Ultrathin Te Films on Si(111): Schottky Barrier Formation and Photovoltaic Applications

Khaleel I. Hassoon

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.

Abstract

In this work, ultrathin trillium films were evaporated on chemically etched silicon substrate. Schottky barrier heights (SBHs) of Te contacting to n-Si were determined by analyzing dark current-Voltage (I-V) curves and illuminated short circuit current-open circuit voltage (I_{sc}-V_{oc}) curves. To eliminate the effect of series resistance we used Norde method to extract effective SBHs. Experimental results showed good reasonable agreement of the barrier height values. There is more than one mechanism to transport the current through the barrier. The possibility of using Te-nSi as a photovoltaic device is presented in this work.

افلام Teعلى (111) Si تكون حاجز شوتاكي والتطبيقات الفوتوفولتائية

الخلاصة

في هذا البحث تم تبخير اغشية تريليوم رقيقة جداعلى قاعدة سليكونية معالجة بعملية الازالة الكيميائية . ارتفاع حاجز شوتكي لاتصال التريليوم مع مع السيليكون السالب تم ايجاده من خلال تحليلات خصائص منحنيات تيار - جهد في حالة الظلام وخصائص منحنيات تيار الدائرة القصيرة - فولتية الدائرة المفتوحة. وللتخلص من تاثيرات مقاومة التوالي تم استخدام طريقة نورد لايجاد ارتفاع الحاجز. اظهرت النتائج التجريبية توافقا في قيم ارتفاع الحاجز.وان هناك اكثر من ميكانيكية واحدة لانتقال التيار عبر الحاجز. كذلك اوضح هذا البحث امكانية عمل اتصال كنبطية فولتائية ضوئية

1-Introduction

Contacts between ultrathin metal layers (≈100Å) and semiconductor are used in optical detectors, solar cells [1], and chemical sensors [2]. In this kind of contacts the barrier height of metal-semiconductor (MS) contact is the most important figure of merit. It can be determined by analyzing current-voltage (I-V) curves and capacity-reverse bias voltage(C-V) curves. These techniques are the most direct to extract the values of SBHs [3]. Conventional (I-V) characteristics depend essentially on the mechanisms of current flow over or through the barrier. Many experimental and theoretical studies of the current flow mechanism in Schottky barriers have been reported [1, 3- 4]. For example Crowell and Sze used Schottky's diffusion theory and Bethe's thermionic theory to evaluate the SBHs [5]. Toyoma studied a larger number of different metal-semiconductor contacts in the thickness range between 50-1500Å and demonstrated that barrier height and effective Richardson constant may vary significantly with thickness and deposition techniques. For many metals ultrathin films (≈100Å) can be deposited to obtain higher barrier height. H. C. Card [8] showed the possibility of extracting such barrier height using (Isc-Voc) measurement.

* Applied Sciences Department, University of Technology /Baghdad.

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2412-0758/University of Technology-Iraq, Baghdad, Iraq

2-Theory

The four mechanisms by which carrier transport occurs in Schottky barriers are thermionic emission over the potential barrier, carrier tunneling through the potential barrier, carrier recombination and/or generation in the depletion region, which is equivalent to minority carrier injection. Among them, the

$$J = J_o \exp[(V/nV_T) - 1] \quad (1)$$

Where J_o is saturation current density, $V_T = \frac{kT}{q}$ is the thermal energy, q is the charge of electron and n is the ideality factor which is given by:

$$\frac{1}{n} = V_T \frac{d\ln(J/J_o)}{dV} \quad (2)$$

When the thermionic emission current being dominant, the expression of J_o will be described as:

$$J_0 = A^* T^2 \exp(-j_{Bn}/V_T)$$

$$J_o = A^* T^2 \exp(-j_{Bn}/V_T) \quad .....(3)$$

Where A^* is the modified Richardson constant, j_{Bn} is the barrier height of metal-semiconductor (n-type) contact. The value of J_o is determined by extrapolation the straight line region of $(I - V)$ semi-log plot into a point where $V = 0$, and the value of j_{Bn} can be calculated from Eqn. (3).

