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EFFECTS IF CDDM REGIME IN INSULATOR WITH TWO SETS OF DISTRIBUTED TRAPS

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Abstract:
THE EFFECTS OF carrier density dependent mobility regime of low mobility insulator operating under steady state single injection space-charge-limited current flow with two sets of traps distributed in energy are investigated for the situation in which the concentration of lower energy trap distribution is larger than or equal to the one of the upper energy trap distribution. The regional approximation method is applied to obtain the simplified solutions for the complete current-voltage characteristic at different injection level of currents. It is shown that the couprate current-voltage characteristic is started from the pure Ohm's law which finally merges into perfect trap-free space-charge-limited current flow for which the cube power law is valid. In the middle span of the characteristic, there are four current-voltage regimes which have complicated characteristic.
Keywords : CDDM, Traps Distribution, Ohmic Regime, Electronic Transport Properties, Trap-Free Regime

LIST IF SYMBOLS

$E = E(x)$	-	electric field at position x
E_c	-	lowest energy level of the conduction band
e	-	magnitude of electronic charge
F(x)	-	position dependent quasi-Fermi level
F_0	-	thermal-equilibrium Fermi level
h	-	proportionality constant
k	-	Boltzmann's constant
L	-	thickness of the insulator
N_c	-	density of states in the conduction band
N_t	-	total concentration of electron trapping states
N_1, N_2	-	concentration of two electron trapping states distributed over energy around levels E_1 and E_2, respectively.
n, n_0	-	concentration of free carriers and its thermal-equilibrium value, respectively
n_t, $n_{t,0}$	-	concentration of trapped carriers and its thermal-equilibrium value, respectively
T_1,T_2	-	characteristic temperature of the first and second distributions, respectively
ε	-	permittivity of the insulator
μ	-	free carrier mobility

Introduction

The steady state space – charge-limited single injection current flow in insulator with various trap configurations and carrier mobility regimes has been investigated from several decades [1-10]. The problem of current injection in to low mobility insulator with two sets of traps distributed over energy is solved with the help of regional approximation method [1-6, 8-10]. The problem is solved for the case of carrier density dependent mobility (CDDM) regime and the concentration of lower energy trap distribution is targer than or equal to one of the upper distribution under space-limited current flow.

GENERAL EQUATIONS

Let us consider an insulator containing significant density of two sets of traps distributed in energy in such a way that the concentration of lower energy trap distribution is larger or equal to the one of upper energy trap distribution. The general equations for the current flow and Poisson's equations are given by [1-5, 8,9]

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

$(\varepsilon/e)\, dE/\, dx = (n-n_0)+ (n_1-n_{t,0})$ (2)

Where J is the current density and x is the distance from the injecting contact. In low mobility insulator, the carrier mobility of the current carriers is directly proportional to the carrier density as [5,8]

$\mu = h\ n\ (x)$ (3)

The present analysis is solved in the presence of the proposed trap distribution around the energy levels E_1 and E_2 in which the case is considered for the concentration of lower trap distribution. N, grater than or equal to one of the concentration of upper trap distribution N_2. The distribution of the trapping states is characterized by the following trap distribution functions as [2,4,8,9]

$$H\ (E) = \frac{N_n}{k\ T_n} \frac{\exp\left[\frac{(E-E_n)}{k\ T_n}\right]}{\left\{exp\left[\frac{(E-E_n)}{kT_n}\right]+1\right\}^2} \quad (4)$$

Where, N_n is the total concentrations of traps, T_n is the characteristic temperature whose magnitude depends on the width of trap distribution. E_n is the energy around which the trap distribution occurs and E is the energy.

REGIONAL APPROXIMITION METHOD

The problem is solved with the help of regional approximation method [1-6, 8-10]. The low mobility insulator is divided in to following regions :

-region I ($O \le x \le x_1$) : perfect insulator region :

$[\ E_c\ F(x)\ E_c - k\ T\ In\ (N_c\ /\ N_t)\ ]$,

$n_t\ (x) = n\ (x) - n_0 \cong n\ (x) > n_t\ (x) > n_0$,

$J = ehn^2E,\ \frac{\epsilon}{e}\ -\frac{dE}{dx} = n$ (5)

$n(x_1) = n_1\ (x_1) = N_1 + N_2 = N_t$; (6)

- region lla ($x_1 \le x \le x_{ab}$) : trapped charge region a :

$[\ Ec - kT\ In\ (N_c/N_t) \ge F(x) \ge E_2]$,

$n_t\ (x) = N_1 + N_2 = N_t$,

$J = ehn^2\ E,\ \frac{\epsilon}{e}\ -\frac{dE}{dx} = N_t$ (7)

$n\ (x_{ab}) = N$; (8)

-region llb ($x_{ab} \le x \le x_{bc}$) : trapped charge region a :

