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STUDY OF LOW FIELD REGION IN SINGLE INJECTION SOLID STATE DIODE WITH TRAPS LYING BELOW THE FERMI LEVEL

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Analytical expressions for the study of low field region in the single injection solid state diode with traps lying below the fermi level operating in the high field conditions have been given with the help of dimensionless variables. It is shown that the current-voltage characteristic follow 3/2-power low at high injection level.

INTRODUCTION

The studies on space-charge-limited single injection current insulators operating under high tield regime have been made by several workers from a long time [1-5]. The mobility is field dependent at high fields. Here, the contribution of low field region in current-voltage characteristic is taken into consideration in the previous basis [6, *7,* 8] which is generally neglected by the workers of the field.

Consider an insulator containing significant density a single set of traps lying below the Fermi level. The general equations characterizing the current flow and Poisson's law are given by :

$$J = e\,\mu\,(E)\,n\,(x)\;E(x) \qquad \dots (1)$$

$$\frac{\varepsilon}{e}\cdot\frac{dE}{dx} = (n(x) - N_0) - (p_{t,0} - p_t)$$

$$= \left(n - \frac{N_1 N}{gn}\right) + \left(\frac{N_1 N}{gN_0} - N_0\right) \qquad \dots (2)$$

where the deep traps relations in equation (2) are used [3], In the above equation, $\mu(E)$ is the high field mobility of the current carriers, $n(x)$ and N_0 are the free electron concentration and its thermal equilibrium value, N is the concentration of traps, g is the statistical weight of the traps. $P_{t,\,0}$ = Hole occupancy of thermal equilibrium, p_t = total traps – trapped electron. The high field mobility relationship derived by Gisolf and Zijistra [–1] in given by for $E > Ec$

$$\mu(E) = \mu_0\sqrt{\frac{E_c}{E_x}} \qquad \dots (3)$$

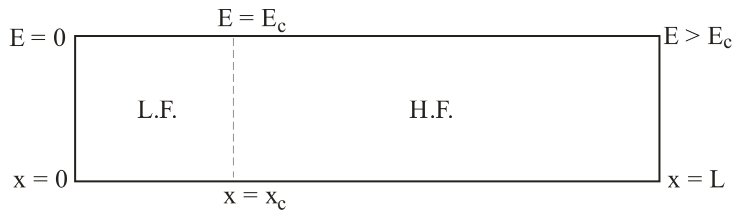
where μ_0 is the low field mobility constant and EC is the critical field strength at which high field effect starts. These equations are subjected to an usual boundary condition for ohmic contact.

$$E(0) = 0 \qquad \ldots (4)$$

It is evident from equation (3) & (4) that there is a low field strength is smaller than *EC*. The contribution of low field region is negligibly small at sufficient high fields [7, 8].

CURRENT-VOLTAGE CHARACTERISTIC

The insulator can be divided into two regions with the help of regional approximation method which is extensively applied in single injection theories [3-8]. The presence of two regions in the insulator is depending on the applied voltage.



(i) At low fields ($E < Ec$); The entire insulator is operating under low field mobility regime in which the mobility is constant throughout the insulator.

(ii) For medium fields ($E > Ec$); The insulator containing two regions which are well separated by an imaginary transition plane x where E (x_c) = Ec. The region $(0 \le x \le x_c)$ is low field region and the region $(x_c \le x \le L)$ if high field region where the mobility is field dependent. The transition plane shifted towards cathode when the electric field across the diode increases.

(iii) At sufficient high fields ($E > Ec$); The low field region negligibly small which exists at the cathode. In this situation, the high field region can be assumed to fill the entire insulator.

Thus, the complete current-voltage characteristic is strongly dependent on the applied electric field. The current- voltage characteristic can be obtained conveniently with the help of the following dimensionless variables.

