SCHOTTKY BARRIER DIODE CHARACTERISTICS UNDER HIGH LEVEL INJECTION

W. T. NG, S. LIANG and C. ANDRE T. SALAMA
Department of Electrical Engineering, University of Toronto, Toronto, Ontario, M5S, 1A4, Canada

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Abstract—The $J-V$ characteristics of Schottky barrier diodes with long drift regions are discussed in this paper. A simple physical model describing conductivity modulation effects under high level injection is derived. Solution for the electron and hole carrier profile, current densities, electric field, voltage drop and the amount of stored charge as a function of the total current density is presented. An empirical model which spans low and high injection levels is also proposed. The model uses the traditional formula for low injection condition and switches gradually to the high level injection model derived here when the amount of minority carrier injection becomes appreciable. The validity of the complete model is verified by comparison with simulated and experimental results.

NOTATION

- $A^{**}$: effective Richardson constant for holes (A/(cm·K$^2$))
- $A^*$: effective Richardson constant for electrons (A/(cm·K$^2$))
- $D_2$: ambipolar diffusion constant (cm$^2$/s)
- $D_e$: electron diffusion constant (cm$^2$/s)
- $D_p$: hole diffusion constant (cm$^2$/s)
- $E$: electric field (V/m)
- $e_1$: empirical constant used in $m(n_i)$
- $e_2$: empirical constant used in $m(n_i)$
- $J$: total current density (A/cm$^2$)
- $J_J$: current density obtained from the low level injection $J-V$ relationship (A/cm$^2$)
- $J_H$: current density obtained from the high level injection $J-V$ approximation (A/cm$^2$)
- $J_p$: hole current density (A/cm$^2$)
- $J_e$: electron current density (A/cm$^2$)
- $J_{s0}$: saturation current density for Schottky contacts on p-type silicon (A/cm$^2$)
- $J_{sH}$: saturation current density (A/cm$^2$)
- $kT/q$: thermal voltage (V)
- $L_d$: drift region length ($\mu$m)
- $L_a$: ambipolar diffusion length ($\mu$m)
- $L_n$: electron diffusion length ($\mu$m)
- $L_p$: hole diffusion length ($\mu$m)
- $N_A$: acceptor concentration in the p-type drift region (cm$^{-3}$)
- $N_{A+}$: acceptor concentration in the $p+$ region (cm$^{-3}$)
- $n_i$: intrinsic carrier concentration (cm$^{-3}$)
- $n_{e0}$: equilibrium electron concentration in the p-drift region (cm$^{-3}$)
- $n_e$: electron concentration (cm$^{-3}$)
- $n_i$: electron concentration at the depletion edge (cm$^{-3}$)
- $\phi_{b}$: effective barrier height for holes with shallow adjust implant (eV)
- $\phi_{b0}$: barrier height for holes without shallow adjust implant (eV)
- $\sigma$: surface recombination velocity at the $p/p+$ interface (cm/s)
- $\tau_a$: ambipolar lifetime (s)
- $\tau_{n0}$: electron lifetime under low level injection (s)
- $\tau_{p0}$: hole lifetime under low level injection (s)
- $\mu_e$: ambipolar mobility (cm$^2$/V·s)
- $\mu_e$: electron mobility (cm$^2$/V·s)
- $\mu_p$: hole mobility (cm$^2$/V·s)

INTRODUCTION

Under low level injection, Schottky barrier (SB) diodes are primarily majority carrier devices and the $J-V$ characteristics of the diode is given by the exponential relationship[1]

$$J = J_s \exp \left( \frac{q(V - J_s R)}{kT} \right) - 1,$$

where $J_s$ is the forward current density, $V$ is the terminal voltage, $R$ is the total series specific resistance in $\Omega$·cm$^2$, $J_s$ is the saturation current and $kT/q$ is the thermal voltage.

However, when operating under high current density, SB diodes with high majority carrier barrier heights inject an appreciable amount of minority carriers (high level injection)[2-4] into the drift region. The injected carriers give rise to conductivity modulation within the drift region of the diode, and the forward $J-V$ characteristics are significantly altered from the classical exponential relationship.

Minority carrier injection in SB diodes, primarily under low to moderate injection levels, has been investigated previously[5,2,6]. Recently, Chuang[7] developed an implicit solution for the $J-V$ characteristics of epitaxial SB diodes that is accurate for current densities up to $10^4$ A/cm$^2$. But since recombination within the epitaxial layer was neglected, the...
applicability of Chuang's work is limited to planar Schottky diodes with short drift regions.

