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# PHYSICS OF SEMICONDUCTORS AND DIELECTRICS

## DEFECT FORMATION KINETICS IN ALKALI HALIDES IN VERY STRONG ELECTRIC FIELDS

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*Experimental investigations of defect formation in alkali halide crystals have been carried out over a broad range of electric fields from $10^4$ to $10^7$ V/cm with different field pulse widths. It is shown that not only the electric field strength but the length of time it is applied is important. The effect of defect formation processes on the shapes of the current–voltage and voltage–brightness characteristics of the samples was studied in the indicated field range. The defect formation mechanism in alkali halide crystals in very strong electric fields has been better defined.*

Various point and line charged defects are present in NaCl crystals. When an external electric field is applied to the crystal these charged defects move within the crystal which leads to their interaction and multiplication [1, 2]. With the action of a single very strong electric field pulse on the crystal during measurements of the electroluminescence characteristics of NaCl formation of new charged dislocations can also be observed, which should be accompanied by generation of excess point defects. This in turn affects the crystal properties and the form of the measured properties. Therefore in the present work we have studied defect generation in thin (2-6 $\mu$m) single-crystal layers of NaCl with different pulsewidths of very strong (E = $10^4$-$10^7$ V/cm) electric fields and the appearance of defects in the process of measuring the current–voltage (I–V) characteristics and a possible change in the shape of the I–V characteristics due to the generation of these defects.

The starting material for the investigations was crystals grown from a melt of OSCh grade NaCl by the Kyropoulos method. The experimental samples were prepared by the method described in [3]. After sample preparation by the surface selective etching method using an etchant of the composition indicated in [4] the initial dislocation density was determined and turned out to be $(1\text{-}6)\cdot 10^5$ cm$^{-2}$. Then the samples were subjected to a pulsed electric field and the dislocation density was determined again. The studies done showed that dislocation generation begins during a 50 msec electric field pulse, in contrast to [4] in which the field pulse width amounted to 1 msec for fields with a strength E = $10^4$ V/cm. With a change of the electric field strength to $6\cdot 10^4$ V/cm a small increase was observed in the dislocation concentration in comparison to the initial concentration. A further increase of the field strength led to a sharper increase in the dislocation concentration (curve 1 in Fig. 1). If a short 0.2 msec electric field pulse was fed to the sample then the intense growth of the dislocation density began in fields with much higher strength, E = $3\cdot 10^6$ V/cm (curve 2 in Fig. 1). This means that not only in the strength of the electric field but also the pulse width is important for the onset of dislocation generation.

The following is a possible mechanism for field generation of dislocations. Since dislocations have charge [5], under the action of the electric field they can move within the crystal. During dislocation motion with their mutual intersection and mutual action with pinning sites there is dislocation multiplication by one of the mechanisms described for example in [1, 2]. If the sample is supplied with short pulses of high strength and the same amplitude first with forward and then reverse polarity (with common pulse width of 50 msec) as in [6] then this limits the motion and possibly the dislocation generation connected with it. The experiments which were done showed (curve 3 in Fig. 1) that with such an action of the electric field there was actually no observed substantial growth of the dislocation concentration up to a field E = $10^6$ V/cm. However in fields with

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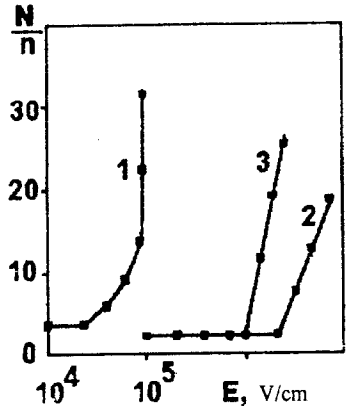


Fig. 1

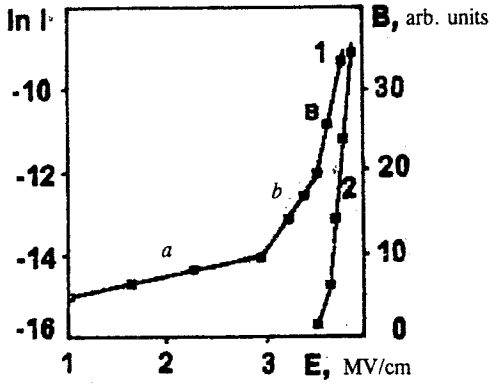


Fig. 2

Fig. 1. Change in the dislocation concentration under the action of an electric field for different durations of the exciting voltage: 1) 50 msec; 2) 0.2 msec; 3) pulses of forward and reverse polarity (0.2 msec) with a common width of 50 msec; n is the dislocation concentration before the application of the field and N is the dislocation concentration after the application of the field.

