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NEGATIVE PHOTOMECHANICAL EFFECT IN CADMIUM SULFIDE

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In works devoted to the investigation of the photomechanical effect in semiconductors, attention is drawn to the close connection of this phenomenon with the internal photoeffect ([1]). In these experiments, as a rule, the studies were carried out on semiconductors with bipolar photoconductivity of the Ge, Si type, whose microhardness under illumination decreased by approximately 70% relative to the dark value.

In monopolar photoconductors, where the highest quantum yield is observed, the photomechanical effect has been studied much less. This is apparently connected with the fact that in the latter case the softening of the specimen under illumination is much less pronounced than in bipolar photoconductors. Thus, for example, it follows from ([2]) that in cadmium sulfide the decrease in microhardness under illumination does not exceed 40%.

The facts indicated, it seems to us, already in themselves testify to a deep connection between the photomechanical effect and photoconductivity. Indeed, in the general case, irradiation of a semiconductor with light from the region of intrinsic absorption creates some number of broken valence bonds (holes) and free electrons. Both, evidently, contribute to the softening of the crystal lattice ([3]), but to different degrees, depending on the type of photoconductor. In bipolar photoconductors both factors are strong, since under the action of light holes and electrons are generated simultaneously. In monopolar photoconductors, however, as a consequence of the capture of one kind of carrier (electrons or holes) by metastable sticking levels, only that factor manifests itself which corresponds to the remaining type of carriers. In the case of cadmium sulfide—a typical electronic photoconductor—such a factor will be nonequilibrium free photoelectrons, which, by exerting a screening action on the valence bonds, bring about softening of the crystal. The valence bonds destroyed by photons here are immediately "healed" by the action of sticking levels, which capture holes from the valence band.

This explains the fact that in monopolar photoconductors the photomechanical effect is expressed more weakly than in bipolar ones. On the other hand,

Fig. 1. Change in the microhardness of cadmium sulfide crystals with increasing intensity of infrared light

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monopolar photoconductors constitute a good object for studying the role of the separate factors that determine the photomechanical effect.

In connection with the above, it is of interest, in particular, to clarify the question of how sensitive the mechanical properties of CdS crystals are to changes in the concentration of free electrons. The most "pure" method of changing this concentration is, obviously, the use of illumination.

Usually the photomechanical effect develops in the same direction as photoconductivity, i.e., with an increase in illumination intensity, the degree of softening of the crystal increases simultaneously with the photocurrent. At the same time, it is known that in many semiconductors, including cadmium sulfide, negative photoconductivity can be observed under irradiation with infrared light, when the current in the crystal turns out to be smaller in magnitude than the dark current. Investigation of the photomechanical effect

under these conditions could serve to clarify its relation to the concentration of free electrons in the CdS crystal.

In the present work, crystals of cadmium sulfide exhibiting negative photoconductivity were used; they were grown at the Institute of Semiconductors of the Academy of Sciences of the Ukrainian SSR by the gas-phase reaction method. The crystals were plates measuring $5 \times 5 \times 0.3$ mm^3. The *c*-axis of the crystals was oriented in the plane of the plate. A 500-W tungsten lamp with an IKS-3 filter served as the source of infrared light. During illumination of the samples, measures were taken to prevent their heating. Microhardness was measured with a PMT-3 instrument under a load of 10 g.

The curve expressing the dependence of the microhardness of CdS crystals on the illumination intensity is shown in Fig. 1. Also shown there is an oscillogram of the kinetics of negative photoconductivity in the samples studied.

Fig. 1. Change in the microhardness of cadmium sulfide crystals with increasing intensity of infrared light.

It is evident from Fig. 1 that in the present case the photomechanical effect, like the photoconductivity, has a negative sign; i.e., with increasing light intensity, instead of softening of the crystal its hardening takes place. This phenomenon is not difficult to understand from the considerations given above, proceeding from the features of its relation to the internal photoeffect in monopolar semiconductors.

Negative photoconductivity in cadmium sulfide is currently classified as an extreme case of the well-studied effect of infrared quenching of the photocurrent (^{4}). In negative photoconductivity, the Fermi level makes possible the excitation, under the action of infrared illumination, of valence electrons to certain metastable levels characterized by a low rate of thermal excitation into the conduction band. At the same time, levels of another type, located below the Fermi level and possessing a large capture cross section ($\sim 10^{-15}$ cm^2) for charge carriers of both signs, ensure a high rate of recombination of photoholes with free equilibrium electrons, thereby reducing the dark conductivity. A necessary condition for observing the negative photoeffect is the fulfillment of the inequality:

$$\frac{S_{nR}}{S_{nM}} > \exp\left(\frac{|E_M, E_f|}{kT}\right),$$

where S_{nM} is the capture cross section of free electrons by the metastable level; S_{nR} is the capture cross section of free electrons by the recombination level; $|E_M, E_f|$ is the energy interval (absolute value) between the metastable level and the Fermi level. The decrease in the dark concentration of free electrons upon illumination is accompanied by a weakening of their screening action on the valence bonds, which, as noted above, is the principal factor in the optico-mechanical effect in CdS crystals. The latter is manifested in an increase in microhardness under the action of light.

In conclusion, the authors consider it a pleasant duty to express their gratitude to B. Bulakh for kindly providing the CdS crystals.

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Note: Figure translations are in progress. See original paper for figures.