THE UNIVERSITY OF MANITOBA

Avalanche Breakdown and Microplasma Noise in Space-Charge-Limited Anthracene Diode

by

Donald K.M. Yau

A Thesis

Submitted to the Faculty of Graduate Studies

in Partial Fulfillment of the Requirements for the Degree

of Master of Science

DEPARTMENT OF ELECTRICAL ENGINEERING

Winnipeg, Manitoba

October, 1972

ABSTRACT

The current-voltage (I-V) characteristics of a space-charge-limited anthracene diode near the breakdown region has been studied. A physical model for microplasma noise in the space-charge-limited solid-state diode has been developed. The temperature dependence of breakdown voltage has been measured. The results show that the postbreakdown current decreases as the temperature is increased and the breakdown voltage increases with increase of temperature. The onset of microplasma breakdown is used to measure the temperature coefficient of the breakdown voltage. This measurement has been justified by comparing the results obtained from silicon p-n junctions and the existing data published in the literature. The temperature dependence of the threshold voltage is in reasonable agreement with the theory.

Low frequency noise measurement is performed on the device. Low frequency excess noise is found to be caused by the bulk effect. The results show that the low frequency noise has a f^{-1} dependence.

The effect of pulsed radiation on the I-V characteristic has also been investigated. We found that although the steady-state photoresistivity of an anthracene space-limited diode is very large, it is a poor light detection device for pulsed type of irradiation.

TABLE OF CONTENTS

LIST OF FIGURES

(LIST OF FIGURES - continued)

ACKNOWLEDGEMENTS

The author would like to express his thanks to Dr. S.T. Hsu for his invaluable advice and continuous encouragement. He is also indebted to all the technical staff of Electrical Engineering of the University of Manitoba for their laboratory assistance.

CHAPTER I

INTRODUCTION

Anthracene $C_{14}H_{10}$ has served as a model system for attempts to understand molecular crystals. The avalanche breakdown phenomena in inorganic semiconductors have been studied very extensively in the past twenty years. This breakdown can be either radiative or nonradiative. Avalanche breakdown with associated light emission on a single-hole-injection space-charge-limited anthracene diode has been observed by Hsu [22] . Large amplitude noise arising from current instability at the onset of breakdown was noted by the author and was found to be microplasma noise. McKay [33] showed that in silicon, during the microplasma instability, practically all the current is carried by a series of current pulses of constant amplitude but of random lengths and occurrence. At the very onset of breakdown these pulses are very short so that total current is small; as the voltage is increased above that at which pulses first appear, the pulses are observed to increase slightly in amplitude, to have much longer average duration and to be of more frequent occurrence, until a voltage is reached at which the current remains flowing continuously. At higher voltages other similar sets of pulses may occur. These observations by McKay suggested localized breakdown regions (microplasmas), each of which requires a slightly different breakdown sustaining voltage and each having a range of voltages in which the localized breakdown is bistable. This interpretation was confirmed by Chynoweth and Pearson [7] who observed recombination radiation from individual microplasmas in shallow diffused junctions; they were able to correlate the onset of each set of light spot in the junction with the onset of each set of current pulses observed.

Ideal p-n junction diodes exhibit V-I characteristics with a sharply defined breakdown point under reverse bias. In general, practical solid state devices do not have a sharply defined breakdown point. There is always an uncertainty in the breakdown voltage that is due to soft junction, and so there is always a bend or a knee around the breakdown point indicating the transition region. In this thesis, the author attempts to take care of the breakdown voltage by noting the onset of microplasmas. Experimental work was carried out by using the above assumption to determine the temperature coefficient which was then compared with the established data. The end result has indicated a favourable justification of this assumption. Low frequency noise and photo effects on anthracene are also investigated.

Chapter II presents a brief review of the previous theoretical analysis on the avalanche breakdown mechanism in semiconductor devices and some of the experimental results obtained by several investigators. In Chapter III, an analysis of microplasma phenomenon is presented and a model of 'turn-on' and 'turn-off' of microplasma in anthracene is proposed. The experimental techniques are given in Chapter IV. Chapter V presents experimental data. The analysis of the experimental data is discussed in Chapter VI. Finally, conclusions are drawn from the experimental observations as presented in Chapter VII.

