CARRIER NUMBER FLUCTUATIONS IN INSULATING MATERIALS WITH TRAPS LYING ABOVE THE FERMI LEVEL

Pradeep Sharma
Asstt. Professor
Sidharth Mahavidhyalay
Ludhpura, Jaswantnagar, Etawah (India)

Abstract: The complete noise characteristic of carrier density fluctuations at low frequency in single injection current flow in insulator containing significant density of traps lying above the Fermi level is studied in the complete range of current-voltage characteristic. The noise characteristic is divided into five noise regimes. It is shown that the low frequency noise is very much dependent on the injection level of current.

Keywords: *Fluctuations, Fermi level, current-voltage*

1. INTRODUCTION

The single injection current flow in insulators is usually dominated by the presence of space charge and the trapping effects [l-5l- The nonlinear effects on current-voltage characteristic give variations in the low frequency noise characteristic. The carrier density fluctuations in an insulator give the low frequency noise source in injection devices. The presence of trapping states in the forbidden gap of insulator modulates the noise characteristic [2, 6, 7].

2. CARRIER INJECTION

Let us consider a single injection current flow in insulator with traps lying above the Fermi level. The insulator is divided into four regions [1-4] with the heir of three imaginary transition planes x_1, x_2 and x_3. which are shifted towards the anode with the increase of injection level of current. The general equations of the problem in regional approximation scheme are given by [1]

Region-I $\left(0 \le x \le x_1\right) : n_0 \ll n\left(x\right), N_t \gg n\left(x\right)$ (1)

$$J = e\,\mu n\left(x\right) E\left(x\right), \quad \frac{\varepsilon}{e}\frac{dE}{dx} = n\left(x\right)$$

Region-II $\left(x_1 \le x \le x_2\right) : n_0 \ll n\left(x\right), N_t$ (2)

$$J = e\mu n(x)E(x), \ \frac{\square}{e}\frac{dE}{dx} = N_t,$$

Region-III $(x_2 \square x \square x_3)$: $n_0 \square n(x) \square N_t$ (3)

$$J = e\mu n(x)E(x), \ \frac{\square}{e}\frac{dE}{dx} = \frac{n}{e}$$

$$\square = \frac{n(x)}{nt(x)} \square 1 \qquad (4)$$

Region-IV $(x_3 \square x \square L)$: $n(x) \square n_0 \square n_0$ (5)

$$J = e\mu n_0 E, \ \frac{\square}{e}\frac{dE}{dx} = 0,$$

where J is the current density, μthe mobility of current carriers, n(x) the concentration of carriers at distance x_0, n the thermally generated free carriers, N, the density of total traps, E(x) the electric field strength at position x, $\square$ the permittivity of the insulator, $\square$ the ratio of free to total carrier density and I- the device length.

The imaginary transition planes connecting the different regions are defined as [1]

$$n(x_1) = N_t, \ n(x_2) = \frac{N}{g} = \frac{N_c}{g}\exp\left(\frac{\square E_t \square E_c}{kT}\right) n(x_3) = n_0 \qquad (6)$$

where,

$$x_1 = \frac{\square J}{2B^2e^2n_0^2\mu} = \frac{\square J}{2e^2 N_t^2 \mu} \qquad (7)$$

$$x_2 = \frac{\square J}{2n_0^2 B C \mu} = \frac{\square J}{\square e^2 n_0^2 \mu B^2} \qquad (8)$$

$$x_3 = \frac{\square \square J}{2e^2 n_0^2 \mu} \tag{9}$$

$$B = \frac{N_t}{n_0}, C = \square B = \frac{\square N_t}{n_0} \tag{10}$$

In the above equations (6) - (10), g is the degeneracy factor of trap states for electrons, N_c the effective density of states in the conduction band, E_t, the energy level of trapping centres, E_c the energy level at conductionband edge, k Boltzmann constant and T the lattice temperature. The detailed theory of single injection current flow in insulator with traps lying above the Fermi level follows from elsewhere [1-5].

3. CARRIER DENSITY FLUCTUATIONS

The carrier density fluctuations are started from the pure ohm's law regime which finally merges into space charge regime after passing through the trap controlled regimes [1-7]. Adopting usual procedure [2], the equations (1)-(10) are used to derive the noise resistance expressions in the four different regions as given below :-

Region-I

$$R_I = \frac{\square^2 J^5 S}{288 B^8 e^7 \mu^4 n_0^8 kT}, \tag{11}$$

Region-II

$$R_{II} = \frac{\square^2 J^5 S \left(64 B^6 + C^6 \square 16 B^3 C^3\right)}{1152 B^8 c^6 e^7 n_0^8 \mu^4 kT}, \tag{12}$$

Region-III

$$R_{III} = \frac{\square^2 J^5 S \left(C^8 \square 168 C^4\right)}{288 e^7 n_0^8 \mu^4 B^2 C^6 kT}, \tag{13}$$