Fig. 2. Typical I–V characteristics (1) and voltage-brightness characteristics (2) for a NaCl sample.

$E > 10^6$ V/cm a sharp increase of the dislocation concentration begins somewhat earlier than with the action of a short (0.2 msec) single pulse although it is assumed that in Fig. 1 curves 2 and 3 should coincide over the whole range of fields. Probably with the action of a reverse polarity pulse the system of dislocations does not fully recover into the initial state, evidently due to the binding of some of the dislocations at pinning sites. Moreover with $E > 10^6$ V/cm a substantial contribution to the dislocation generation can come from other mechanisms of dislocation generation. Additional studies were carried out to refine these mechanisms.

Comparisons were made between the measured current–voltage and voltage–brightness (V–B) characteristics and the change in the dislocation density. Measurements of the I–V and V–B characteristics were done from the points for single pulses of exciting voltage of the same polarity and short duration (0.2 msec). As shown in [6] such a method allows one to obtain good reproducibility of the results in measurements of the I–V characteristics. In order to obtain the dislocation pattern corresponding to a certain part of the I–V characteristic the measurements on the samples were stopped at some electric field strength and the dislocation density was determined by the selective etching method. The typical forms of the I–V and V–B characteristics are shown in Fig. 2. Regions *a* and *b* of the I–V characteristics were due as in [6] respectively to the current from field emission from the electrode into the dielectric and from collisional ionization.

It was established that over the whole range of fields up to the onset of luminescence (curve 2 of Fig. 2) there is no significant growth of the dislocation density and the appearance of luminescence nearly coincides with the sharp increase in the dislocation concentration (by approximately 30-fold) relative to the initial value, i.e., before the action of the electric field. During visual observations of the dislocation pattern in the experiments for curves 2 and 3 of Fig. 1 on the surface of the film a localized arrangement of regions with an increased density of dislocation etch pits was observed. It is evident that at these sites there is localized current flow which can arise due to the distortion of the field uniformity in the sample from the occurrence of bulk charges [6] which produces motion of charged defects. As a consequence of the local current flow there can be heating and as shown in [7] thermal shock and a related sharp increase in the defect concentration in the vicinity of such a channel. Luminescence from the film occurs at these sites since the concentrations of structural defects which are the luminescence centers is much higher at them. Luminescence does not occur in the sample when one does not reach the needed dislocation and point defect concentrations despite the fact that in the range of fields $E = (1\text{-}3)\cdot 10^6$ V/cm there are collisional ionization processes. Actually for the appearance of luminescence it is necessary to have not only collisional ionization but also luminescence centers [8].

Thus in the present work with the help of the studies which were done on the site of the appearance of luminescence, the dislocation pattern, and the electro-optic characteristics of electroluminescence of NaCl we have shown a connection of the defect formation processes and the electro-optical characteristics of the electroluminescence of alkali halide crystals (AHC). Indeed, the larger the electric field strength the more intense these processes occur in the AHC film. With an electric field strength more than $10^6$ V/cm even during the action of one short (0.2 msec) pulse of voltage in the film irreversible changes in the ionic subsystem of the crystal can occur which turn out to essentially affect the form of the measured properties [6]. In our view the kinetics of defect formation in AHC in an electric field with $E < 10^6$ V/cm is due to multiplication of dislocations due to their intersection and mutual action during motion (field mechanism), while with $E > 10^6$ V/cm it is due to generation of dislocations arising from thermal shock caused by localized current flow coming from distortion of the uniformity of the electric field due to the motion of charged defects [7].

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