

Exciton-absorption domains (autowaves) in cadmium sulfide

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A multistability of the states of absorption domains (waves) has been detected in semiconductors. Exciton-absorption domains have also been observed.

The first semiconductor in which absorption domains were detected was zinc selenide.¹ It was found that a strong-absorption domain localized at the back of the sample loses its stability as the optical power is raised, and it begins to pulsate. As a result, periodic changes occur in the signal representing the light transmitted through the sample. Corresponding to two limiting cases of this instability are slight pulsations of a localized domain and the formation of domains which periodically move away from the back of the sample along the optical channel and disappear in the interior of the sample. The process by which a domain moves is described well in the model of a thermal-conductivity propagation of an optical discharge in a gas.^{2–5}

In zinc selenide, the strong absorption in a domain results from interband transitions.⁴ Transitions of only a single type occur. On the other hand, we know⁶ that in a semiconductor with a large exciton binding energy the fundamental absorption edge is formed by exciton transitions at temperatures up to room temperature. There is accordingly particular interest in studying the behavior of domains associated with exciton absorption in semiconductors.

For the experiments we selected the semiconductor cadmium sulfide, for which the exciton ground states *A*, *B*, and *C* have a large binding energy (30 meV).⁶ The incident light from a cw argon laser, with a wavelength of 514.5 nm and a power no higher than 1 W, was modulated by a mechanical chopper to reduce the heating of the sample. To obtain the resonant nonlinearity in the growth of the absorption coefficient required for the formation of domains,^{1,4} we tuned the fundamental absorption edge of the semiconductor with respect to the energy of the incident photon by varying the temperature. Domains were formed near the back of the bulk samples by sharply focusing the light onto the back of the sample, by the technique described in Ref. 4. The properties of the absorption domains were studied on the basis of the time evolution of the signal representing the light transmitted through the sample.

Let us consider the basic aspects of the behavior of absorption domains for the geometry in which the polarization vector is parallel to the optic axis of the crystal ($\mathbf{E} \parallel \mathbf{C}$). At temperatures below the critical temperature ≈ 254 K, only a single state of strong absorption of a domain is observed, in a relatively narrow interval 5–7 K. More than a single stable state of strong absorption of a localized domain can be observed as the temperature is lowered. Figure 1 shows the behavior of the output signal for the case in which there is a transition from one stable state of strong absorption (Fig. 1b)

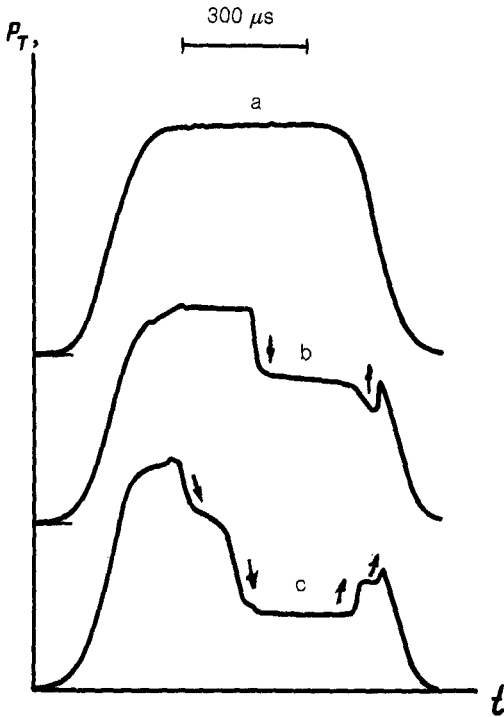


FIG. 1. a—Shape of the incident light pulse; b,c—signals representing the light (P_T) transmitted through a sample 1.45 mm thick versus the time t . The sample temperature is $T = 234$ K; the power of the incident light is (b) $P_0 = 370$ mW or (c) $P_0 = 410$ mW. The signals are plotted in a linear scale, in arbitrary units, along the ordinate. The arrows show switchings from one absorption state to another.

to two (Fig. 1c) upon a slight increase in the power of the incident light. The formation of domains at the back of the sample at temperatures above the critical temperature is prevented by the decrease in the optical power in the interior of the sample at the absorption tail of the semiconductor.

