YU ISSN 0015—3206
FZKAAA 22 (4) 589 (1990)

INJECTION OF CHARGE CARRIERS IN ALKALI HALIDES*

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Received 30 September 1989

UDC 538.95

Original scientific paper

Single crystals of KCl, KBr and KCl : KBr have been grown by Kyropoulos method. Electron injection has been employed in these crystals through heterogeneous contacts under different temperature and applied electric fields. The ionic zone followed by electron traping zone is observed and simultaneous current growth and optical absorption have been studied during traping zone. Before the advent of third zone the original transparence of the crystal is regained with the decay of induced defect centers. From the decay time, mobility of these centers and thereby activation energy involved for their migration have been obtained.

1. Introduction

Current injection in insulating materials is a practice which yields many scientific and technological information on the defect states in the forbidden gap of insulators and also the transport coefficients[1]. The function of a contact between a metal and an insulator is either to enable or to block the injection of carriers. Mott and Gurney[2] observe that it is possible to inject electrons from a suitable contact into an insulator.

If a cathode emits more electrons than the space can hold, the remaining electrons will form a negative space charge which will produce a field, thereby reducing

* The paper was presented at the International Conference on Defects in Insulating Crystals held in PARMA, Italy, 1988.

the rate of emanation of electrons. Therefore, the current is controlled by the bulk of the insulator. On an application of an electric field to an alkali halide crystal pressed mechanically between two electrodes and heated, *F* center originates from the pointed tips of the cathode and moves towards the anode[3]. The positive ion vacancies are attracted to the plate and some get destroyed with an outflow of negative charge. An equal number of negative vacancies does not drift out at the pointed cathode rather some electrons are injected into the conduction band. Space charge limited (SCL) current in the crystal reveals four distinct zones[4] under suitable experimental conditions.

The evolution of electrical current and the colour center are intimately related to the applied voltage, temperature and the nature of the specimen.

In the present paper we like to discuss the nature and characteristics of the injection process in pure and defect induced alkali halide crystals during ionic and SCL zones.

2. *Experimental*

Single crystals of KCl, KBr, KCl : KBr (1, 5, 10 mole % KBr) are cleaved from the block of crystals grown by employing Kyropoulos method. A crystal is mounted between a heterogeneous contact[5] of flat platinum anode and a sharp pointed brass cathode and heated in an electrical furnace for electron injection.

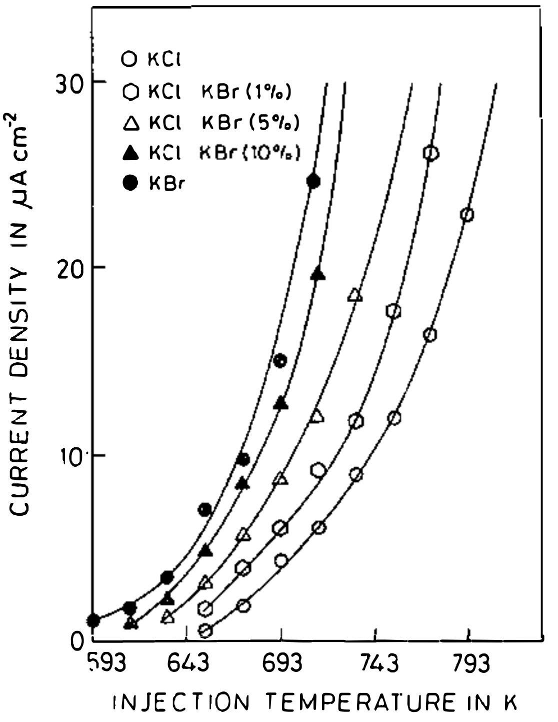

Fig. 1. Ionic current growth under an electric field of 500 V cm^{-1} at different temperaturess.

Ionic Zone: The injection current for a particular electric field of 500 V cm^{-1} at different temperatures are recorded for all the specimens with the help of a (Bausch and Lomb series 5000) pen recorder and are plotted as shown in Fig. 1.

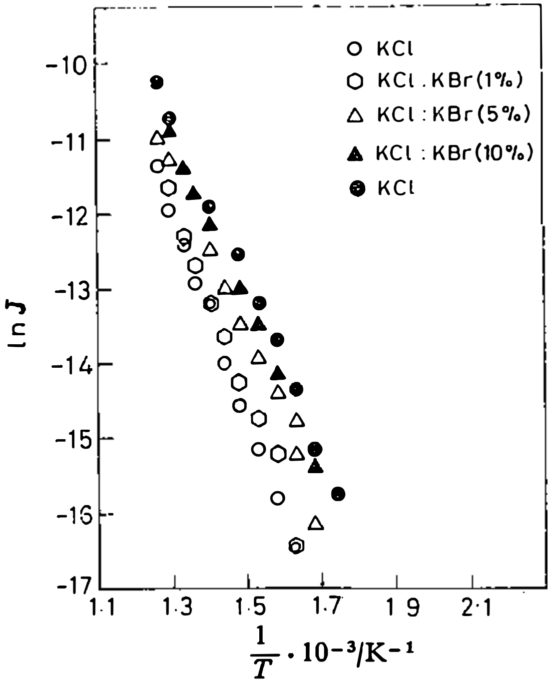

Fig. 2. Logarithm of current density as a function of reciprocal of temperature under electric field at 500 V cm^{-1}.

