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ON SOME CHARACTERISTICS OF A SEMICONDUCTOR SURFACE

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Variations of field, mobile-carrier concentration under different circumstances have been investigated for a semiconductor surface. An approximate analytic solution of Poisson's equation giving the relationship between normalized position and normalized electrostatic potential has been used.

I. INTRODUCTION

There are complete analytical solutions of the Poisson-Boltzmann equation for special cases, complete numerical solutions for general cases, and approximate analytical solutions for intermediate cases in some semiconductor device modelling works for the purpose of scaling [1—7].

The solutions obtained have appropriate uses. De and Ghosh deduced an alternative approximate solution which has been numerically analysed to study the nature of variation of the parameters involved [8,9].

In this presentation, the variations of field, mobile carrier concentration against normalized position throughout the semiconductor have been studied by means of the same solution for the integral of the Poisson equation. The solution, in fact, gives the relationship between normalized position and normalized electrostatic potential under certain approximation [8].

II. MATHEMATICAL DERIVATION

The connection of the potential difference W between the remote region and that at the arbitrary point in the semiconductor with the distance x measured from the surface can be expressed through the Debye length by the integration of the Poisson-Boltzmann equation [1]. The expression for the normalized position is

$$x/L_D = 2^{-1/2}\int_W^{W_s}[\exp U_B+\exp(-U_B)]^{1/2}[\exp U_B\{\exp(-W')+W'-1\}+ \\ +\exp(-U_B)\{\exp(W')-W'-1\}]^{-1/2}\mathrm{d}W'. \tag{1}$$

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The transformation relations existing among various potentials yield

$$U_B - U_S \equiv W_S \qquad \text{and} \qquad U_B - U \equiv W,$$

where U_B = normalized bulk potential, L_D = Debye length, W_S = total potential difference, W = potential difference between the remote region and that at the arbitrary point, U = normalized potential at the arbitrary point, U_S = normalized potential at the surface. It reveals that $U > U_s$. Thus $W_S > W$. For higher values of W_S, there remains scope for securing larger values of W, where e^{-W} may be ignored. Thus the integration of eq. (1) can be performed analytically everywhere except at $W = 1$, $W_S = 1$; here the result would introduce an error. Thus, for $W_S > W$, as $|U_B|$ is large, the eq. (1) can be written as

$$x/L_D = 2^{-1/2}\int_W^{W_S} [(W'-1)) + \exp(-2U_B)\{\exp W' - W' - 1\}]^{-1/2}\mathrm{d}W'. \quad (2)$$

Thus

$$x/L_D \doteq 2^{-3/2}\int_W^{W_S} \{2(W'-1-\exp(-2U_B)(\exp W' - W' - 1)\}(W'-1)^{-3/2}\mathrm{d}W'.$$

The expression for the normalized electric field in this case has been found to be

$$\left|\frac{\mathrm{d}W}{\mathrm{d}(x/L_D)}\right| \approx 2^{3/2}(W-1)^{3/2}[2(W-1)-\exp(-2U_B)(\exp W - W - 1)]^{-1} \quad (3)$$

The normalized carrier number density can be expressed as [2]

$$\left|\frac{\Delta N_p}{\Delta N_{p0}}\right| = 2^{-1/2}\int_W^{W_S} \{\exp U_B + \exp(-U_B)\}^{1/2}(\exp W' - 1)\times$$
$$\times\, [\exp U_B\{\exp(-W') + W' - 1\} + \exp(-U_B)\{\exp W' - W' - 1\}]^{-1/2}\mathrm{d}W'. \quad (4)$$

When $W_S > W$, (4) may be written as

$$\frac{\Delta M_p}{\Delta N_{p0}} \approx 2^{-1/2}\int_W^{W_S} \{\exp W' - 1\}[(W'-1) + \exp(-2U_B)\times$$
$$\times\,\{\exp W' - W' - 1\}]^{-1/2}\mathrm{d}W' = 2^{-1/2}A - x/L_D, \quad (5)$$

where A means the integral,

$$\int_W^{W_S} \exp W'[(W'-1) + \exp(-2U_B)\{\exp W' - W' - 1\}]^{-1/2}\mathrm{d}W'.$$