In this paper, a simple and accurate semiempirical model for the \( J-V \) characteristics of the SB diode will be presented. The forward voltage drop \( V \) across the SB diode will be solved explicitly as a function of the forward current density \( J \). The model takes into account high level injection, drift and diffusion current densities, and the minority carrier reflecting nature of a high–low junction at the ohmic contact. The derived equations can be used in understanding the performance of the SB diodes under high level injection in such applications as high voltage and high power devices\[8,9\] used in monolithic power integrated circuits.

**SCHOTTKY BARRIER MODEL**

SB diodes in a monolithic high voltage integrated circuit (HVIC) environment are fabricated in a lateral structure with a long drift region as shown in Fig. 1. This figure illustrates a SB diode fabricated on a \( p \)-type epitaxial layer. As a first order approximation, the diode can be represented by the one dimensional structure illustrated in Fig. 2(a). A shallow \((n)\) implant of opposite conductivity type to the epitaxial

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Fig. 1. A lateral Schottky barrier diode structure including barrier height adjust implant.

Fig. 2. (a) A one dimensional Schottky barrier diode structure including barrier height adjust implant.

(b) Energy band diagram under forward biased condition.
layer is sometimes used to enhance the majority carrier barrier height, $\phi_{be}$[10]. The corresponding energy band diagram, for the structure under forward bias, is given in Fig. 2(b). The typical forward $J-V$ characteristics for the diode, given in Fig. 3, show three distinctive regions of operation: low level injection, high level injection and a transition region in between. The following sections deal with the derivation of the SB $J-V$ model starting with a discussion of the effect of the shallow implant layer on the barrier height.

(a) Effect of the shallow n implant layer

The Schottky barrier height and consequently the reliability of the contact can be enhanced with the use of a shallow implant layer prior to metallization[10]. The implanted junction depth is usually no more than a few hundred angstroms. The current transport in ion-implanted SB diodes has been studied by Pai et al. [11]. Referring to the p-type SB diode of Fig. 2, for a high implant dose $Q_i$, the hole current density is given by

$$J_p = -J_m \exp\left(\frac{qV_s}{kT}\right) - 1$$

where $n_i$ is the intrinsic carrier concentration, $D_p$ is the hole diffusion constant for holes, and $V_s$ is the potential difference between $\phi_{be}$ and $\phi_p$ in the depletion region.

Comparing eqn (2) with the equation obtained from thermionic emission–diffusion theory[11], and expressing the hole current density $J_p$ as

$$J_p = -J_m \exp\left(\frac{qV_s}{kT}\right) - 1$$

The saturation current density $J_m$ is given by

$$J_m = \frac{q n_i^2 D_p}{Q_i}$$

and can also be expressed as

$$J_m = A^{**} T^3 \exp \left(\frac{-q \phi_{be}}{kT}\right)$$

where $A^{**}$ is the effective Richardson constant for holes, and $\phi_{be}$ is the hole barrier height. Therefore, the barrier height $\phi_{be}$ can be expressed in terms of $Q_i$ as

$$\phi_{be} = \frac{kT}{q} \ln \left(\frac{A^{**} T^3 Q_i}{q n_i^2 D_p}\right)$$

and $Q_i$ can be used to adjust the effective barrier height in the SB diode.

(b) $J-V$ Characteristics under high level injection

The excess minority and majority carriers injected into long drift region and responsible for modulating the conductivity in that region. Therefore, in order to determine the $J-V$ characteristics of the Schottky diode, the carrier profiles must be calculated. In this derivation, the electron and hole profiles, current densities, the electric field, as well as the amount of stored charge will be obtained as a function of the total current density $J_{total}$. Assuming that charge neutrality holds in the drift region, then

$$p(x) = n(x) + N_A \quad W_d < x < L_d$$

where $n$ and $p$ are the electron and hole concentrations respectively, $N_A$ is the acceptor doping in the drift region, $W_d$ is the depletion width and $L_d$ is the length of the drift region. Under high level injection, $n$ and $p$ are much greater than $N_A$, therefore

$$p(x) \approx n(x)$$

Assuming that $N_A$ is constant throughout the drift region, the partial derivatives of the carrier profiles are also equal.