CHAPTER II

AVALANCHE BREAKDOWN IN SEMICONDUCTORS

2.1 REVIEW ON AVALANCHE BREAKDOWN AND BASIC CONCEPTS

In order to have a thorough understanding and to fully utilize the characteristics of avalanche breakdown diodes, it is necessary to gain some understanding of the basic theories that govern the breakdown mechanism. Physically, junction breakdown in excess of eight volts is the process of secondary ionization or avalanche breakdown. The basic mechanism of avalanche breakdown is similar to the Townsend discharge in gas-filled tubes. It relies on the ionization of carriers and on impact collision of atoms by other carriers which have been imparted sufficient energy by an electric field. Suppose a free electron or hole exists within the depletion layer of the junction and an electric field is applied. An increased velocity in the direction of the electric field and hence an increase in the carrier's kinetic energy, is given to the free carrier. As a result of the lattice structure in the crystal, the free carrier may collide with an atom within the junction and, because of its high energy level, may knock off carriers from the atom. If sufficient energy still remains in the original colliding carrier, additional collisions will occur and thus other carriers will be freed from additional atoms. The newly released carriers now gain sufficient energy from the field to initiate new collisions. Although some breakdown in solid crystals relying only on the ionization of electrons have been observed [58], generally it is necessary that both electrons and holes be ionized in order to provide the positive feedback or regenerative mechanism [33].

McKay [33] , [34] has shown that even before the junction breaks down completely, a given carrier injected into the depletion layer of the reverse-biased junction results in a current flow greater than that of injected carrier. Thus a multiplication of carrier has occurred. When the applied voltage across the junction approaches the breakdown voltage, V_B, the multiplication factor increases very rapidly and, in fact, the point of breakdown is defined as the point at which the multiplication factor, M, becomes infinite.

In addition to the actual breakdown, the multiplication effect produces additional results, such as, any degree of reverse leakage currents will be multiplied in the region of prebreakdown, thus producing a certain amount of softness in the characteristic curve, especially at elevated temperatures.

McKay [33] expressed the value of M mathematically as;

$$M = \frac{1}{1 - \int_o^w \alpha_i \, dx} \qquad \ldots(1)$$

where α_i is the rate of ionization and w is the effective width of the actual junction.

Miller [35] has given a relation evolved from observation for the multiplication factor in step junctions:

$$M = \frac{1}{1 - (V_R/V_B)^n} \qquad \ldots(2)$$

where V_R is the applied voltage, V_B is the body breakdown voltage due to avalanche, and n is the number that depends on the resistivity and the resistivity type of the high-resistivity side of the junction.

The rate of ionization α_i is defined as the number of hole-electron pairs produced by a given carrier per cm. of path travelled in the direction of the field. The ionization rate is slightly different for holes and electrons and is also a function of the semiconductor material and the applied field. In equation (1), McKay assumed that the ionization rates for holes and electrons were equal.

The value of α_i and its dependence on the strength of the applied electric field were investigated by Chynoweth [8], who found from experiment that the ionization rate obeyed a function in the empirical form of

$$\alpha_i(E) = a\, e^{-(b/E(r)^m)} \qquad \ldots(3)$$

where E is the value of the electric field and a, b, and m are empirical constants. Maserjian [29] has shown that for an abrupt junction the values of the constant a for silicon and germanium are 9×10^5 and 1.2×10^7, respectively. The values of b for silicon and germanium are 1.8×10^6 and 1.4×10^6

respectively.

Mathematically we may define the point of breakdown as being the condition

$$\int_0^W \alpha_i \, dx = 1 \qquad \ldots(4)$$

One significant parameter in any theory of breakdown is the temperature coefficient. McKay [33] observed that the multiplication curve of a junction has the same temperature coefficient as the breakdown voltage. The temperature dependence of the avalanche breakdown voltage for linear-gradient junctions can be described approximately by

$$V_B(T) = V_B(T_o)[1 + \beta'(T - T_o)] \qquad \ldots(5)$$

where $V_B(T_o)$ = breakdown voltage at room temperature T_o

$V_B(T)$ = breakdown voltage at the temperature T

β' = temperature coefficient.

McKay [33] established that all junctions showed positive temperature coefficients for the multiplication characteristics. The coefficient was defined by $(1/V_a)(dV_a/dT)$ for a given value of the multiplication. The extent of the variation of the junction width with temperature is usually negligible. From (5), the field dependence on temperature was deduced to be

$$E_B(T) = E_B(T_o)[1 + \beta\ (T-T_o)] \qquad \ldots(6)$$

where $E_B(T)$ = maximum field at breakdown at temperature T

$E_B(T_o)$ = breakdown field at temperature T_o

$\beta = 0.5 \ \beta'$.

To derive from this the temperature coefficient of α_i (7), we let $M \to \infty$. McKay showed that

$$\frac{1}{\alpha_i}\left[\frac{\partial \alpha_i}{\partial T}\right] = -\beta \left\{ 1 + \frac{E_B}{\alpha_i}\left[\frac{\partial \alpha_i}{\partial E_B}\right]_T \right\} \qquad \ldots(7)$$

where all quantities are evaluated at $T = T_o$. $\frac{\partial \alpha_i}{\partial E_B}$ can be obtained by differentiating the curve plotted as ionization rate α_i verses electric field E, so that if β is known, $\frac{\partial \alpha_i}{\partial T}$ can be determined or vice-versa. It should be noted that equation (7) is applicable only to step junctions and is subject to the assumption of equation (1).