$$u = \frac{EN_0\,\mu_0\,[E\,.E\,(x)]^{1/2}}{J}, \qquad w = \frac{e^2 N_0^2\,\mu_0 E_c^{1/2} x}{\varepsilon\, J\,[E\,(x)]^{1/2}}$$

and
$$v = \frac{e^3 N_0^3\,\mu_0^2\,V\,(x)\,E_c}{\varepsilon\, J^2 E\,(x)} \qquad \ldots (5)$$

$$w = \frac{2N_0\,\sqrt{E\,(x)}\,dx}{\sqrt{E\,(x)}\,dw + \frac{w}{2}[E\,(x)]^{-1/2}\,dE\,(x)} = \frac{N_0}{u} - N_0 + (BN_0 - BN_0 u)$$

$$udw + wdx = \frac{2u^2 du}{1 + (B-1)\,u - Bu_2}$$

$$[uw]_{u_0 w_0}^{uw} = \frac{2}{B}\left[u - \frac{1}{B\,(B-1)} l_n\,(1 + Bu) + \frac{B}{B+1} l_n\,(1-u)\right]_{uc}^{u}$$

$$w = -\frac{2}{Bu}\left[(u - uc) - \frac{1}{B(B-1)} l_n \left(\frac{1+Bu}{1+Buc} + \frac{B}{B+1} l_n \frac{1-u}{1-uc}\right)\right] + \frac{u_c wc}{u}$$

for $E > Ec$, the equations (1) – (5) give the dimensionless variable w at anode as :

$$wa = \frac{2}{Bu_a}\left[(u_a - u_c) - \frac{1}{B(B+1)} l_n \left(\frac{1+Bu_a}{1+Bu_c}\right) + \frac{B}{B+1} l_n \left(\frac{1-u_a}{1+u_c}\right)\right] + \frac{u_c \omega_c}{u_a} \quad \dots (6)$$

where $B = \dfrac{N_1 N}{g N_0^2} = \dfrac{p_{t,0}}{N_a} = 10$ the subscripts "a" and "c" on any dimensionless variable yield that value at anode and the transition plane x_c. respectively. The values u_c and ω_c at transition plane are obtained by substituting $E(x) = Ec$ in eq. (5).

$$v = \frac{1}{u^2} \iint u^2 (udw + wdu)$$

$$= \left[\frac{1}{3}(u^3 - u_c^3) + \left(\frac{B-1}{B}\right)\left(\frac{u^2 - u_c^2}{2}\right) + \left\{\frac{B^2 - B + 1}{B^2}\right\}(u - u_c) + \frac{B}{B+1} l_n \frac{1-u_a}{1-u_c} - \frac{1}{B^3} l_n \left(\frac{1+Bu_a}{1+Bu_c}\right) + v_c\right]$$

The variable v can be written as

From equation (5), the dimensionless variable v at anode obtained as :

$$v_a = -\frac{2}{Bu_a^2}\left[\frac{1}{3}(u_a^3 + u_c^3) + \left(\frac{B-1}{B}\right)\left(\frac{u_a^2 - u_c^2}{2}\right) + \frac{B^2 - B + 1}{B^2}(u_a - u_c) + \frac{B}{B+1} l_n \left(\frac{1-u_a}{1-u_c}\right) - \frac{1}{B^3 (B+1)} l_n \left(\frac{1+Bu_a}{1+Bu_c}\right) + v_c\right] \quad \dots (7)$$

here V_c is obtained from by putting $E\ (x) = E_c$ and $V\ (x) = V\ (x_c)$ from equation (5), the current density J and voltage V are calculated in terms of three dimensionless variables :

$$J = \left[\frac{e^3 N_0^3 \mu_0^2 E_c L}{\varepsilon}\right]^{1/2} \frac{1}{\sqrt{u_a \omega_a}} = 1.28 \times 10^6 \times \frac{1}{\sqrt{u_a w_a}}$$

and

$$V = \frac{e N_0 L^2}{\varepsilon} . \frac{v_a}{w_a^2} = 16 \times \frac{v_a}{w_a} \quad \dots (8)$$

where the variables w_a and v_a are given by equations (6) and (7) respectively.

The complete current-voltage characteristic of an insulator with thermal free carriers operating high field condition is plotted on a log-log scale in fig. 2 by using the equations (6) to (8). To obtain the dimensionless variables w_a and v_a from equations (6) and (7) respectively of the numerical tabulation is done for various values of v_a varying from 0 to 1. In drawing the figure it is assumed that the electric field is sufficiently high to highest the dimensionless variables u_c, ω_c and v_c in equation (6) and (7).