$$\frac{\partial p(x)}{\partial x} = \frac{\partial n(x)}{\partial x}$$

Since both drift and diffusion current components are equally important under high level injection, both terms must be included in the one dimensional transport equation.

$$J_n = q \mu_n n(x) E(x) + q D_n \frac{\partial n(x)}{\partial x}$$

$$J_p = q \mu_p p(x) E(x) - q D_p \frac{\partial p(x)}{\partial x}$$

In steady state, the total current density flowing through the structure must be constant and independent of $x$.

$$J_h = J_n(x) + J_p(x) = \text{constant}$$

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![Fig. 3. Forward $J-V$ characteristics of a Schottky barrier diode showing the three regions of operation. Curve (1) is the high level injection approximation and curve (2) is the low-injection exponential curve.](image-url)
Adding eqns (10) and (11), the total current density can be expressed as
\[ J_h = q[\mu_e n(x) + \mu_p p(x)]E(x) + qD_n \frac{\partial n(x)}{\partial x} - qD_p \frac{\partial p(x)}{\partial x} \] (13)

Applying the assumptions in eqns (8) and (9), the electric field can be written as
\[ E(x) = \frac{J_h}{q(\mu_e + \mu_p)n(x)} - \frac{D_n - D_p}{(\mu_e + \mu_p)n(x)} \frac{\partial n(x)}{\partial x} \] (14)

Substituting this result into eqn (10), the electron current density becomes
\[ J_e = \frac{\mu_e}{\mu_e + \mu_p} J_h - \frac{q\mu_e}{\mu_e + \mu_p} (D_n - D_p) \frac{\partial n(x)}{\partial x} + qD_n \frac{\partial n(x)}{\partial x} \] (15)

Applying Einstein’s relationship \( D = \mu(kT/q) \), the term
\[ \left( \frac{\mu_e D_p + \mu_p D_n}{\mu_e + \mu_p} \right) = 2D_n D_p \frac{D_n}{D_n + D_p} = D_a \] (17)
can be defined as the ambipolar diffusion coefficient. The expression for the electron current density \( J_e \) can then be simplified to
\[ J_e = \frac{\mu_e}{\mu_e + \mu_p} J_h + q\left( \frac{\mu_e D_p + \mu_p D_n}{\mu_e + \mu_p} \right) \frac{\partial n(x)}{\partial x} \] (16)

Neglecting Auger recombination,1 the rate of change in electron carrier density in the drift region can be described by the continuity equation[1]
\[ \frac{\partial n}{\partial t} = \frac{1}{q} \frac{\partial J_e}{\partial x} + \frac{n(x)p(x) - n_i^2}{\tau_m(n(x) + n_i) + \tau_n(p(x) + n_i)} \] (20)
The second term in eqn (20) represent the recombination rate of electrons in the p drift region, while \( \tau_m \) and \( \tau_n \) are the lifetimes for electrons and holes under low level injection, respectively. Under high level injection, \( n(x) = p(x) \gg n_i \). The ambipolar life-time can be obtained from the above expression as[12]
\[ \tau_a = \tau_m + \tau_n \] (21)

Under steady state conditions, eqn (20) reduces to
\[ \frac{\partial n}{\partial t} = 0 = -\frac{1}{q} \frac{\partial J_e}{\partial x} + \frac{n(x)}{\tau_a} \] (22)

Taking the partial derivative of eqn (18), and noting that the total current density \( J_h \) is constant and independent of \( x \), \( \partial J_e/\partial x \) becomes
\[ \frac{\partial J_e}{\partial x} = qD_n \frac{\partial^2 n(x)}{\partial x^2} \] (23)

Substituting this into eqn (22), the minority carrier density can be expressed as
\[ \frac{\partial^2 n}{\partial x^2} \left( \frac{n(x)}{L_a^2} \right) = 0 \] (24)

where \( L_a \) is the ambipolar diffusion length
\[ L_a = \sqrt{D_a \tau_a} \] (25)
The solution for the minority carrier density obtained from eqn (24) is in the form
\[ n(x) = C_1 \exp \left( \frac{x}{L_a} \right) + C_2 \exp \left( -\frac{x}{L_a} \right) \] (26)

To obtain the values of the constants \( C_1 \) and \( C_2 \), two boundary conditions are needed.

