

Luminescence of absorption domains (autowaves) in cadmium sulfide

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Absorption domains in cadmium sulfide are relaxation waves with an end state in the region of the Urbach absorption tail. Structurally, they are similar to combustion waves studied in the kinetics of chemical reactions. A blueshift of the luminescence line of traveling domains has been observed with an increase in the power of the light.

The domain instability caused in a semiconductor by light consists of the formation, in the light channel, of regions with distinct values of physical properties, e.g., the density of photoexcited carriers, the temperature, and the absorption coefficient. Previous experiments have dealt with only the dynamic properties of absorption domains in several semiconducting compounds of the II–VI and III–VI groups.¹ Data on the structure of absorption domains are required for reaching a better understanding of the nature of this phenomenon. The parameters most important to determine for domains of a thermal nature are the maximum temperature of the domain, or the temperature in the zone of the most efficient conversion of the incident light into heat, and the corresponding values of the absorption coefficient.² In the present experiments we took up this problem with the help of a method involving a recording of the luminescence spectra of absorption domains with a spatial resolution of 5–10 μm and a spectral resolution of about 1 meV. The luminescence spectra and the dynamic behavior of the absorption domains were measured with the help of a computer-controlled data acquisition system based on an IBM PC-AT 286 computer. The apparatus included an optical multichannel analyzer, an MDR-12 spectral instrument, and an RM-3315 oscilloscope.

The experiments were carried out at room temperature on cadmium sulfide samples 1.3–2.0 mm thick. The incident light beam was directed along the optic axis of the crystal. The domains were excited by light at the second harmonic (with a photon energy of 2.33 eV) of a quasi-cw Nd:YAG laser (an Argo-1 laser, from the Fiztekhn Center for Creative Work of Youth in Science and Technology). This laser could be

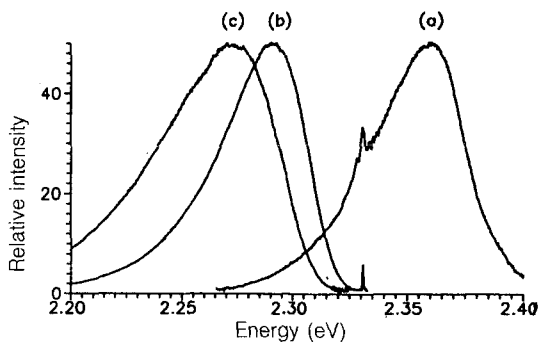


FIG. 1. a—Luminescence spectrum of cadmium sulfide in the original (domain-free) state of the crystal, with an incident-light power $P_0 = 30$ mW; b,c—luminescence spectra of absorption domains localized at the front of the crystal, at a power level of (b) $P_0 = 445$ mW or (c) $P = 505$ mW.

operated as either a cw or Q -switched laser, with a restructuring of the pulse length from 0.2 to 25 μ s at an average output power of 500–600 mW. The technique for exciting the domains is described in Ref. 1.

In the original, quasihomogeneous (domain-free) state of the temperature field in the crystal, the luminescence is an anti-Stokes luminescence. The peak of the line is on the short-wavelength side of the excitation line (Fig. 1a). An increase in the power level of the cw excitation results in a smooth shift of the luminescence line toward lower energies. When a certain critical power level of the incident light is exceeded, absorption domains form near either the middle or the rear of the sample, in a process accompanied by an abrupt change in the position of the absorption line.

For the absorption domains localized near the front of the sample, the results on the luminescence spectra of the absorption domains reveal the following. As the power of the incident light is raised, the luminescence line (Fig. 1, b and c) shifts toward lower energies, as in the spectra for the quasihomogeneous state of the crystal.

The absorption domains which form at the rear of the sample may be either localized or traveling, as was shown previously.¹ The domains of this type exhibit a fundamentally different behavior in their absorption spectra. This behavior can be summarized as follows. The luminescence line (Fig. 2) has an essentially constant shape. The position of this line depends weakly on the excitation conditions and on the region of the domain from which the luminescence signal is detected. The peak of this line lies near the excitation line. The half-width of the line is 30–50% larger, on the average, than that for the line of a domain localized at the front of the sample, at the same spectral position.

The lowest-energy position of the line is found for a localized domain at the maximum value of the light intensity at which the domain is still stable. As soon as slight fluctuations of a localized domain arise,¹ however, this line shifts a few millielectron volts back in the blue direction.