SCL Zone: An optical arrangement has been made to study the growth of colouration during second stage injection process. A monochromatic beam of light is allowed to pass through the crystal insitu within the furnace and the transmitted light is received by an electronically controlled PM tube. Simultaneous record of injection current and photo currents with time have been noted through the pen recorder. The colouration process is stopped just before the onset of the saturation zone (third zone). A typical data for a KBr crystal is shown in Fig. 3. As soon as the third zone is reached the polarity of the electrodes are reversed and the injection is continued until the crystal regain its original transparency. The growth and decay of colour centers are depicted in Fig. 4 for KCl : KBr (4 mole%) as an illustration.

3. *Results and discussion*

Ionic injection is the first step to create defect centers within the crystal since, an ohmic contact is fundamental to enable electrons to stream through the crystal for SCL injection. Following Mott and Gurney[2] an analogy between injection current in vacuum and that in an insulator like alkali halides may be drawn.

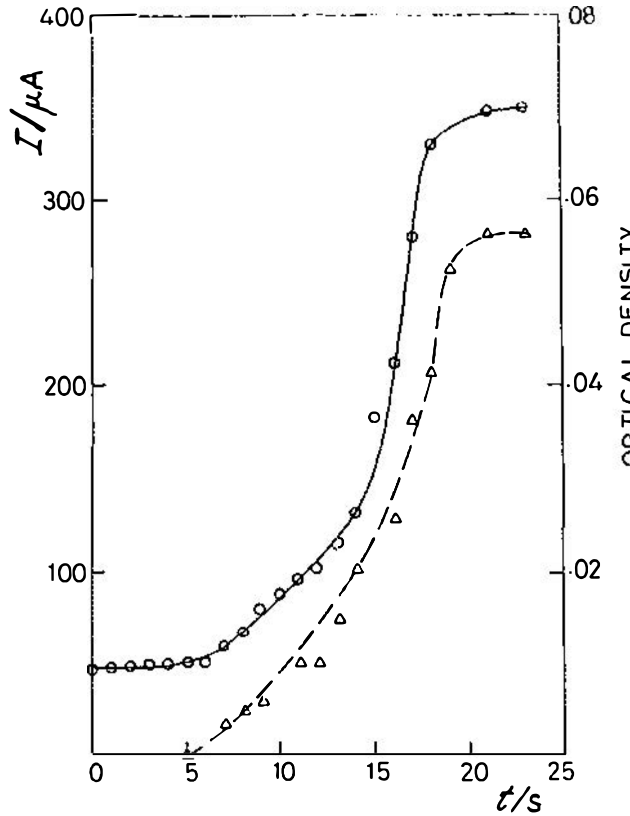

Fig. 3. Injection current (o) and optical density (Δ) against time during colouration for KBr at 723 K under electric field of 800 V cm^{-1}.

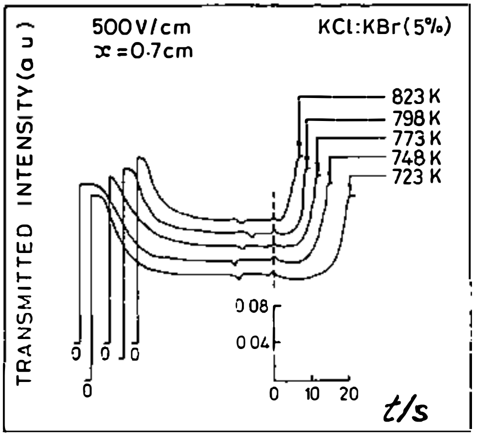

Fig. 4. Growth and decay of defect center under an electric field 500 V/cm at various temperatures for KCl : KBr (5%) crystal.

Let us write the current density in any insulator as:

$$J = en(x)\,\mu\,E - eD\frac{\mathrm{d}n(x)}{\mathrm{d}x}$$

where, E, $n(x)$, μ and D are, respectively, the electric field, carrier concentration for a distance x, mobility and diffusion coefficient of the carrier.

