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THE DETERMINATION OF SOME PARAMETERS OF Sn/P-Si SCHOTTKY DIODES WITH SERIES RESISTANCE

Abdülmecit TÜRÜT
Atatürk Üniversitesi Fen-Edebiyat Fakültesi, Fizik Bölümü-ERZURUM

Necati YALÇIN
Erciyes Üniversitesi Fen-Edebiyat Fakültesi, Fizik Bölümü KAYSERİ

Ahmet KARAPINAR
Erciyes Üniversitesi Meslek Yüksek Okulu-KAYSERİ

SUMMARY

The current density-voltage (J-V) and the capacitance-voltage (C-V) characteristics for Sn/p-Si Schottky diode with series resistance are investigated. The ideality factor n, the barrier heigth Φ_B and the series resistance R of the diode are determined by forward current density-voltage characteristics using a plot of dV/d(lnJ) vs J and a plot of the function H(J) vs J, where $H(J)=V-n(kT/q)\ln(J/R^*T^2)$. The values obtained from the forward characteristics are compared with the values from the reverse characteristics. It is seen that the values are in good agreement with each other and the theoretical predictions. In addition, it has seen that the effects of space-charge-limited current were optained at forward bias for high voltages.

SERİ DİRENÇLİ Sn/P-Si SCHOTTKY DİYOTLARININ BAZI PARAMETRELERİNİN TAYİNİ

ÖZET

Bu çalışmada seri dirençli Sn/p-Si Schottky diyodunun akım yoğunluğu-gerilim (J-V) ve sığa-gerilim (C-V) karakteristikleri incelendi. Diyodun idealite çarpanı n, engel yüksekliği Φ_B ve seri direnci R; [H(J)-J], [dV/d(lnJ)-J] grafikleri kullanılarak doğru besleme akım yoğunluğu-gerilim karakteristikleri yardımıyla tayin edildi, burada $H(J)=V-n(kT/q)\ln(J/R^*T2)$ dir. Doğru besleme karakteristiklerinden elde edilen değerler ters besleme karakteristiklerinden elde edilen değerlerle karşılaştırıldı. Bu değerlerin birbirleriyle ve teorik sonuçlarla uyum içinde olduğu bulundu. Ayrıca, doğru beslemede, büyük gerilimlerde uzay yükü ile sınırlı akım etkilerinin elde edildiği görüldü.

INTRODUCTION

The carrier transport mechanisms in Schottky diodes have been rewieved by Rodherick [1]. In generally, semiconductor-metal rectifying structures forming with high resistivity materials work as a space charge limited current diode at forward bias for high voltages, if it contains an ohmic contact at the backside of the rectifying contact. The main properties of this kind of devices have been investigated by several authors [2-4].

The reverse bias current density-voltage and capacitance-voltage characteristics can be used to determine the barrier heigth of the rectifying contact and the carrier density of semiconductor. For forward bias, the effect of the series resistance of ideal Schottky diodes (i.e. $n=1$) was first examined by Norde [5]. Nord's approach was used to extract the values of n, Φ_B and R by Sato and Yasumura [6] for the $n>1$ cases. Their study requires two experimental current-voltage measurements at two different temperatures. An alternative approach to determine the values of n, Φ_B and R was proposed by Cheungs [7]. The proposed technique depends on single I-V measurement.

In this paper, we wish to determine the values of the parameters (n, Φ_B, R, N_a and V_d) of the Sn/p-Si Schottky diode using the Cheung's model (related with forward I-V characteristics), the reverse bias I-V and C-V characteristics. In addition, we want to show that the space charge limited current effects will be obtained at forward bias for high voltages.