In general, the definition of breakdown voltage V_B is the value of reverse voltage that causes the diode to enter the breakdown or high reverse current region. If all the diodes has a characteristic in which the transition from reverse leakage to breakdown was as sharply defined as an ideal diode, it would be easy to define V_B as the voltage at the exact point of transition. Unfortunately, this is not the case in general. In many cases the breakdown transition has a certain softness in the knee region. The end result is that a meaningful specification of the breakdown voltage V_B must include a specification of the reverse current I_R at which it is to be measured. The temperature at which the test is performed and the thermal resistance between the device leads and the ambient can also influence the value of V_B. There is always an uncertainty in the breakdown voltage V_B due to soft junction.

Avalanche breakdown was observed in homogeneous materials as well as in p-n junction. Anthracene is a molecular semiconductor and exhibits avalanche breakdown under high voltage. The sample used was a conventional single injection space-charge-limited diode. The fact that the postbreakdown current decreased as the temperature was increased was justified that breakdown was an avalanche. The breakdown voltage varied as temperature was varied. If the current-voltage curve was used to specify the breakdown value, the expected breakdown point would be such that the current increased very rapidly with voltage. However, in space-charge-limited diodes, this breakdown voltage is not well-defined; thus the conventional I-V curve would not give a clear picture at breakdown.

2.2 THEORETICAL CALCULATION OF AVALANCHE BREAKDOWN

The mathematical calculation of breakdown mechanism in ordinary p-n junctions is analyzed as follows:

Let α_n = electron ionization rate, i.e. the number of electron-hole pairs generated by one electron travelled a unit distance;

α_p = hole ionization coefficient.

In general, the ionization rates for electrons and holes are different. Therefore α_n is not equal to α_p. It is assumed that the depletion width of a junction under study is as that shown in Figure 1.1, where I_{po} is the incident current at left-hand side of the depletion region. Through the process of secondary ionization the hole current will increase with distance through the junction and reach a value MI_{po} at the right-hand side of the junction. Since at steady state the total current is constant,

$$I = I_p + I_n \qquad \ldots(1)$$

There are I_n/q electrons per second and I_p/q holes per second crossing the differential section dx. The hole current $I_p(x)$ changes by an amount equal to the number of electron-holespairs generated per second in the range dx (times electronic charge) or the increment of hole current is

$$dI_p = \alpha_p I_p dx + \alpha_n I_n dx$$

i.e.

$$\frac{dI_p}{dx} = \alpha_n I + (\alpha_p - \alpha_n) I_p \qquad \ldots(2)$$

Equation (2) has a solution subject to a boundary condition.

$$I = I_p(W) = M_p I_{po} \qquad \ldots(3)$$

It is assumed that at x = W the electron current is negligibly small compared to the hole current. Similarly,

$$I = M_n I_{no} = I_n(o) \qquad \ldots(4)$$

This approximation can be made only when M_n, $M_p >> 1$.

$$I_p(x) = I\left\{\frac{1}{M_p} + \int_o^x \alpha_n \exp\left[- \int_o^x (\alpha_p - \alpha_n)\, dx' dx\right]\right\} \cdot \exp\left[\int_o^x (\alpha_p - \alpha_n)\, dx\right] \qquad \ldots(5)$$