The normalized position x/L_D then can be written as

$$x/L_D = 2^{-1/2}\int_W^{W_S} (W'-1)^{-1/2}\mathrm{d}W' -$$
$$-\, 2^{-3/2}\int_W^{W_S} \exp(-2U_B)\{\exp W' - W' - 1\}(W'-1)^{-3/2}\mathrm{d}W'.$$

Expressing U_B in terms of U,

$$x/L_D = 2^{1/2}\{(W_S-1)^{1/2} - (W-1)^{1/2}\} -$$
$$-\, 2^{-3/2}\int_W^{W_S} \exp(-W'-2U)(W'-1)^{-3/2}\mathrm{d}W' +$$
$$+\, 2^{-3/2}\int_W^{W_S} \exp(-2W'-2U)(W'-1)^{-3/2}\mathrm{d}W' + \quad (6)$$
$$+\, 2^{-3/2}\int_W^{W_S} \exp(-2W'-2U)W'(W'-1)^{-3/2}\mathrm{d}W'.$$

Following the method of the incomplete factorial function, the integrals (6) can be calculated explicity and the result is

$$x/L_D = 2^{1/2}\{(W_S-1)^{1/2} - (W-1)^{1/2}\} +$$
$$+\, 2^{-1/2}[\exp(-2U-1)[[(W_S-1)^{-1/2}\{W_S - (W_S-1)^2/6 + (W_S-1)^3/30 -$$
$$-\, (W_S-1)^4/168 + \cdots\} - (W-1)^{-1/2}\{W - (W-1)^2/6 + (W-1)^3/30 -$$
$$-\, (W-1)^4/168 + \cdots\}]\{1 - 2^{3/2}\exp(-1)\} + 2^{-1/2}\exp(-1)[(W_S-1)^{1/2}$$
$$\{1 - (W_S-1)/3 + (W_S-1)^2/10 - (W_S-1)^3/42 + (W_S-1)^4/216 - \cdots\} -$$
$$-\, (W-1)^{1/2}\{1 - (W-1)/3 + (W-1)^2/10 -$$
$$-\, (W-1)^3/42 + (W-1)^4/216 - \cdots\}]]].$$

The first integral on the right-hand side of (5) is determined in the same way. Thus the expression for $|\Delta N_p/\Delta N_{p0}|$ is obtained as

$$\left|\frac{\Delta N_p}{\Delta N_{p0}}\right| = 2^{1/2}\{(W_S-1)^{1/2} - (W-1)^{1/2}\} - 2^{-1/2}[\exp(-2U-1)\times$$
$$\times\, [[(W_S-1)^{1/2}\{W_S - (W_S-1)^2/6 + (W_S-1)^3/30 - (W_S-1)^4/168 + \cdots\} -$$
$$-\, (W-1)^{-1/2}\{W - (W-1)^2/6 + (W-1)^3/30 - (W-1)^4/168 + \cdots\}]\times$$
$$\{3 - 2^{3/2}\exp(-1)\} + \{2^{-1/2}\exp(-1) - 1\}[(W_S-1)^{1/2}\{1 - (W_S-1)/3 +$$
$$+\, (W_S-1)^2/10 - (W_S-1)^3/42 + (W_S-1)^4/216 - \cdots\} - (W-1)^{1/2}\times$$

$$\times \{1-(W-1)/3+(W-1)^2/10-(W-1)^3/42+(W-1)^4/216-\cdots\}]]]+$$
$$+2^{1/2}\exp(1)[(W_S-1)^{1/2}\{1+(W_S-1)/3+(W_S-1)^2/10+(W_S-1)^3/42+$$
$$+(W_S-1)^4/216+\cdots\}-(W-1)^{1/2}\{1+(W-1)/3+(W-1)^2/10+$$
$$+(W-1)^3/42+(W-1)^4/216+\cdots\}]+2^{-1/2}\exp(-2U)[(W_S-1)^{-1/2}-$$
$$-(W-1)^{-1/2}]. \quad (7)$$

III. NUMERICAL ANALYSIS AND DISCUSSION

The expressions (3) and (7) are used in the calculation of field and mobile carrier concentrations and their corresponding variations for different values of W_S and $|U_B|$.

