Effect of electric field on deformation induced-light emission of ZnS crystals

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A change (increase or decrease) in the number of the deformation-induced light flashes was observed. This change, which depends on the polarity of the electric field (U), seems to be the consequence of the influence of U on the dislocation motion and multiplication processes.

Emission of short light pulses has been observed in[1] following plastic deformation of ZnS crystals. The flashes are of dislocation origin, and their number per unit time characterizes the rate $\dot{\epsilon}$ of plastic deformation of the crystal. The emission turned out to be very sensitive to changes of $\dot{\epsilon}$, as revealed by the motion and multiplication of the dislocations.[2] It seemed desirable therefore to use the light-emission procedure to investigate various factors that influence plastic deformation of crystals.

We investigated the effect of an electric field on deformation-stimulated light emission. This investigation is of interest also because hardening of ZnSe crystals by an electric field (U) was observed in[3] and was independent on the polarity of U; this is the electroplastic effect (EPE) which is even in the field. In this study we observed new experimental facts. Depending on the electric-field polarity, the ZnS crystals become hardened or softened—an "odd" EPE. A mechanism is proposed for this process.

The tests were made on ZnS crystals grown from the melt by the Bridgman method. The sample faceting was $(1\bar{2}10)$ and $(10\bar{1}1)$, and the slip plane (0001), which is active under uniaxial deformation, was inclined 45° to the deforming stress (Fig. 1). The procedure used to load the crystals and to register the light emission is described in[1].

To study the influence of the electric field (U) on the deformation-induced glow, we used two methods: the electric voltage was applied either to indium contacts soldered to the sample, or to the electrodes of a capacitor in which the crystal was placed. The indium contacts were deposited by ultrasonic soldering on the crystal face with indices $(10\bar{1}1)$.

Loading the ZnS crystals with a rectangular pulse of mechanical stress of amplitude $\sigma > \sigma_{el}$(σ_{el} is the elastic limit) produced a series of flashes of light. Each flash was formed by a large number ($\sim 10^3$) of dislocations making up a slip band.[1] The amplitudes and durations of the flashes in each series were close to one another, and the glow could therefore by characterized by the number of light flashes per unit (N). The quantity N turns out in this case to be proportional to the rate of plastic deformation $\dot{\epsilon}$. The factors that lead to the change of $\dot{\epsilon}$ should cause a change in N. Indeed, as shown in[2], additional illumination of the crystal with light in the activator absorption bands leads to the onset of photo-barriers that change the character of the plastic deformation of the crystal and suppress, partially or fully, the crystal light emission, with N always proportional to $\dot{\epsilon}$.

The main experimental results obtained by us is that an external electric field (U) changes the value of N,

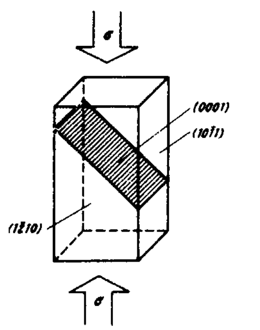

FIG. 1. Orientation of the ZnS sample under uniaxial deformation. The face indices are given in the hexagonal system.

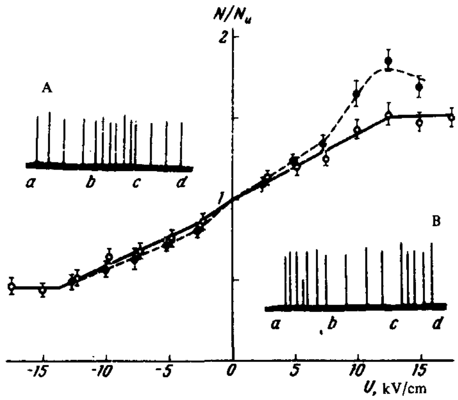

FIG. 2. Dependence of the ratio N/N_U on the magnitude and polarity of the electric field (U) in ZnS crystals: dark circles—U applied to contacts soldered to sample; light circles—U applied to the electrodes of a capacitor in which the sample was placed. A, B—oscillograms illustrating the influence of fields of opposite polarity on the light flashes. a and d—instants of loading and unloading the crystal; b and c—instants when the external voltage was turned on and off. $T = 340\,°K$.