Region-IV

$$R_{IV} = \frac{J^3 S}{2 e^3 \mu^2 n_0^4 kT} \square L^{\square} \square \frac{C \square J}{2e^2 n_0^2 \mu B} \square^2, \tag{14}$$

where S is the cross - sectional area.The total noise resistance of the sample is given by

$$R_n = R_I + R_{II} + R_{III} + R_{IV} \tag{15}$$

$$= \frac{J^3 S}{2e^3 \mu^2 n_0^4 kT}\left[\frac{\square^2 J^2}{144 B^8 e^4 \mu^2 n_0^4} + \frac{\square^2 J^2 \left(64 B^6 + C^6 - 16B^3C^3\right)}{576 B^8 C^6 e^4 n_0^4 \mu^2}\right.$$

$$\left. + \frac{\square J^2 \left(C^8 - 8C^4 + 16\right)}{144 e^4 \mu^2 n_0^4 B^2 C^6} + \left(L - \frac{C - J}{2e^2 n_0^2 \mu B}\right)^2\right]$$

4. COMPLETE NOISE CHARACTERISTIC

The complete low frequency noise characteristic estimated in the complete range of current-voltage characteristic as given in order [1, 2, 4] :

(a) **True Ohm's regime:** At very low injection level the region IV is only present in insulator to contribute the low frequency noise. The imaginary transition plane x_3, is close to the cathode because the regions I-III are very small due to low injection level of current. The noise resistance is evaluated as [2,7].

$$R_t = \frac{J^3 L^2 S}{2e^3 \mu^2 n_0^4 kT} \tag{16}$$

(b) **Ohmic regime:** The low frequency noise characteristic in the ohmic regime is considered for the injection level cf current at which all the regions are present in the insulator. The noise resistance for this regime is derive! from equation (15) as

$$R_0 = \frac{\square^2 J^5 S}{1152\, e^7 \mu^4 n_0^8 B^8 C^6 kT}\left[128B^6 + 148B^6C^8 - 32B^6C^4\right.$$

$$\left. - 16B^3C^3 \_ 5C^6\right] + \frac{J^3 S}{2e^3 \mu^2 n_0^4 kT}\left(L - \frac{C - J}{e^2 n_0^2 \mu B^2}\right)^2 \tag{17}$$

which is a complex equation depending on the current -density and various physical parameters of the device.

(c) **Shallow trapu square law regime :** It is the regime in which the three regions I, II and III contribute to the noise characteristic. The noise resistance of this regime is derived with the help of equations (7), (8) and (ll)-(13) as

$$R_{ST} = □ \frac{□^2 J^5 S}{18 B^4 e^7 n_0^8 \mu^4 kT} □ \left[\frac{1}{16 B^4} + \frac{64 B^6 + C^6 □ 16 B^3 C^3}{64 B^4 C^6} + \frac{1}{e^2 C^4} + \right.$$

$$\left. - \frac{J^3 S L^2}{9 □^2 e^3 n_0^4 B^2 C^2 \mu^2 kT} + \frac{J L^4 e S}{18 □^2 □ kT} □ \right] \qquad (18)$$

which shows that the different noise regimes are obtained for different set of trapping states characterized by the parameters B, C and □.

(d) **Trap-filled-limit regime :** The regions I and II contribute to the low frequency noise characteristic. It is the noise regime in which all the trapping states are gradually filled with current carriers. The noise resistance of the diode in this regime is derived frcrr. equations (7), (8), (11) and (12) as

$$R_{TFL} = \frac{5 □^2 J^5 S}{1152 B^8 e^7 \mu^4 n_0^8 kT} □ \frac{J^3 L^2 S}{72 B^8 □ e n_0^2 \mu kT} + \frac{e^5 \mu^2 B^4 n_0^4 S L^6}{18 □^4 J kT}, \qquad (19)$$

where the small change in the current density gives a largi change in noise resistance.

(e) **Trap free square law regime:** It is the pure space charge regime in which the low frequency noise is contributed by only region. .All the trapping states are filled with electrons. The noise resistance for trap free regime: is derived from equations (7) and (11) as

$$R_S = \frac{e J L^4 S}{18 □^2 kT} \qquad (20)$$

where the noise resistance is linearly dependent on tr.e current density and independent of trapping states.

5. DISCUSSION AND CONCLUSION

In the present analysis, the analytical expressions for complete low frequency noise characteristic have beer-evaluated for the five current-voltage regimes of single injection solid state diode with traps lying above the Fermi level corresponding to different injection level of currents. The value of noise resistance at low injection level is a constant quantity in true ohm's regime. Because, the concentration of injected current carriers is negligibly small at very low injection level. Therefore, the contribution to the low frequency noise by the carrier density fluctuations is obtained due to the fluctuations of free carriers present before current injection in insulator.

All the four regimes are present in the insulator in ohmic regime in which the fluctuations are occurring in all the parts of the insulator. The injection level increases to-a level at which the current flow is admixture of ohmic trap controlled and space-charge-limited current conduction. Therefore, the noise characteristic in ohmic regime is **very** complicated due to the presence of different noise sources.

The injection level further increases in the shallow trap square law regime in which the injected current carriers increases much more than the true Ohm's and Ohmic regimes. Therefore, the trapping effect increases to change the low frequency noise characteristic.

The trapping effect is dominated on the low frequency noise characteristic in the trap-filled-limit regime. The carrier density fluctuations are destructively dominated by trapping concentration present in the insulator. Finally, the low frequency noise of the diode at high injection level' of current is—controlled by the space charge in the perfect trap free regime and the trapping and ohmic effects are negligibly small in this last regime. It may be concluded that the complete low frequency noise characteristic has different noise regimes according to the injection level cf current and the correct interpretation of noise characteristic is obtained by considering all the physical parameters present in the insulating materials.

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