MATERIAL AND METHOD

a) Basic Equations

The primary conduction mechanisms in Schottky barriers are majority carrier flow over the barrier by thermonic emission in lightly and moderately doped semiconductor [8]. For the ideal thermionic emission case, the forward current density-voltage (J-V) characteristics of a Schottky diode are given by

$$J = J_s[\exp(qV/kT) - 1] \tag{1}$$

In the practice, Schottky diodes show deviations from ideal thermionic emission behaviour. The current density-voltage relationship taking into account nonideal behaviors is

$$J = J_s[\exp(qV_F/nkT) - 1] \tag{2}$$

where q is the electronic charge, V_F is the applied voltage across the depletion layer, k is the Boltzmann's constant, T is the absolute temperature and n is the idealite factor which is a dimensionless constant. J_s is the saturation current and it is expressed by

$$J_s = R^{*}T^{2}\exp(e\ \Phi_B/kT), \tag{3}$$

where R^{*} is the Richardson's constant and Φ_B is the barrier height of diode.

In forward bias, the effect of the diode series resistance R is usually considered as a series combination of a diode and a resistor with resistance R through which the current I flows. The voltage across the diode can be expressed in terms of the total voltage drop V across the series combination of the diode and the resistor. Thus, V_F=V-IR, when the applied forward bias voltage V_F is larger than kT/q, the forward current density-voltage relation (2) becomes

$$J = J_s \exp[q(V - IR)/nkT] \tag{4}$$

According to Cheung's model, equation (4) can be rewritten as

$$V = RAJ + n\,\Phi_B + (n/\beta)\ln(J/R^*T^2) \tag{5}$$

where $\beta = q/kT$, A is the diode effective area. Diferentiating equation (5) with respect to lnJ, we obtain

$$dV/d(\ln J) = RAJ + n/\beta \tag{6}$$

Thus, a plot of $dV/d(\ln J)$ vs J will give RA as the slope and n/β as the $dV/d(\ln J)$ axis intercept. To evaluate Φ_B, a function H(J) can be defined as follows:

$$H(J) = V - (n/\beta)\ln(J/R^*T^2) \tag{7}$$

If the value V in equation (5) is substituted in equation (7),

$$H(J) = RAJ + N\,\Phi_B \tag{8}$$

A plot of H(J) ve J will also give a straight line so that this line intercepts with H(J)-axis at $n\,\Phi_B$. Using the n value obtained from equation (6), the Φ_B parameter can be determined. The slope of this plot also provides a second determination of R which can be used to chek the consistency of this approach. Two different plots of J-V data obtained from single measurement can determine all the three key diode parameters:n, Φ_B and R.

If applied voltage V, in forward bias, is equal to the V_D diffusion potential at the Schottky contact, the flat-band case is obtained. At higher voltages than V_D, the majority carrier injection from ohmic contact and the emission of the minority carries from rectifying contact become more effective in the current flow. The minority carrier injection term can be neglected in comparison with the majority carrier injection at high voltages. Thus, the current density-voltage relationship is given by reference [4]

$$J = (9/8)\varepsilon\varepsilon_0\mu_p(V^2/d^3) \tag{9}$$

where μ_p is the hole mobility, ε is the dielectric constant of semiconductor, ε_0 is the free space permitivity, d is the diode thickness and V is the applied voltage.

The reverse bias current density-voltage characteristics for Schottky diodes, including image force lowering, are given by reference [8]

$$J = J_s\exp(\alpha\ (V + V_D)^{1/4}) \tag{10}$$

where is a constant. The J_s saturation current in equation (10) is the same with the equation (3). The Schottky plot $\ln J-(V + V_D)^{1/4}$ obtained from the reverse current-voltage measurements enable the determination of the barrier height Φ_B.