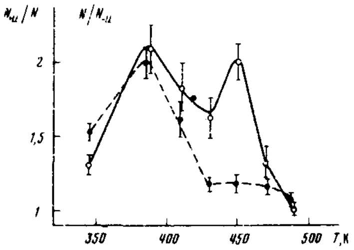

FIG. 3. Temperature dependence of the relative change in the number of light flashes, for ZnS crystal following application of a hardening electric field (U) (●) and a softening electric field ($-U$) (○).

and the character of this change depends on the magnitude and polarity of U. A field of one polarity increases the number of flashes per unit time, and that of the opposite polarity decreases it (Fig. 2). The average flash amplitude changes insignificantly.

Simultaneously with recording the number of luminescence pulses (N_U) produced when the crystal is deformed in an electric field, we measured the residual deformation $\Delta\epsilon_U$ ($\Delta\epsilon_U/t = \dot{\epsilon}$, where t is the time). It turns out that N_U is proportional to $\Delta\epsilon_U$, i.e., an external electric field, just as illumination of the deformed crystal by light,[2] does not affect the light-emission centers, but changes the conditions of motion and multiplication of the dislocations. The change of the ratio $N/N_U = \Delta\epsilon/\Delta\epsilon_U$ ($\Delta\epsilon = \Delta\epsilon_{U=0}$) as a function of the magnitude and polarity of the electric field is shown in Fig. 2. It is seen from this figure that an increase of the electric field to a value $|U| \sim 12$ kV/cm is accompanied by a monotonic increase (decrease) of the ratio N/N_U. At $|U| > 12$ kV/cm, the growth of N/N_U stops simultaneously with the onset of electroluminescence of the crystal.

It should be noted that the influence of the field on the plastic deformation is practically independent of the method whereby the field is applied—through contacts soldered to the sample or through the electrodes of the capacitor in which the crystal is placed.

The effect of temperature on the field-induced change of the rate of plastic deformation is illustrated in Fig. 3. A low-temperature is common to the electric fields of both polarities (which harden or soften the crystal).

As noted in[3], a possible mechanism of a polarity-independent EPE, which has a threshold character, is the onset of additional dislocation pinning in the presence of a strong electric field, as a result of injection of minority carriers from the contact into the volume of the ZnSe crystals. This assumption is favored by the fact that the field exerts no hardening action on the ZnSe crystal when U is applied to the electrodes of the capacitor in which the sample is placed.

Comparing the experimental data described in[3] with the results obtained in this paper we reach the conclusion that we have observed in the ZnS crystals, more readily, a fundamentally different effect of an electric field on plastic deformation of the crystal. The "odd" EPE and its properties can be easily explained by assuming that the dislocation in ZnS are charged. Owing to the electrostatic interaction with the charged dislocation, the effect of turning on the electric field is equivalent to a corresponding increase or decrease of the external load by an amount $\Delta\sigma$, which can be easily determined by comparing the plots of $N = N(\sigma)$ (Fig. 1 of[1]) and $N/N_U = f(U)$ (Fig. 2). From the equality of the electrostatic and mechanical forces acting on the dislocation ($\Delta F + (\Delta\sigma/2)(\Delta\sigma/2)b$, where b is the Burgers vector) we can obtain the dislocation charge (q), found to be 10^{-2} cgs esu/cm.

The motion of the charged dislocations should lead to the appearance of a charge on the crystal surface.[4,5] We observed on the $(10\bar{1}1)$ faces pulses of electric potential of duration $\tau_{0.5} \sim 40$ nsec. They appear in synchronism with the light flashes, and are therefore formed, just like the luminescence pulses, by the dislocations moving in the slip band. The charge corresponding to one flash turned out to be 1.7×10^{-10} C. This charge can be produced if the average charge of each of the 10^3 dislocations forming the flash, meaning also the charge pulse, is equal to 0.5×10^{-2} cgs esu/cm, which is of the same order as the estimate obtained above.

Within the framework of the concepts developed here, a decrease in the number of light flashes (hardening of the sample) should be expected when the polarities of the external electric field and of the light flashes coincide. Experiment confirms this assumption.

We have thus observed in this study a change in the plasticity of the crystal. This change depends on the polarity of the electric field and is due most likely to electrostatic interaction between the external electric field and charged dislocations.

We note in conclusion that an electric field applied to the surfaces $(1\bar{2}10)$ of the ZnS crystals, regardless of the polarity, increases the rate of the plastic deformation, meaning a softening of the sample.

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