At \( x = W_1 \),
\[ n(W_1) \approx n(0) = n_i \quad \text{assuming} \ W_1 \approx 0 \] (27)

where \( W_1 \) is the depletion width at the metal-semiconductor junction, and \( n_i \) is the injected electron carrier concentration at the depletion edge.

At \( x = L_a \), the electron concentration is determined by the surface recombination velocity \( \sigma \) at the p/p+ high low junction and the electron current density flowing through it[13]
\[ n(L_a) = -\frac{J_n(L_a)}{q\alpha} \] (28)

Using these two boundary conditions, the minority carrier profile can be written as$\dagger$
\[ n(x) = \left\{ n_i \cosh \left( \frac{x - L_a}{L_a} \right) - n_i \frac{\alpha L_a}{D_a} \sinh \left( \frac{x - L_a}{L_a} \right) \right\} \left\{ -\frac{\mu_e J_n L_a}{q(\mu_e + \mu_p)} \frac{n(x) - n_i}{\tau_m(n(x) + n_i) + \tau_n(p(x) + n_i)} \right\} \] (29)

The dependence of \( n_i \) on the total forward current density \( J_n \) can be derived by recalling that the electron and hole current densities at \( x \approx 0 \) are given by:
\[ J_e = \frac{\mu_e}{\mu_e + \mu_p} J_h + qD_n \frac{\partial n}{\partial x} \] (30)

and
\[ J_p = -J_n \exp \left( \frac{qV}{kT} \right) \] (31)

$\dagger$Auger recombination is apparent only at very high injection levels, usually greater than \( 10^{10}\) cm\(^{-3}\). The SB diodes in this study do not exhibit injection level of such magnitude, therefore it is reasonable to neglect Auger recombination in the derivation.
$\dagger$For small value of \( \sigma \), the high-low junction acts as a reflecting contact for minority carriers and accumulation in the drift region can occur.
$\dagger$For small \( L_a \), \( n(x) \) can be reduced to the linearly approximated solution as introduced by Chuang et al.[6].
Equation (31) results from the Thermionic Emission-Diffusion Theory developed by Crowell and Sze[14]. This equation is valid for the majority carrier (holes) transport through the SB diode under both low level and high level injections. Since charge neutrality requires that

\[ n_1 + N_A = p_1 \]  

(32)

where \( n_1, p_1 \) are the electron and hole concentrations at the depletion edge \( W_1 \). Also the \( pn \) product can be given as

\[ n_1 p_1 = n_t^2 \exp\left( \frac{q V_t^*}{kT} \right) \]  

(33)

The exponential in eqn (33) can alternately be expressed as

\[ \exp\left( \frac{q V_t^*}{kT} \right) = \frac{n_t^2 + N_A n_1}{n_t^2} \]  

(34)

Thus the total current density \( J_b = J_n + J_p \) at \( x \approx 0 \) becomes

\[ J_b = \frac{\mu_n}{\mu_n + \mu_p} J_n + qD_a \frac{\partial n(x)}{\partial x} - J_p n_1^2 + N_A n_1 \]  

at \( x \approx 0 \)  

(35)

Taking the partial derivative of eqn (26) and substituting into eqn (35), a quadratic equation for the injected minority carrier concentration can be obtained. The solution for \( n_1 \) at the depletion edge can be shown to be

\[ n_1 = -B + \sqrt{B^2 - 4AC} \]  

(36)

where

\[ A = J_p n_1 \]  

\[ B = J_p N_A + \frac{qD_a}{L_a} \left[ \frac{\sinh(L_0/L_a)}{\sinh(L_0/L_a)} + \frac{\sigma L_0}{D_a} \cosh(L_0/L_a) \right] \]  

\[ C = \frac{n_t^2 J_b}{\mu_n + \mu_p} \left( \frac{\mu_n}{\cosh(L_0/L_a)} + \frac{\mu_p}{\sigma L_0/D_a} \sinh(L_0/L_a) \right) \]  

(37)

(38)

(39)

Equation (36)-(39) represent a solution for the minority carrier concentration \( n_1 \) at the depletion edge as a function of the total current density \( J_b \). This value of \( n_1 \) can then be substituted into eqn (29) in order to calculate the minority carrier density \( n(x) \) as a function of the forward current density \( J_h \).