In order to obtain a significant change in the luminescence spectrum of a traveling domain, it was necessary to raise the power of the incident light substantially in

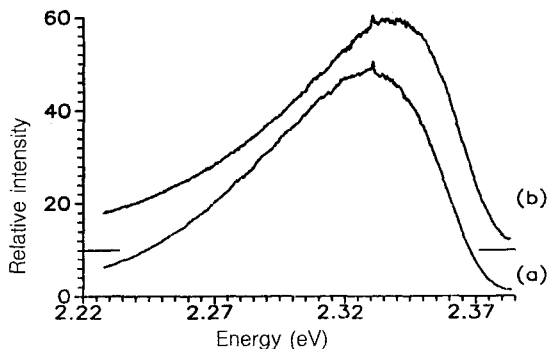


FIG. 2. Luminescence spectra of absorption domains traveling through the interior of the sample at various power levels of the incident light. a— $P_0 = 540$ mW, with an average domain velocity $v \approx 0.7 \times 10^3$ cm/s; b— $P_0 = 2.4$ W, with $v \approx 2.6 \times 10^3$ cm/s.

these experiments. For example, a quadrupling of the incident power (Fig. 2) resulted in a shift of the line by 6 to 8 meV. This shift, however, is toward higher, rather than lower, energies! The velocity of the domain increases in the process.

At a modest density of photoexcited carriers (not above 10^{16} cm $^{-3}$ in these experiments) the temperature of a domain can be determined from the spectral position of the luminescence line, which traces the thermal shift of the fundamental absorption edge. For domains localized at the front of the sample, this method yields the highest domain temperature, in the interval 380–420 K. For domains (either localized or traveling) which form at the rear of the sample, we can work from the luminescence to find the temperature in the active zone for the conversion of optical energy into thermal energy. This temperature turns out to be 330–370 K. An estimate of the maximum temperature of domains of this sort yields a value no higher than 390–400 K. The maximum values of the absorption coefficient corresponding to these temperatures are $(1-3) \times 10^3$ cm $^{-1}$ for domains at the front of the sample and $(3-10) \times 10^2$ cm $^{-1}$ for traveling domains and for domains localized at the rear.

These values are at least an order of magnitude lower than those predicted by a model developed previously for a purely heat-conduction motion of a domain.^{1,3} According to that model, the maximum absorption coefficient should be in the region of interband transitions and should be no less than 10^4 cm $^{-1}$, and the temperature of a domain should reach 480–500 K. The values found experimentally are in a part of the Urbach absorption tail^{4,5} which had previously been regarded as unstable and which had been eliminated from consideration.^{1,3}

Incorporating the Urbach rule and the linear temperature dependence of the width of the band gap of a semiconductor,^{4,5} we find a sharp exponential behavior of the absorption coefficient and of the heat-evolution function as functions of the temperature in the region of interest here: $\alpha_0 \exp(T/\Delta T)$. The problem of the behavior of an absorption domain in a semiconductor in an external light field thus becomes analogous to the problem of the kinetics of chemical combustion reactions,⁶ where the corresponding coefficient in the heat evolution is of the form $\exp(-\epsilon/T)$. The ab-

sorption domain has the structure of a relaxation wave,⁶ rather than the structure of a switching wave as had previously been suggested.^{1,3}

The shift of the luminescence line of the domains which form at the front of the sample upon a change in the power of the light (Fig. 1), with an average coefficient $\beta = - (3-4) \times 10^2$ meV/W, is explained on the basis of an increase in the maximum temperature of a domain and a corresponding local decrease in the width of the band gap. The weak dependence of the parameters of the luminescence line on the power of the incident light for the domains which arise at the rear of the sample (Fig. 2; $\beta \simeq 3$ meV/W) indicates that most of the increment in this power is dissipated on an increase in the velocity of the domain, rather than on an increase in the temperature of the domain. The fact that the line shifts in the direction opposite that in the preceding case (of domains at the front of the sample) as the power of the light is varied is an unexpected result.

The blueshift of the luminescence line of traveling absorption domains (Fig. 2) apparently cannot be explained by processes which occur in the electron subsystem. The reason is that under these experimental conditions the electron-hole plasma was nondegenerate, and amplification processes could not have affected the shape of the luminescence line. We believe that the primary reason for this aspect of the behavior of the luminescence is a decrease in the maximum temperature of a traveling domain. This result is not explained by the existing models^{2,3,6} of absorption waves which would be formed by the light.

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¹V. A. Stadnik, *Fiz. Tverd. Tela (Leningrad)* **30**, 3571 (1988) [*Sov. Phys. Solid State* **30**, 2052 (1988)].

²Yu. P. Raizer, *Usp. Fiz. Nauk* **132**, 549 (1980) [*Sov. Phys. Usp.* **23**, 789 (1980)].

³S. É. Esipov, *Zh. Eksp. Teor. Fiz.* **94**, 118 (1988) [*Sov. Phys. JETP* **67**, 1363 (1988)]; *Zh. Eksp. Teor. Fiz.* **97**(3), 1030 (1990) [*Sov. Phys. JETP* **70**, 578 (1990)].

⁴F. Spiegelberg, E. Gutsche, and J. Voight, *Phys. Status Solidi b* **77**, 233 (1976).

⁵F. V. Kusmartsev and S. V. Meshkov, *Zh. Eksp. Teor. Fiz.* **94**(10), 250 (1988) [*Sov. Phys. JETP* **67**, 2098 (1988)].

⁶A. G. Merzhanov and É. N. Rumanov, *Usp. Fiz. Nauk* **151**, 553 (1987) [*Sov. Phys. Usp.* **30**, 293 (1987)].

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