$[E_2 \ge F(x) \ge E_1]$,

$n_t\ (x) = N_1 + N_2\ [n\ (x)\ /\ N]^{1/t}\ N_1$

$J = ehn^2E,\ \frac{\epsilon}{e}\ -\frac{dE}{dx} = N_1$ (9)

$n\ (x_{bc}) = M$; (10)

-region llc ($X_{bc} \le x \le x_2$) : trapped charge region C :

$[E_1 \ge F(x) \ge F^0 + 0.7\ kT]$,

$n_t\ (x) = N_1\ [\ n(x)/M]$

$J = ehn^2E,\ = N_1\ [n(x)/M]^{1/m}$ (11)

$n(x_2) = n_0$; (12)

- region III ($X_2 \le x \le L$) : Ohmic region :

$[F_0 + 0.7\ k\ T \ge F(x) \ge F_0]$,

$n_0 \approx n\ (x)$

$J = ehn_0^2\ E,\ \frac{\epsilon}{e}\ -\frac{dE}{dx} = 0$ (13)

Where $M = N_c \exp\left[\frac{(E_1 - E_c)}{kT}\right]$ (14)

$N = N_c \exp\left[\frac{(E_2 - E_c)}{kT}\right]$ (15)

$M = \frac{T_1}{T}$ and $t = \frac{T_2}{T}$ (16)

The continuity of electric field strength is valid at the four imaginary transition planes. The critical currents and critical voltages are defined by.

$X_2\ (J_{cr,1}) = L,\ x_{bc}\ (J_{cr,ab}) = L,\ x_{ab}\ (J_{cr,bc}) = 1,\ x_1\ (J_{cr,2}) = L$ (17)

$X^2\ (V_{cr,1}) = L,\ x_{bc}\ (V_{cr,ab}) = L,\ x_{ab}\ (V_{cr,bc}) = L,\ x_1\ (V_{cr,2}) = L$ (18)

Applying the previous procedures [1-4, 8,9], the four imaginary transition planes are obtained from the Eqs. (5) – (16) as :

$$X_1 = \frac{2\,\epsilon\,J}{3e^2hN_t^3}, \quad X_{ab} = \frac{\epsilon J}{e^2hN_tN^2}\left[1-\frac{N_2}{3\,N_t^2}\right] \quad (19)$$

$$X_{bc} = \frac{\epsilon J}{e^2hM^2N_1}\left\{1-\frac{M^2}{N^2}\left(1-\frac{N_1}{N_t}\right)\right\},\ X_2 = \frac{2m}{2m+1}\ \frac{\epsilon J}{e_2N_1n_0^2}\left[\frac{M}{n_0}\right] \quad (20)$$

The distribution of electric field strength in the different regions is derived from Eqs. (5) – (20) as

region 1 :

$$E\,(x) = \left[\frac{9J}{4\epsilon^2h}\right]^{1/3} x^{2/3} \quad (21)$$

region lla :

$$E\,(x) = \frac{eN_tx}{\epsilon} + \frac{J}{3ehN_t^2} \quad (22)$$

Region llb :

$$E\,(x) = \frac{eN_1.x}{\varepsilon} + \frac{J}{ehN^2}\left\{\left\{1-\frac{N_1}{N_t}\left(1-\frac{N^2}{3N_t^2}\right)\right\}\right. \quad (23)$$

Region llc :

$$E\,(X) = \left[\frac{(2m+1)}{2m} + \frac{eN_1}{\varepsilon}\left(\frac{J}{ehM^2}\right)^{1/2x}\right]^{[2m/(2m+1)]} X^{[2m/(2m+1)]} \quad (24)$$

Region lll :

$$E(x) = \frac{J}{ehn_0^2} = \text{constant} \quad (25)$$

COMPLETE CURRENT –VOLTAGE CHARACTERISTICS

The complete current voltage characteristic is divided into six current voltage regimes depending on the current injection levels. These regimes are well separated by critical currents and critical volgages defined by Eqs. (17) and (18) resp..the complete characteristic is described below.

4.1 True OHM's regime ($J << J_{cr,1}$)

The injection level is very low in the starting of the complete current-voltage characteristics. Therefore all the four imaginary transition planes are very close to the cathode and the region III is considered to occupy the entire insulator. The current-voltage characteristics of the low mobility insulator under true Ohm's regime is given from the Eq. (25) as:

$$J = eh\ n_0^2\ \frac{V}{L} \quad (26)$$

Which represents the pure Ohm's law for the single injection current flow under CDDM regime?