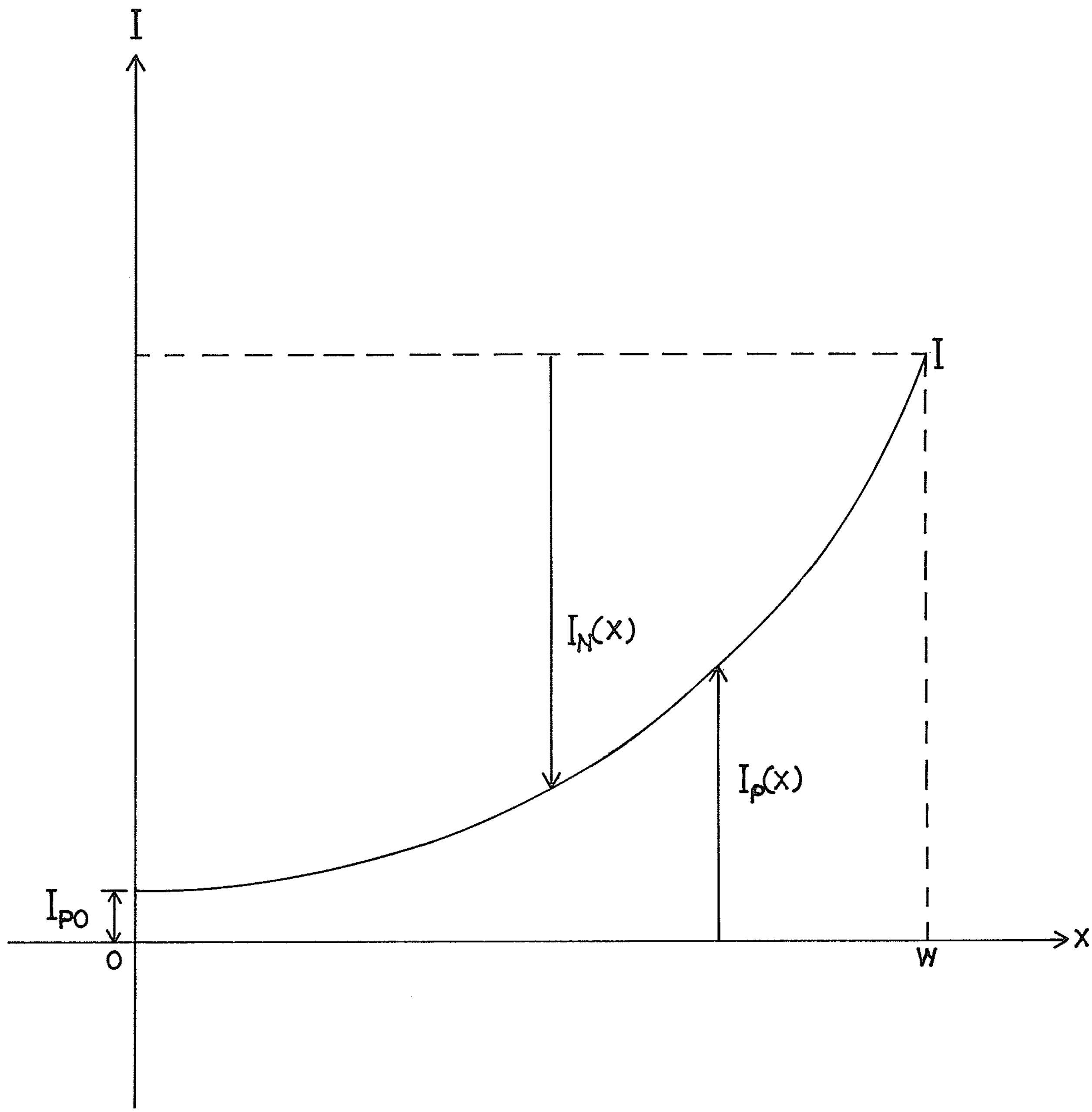

FIG. 2.1. CURRENT DISTRIBUTION IN DEPLETION REGION.

where M_p is the multiplication factor for holes and is defined as

$$M_p = \frac{I_p(W)}{I_p(o)} = \frac{I}{I_p(o)} \qquad \ldots(6)$$

since $I_p(W)$ and the total current I are identical. The multiplication factor is obtained from (5) and (6). From (5) we can write

$$I_p(x) = \frac{I\{\frac{1}{M_p} + \int_o^x \alpha_n \exp\left[-\int_o^x (\alpha_p-\alpha_n)\, dx'\right]dx\}}{\{\exp\left[-\int_o^x (\alpha_p-\alpha_n)\, dx'\right]\}}$$

$$I_p(x)\ \{\exp\left[-\int_o^x (\alpha_p-\alpha_n)\, dx'\right]\} = I\{\frac{1}{M_p} + \int_o^x \alpha_n \exp\left[-\int_o^x (\alpha_p-\alpha_n) dx'\right]dx\}$$

as $\quad I_p(W) = I$, at $x = W$, we have

$$\exp\ \{-\int_o^W (\alpha_p-\alpha_n)\, dx'\right] = \frac{1}{M_p} + \int_o^W \alpha_n \exp\ \{-\int_o^x (\alpha_p-\alpha_n)\, dx'\}dx$$

$$\therefore\ \frac{1}{M_p} = \exp\left[-\int_o^W (\alpha_p-\alpha_n)\, dx\right] - \int_o^W \alpha_n \exp\ \{-\int_o^X (\alpha_p-\alpha_n)\, dx'\}dx \qquad \ldots(7)$$

Now

$$\int_o^W (\alpha_n-\alpha_p) \exp\left[-\int_o^x (\alpha_p-\alpha_n)\, dx'\right]dx$$

$$= \exp\left[-\int_o^x (\alpha_p-\alpha_n)\, dx'\right] \Big|_{x=o}^{W}$$

$$= \exp\left[-\int_o^W (\alpha_p-\alpha_n)\, dx\right] - 1 \qquad \ldots(8)$$

From (7) and (8) we have

$$\frac{1}{M_p} = \exp\left[-\int_o^W (\alpha_p-\alpha_n)\ dx\right] - \int_o^W (\alpha_n-\alpha_p)\ \exp\left[-\int_o^x (\alpha_p-\alpha_n)dx'\right]dx$$

$$- \int_o^W \alpha_p\ \exp\ \left[-\int_o^x (\alpha_p-\alpha_n)\ dx'\right]dx$$

$$\frac{1}{M_p} = \exp\left[-\int_o^W (\alpha_p-\alpha_n)dx\right] - \exp\left[-\int_o^W (\alpha_p-\alpha_n)dx\right] + 1 - \int_o^W (\alpha_p-\alpha_n)dx'\right]dx$$

$$\therefore 1 - \frac{1}{M_p} = \int_o^W \alpha_p\ \exp\ \left[-\int_o^x (\alpha_p-\alpha_n)\ dx'\right]dx \qquad \ldots(9)$$