If the base material presents a large series resistance to the contact, the straight line part of that plot will be very small and difficulties will arise of getting a reliable value of J_o . Taking series resistance in consideration, Norde

dominant modes of carrier flow in metal-semiconductor contact are thermionic emission and carrier tunneling [3]. In the case of thermionic emission, the total current density J as a function of applied voltage can be expressed as the following equation [1]:

[7] suggested the function $F(V)$ which is given by:

$$F(V) = \frac{V}{2} + V_T \ln\left[\frac{A^* T^2}{I}\right] \quad .... (4)$$

And the value of j_{Bn} will be computed by:

$$j_{Bn} = F(V_o) + \frac{V_o}{2} - V_T \quad .... (5)$$

Where $F(V_o)$ is the local minimum point of $F(V) - V$ curve, and V_o is corresponding point of V . Consequently, the series resistance R_S can be written as:

$$R_S = \frac{V_T}{I_o} \quad ..... (6)$$

Where I_o is the corresponding current to V_o .

Under illumination conditions, the open circuit voltage can be related with the short circuit current density by the relation:

$$V_{OC} = nV_T \left(\frac{J_{SC}}{J_o}\right) \quad ...... (7)$$

* Applied Sciences Department, University of Technology /Baghdad.

By varying incident power density and using Eqn.(7) the slop of $V_{OC} - \log J_{SC}$ give the value of n under illumination and the intercept of the resulting straight line with $J_{SC} - axis$ provides J_o.Thereby the barrier height can be estimated from Eqn.(3).

A (C-V) measurement is another method widely used to calculate SBHs and substrate concentration. Capacitance-Voltage relationship for abrupt junction is given by:

$$C^{-2} = (2/qe_s N_D)(V_{bi} - V - V_T) \quad \ldots(8)$$

Where C is junction capacitance perunit area, N_D is donor concentration, e_s is semiconductor permittivity and V_{bi} is the built-in potential.

From Eqn.(9) the extrapolated straight line of $(C^{-2} - V)$ plot intersects the voltage axis at the value of $V_{bi} - V_T$, and SBH may be determined by:

$$j_{Bn} = V_{bi} + V_n \quad \ldots..(9)$$

where $V_n \equiv E_C - E_F$ is the difference between the bottom of the conduction band energy and Fermi level. This difference can be evaluated by [1]:

$$V_n = V_T \ln(N_C / N_D) \quad \ldots.(10)$$

Where N_C is the effective density of states at the bottom of conduction band ($N_C = 2.8\times10^{19}$ cm^{-3} for silicon).

Lifetime is important in photovoltaic applications and solar cell design. This parameter was measured using open circuit voltage decay technique which is an accurate technique. Since these cells are horizontal-junction devices. The decay mode will correspond to a condition of intermediate injection, where the excess minority carrier concentration in the base is greater than the thermal-equilibrium minority carrier concentration but less than thermal equilibrium majority carrier concentration. Under these conditions the minority carrier lifetime can be determined from the following expression [12]:

$$t = \frac{kT}{q}\left|\frac{1}{dV_{OC}/dt}\right| \quad \ldots\ldots(11)$$

where t is the decay time.

3-Experimental Details

Single-crystal silicon wafers of n-type conductivity and (111) orientation are used as substrate. Their thickness is 0.055 cm and resistivity in the range 3-5 Ω.cm. Prior to deposition of trillium, these wafers were cut to pieces of area 0.12 cm^2, then chemically etched in dilute of hydrofluoric acid for 2 min. to remove the native oxide. High purity trillium was evaporated by thermal evaporation technique to obtain ultrathin film (100Å) deposited on silicon mirror-like surface. The back metallization was accomplished also by vacuum depositing of aluminum (2000Å). The evaporation for the two depositions processes was achieved under vacuum pressure down to 10^{-6} Torr. Using tube furnace with vacuum pressure down to 10^{-3} the annealing process has been done at temperature 473 K for 30 min.

Fig.(3) exhibits the variation of V_{OC} against $\log J_{SC}$. The linear variation enables one to determine J_O and the corresponding value of j_{Bn}. (C^{-2}-V) plot is given in Fig. (4). The figure illustrates a good conformity with Eqn. (8) and obviously indicates that the

These values are higher than the theoretical value by factor about 2.5. This can be attributed to the fact that Te-nSi contact is inconsistent with Schottky model, and this may be elucidated as the following: the work function of Te will be greater when Te brings into contact with nSi [3].

* Applied Sciences Department, University of Technology /Baghdad.

junction is an abrupt type. Donor concentration (N_D) has been determined from the slope of the plot and it was 1.1×10^{15} cm^{-3}.

4-Results And Discussions

A semi-log (I-V) plot under forward bias for Te-nSi Schottky diode is presented in Fig.(1). The ideality factor is about 2, this value reflects that the carriers transport is taken place by tunneling and recombination mechanisms associated with thermionic emission mechanism [9] also its obv ious from this figure that the precise extrapolation of the curve to the J-axis is difficult to obtain. Thus , the employing of Norde method is inevitable to determine the barrier height. Fig. (2) demonstrates the variation of F (V) against V for Te-nSi contact. j_{Bn} has been extracted from the local minimum point of the curve and tabulated in Table (1).