The voltage drop across the drift region can be evaluated by integrating the electric field \( E(x) \) as given in eqn (14)

\[ V_d(J_b) = -\int_0^{L_d} E(x) \, dx \]  

(40)

(c) \( J-V \) Characteristics under low level injection

For low level injection, the \( J-V \) characteristic can be represented accurately by the exponential relationship

\[ J_1 = J_p \left[ \exp\left( \frac{q(V - J_1 R_d)}{kT} \right) - 1 \right] \]  

(47)

where \( R_d \) is the drift region resistance without conductivity modulation and can be expressed as

\[ R_d = \frac{L_d}{q \mu_p N_A} \]  

(48)
Since \( N_A \) is usually low for breakdown reasons, \( R_d \) could be quite large.

(d) \( J-V \) Characteristics in the transition region

To model the complete range of injection level in the SB diode, the model must use eqn (47) at low level injection and switch gradually to the high level injection approximation given by eqn (44). The total current density can be represented empirically by the following equation

\[
J = m(n_i)J_i + [1 - m(n_i)]J_h
\]

where

\[
m(n_i) = \begin{cases} 1 & n_i < N_A \\ 0 & n_i \geq N_A \end{cases}
\]

The \( J-V \) curves for the high level injection approximation and the low current exponential relationship are plotted in Fig. 3 as curves (1) and (2) respectively. The point of switchover can be determined by evaluating the amount of minority carrier injection \( n_i \) estimated from the high level injection eqn (36).

One of the functions that satisfies the criteria for \( m(n_i) \) is the simple reciprocal function,

\[
m(n_i) = 1 \left[ 1 + \left( \frac{e_1 n_i}{N_A} \right)^{e_2} \right]^{-1}
\]

where \( e_1 \) and \( e_2 \) are empirical constants. In eqn (51), \( e_1 \) \((<1)\) was introduced as a correction factor to compensate for the fact that \( n_i \) is calculated under high level injection condition. This value of \( n_i \) is higher than the actual amount of electrons injected under moderate injection levels in the transition region. Thus if the actual amount of injected minority carrier concentration \( e_1 n_i \) is less than the background concentration \( N_A \), conductivity modulation is ignored. The effective current density is then given by \( J_i \). If \( e_1 n_i \) is greater than \( N_A \) then \( J_h \) dominates. The function \( m(n_i) \) is plotted in Fig. 4 for different values of \( e_2 \). For small \( e_2 \), the transition from 1 to 0 is very gradual. For large \( e_2 \), the plot for \( m(n_i) \) resembles a step function. The parameter \( e_2 \) can be used to control the rate of switch over from high to low level injection in the transition region.

The values for \( e_1 \) and \( e_2 \) can be extracted from measured \( J-V \) curves. Typical values for \( e_1 \) are in the range of 0.05-1.0, while values for \( e_2 \) are usually in the range of 5-20.

### DEVICE FABRICATION

To verify the validity of the high level injection model, SB diodes were fabricated using aluminum electrodes on both \( n^- \) and \( p^- \)-type silicon. The resistivity for both the \( n^- \) and \( p^- \)-type epitaxial layers was 5 \( \Omega \)cm. The drift region length \( L_d \) was 28 \( \mu \)m. The device area of the SB diodes was 8.13 \( \times 10^{-5} \) cm\(^2\). The \( p^- \)-type Schottky diode had an arsenic surface implant dose of \( 1 \times 10^{12} \) cm\(^{-2}\) at 25 keV. The implanted ions were activated at 850°C for 20 min. The \( n^- \)-type diode did not have a surface implant. The aluminum metallization for the \( n^- \) and \( p^- \)-type Schottky diodes was annealed in forming gas for 20 min at temperature of 300°C.

### MODEL VERIFICATION

A comparison between the model predictions and two dimensional simulations obtained using PISCES II B[15] was carried out to validate the assumption used in the model. Specifically, the electron concentration and the electric fields predicted by the model and those predicted by the simulator were compared. Furthermore, a comparison between experimental results and the model prediction was carried out. The model parameters required for the comparison were extracted directly from the fabricated SB diodes. The saturation current density \( J_s \) and the series contact resistance \( R_s \) were obtained from \( J-V \) measurements. The list of parameters for the \( p^- \)-type SB diode are given in Table 1.