The breakdown voltage V_B is defined as the voltage where M becomes infinite. If the ionization rates for electrons and holes are the same, breakdown occurs where an electron (or hole) produces exactly one secondary on the average in one transit. If the ionization rates are different, then the carrier which ionizes most must produce more than one secondary to compensate for the other type of carrier which causes lesser ionization. It can be shown that the breakdown condition is symmetrical. That is, if

$$\int_o^W \alpha_p\ \exp\ \left[-\int_o^x (\alpha_p-\alpha_n)\ dx'\right]dx = 1\ ,$$

then

$$\int_o^W \alpha_n\ \exp\ \left[-\int_x^W (\alpha_n-\alpha_p)\ dx'\right]dx = 1\ . \qquad \ldots(10)$$

Experimentally it is found that

$$\alpha_n \quad \text{or} \quad \alpha_p = \alpha_o \left(\frac{E}{E_o}\right)^n \qquad \ldots(11)$$

where α_o and E_o are constants and $\alpha = \alpha_\infty \exp\ (-b/E)^m$

where b is an electric field that is in general different from $\xi_i/q\ell$, if ξ_i is the ionization threshold and ℓ is the mean free path, respectively.

To extend the multiplication integral over a wide range of multiplication it is necessary to account for ionization by both electrons and holes.

Let

$$\alpha_p = \gamma \, \alpha_n \qquad \text{...(12)}$$

With the assumption of constant γ, the multiplication integral (9) becomes

$$1 - \frac{1}{M_p} = \frac{\gamma}{1-\gamma} \left\{ \exp \left[- \left(1 - \frac{1}{\gamma}\right) \int_o^W \alpha_p \, dx \right] - 1 \right\}$$

$$1 - \frac{1}{M_n} = \frac{1}{\gamma - 1} \left\{ \exp \left[\int_o^W (\gamma - 1) \, \alpha_n \, dx \right] - 1 \right\} \qquad \text{...(13)}$$

where the value of γ should be chosen at the maximum field. Avalanche breakdown occurs at

$$\int_o^W \alpha_n \, dx = \frac{\ell_n \gamma}{\gamma - 1}$$

or

$$\int_o^W \alpha_p \, dx = \frac{\gamma \ell_n \gamma}{\gamma - 1} \qquad \text{...(14)}$$

2.2.1 Step Junction

A step junction is defined as having constant impurity density on either side of an abrupt step on density, as in Figure 1.2(a). The field varies linearly with distance, and the width W is related to voltage V by

$$V = \frac{NqW^2}{2\varepsilon} \qquad \ldots(15)$$

where

$$\frac{1}{N} = \frac{1}{N_D} + \frac{1}{N_A}$$

ε = permittivity

V = sum of applied and 'built-in' voltage.

The maximum field is

$$E_m = 2\,\frac{V}{W} = \frac{qNW}{E}$$

and

$$E(x) = 2\,\frac{V}{N} \cdot \frac{x}{W} \qquad \ldots(16)$$

where E is assumed to be zero at x = 0. Actually, equation (16) strictly applies only to one-sided junctions (i.e. $N_D >> N_A$). For junctions that have significant width on both sides of the junction, E(x) must be represented by two straight lines. Figure 2.2 shows a one-sided equivalent for a two-sided step junction.

The ionization integral is

$$\int_o^w \alpha dx = \int_o^w \alpha_\infty \, e^{-bw^2/2Vx} \, dx \qquad \ldots(17)$$

Let z = x/w, then

$$\int_o^w \alpha dx = \alpha_{max} W_{eff} \qquad \ldots(18)$$

$$W_{eff} = W \int_o^1 \exp \left[(1 - \frac{1}{z}) \frac{b}{E_{max}} \right] dz \qquad \ldots(19)$$

The determination of the ionization integral involves (i) determination of E_{max} and (ii) determination of α_{max} and

