

Instability of a strong-absorption domain in a semiconductor

V. A. Stadnik

Institute of Solid State Physics, Academy of Sciences of the USSR

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Experiments reveal that an instability of a strong-absorption domain causes oscillations in a laser beam transmitted through a semiconductor.

In semiconductors on which an electric field (for example) is imposed, we know that domains of various types form, either localized at inhomogeneities or moving through a homogeneous sample.¹ However, the literature reveals no previous report of the observation of a corresponding effect in a semiconductor subjected to a laser beam. A similar effect which occurs in gases, the “optical discharge,”² was discovered soon after the development of powerful lasers; by now this effect has been studied in detail. Our purpose in the present experiments was therefore to study the formation of moving domains in a semiconductor subjected to a laser beam.

A thermal mechanism is used to cause a sharp, nonlinear increase in the absorp-

tion coefficient. The semiconductor is excited by a laser beam with a photon energy smaller than the gap width, $h\nu < E_g$. This excitation moves the fundamental absorption edge in the long-wavelength direction and switches part of the sample into a second state with $h\nu > E_g$ and with an absorption coefficient two or three orders of magnitude higher. In other words, a strong-absorption domain forms. If the dimensions of the sample are at least an order of magnitude greater than the thickness of this domain, then it becomes possible to observe not only localized but also moving domains in the sample.

The samples in the present experiments are ZnSe single crystals ($E_g = 2.68$ eV at 290 K) with dimensions of $2 \times 4 \times 8$ mm. The samples are excited by the beam from ILA-120 cw argon laser ($h\nu = 2.54$ eV). The light intensity in the sample is 10–100 kW/cm². Localized and moving domains of strong absorption are detected by detecting the luminescence with the help of an MBS-9 microscope, since an interband excitation of ZnSe occurs in the region of the domain. The time evolution of the light transmitted through the sample is simultaneously measured.

Analysis of the experimental results shows that the localization of a domain occurs at either the front or back side of the sample. In this letter we will discuss only the behavior of a domain which is localized at the back side, as the intensity of the incident light is increased, since we did not observe an instability of a domain localized at the front side in these experiments.

At an incident intensity just slightly above the threshold for the maintenance of a domain localized at the back side of the sample (Fig. 1a), we observe a signal at the exit from the sample which is constant—which does not vary in time.

Increasing the intensity of the incident light causes a gradual increase in the thickness of the localized domain, or it moves the domain into the interior of the sample. When a certain critical intensity is reached, the light transmitted through the sample acquires weak, essentially sinusoidal oscillations, whose amplitude increases smoothly from zero with increasing intensity of the incident light. The displacement of

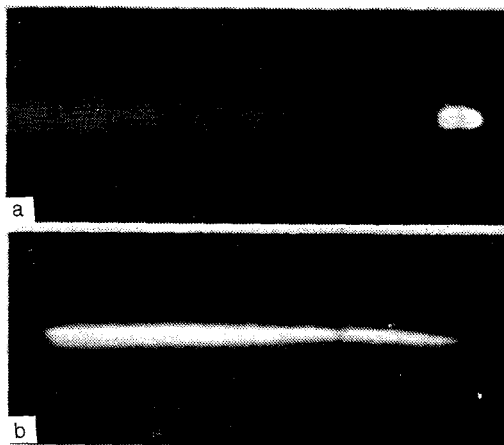


FIG. 1. a—Strong-absorption domain localized at the back side of the sample (the diameter of the domain is $\approx 35 \mu\text{m}$, and its thickness $\approx 30 \mu\text{m}$); b—motion of a domain in the strong-oscillation regime (the distance traveled by the domain is $\approx 32 \mu\text{m}$).