A study of the behavior of an absorption domain as a function of the sample temperature and the optical power revealed that for each of the strong-absorption states shown in Fig. 1 it is possible to observe both weak and strong pulsations in the output signal.^{1,4} It turns out that the period of the pulsations of the localized domain is essentially independent of the absorption state of the domain. This fact agrees with a result found earlier: that the period of slight pulsations is determined by the time scale for transverse heat removal from the optical channel.^{1,4} The minimum period of the slight pulsations was about 4 μ s.

In the case in which moving domains and strong pulsations in the output signal form, the typical distance traveled by a domain in the interior of the sample is 100–400 μ m. The duration of the stage of domain motion varies from 40 to 100 μ s for the first two states. The most important parameter of a moving domain is its velocity. An



FIG. 2. Three states of strong absorption of a moving domain in the time evolution of the output signal, detected in the same geometry of the contracting optical channel with $E \parallel C$ under the following experimental conditions: a— $T = 240$ K, $P_0 = 780$ mW; b— $T = 248$ K, $P_0 = 640$ mW; c— $T = 248$ K, $P_0 = 960$ mW.

estimate of the average velocity of a domain yields values in the interval $3 \times 10^2 - 10^3$ cm/s.

Under conditions such that we observe two moving-domain states (Figs. 2a and 2b) we can detect a third absorption state as the incident optical power is increased (Figs. 2b and 2c). In the latter case, the downward switching is usually a complicated, multistep process (Fig. 2c), because of the passage through intermediate states. As the sample temperature is lowered, the critical power levels for the maintenance of pulsations of each type in each of the states increase, and the number of observed states

decreases. This circumstance explains the difference in the parameter values in the Fig. 2 caption.

We are restricting the present letter to a discussion of the behavior of the moving absorption domains. A multistability of the states of an absorption domain in cadmium sulfide is possible even in the absence of exciton effects, since two types of interband transitions from the B and C valence subbands are allowed by the selection rules in the geometry $E||C$ (Ref. 6). In this case, a stability analysis ignoring diffusion and thermal conductivity^{3,5} can explain the existence of only two (not three!) absorption states of a moving domain. Incorporating the exciton features of the absorption coefficient nevertheless does not lead to an increase in the number of states of a domain because of a broadening of the B and C exciton lines at the temperatures used in these experiments. In order to explain the multistability of the absorption states of moving domains in cadmium sulfide, it is thus necessary to solve the complete problem of the thermal-conductivity conditions during the motion of a domain.^{3,5} A simplified analysis of this problem in the one-dimensional approximation³⁻⁵ shows that the lowest critical power for the sustenance of steady-state motion corresponds to a domain in which the absorption stems from transitions to the ground state of a B exciton, since the line of a B exciton lies closest to the energy of the incident photon in the initial conditions. If an absorption domain associated with interband transitions from valence subbands B and C is to arise in the structure, there must be an increase in the power of the incident light. This increase causes an increase in the maximum domain temperature and thus a decrease in the band gap of the semiconductor. The absorption of a B exciton shifts away from the region of the maximum temperature to the front of the domain in the process. At this front, the absorption is under subcritical conditions, and a domain of purely exciton absorption cannot form.

Taking these conclusions into account, we can explain the experimental results in the following way. Since the first and second absorption states of a moving domain differ only negligibly in properties (Figs. 2a and 2b), these states must be associated with closely spaced transitions from the B valence subband to the exciton ground state and the conduction band. The first state (Fig. 2a) is a purely exciton state, while transitions of both types participate in the formation of the second state (Fig. 2b). The behavior of the third moving-domain state is noticeably different from that of the first two states (Fig. 2). It may be a consequence of the appearance of an additional-absorption domain in the structure, because of transitions from the C valence subband.

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