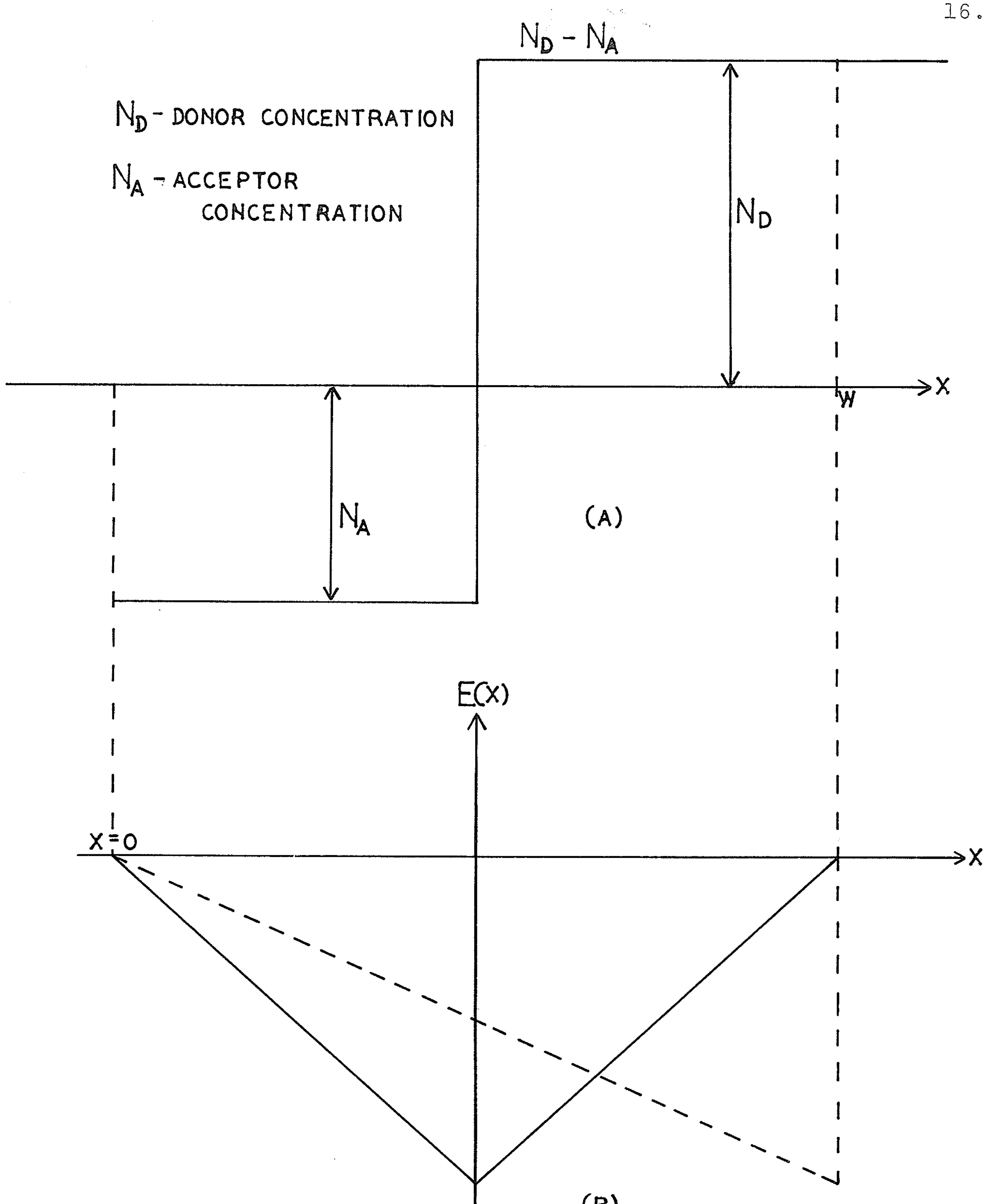

FIG. 2.2(A). IMPURITY DENSITY IN A STEP JUNCTION.

(B). FIELD DISTRIBUTION IN A STEP JUNCTION.

W_{eff}. Assuming that $m = \frac{b}{E_o} >> 1$, the empirical forms are as follows,

$$1 - \frac{1}{M_n} \cong \frac{\ell n \gamma}{\gamma - 1} \left(\frac{V}{V_B}\right)^{(m+1)/2}$$

$$1 - \frac{1}{M_p} \cong \frac{\gamma \ell n \gamma}{\gamma - 1} \left(\frac{V}{V_B}\right)^{(m+1)/2} \qquad \ldots(20)$$