Reverse $(I-V)$ properties under white light illumination with different levels of power density are shown in Fig. (5).

is calculated from Equation(12). Fig. (6) shows the photograph of V_{OC} Decay curve. The experimental setup of lifetime calculation is presented elsewhere[9].The lifetime of Te-nSi The lifetime for as-deposited Te-nSi contact was around $8mm$, this value gives an indication that the recombination rate is low(i.e. minimum defects associated with the fabrication process).

From the figure it is evident that the generated photocurrent is significantly increased with light intensity (linear characteristics) and Te-nSi contact can be used as a power meter device. A good linearity can be concluded from Fig.(6) with linearity factor m=0.96 which is nearly equal to the ideal value(1).

5-Conclusions

Experimental study of near ideal rectifying contact Te-nSi has been shown that the barrier height does not obey to the simple theory proposed by Schottky. Three creditable methods are used to determine the value of the barrier height. There was a good agreement between these methods. $J-V$ characteristics revealed that the carrier transport mechanism across the junction is comprised of more than one mechanism.

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* Applied Sciences Department, University of Technology /Baghdad.

Table (1) Results of barrier heights and ideality factors contact

J-V					J_{SC}-V_{OC}			C-V	
$F(V_o)$	$I_o(\mu A)$	$R_S(k\Omega)$	n	j_{Bn}	$J_o(\mu A/cm^2)$	n	j_{Bn}	V_{bi}	j_{Bn}
0.745	18.2	1.42	2.8	0.75	2.8	3.4	0.74	0.75	0.76

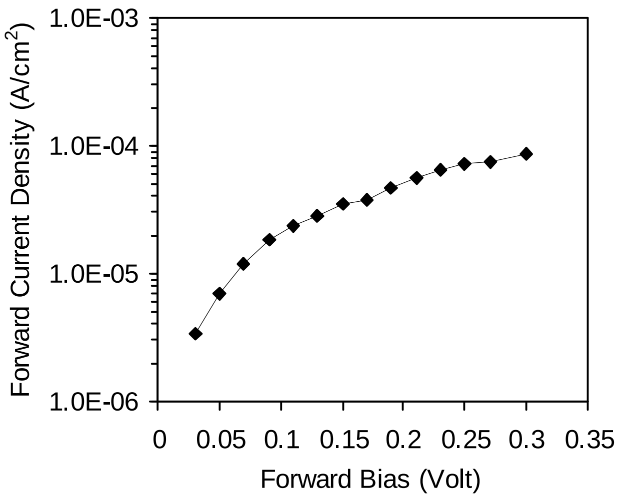

Figure (1) (J-V) characteristics of Te-nSi

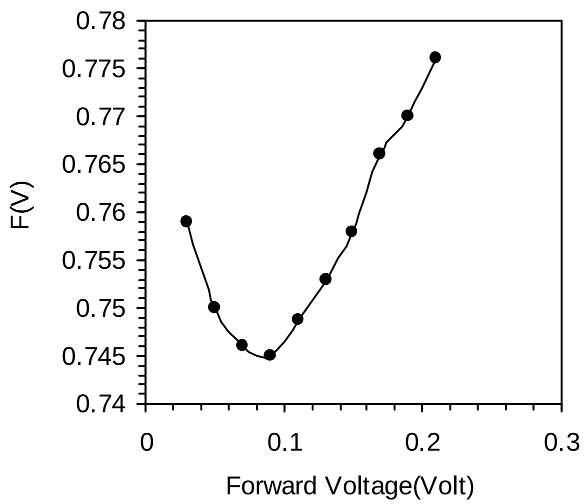

Figure (2) Norde function as a function of forward bias.

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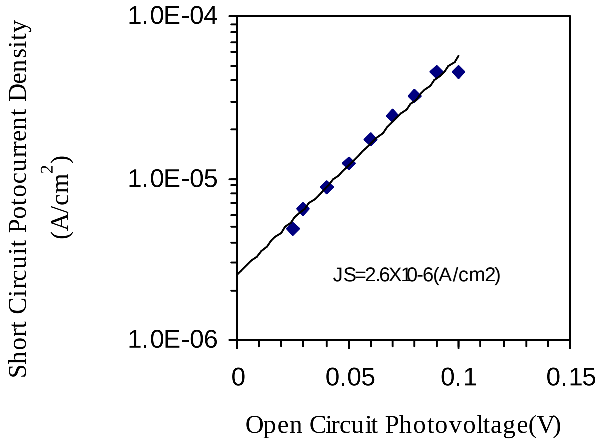

Figure(3) Photovoltaic characteristic of as-deposited Te-nSi.