### Table 1. Parameters used in the calculated model and PISCES simulation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Calculated model</th>
<th>PISCES II B simulation</th>
<th>Units</th>
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<td>1.45 ( \times 10^{10} )</td>
<td>—</td>
<td>cm(^{-3})</td>
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<tr>
<td>( \mu_{so} )</td>
<td>900</td>
<td>900</td>
<td>cm(^2)/V.s</td>
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<td>( \mu_{po} )</td>
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<td>350</td>
<td>cm(^2)/V.s</td>
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<td>( \tau_s )</td>
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<td>( \mu )s</td>
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<tr>
<td>( Q_0 )</td>
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<td>cm(^{-2})</td>
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<tr>
<td>( J_{hs} )</td>
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<td>8.7 ( \times 10^{-13} )</td>
<td>A/cm(^2)</td>
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<td>cm/s</td>
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<td>( \sigma_t )</td>
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<td>( L_s )</td>
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<td>cm</td>
</tr>
<tr>
<td>( N_A )</td>
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<td>1.0 ( \times 10^{13} )</td>
<td>cm(^3)</td>
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<td>( N_A^* )</td>
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<td>2.2 ( \times 10^{-13} )</td>
<td>( \Omega ) cm</td>
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<tr>
<td>( e_2 )</td>
<td>8</td>
<td>—</td>
<td>—</td>
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*This parameter is calculated by PISCES II B internally.

### (a) PISCES simulations

The electron carrier densities calculated for various \( p^- \)-type SB diode structures from the high level injection model were compared with the PISCES simula-
Schottky barrier diode characteristics

Fig. 5. Calculated and simulated minority carrier density at a forward current density of 510 A/cm² for diodes with various drift region lengths.

Fig. 6. Calculated and simulated electric field at a forward current density of 510 A/cm².

The forward current density used in the calculation and the simulation was 510 A/cm² to ensure high level injection mode of operation. As seen, the calculated minority carrier densities are within 20% of the simulated values for diodes with \( L_d \) ranging from 15 to 50 µm.

For SB diodes with short drift region lengths (i.e. \( L_d \ll L_a \)) as shown in curve (1), the electron carrier densities vary almost linearly with the distance \( \chi \). This result is similar to the one observed by Chuang et al.\[6\]. However, for SB diodes with drift region lengths that are comparable to or longer than the ambipolar diffusion length as illustrated in curves (2) and (3), recombination of the carriers within the drift region can no longer be neglected. The electron carrier density for these structures vary non-linearly along the \( x \)-axis as predicted by eqn (29).

The simulated and calculated electric fields in the drift region for a p-type SB diode with \( L_d = 28 \) µm are compared in Fig. 6. The calculated electric field was found to be in close agreement with the simulation. Both curves show a high electric field strength at the Schottky contact end. The electric field then drops rapidly in the drift region where resistance is very low due to the effect of conductivity modulation.

(b) Experimental results

The measured \( J-V \) characteristics for the p-type SB diode is plotted as a solid line in Fig. 7. The calculated \( J-V \) curve obtained from the model is shown as a dashed line. As can be seen, calculated \( J-V \) curve was able to model the measured data over most part of the current density range. The maximum relative error obtained for this diode is no more than 10% in the high level injection region. The model also showed similar accuracy when applied to an n-type Schottky diode as illustrated in Fig. 8.

The current waveform for the p-type Schottky diode in reverse recovery is as shown in Fig. 9. The storage time \( t_s \) for the p-type Schottky diode was measured at various forward current density (600–1500 A/cm²). The peak reverse recovery current density was kept at 615 A/cm² constant. As noted in Fig. 10, the values of the storage time calculated from the high level injection approximation given in eqn (46) are in close agreement with measurement. The maximal error observed is 12%.

Fig. 7. \( J-V \) characteristics of a Schottky barrier diode on p-type silicon.

Fig. 8. \( J-V \) characteristics of a Schottky barrier diode on n-type silicon.
CONCLUSIONS

A model of the $J-V$ characteristics of SB diodes at high level injection was presented. This model takes into account the effect of high level injection and provides very good agreement with the measured data. An empirical formula was introduced to combine the high level injection model with the traditional low level exponential $J-V$ equation. This enables a good fit to the measured $J-V$ characteristics over a wide range of current density level. At the same time, the model is able to provide solution for other physical quantities such as minority and majority carrier profiles, current densities electric field, and storage time. The insight gained from this analysis can be easily adapted to model other more complicated device structures that incorporate the SB diode.

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