The barrier height of Schottky diode can also be determined by the capacitance-voltage measurement because the deplation layer capacity changes with the applied voltage. The deplation layer capacitance per unit area is given by (8),

$$C = (dQ/dV) = (q\ \varepsilon\varepsilon_0 N_a)/2(V_D - V - kT/q)^{1/2} \tag{11}$$

where $V_D >> kT$, the applied voltage V is equal to -V. The equation (11) can be rewritten in the from

$$C^{-2} = [2(V_D - V)/(q\ \varepsilon\varepsilon_0\ N_a)] \tag{12}$$

A plot of C^{-2} vs -V will a straight line and the slope of this plot permits to determine the N_a acceptor density. The intercept of the straight line with V-axis is equal to the V_D diffusion potential.

b) Experimental Procedure

Sn/p-Si Schottky diode was studied in the present work. The orientation and resistivity of p-type Si are [111] and about 1150 Ω -cm, respectively. The crystals were mechanically polished by SiC powder and chemically etched by CP-4 ($2HNO_3$: 1HF : $1CH_3COOH$) The etching process was continued until to reduce the thicknesses desired value. The metals Al (99.99% pure) and Sn (99.99% pure) were used for construction the contacts. A back p^+ layer for ohmic contact was applied to the p-type Si prior to diode formation by alloying the Al/p-Si system at eutectic temperature [8]. For the rectifying contact, the metal Sn was evaporated to the other side of the crystal. All the evaporation and alloying processes were carried out in a vacuum of the order of 10^{-5} Torr. The geometric area of contact was equal to 4.9×10^{-2} cm^2 and the diodes thicknesses were approximately between 20 μm and 35 μm.

The current voltage and capacitance voltage measurements were taken with the classical DC methods.

RESULTS AND DISCUSSIONS

Figure 1 shows the typical forward and reverse J-V characteristics of Sn/p-Si diode. These characteristics were taken in the dark at room temperature (300 K). Figure 2 shows the plots of (dV/d(lnJ)-J and H(J)-J for the forward current-voltage values of the diode. The slope of the plot of dV/d(lnJ)-J yields the series resistance (Eq.6). This is R=59.8 k Ω. The intercept of the straight line provides the ideality factor n. The n value is about 1.04. The plot of H(J)-J is a straight line as shown in Figure 2. The slope of this line is used for the second determination of the series resistance (Eq.8). This is R=71.3 k Ω. The values of R obtained from two different methods are reasonable with each other within 15%. Using the n value calculated above, the Φ_B potential barrier is found from the plot of H(J)-J (Eq.8). This value is $e\Phi_B$=0.77 eV. The reverse J-V characteristics of the diode couldbe explained in terms of the thermionic emission. The Schottky plot of $\ln J-(V+V_D)^{1/4}$ is a straight line whose intercept with the J-axis gives the value 1.1×10^{-6} A/cm^2 for J_s. Using the equation (3), the barrier hight $e\Phi_B$ is obtained about 0.76 eV.

The characteristics C^{-2} vs V drawn with the capacitance-voltage values is a straight line as seen in Figure 4. The slope of the straight line enables to calculate the dopant concentration being $N_a=1.13\times10^{19}$ m^{-3} (Eq.12), which is in good agreement with the 1.21x1019 m-3 value obtained from the resistivity of p-Si. The intercept of the C^{-2}-V characteristics with V-axis gives the V_D diffusion potential which has the value about 0.41 V. If this value is added to the E_f Fermi level (measured from the top of the valance band),the $e\Phi_B$ potantial barrier is found as 0.75 eV.

For $\epsilon_0=8.85\times10^{-12}$ F/m, $\mu_p=450$ $cm^2/V.s$(8), $R^*=93$ A $(cm.K)^{-2}$ [9], V=3V and d=32 μm, it is possible to estimate the magnitute of the space charge limited current density by using the equation (9). Here $J=1.45\times10^{-1}$ A/cm^2 and this value is in good agreement with the measured value shown in Figure 1.

As a result, for $(3kT/q) < V < V_D$, Sn/p-Si structures obey the Schottky contact characteristics given by equation (4) at forward bias. At the higher voltages V_D, carries injected from ohmic contact become more effective at current flow and the characteristics show space charce limited current effects. There are very good agreement between the measured and calculated current values at space charge limited region. The barrier heights obtained from different ways and the dopant concentrations are also good relation with each other and the theoretical predictions.