4.2 OHMIC REGIME ($J < J_{cr,1}$)

All the five regions are present in the considerable volume in ohmic regime. Therefore, the conduction mechanism is very complicated because they are affected by the ohmic, trapping and space charge mechanism. The current-voltage characteristics of the entire insulator are full of complexities. The Eqs. (19) – (25) give the current-voltage characteristics of low mobility insulator operating under ohmic regime as:

$$V = V_1 + V_{IIa} + V_{IIb} + V_{IIc} + V_{III} = a_1J^2 + b_1J \quad (27)$$

where

$$a_1 = -\frac{\varepsilon}{2e^3h^2N_1M^4(4m+1)}\left[1+4m(M/n_0)^{\frac{(4m+1)}{m}}\right] \quad (28)$$

$$b_1 = \frac{L}{ehn_0^2}$$

The quadratic dependence of the variation of applied voltage on the current density is observed from the Eq. (27) which is the modification of pure Ohm's law ($J \alpha V$).

4.3 FIRST TRAP – FILLED – LIMIT REGIME ($J_{cr,1} \le J \le J_{cr,ab}$)

This regime is started when the imaginary transition plane x_2 approaches to anode. Therefore the current-voltage characteristic of this regime is dominated by the trapping and space-charge effects. The current-voltage characteristic of the insulator operating under first trap-filled-limit regime is derived from Eqs.(19)-(24) as :

$$V = [\,V_1 + V_{IIa} + V_{IIc}\,] = a_2\,J^2 + b_2\,J^{[1/(2m+1)]} \quad (30)$$

Where

$$a_2 = -\frac{\varepsilon}{2e^3h^2M^4N_1}\left[\frac{M}{N}\right]^4\left[1-\frac{N_1}{N_t}\right] \quad (31)$$

$$b_2 = -\frac{\varepsilon}{2e^3h^2M^4N_1}\left[\frac{e^2hM^2N_1L}{\varepsilon}\right]^{\frac{(4m+1)}{(2m+1)}} \quad (32)$$

which represent a complex relationship for the current-voltage characteristic of this regime and the variable parameter m gives a significant complexities.

4.4 SECOND TRAP-FILLED-LIMIT REGIME ($J_{cr,ab} \le J \le J_{cr,bc}$)

The imaginary transition plane X_{bc} is outside the insulator and the regions l, lla and llb contribute the current flow. This regime is space charge trap controlled regime dominated by trapping effects. The expression for the current-voltage characteristic of this regime is evaluated from Eqs. (19) and (21) – (23) as

$$V = a_3J^2 + b_3 J + C_3 \quad (33)$$

where $a_3 = \frac{\varepsilon}{2e^3h^2N_tN^4} (N_1/N_t-1)$ (34)

$$b_3 = \frac{L}{ehN^2} \left[1- \frac{N_1}{N_t}\right], \quad c_3 = \frac{e}{2\varepsilon} N_1L_2 \quad (35)$$

4.5 THIRD TRAP-LIMIT REGIME ($J_{cr.bc} \le J \le J_{cr.2}$)

There are only two regions I and IIa in the mobility insulator operating under third trap-filled limit regime. The trapping states are gradually filled by the injected carriers. The space charge and trapping effects are concomitantly present to influence the conduction mechanism. The current-voltage characteristics for the third trap-filled-limit regime is evaluated from Eqs. (19) and (21) – (22) as:

$$V = V + V_{lla} = a_4J^2 + b_4J + c_4 \quad (36)$$

$$a_4 = \frac{2\varepsilon}{5\, e^3h^2N_t^5}, \quad b_4 = -\frac{L}{3ehN_t^2}, \quad c_4 = \frac{eN_t L^2}{2\varepsilon} \quad (37)$$

Which is a complicated expression for the dependence of current on applied voltages.

4.6 TRAP-FREE REGIME ($J_{cr,2} < J$)

All the trapping states are filled with electrons with the starting of the trap-free regime in the low mobility insulator. The ohmic conduction and strapping effects no longer influence the conduction mechanism of the insulator. It is the pure space-charge-limited current flow regime in low mobility insulator whose current–voltage characteristic is derived from the Eq. (21) as

$$J = \frac{500}{243} \frac{\varepsilon^2 h}{e} \frac{V^3}{L^5} \quad (38)$$

Which is the cube power low for the dependence of current on the voltage in solids.

Discussion and Conclusions

The present paper describe the theoretical investigation of the electronic transport properties of low mobility insulator with the concentration of lower trap distribution larger than or equal to one of the upper trap distribution. The complete current-voltage characteristic contents six current-voltage regimes. The trap free regime is mainly preferred for the practical applications[1-4]. The true ohm's regime which finally merges in to pure space charge trap-free cube low regime after passing through the ohmic and three trap–filled-limit regimes.

The present analysis shows that the distribution of trapping states gives sufficient structure to the complete current-voltage characteristic and it always started from the pure Ohm's law and the last current-voltage regime is that trap-free regime dominated by the injected space charge. The carrier density dependent mobility effects are significant in the last current – voltage regime where the cube power low for the dependence of current on applied voltage occurs.

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