NUMERICAL TABULATION FOR J AND V

S.No.	U_a	w_a	$\frac{v_a}{\omega a^2}$	$\frac{1}{\sqrt{m_a w_a}}$	J	V
1.	0.05	0.0013	22.49	1.20×10^2	$1{,}54 \times 10^8$	$3{,}6 \times 10^2$
2.	0.1	0.004	5.0×10^1	13.75	6.4×10^7	2.2×10^2
3.	0.3	0.013	8.785	2×10^1	2.56×10^7	1.4×10^2
4.	0.3	0.025	6.906	1.2×10^1	1.5856×10^7	1.44×10^2
5.	0.4	0.395	5.7666	8.0×10^0	1.02×10^7	9.22×10^1
6.	0.5	0.059	4.928	6.00×10^0	7.68×10^6	7.9×10^1
7.	0.6	0.084	4.23	4.00×10^0	5.12×10^6	6.8×10^1
8.	0.7	0.118	3.595	3.00×10^0	3.84×10^6	5.7×10^1
9.	0.8	0.171	2.964	3.00×10^0	3.84×10^6	4.7×10^1
10.	0.9	0.27	2.26	2.00×10^0	2.56×10^6	3.6×10^1
11.	0.95	0.378	0.812	$2.0\,0 \times 10^0$	2.56×10^6	2.9×10^1
12.	0.99	0.65	1.217	1.250×10^0	1.60×10^6	2.0×10^1
13.	0.995	0.773	1.062	1.140×10^0	1.46×10^6	1.7×10^1
14.	0.999	1.062	0.816	9.70×10^{-1}	1.24×10^6	1.3×10^1
15.	0.9999	1.479	0.617	8.2×10^{-1}	1.05×10^6	9.8×10^0

The theoretical graph is plotted for cadmium sulphide (CdS) sample at room temperature by selecting, the physical parameters :

$N_0 = 10^{20}\, m^{-3}$, $\mu_0 = 2 \times 10^{-2}\, m^2/vs$, $L = 10^{-5}$ m, $e = 10^{-10}$ f/m

$E_c = 10^7$ v/m and $B = 10$

The complete current-voltage characteristic drawn in fig. 2 shows that the curve is having two clear current-voltage regime.

The current-voltage characteristics in both the regions can be obtained from the slope of the curve seperately. The current-voltage characteristic in the lower position of the curve follows $J \alpha V^{4/5}$. On the otherhand, the upper curve shows a 3/2-power law dependence of current density on voltage. There regimes correspond to modified ohmic and space-charge-limited regime.

In current injection at low fields, the current-voltage characteristic is always started by ohmic regime ($J \alpha V$) [2, 3].

The modified ohmic current-voltage characteristic in current injection at high field [4, 5] is $J \alpha V^{1/2}$. Now it is well established fact that in the space charge-limited current in injection at high fields [1, 6] follows 3/2-power law.

Caption of the figure

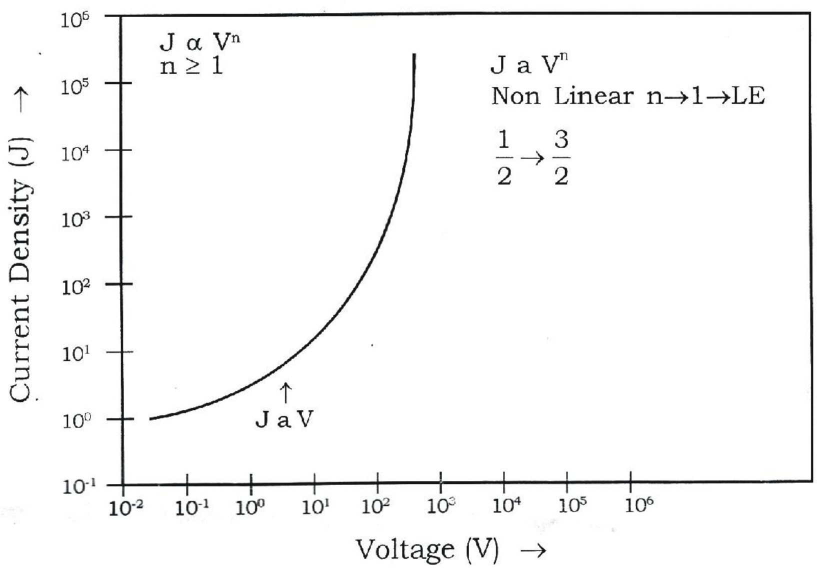


Fig. 2. SCL Current-voltage characteristic of an insulator with traps lying below the fermi level

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