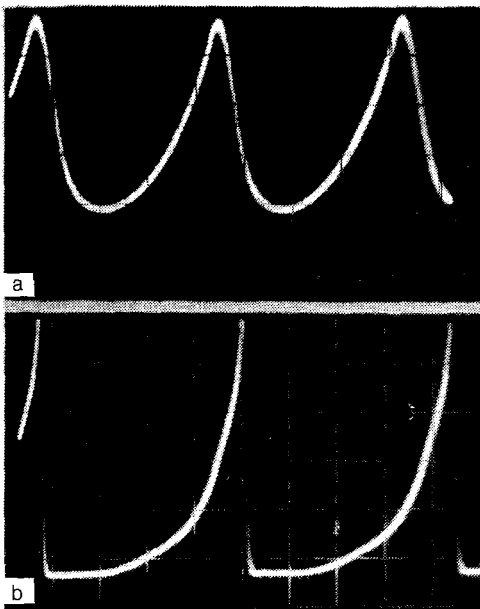


FIG. 2. a—Regime of weak oscillations in the light transmitted through the sample ($T = 76 \mu\text{s}$); b—regime of strong oscillations ($T = 86 \mu\text{s}$).

the front of the domain in a situation with these weak oscillations is smooth and monotonic and does not exceed the maximum thickness of a localized domain. As the amplitude of the oscillations increases, the shape of the output signal deviates from sinusoidal (Fig. 2a). It was found, however, that the oscillation period T does not depend on the shape of the signal or on the incident intensity. It is related to the domain diameter d . The relationship can be described within the experimental error ($\sim 20\%$) by $Td^{-2} = \text{const}$. In the experiments, T was varied from 10 to $280 \mu\text{s}$ by focusing the light near the back side of the sample.

When the intensity of the incident light is increased further, the distance traveled by the domain increases, and there is a smooth change in oscillation regime. The distance traveled by the domain in this case (Fig. 1b) is at least an order of magnitude greater than the thickness of a localized domain (Fig. 1a), but the domain does not reach the front side of the sample, and it undergoes a recombination in the interior. The shape of the oscillations, definitely not sinusoidal (Fig. 2b), varies with the intensity of the incident light and with the geometry of the light channel. The oscillation period depends on the distance traveled by the domain, varying from 80 to $600 \mu\text{s}$ in these experiments. The average domain velocity is estimated to be $\mu \cong (1-3) \times 10^2 \text{ cm/s}$. The sharp downward switching, which is characteristic of the regime of strong oscillations occurs in $1-5 \mu\text{s}$. The maximum amplitude of the output signal is at least five times the minimum amplitude, indicating a complete recombination of the domain in the interior of the sample, since the transmission of a localized domain is $\cong 20\%$.

Since the form of the nonlinear absorption coefficient in this case is the same as that observed in a study of the optical discharge, a phenomenological description of

the motion of the strong-absorption domain in a homogeneous semiconductor can be obtained by using the well-developed theory for the thermal-conductivity regime of the propagation of an optical discharge. Raizer² gave a solution for the velocity and thickness of a domain as functions of the intensity of the incident light. If the light intensity is well above the threshold required for maintaining the steady-state motion of a domain, the velocity is estimated to be $\mu \cong 10^2\text{--}10^3$ cm/s. This figure agrees well with the value found experimentally.

The domain velocity is a multivalued function of the light intensity,² and the lower branch of this function is unstable. In the spatially homogeneous case, the motion of a domain with a nonzero velocity is possible even when the light intensity is above a certain critical level. This fact leads to the following explanation for the strong-oscillation regime (Figs. 1b and 2b): A domain forms at the back side of the sample. When the light is sufficiently intense, the domain detaches from an inhomogeneity and moves in the direction opposite the incident light, through the light channel, whose geometry is determined by the caustic surface of the lens. In the experiments, the domain goes through a region of maximally sharp focusing, and the intensity of the light incident on the domain begins to decrease. At a certain point, this intensity drops below the critical density at which the motion of the domain is possible, and the domain disappears. After this event, a new domain forms at the back side of the sample, and the process repeats itself.

The regime of weak oscillations in the light transmitted in the sample seems to be related to the detachment of a localized domain from the back side of the sample when the intensity of the incident light is below the critical level required for the maintenance of the steady-state motion of a domain in the spatially homogeneous case. The experimental data also suggest that this oscillation regime stems from a relatively small periodic change in the thickness of the domain.

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¹V. L. Bonch-Bruевич, I. P. Zvyagin, and A. T. Mironov, *Domennaya élektricheskaya neustoičivost' v poluprovodnikakh* (Domain Electrical Instability in Semiconductors), Nauka, Moscow, 1972.

²Yu. P. Raizer, *Usp. Fiz. Nauk* **132**, 549 (1980) [*Sov. Phys. Usp.* **11**, 789 (1980)].

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