Now, the potential barrier height as seen from the Fermi level to the bottom of the conduction band of the insulator comprises of potential energy barrier, image force and also the potential energy due to the applied field. Within some limitations of the field and temperature and making some algebraic manipulations we arrive at a situation for large x,

$$J = (e\,\mu\,E\,n_c)\exp\left(-\frac{W_0}{KT}\right) = A\exp\left(-\frac{W_0}{KT}\right)$$

where, n_c is the effective density of states in the conduction band and $W(x) = W_0$ corresponding to minimum potential energy. Values of injection current against reciprocal of temperature is plotted as in Fig. 2. which verifies the above equation. The activation energy is evaluated as shown in the table. It is evident

TABLE 1.

Specimen	Measured activation energy in eV	Computed activation energy in eV
KCl	1.15	1.15
KCl : KBr (1%)	1.09	1.07
KCl : KBr (5%)	1.01	1.00
KCl : KBr (10%)	0.99	0.98
KBr	0.77	0.78

Activation energy value for KCl, KCl : KBr (1, 5, 10%) and KBr.

that the formation of ohmic contact is highly suitable for KBr while in KCl it is difficult to achieve such a situation. In the mixed states where KCl contains more and more KBr, the activation energy goes on decreasing its values, suggesting the characteristic nature of the induced materials. From the growth and decay of colour center plots (Fig. 4), the optical absorption at any point can be measured from the ratio between the zero time per height to that at any point of interest. From the decay part of the colouration curve we measured the transit time to find mobility of defect centers. The mobility of defect center $\mu_F = \frac{xL}{tE}$, where, t is the transit time of decay of the defect centers through a distance x inside the crystal by apply-

TABLE 2.

Injection temperature in K	Mobility ($\times 10^{-3}$) in $cm^2 V^{-1} s^{-1}$					Activiation energy in eV				
	KCl	KCl : KBr 1%	KCl : KBr 5%	KCl : KBr 10%	KBr	KCl	KCl : KBr 1%	KCl : KBr 5%	KCl : KBr 10%	KBr
723	0.05	0.05	0.07	0.09	0.15	0.55+	0.54+	0.52+	0.50+	0.46+
748	0.07	0.08	0.10	0.12	0.18	0.53*	0.53*	0.51*	0.50*	0.47*
773	0.09	0.11	0.12	0.16	0.24					
798	0.12	0.14	0.17	0.22	0.29					
823	0.17	0.20	0.21	0.27	0.37					

Defect center mobility (μ_F) and activation energy for KCl, KCl : KBr (1, 5, 10%) and KBr crystals under an electric field 500 V cm^{-1}.

+From graph

*From method of average

ing a field E, at various injection temperatures are shown in table along with the activation energy (U) involved in the process through an equation,

$$\mu_F = \mu_0 \exp\left(-\frac{U}{KT}\right),$$

μ_F is temperature dependent, when the field is low.

It has been observed[7] from the thermal decolouration experiment that the elimination of F center is faster in KBr while in case of KCl it is very slow process. The F center mobility value for KBr is larger in comparison with KCl or KCl : KBr crystals (see tables), which is quite expected. It is clear that the ionic process controls the diffusion rate in SCL region, as the rate of accumulation of the halide ions in the ionic stage decides the nature of the ohmic contact for injection. Replacing more and more chlorine atom from the lattice site by bromine atom the ohmic contact condition may be improved, perhaps the rate of accumulation of the bromine ions is more augmented. Our results are obtained from the direct optical absorption data, whereas the previous workers[8] were concentrated to the analysis of SCL current injection.

References

1) M. A. Lampert and P. Mark, *Current Injection in Solids*, Academic Press Inc., N. Y., (1970);
2) N. F. Mott and R. W. Gurney, *Electronic Process in Ionic Crystals*, 1st ed. Oxford University Press, N. Y., (1940);
3) H. N. Hersh and L. Bronstein, Am. J. Physics, **25** (1957) 306;
4) A. G. Andrev, G. B. Semushkin and T. A. Tsikin, Sov. Physics Solid State, **9** (1968) 2564;
5) A. K. Maiti, K. Goswami, A. Manna, S. Choudhuri and A. Choudhuri, Fizika **14** (1982) 7;
6) A. K. Lahiri, A. K. Maiti and K. Goswami, Solid State Commun. **59** (1986) 457;
7) A. K. Maiti, K. Goswami and A. K. Lahiri, Fizika **15** (1983) 247;
8) M. T. Montojo, F. Jaque and C. Sanchez, J. Phys. Chem. Solids, **38** (1977) 657.

UŠTRCAVANJE NOSILACA NABOJA U ALKALNE HALIDE

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Originalni znanstveni rad

Monokristali KCl, KBr i KCl : KBr dobiveni su Kyropoulosovom metodom. U te su kristale uštrcavani elektroni pri različitim temperaturama i primijenjenim električnim poljima. Proučavanjem rasta struje i optičke apsorpcije određena je pokretljivost *F* centara, kao i aktivacijska energija potrebna za njihovu migraciju.