2.2.2 Linearly Graded Junctions

A linearly graded junction is defined as having a constant slope in net impurity density as shown in Figure 2.3. In a linearly graded junction,

$$\rho = q\,ax \;, \; - x_o < x < x_o \qquad \ldots(21)$$

$$E = \frac{-qa}{E} \frac{x_o^2 - x^2}{2} \qquad \ldots(22)$$

$$V = \frac{qa\,W^3}{12E} \qquad \ldots(23)$$

where V = voltage across junction

a = gradient of impurities

$W = 2x_o$ = junction width

The ionization integral is

$$1 - \frac{1}{M_n} = \int_o^W \alpha_n \, dx$$

$$= 2 \int_o^{W/2} \alpha_\infty \exp\left\{- \frac{b}{\frac{qa}{2E}\left[\left(\frac{W}{2}\right)^2 - x^2\right]}\right\} dx$$

$$= \alpha_{max} W_{eff} \qquad \ldots(24)$$

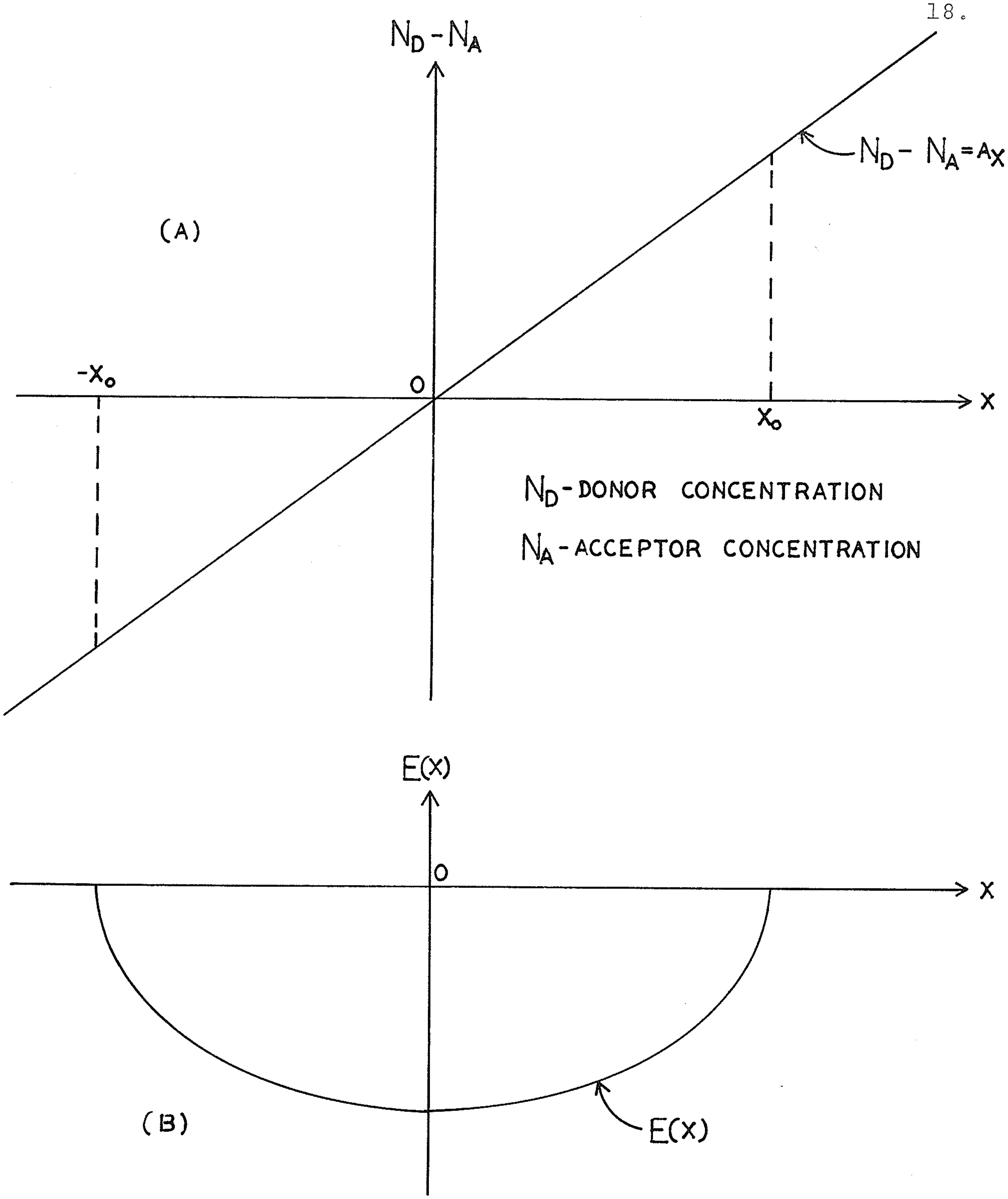

FIG. 2.3(A). IMPURITY DENSITY IN A LINEARLY GRADED JUNCTION.