Plots of normalized electric field versus normalized position are shown in Fig. 1 for $W_S = 10, |U_B| = 10$ and $W_S = 20, |U_B| = 20$. In Fig. 2, the variation of normalized electric field with normalized position is plotted for $W_S = 1$ and $|U_B| = 1$. Here the variation of x/L_D is chosen between a higher negative value and a lower positive value. The expression for the normalized electric field (3) in this situation seems to be more useful under the depletion condition. From the numerical results, plots of $\log|\Delta N_p/\Delta N_{po}|$ against x/L_D are shown in Fig. 3 for different sets of W_S and $|U_B|$. The nature of variation of the normalized field against the logarithmic value of the mobile-carrier concentration for two sets of values of W_S and $|U_B|$ is shown in Fig. 4. It shows that the change in the normalized field is analogical to the change of the doping concentration.

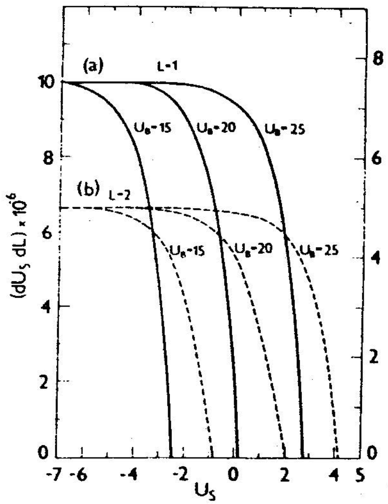

Fig. 1. Plots of normalized electric field versus normalized position for two sets of values of $|U_B|$ and W_S.

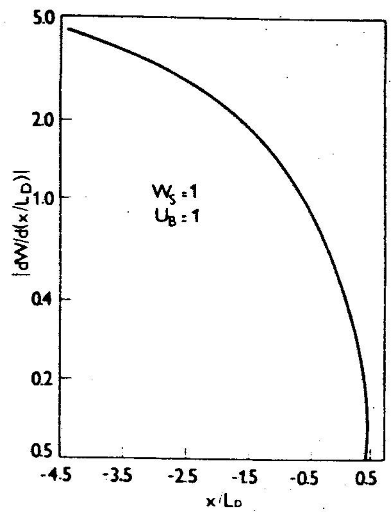

Fig. 2. Variation of the normalized field with a higher negative value and a lower positive value of x/L_D for $W_S = 1$ and $|U_B| = 1$.

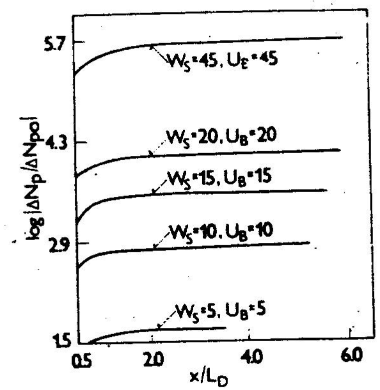

Fig. 3. Plots of $\log|\Delta N_p/\Delta N_{po}|$ vs x/L_D for different sets of W_S and $|U_B|$.

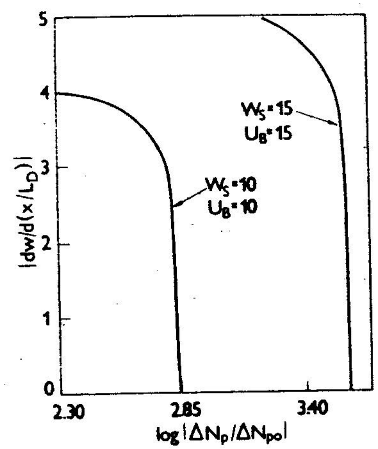

Fig. 4. Variation of $|dW/d(x/L_D)|$ against $\log|\Delta N_p/\Delta N_{po}|$ for $W_S = 10, |U_B| = 10$ and $W_S = 15, |U_B| = 15$.

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О НЕКОТОРЫХ ХАРАКТЕРИСТИКАХ ПОВЕРХНОСТИ ПОЛУПРОВОДНИКОВ

С применением приблизительных аналитический выражений, выражения Поассона изучены при различных обстоятельствах поля и плотности подвижных носителей на поверхности полупроводников. Получено выражение отношения между приведенными позицией и електростатистическим потенциалом.