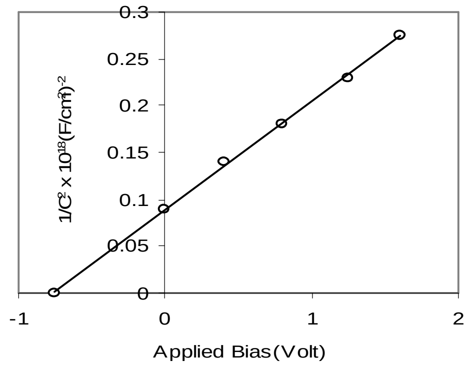

Figure (4) Reciprocal of square capacitance against reverse bias voltage

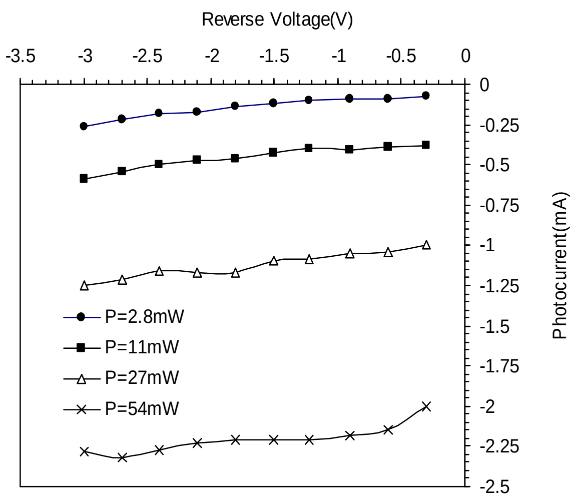

Figure (5) Output photocurrent at different levels of illuminations

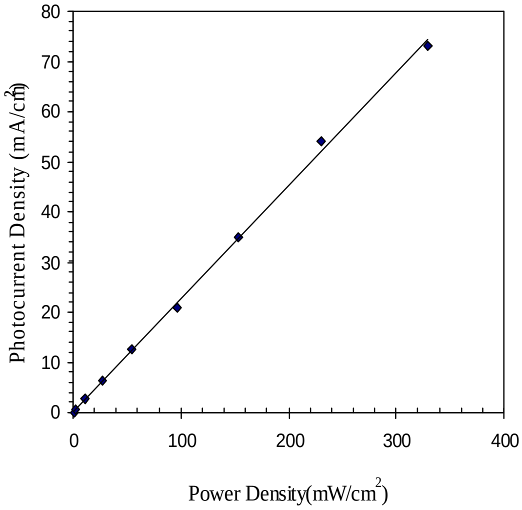

Figure (6) Output Photocurrent Density for different levels of power density

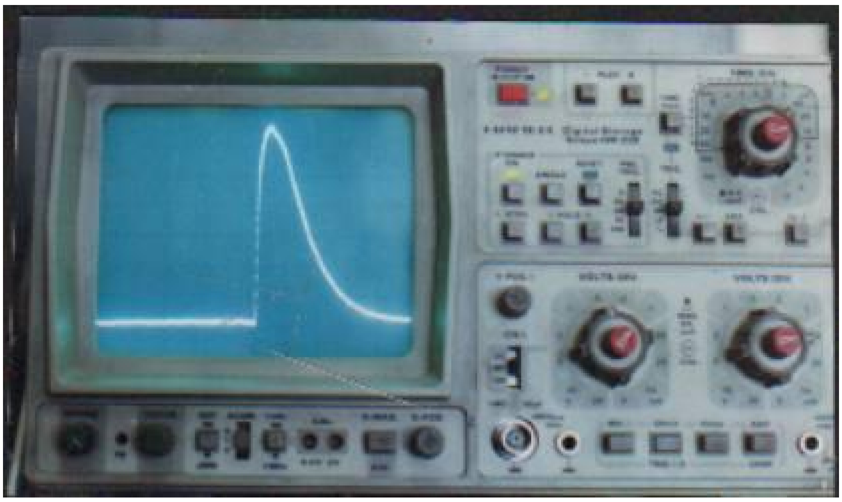

Figure (7) Voc decay curve presented by oscilloscope.