(B) FIELD DISTRIBUTION IN A LINEARLY GRADED JUNCTION.

where $W_{eff} = W \int_o^1 \exp\left(- \frac{E^2}{1-E^2} \cdot \frac{b}{E_m}\right) dE$

$\alpha_{max} = \alpha_\infty e^{-b/E_m}$

The determination of the ionization integral for the graded junction is now identical to the determination of the ionization integral for the step junction except for details. At voltages less than the breakdown voltage the multiplications are

$$1 - \frac{1}{M_n} \cong \frac{\ell_n\gamma}{\gamma-1} \left(\frac{V}{V_B}\right)^{2/3(n+1)}$$

$$1 - \frac{1}{M_p} \cong \frac{\gamma\ell_n\gamma}{\gamma-1} \left(\frac{V}{V_B}\right)^{2/3(n+1)} \qquad \ldots(25)$$

The empirical result agrees with (25) approximately if $\alpha_p \cong \alpha_n$ (γ close to unity) and $b/E_m >> 1$.

In the case where the ratio $\gamma(= \alpha_p/\alpha_n)$ is not constant, it is possible to make some estimates based on upper and lower limits. To calculate the breakdown voltage where M is infinite, we require

$$1 - \frac{1}{M_p} = \frac{\gamma}{1-\gamma} \left\{\exp\left[-(1 - \frac{1}{\gamma}) \int_o^W \alpha_p \, dx\right] -1\right\} = 1 \qquad \ldots(26)$$

as well as

$$1 - \frac{1}{M_n} = \frac{1}{\gamma-1} \left\{\exp\left[(\gamma-1) \int_o^W \alpha_n \, dx\right] -1\right\} \qquad \ldots(27)$$

At finite multiplications the calculation is closely approximated using the physical parameters of the incident carrier. For small multiplication, as in transistor collectors near

$\alpha M = 1$, the calculation for multiplication using the parameters for the incident carrier converges very closely to the true value. In all cases it is of the greatest importance to use the value of γ which is obtained at the maximum field.

CHAPTER III

MICROPLASMA PHENOMENON

3.1 REVIEW ON MICROPLASMA PHENOMENON

In avalanche breakdown the junction does not suddenly begin to conduct very large currents all over the junction, but rather at small discrete points. These small-high-current-density discharges are known as microplasmas. This effect indicates that breakdown occurs in small steps of current. Further increase in applied voltage beyond that which created the first microplasma would not increase the current through individual microplasma appreciably, but rather will produce more microplasmas. Each new microplasma adds its unit of current to the total breakdown value. The individual microplasma switches on and off in the area of initial breakdown, thus producing a distinct noise in the form of erratic current pulses with very fast rise time and of rather uniform amplitude regardless of the level of the breakdown voltage.

Associated with the generation of microplasmas in avalanche breakdown of the junction, there exists an emission of light eminating from the individual microplasma as pin-pointed spots of light. It has been found that microplasmas occur preferentially along areas of scratches or other mechanical effects [39]. It seems to suggest an effect of lattice damage on the junction width, perhaps a sort of dislocation within the junction.

The generation and decay of the microplasmas during junction breakdown takes place in a very short time interval (10^{-10} sec. or lower) and hence the breakdown effect may be used at rather high speeds.

In general it is believed that high field intensity at local avalanche breakdown is involved in production of microplasma. Experimental evidence indicated that microplasmas are caused by localized high field regions within the junction.

Shockley suggested a model for explaining the observed properties of microplasmas. According to his model, field enhancement is caused by precipitates of dielectrics. Traps in microplasma region tend to immobilize a high density of charges. These charges are able to increase the electric field to such a value that breakdown may occur and thus a 'lock on' mechanism is produced. Spherical dielectric precipitate is assumed and since the dielectric constant of the spherical precipitate is much lower than the surrounding material, the field around the periphery will be stronger than the surrounding. Thus high local field intensity results in breakdown. The precipitates are nucleated preferentially at dislocations and so microplasmas occur, in general, preferentially along dislocations.

The most significant electrical behaviour of microplasmas is the characteristic current instability at breakdown.

If the diode is operated with a low resistance in series, the microplasma passes current as square pulses. The length and repetition rate of the pulses fluctuate statistically around an average value corresponding to the DC current flowing through the microplasma region. The repetition rate varies for different microplasmas. From experimental results on large load resistance circuits, Champlin [5] suggested that microplasma is due to a local avalanche breakdown and that the noise pulse is due to charge and discharge of the capacitance across the microplasma region. When the bias voltage is increased, the capacitance is charged up and the voltage across the microplasma region is increased. At breakdown, the resistance of the microplasma spot decreases. The capacitance then discharges through the resistance to decrease the voltage across the microplasma spot. If the voltage is decreased to or below a certain value that the field intensity in the microplasma region is not strong enough to sustain avalanche breakdown, the conduction ceases. After this, the capacitance is then charged up again. Haitz [17] extended this model to explain microplasma phenomenon on small load resistance circuits.

Champlin [5] and McIntyre [31] have independently developed a phenomenological theory describing the statistics of microplasma pulses. According to Champlin the electrical properties of a random bistable microplasma can be qualitatively ascribed with three fundamental parameters: (i) the probability rate for transitions from the non-conducting state to the