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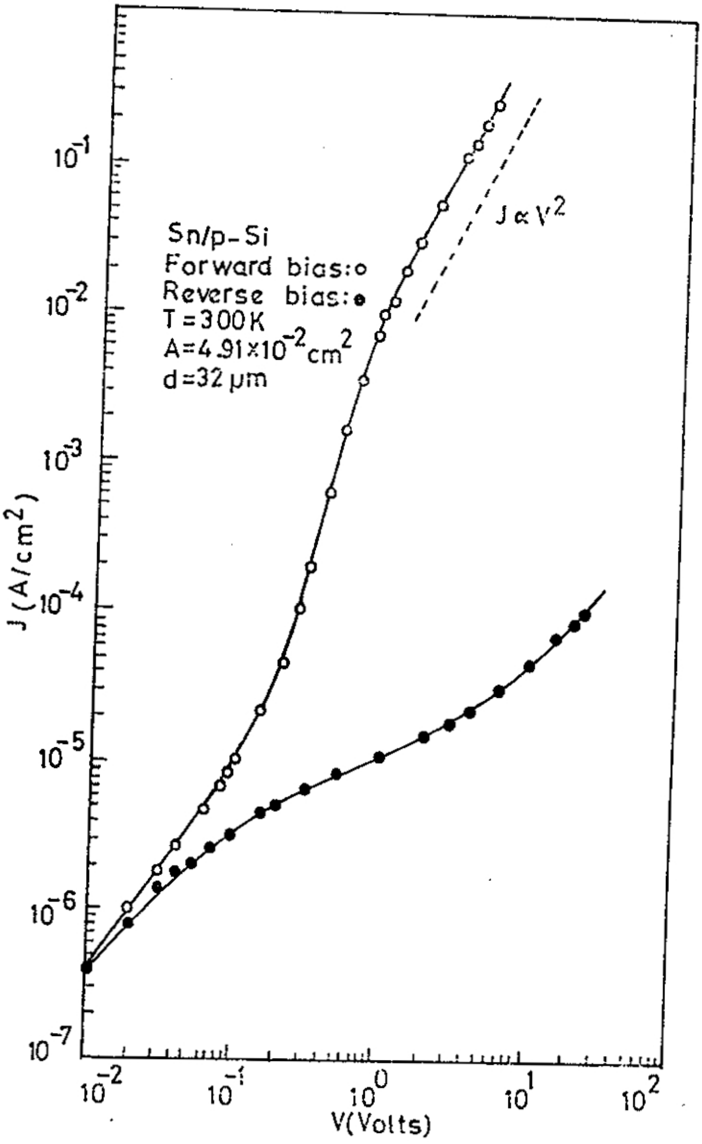

Figure - 1 : Typical current density-voltage characteristic of Sn/p-Si Diode.

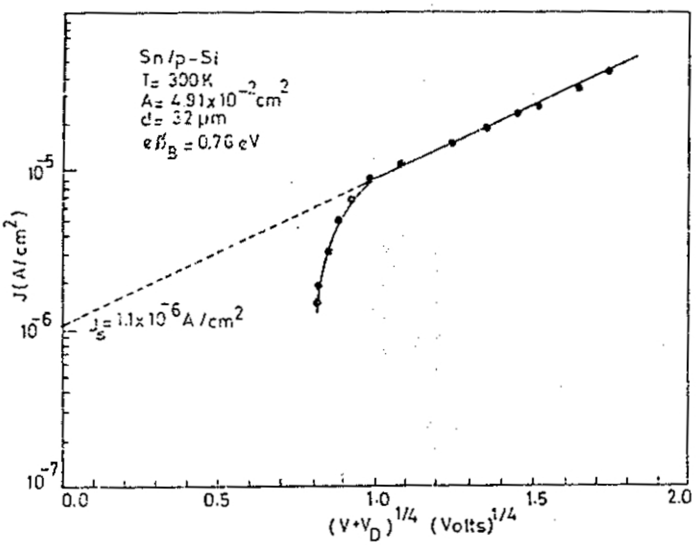

Figure - 2 : Semi-logaritmic plot of the current density versus $(V_d + V)^{1/4}$ characteristic of Sn/p-Si Diode.

