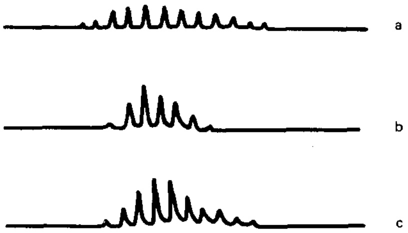

FIG. 1. Oscillograms of USP train entering the sample (a) and leaving the sample at $W_0 = 10^{-3}$ J (b) and $W_0 = 1.5\times10^{-3}$ J (c).

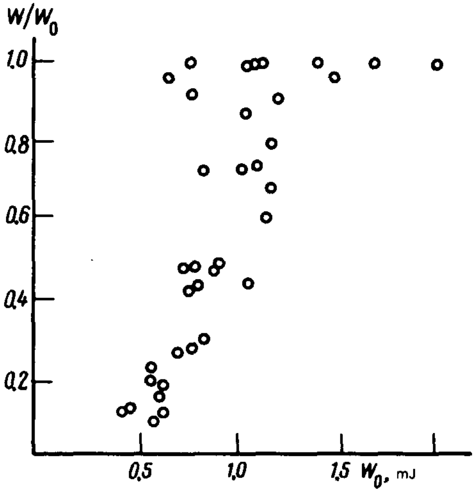

FIG. 2. Dependence of sample transmission on the radiation energy at the entrance to the sample.

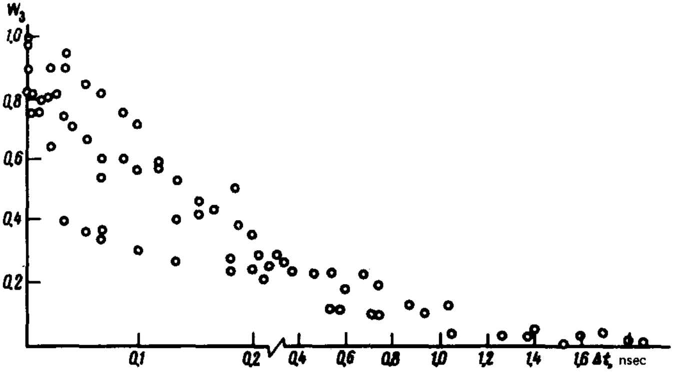

FIG. 3. Dependence of the energy of the sounding beam on the delay time.

amplitude, the nonlinear dependence of the transmission on the excitation level (Fig. 2), and the saturation of the transmission at high excitation levels (in this case the transmission is $W/W_0 \approx 1$ for individual USP of the train; this suggests that the anomalously large sample transmission is not connected with saturation). Notice should be taken that the threshold for the onset of SIT in resonant exciton excitation is lower than in interband transitions.[4]

The exciton relaxation times were measured by a sounding method.[9] We investigated the state of the semiconductor at various instants of time after the passage of a high-power USP. To this end, a weak wounding pulse (part of the second-harmonic radiation from the same laser) was applied to the $CdS_{0.75}Se_{0.25}$ crystal at a small angle (~1°), with a continuously variable time delay (Δt) relative to the main pulse. Both beams practically overlapped in the crystal, and at the same time were directed to different calorimeters located ~1 m from the sample. The power of the sounding pulse was insufficient to induce transparency in the semiconductor. The dependence of the sounding-beam energy on Δt is shown in Fig. 3. The scatter of the energy values at small delays can be attributed to T_2-relaxation1); at $\Delta t \lesssim T_2$, the transmission varies in a wide range, since the medium can be in practically in any state (the laser emits a set of pulses with different intensities). The smooth decrease of the curve can be attributed to the saturation effect. The number of excited excitons decreases with the relaxation time T_1 and at the same time the absorption of the sounding beam increases. The relaxation times estimated from the plot are $T_1 \approx 0.8$ nsec and $T_2 \lesssim 0.2$ nsec.

The features of nonlinear absorption of USP of light and the values of the measured relaxation times suggest that the observed phenomena are connected with self-induced transparency of the excitons.

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1)A detailed description of the measurement method will be published elsewhere.

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