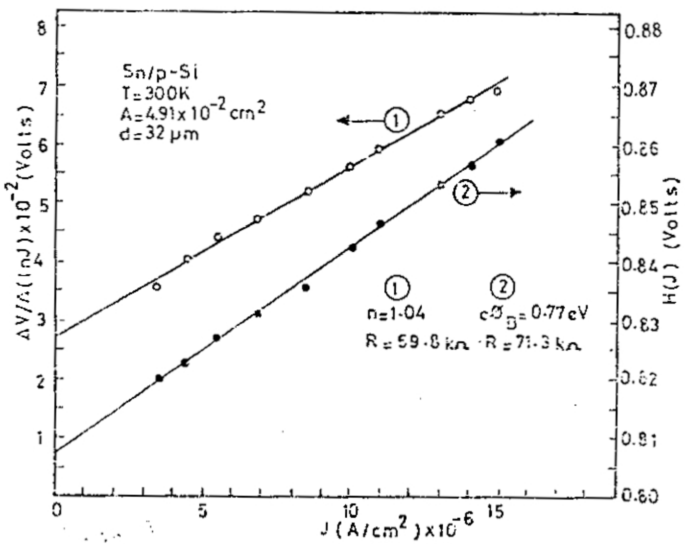

Figure - 3 : The plots [dV/d(lnj)] versus j and H(j) obtained from experimental current-voltage measurements.

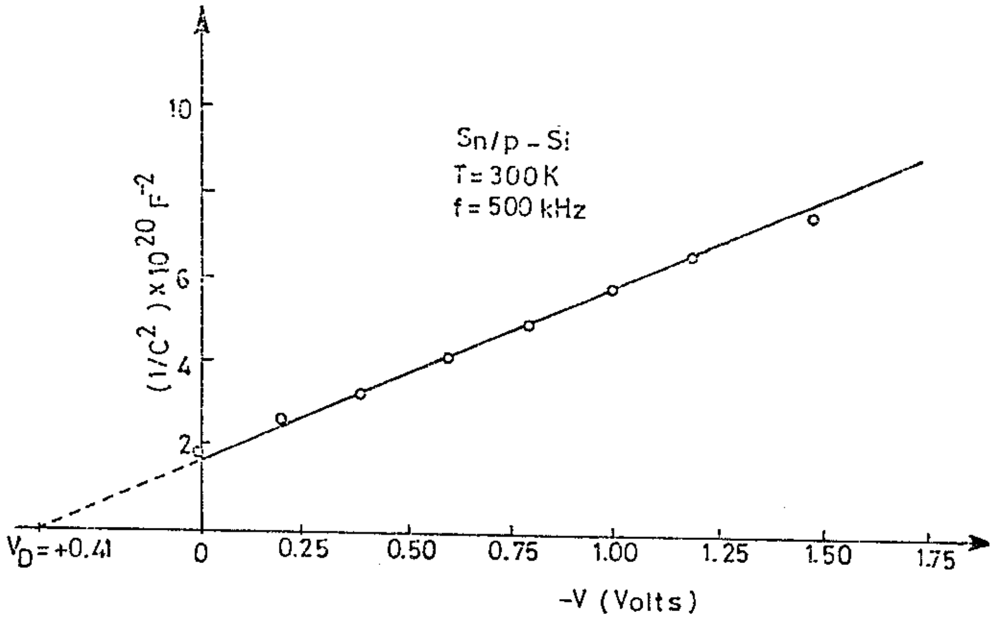

Figure - 4 : The characteristic of C^{-2} versus V of Sn/p-Si Schottky diode at reverse bias.