

## Electrical and Photovoltaic Properties of Sb-pSi Contact

Ammar Mukhleef Jasim\*

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### Abstract

In the present work, the electrical and photovoltaic properties of Sb-pSi contact were investigated for the first time. Two creditable methods were used to determine the value of barrier height for this contact. Experimental results showed a reasonable agreement with the simple Schottky-Mott theory. The contact showed good response to white light when it works under bias condition.

### دراسة الخصائص الكهروإلكترونية للمفروق Sb-pSi

#### الخلاصة

في هذا البحث جرى دراسة الخصائص الكهربائية والفولتية الضوئية لاتصال Sb-pSi ولأول مرة على حد علمنا . استخدمت طريقتان موثقتان لإيجاد قيمة حاجز الجهد لهذا الاتصال , إذ أظهرت النتائج اتفاقاً مقبولاً لقيمة ارتفاع الحاجز مع نظرية شوتكي - موت البسيطة . أظهر الاتصال استجابة جيدة للضوء الأبيض مما يؤهله للعمل كدايود ضوئي في مدى الأشعة المرئية.

### 1. Introduction

Metal – semiconductor photodiodes have attracted great attention for optoelectronic devices because of [1-3]:

- (a) their fast response;
- (b) a thin entrance window which allows the carriers to be generated in the sensitive region;
- (c) fabrication of the devices at room temperature so that no degradation in diffusion length and life time occurs; and
- (d) ability to be used on polycrystalline substrates.

In Schottky photo detectors, the junction or barrier consists of a layer of metal, usually transparent and a semiconductor, usually n-type silicon or gallium arsenide. The electron-hole pairs generated by incident radiation are separated by the potential barrier between the metal and the semiconductor [4].

In literature, Cu-CdS, Au-Si, Au-GaAs and so on [4] have been reported as Schottky photo detectors in the visible range (0.4-0.7  $\mu\text{m}$ ), while Ge Schottky photodiodes have been investigated and found to be working in the range (1-2  $\mu\text{m}$ ) [3].

The most important factor of metal-semiconductor (MS) contact is the value of the barrier height ( $\Phi_{\text{BP}}$ ). Many theories have been presented to explain the mechanism of current transport through such contact. The oldest successful one in the thermoionic emission theory was established by Bethe in 1942 [4]. Crowel and Sze [5] later refined this in 1966; the epitaxial silicide process developed by Tung in 1984 provides a new insight into intrinsic metal-semiconductor properties. A depth treatment and application of Schottky barrier structure can be found in references [5],[6].

\* School of Applied Sciences, University of Technology.

In this work, we have attempted to evaluate the barrier height of Sb-pSi and compare results with the Schottky simple theory.

## 2. Experimental procedure

Substrates of p-type single-crystal Si wafers [7] of resistivity 3-5 ohm-cm with 550 mm thick and 0.12cm<sup>2</sup> area and Silicon wafers were used to fabricate Sb-pSi Schottky contact cut from (111) orientation, and were used in the present study.

A layer (15nm thick) of a high purity Antimone (99.999%) was deposited onto mechanically polished silicon wafers using thermal evaporation technique. Prior to deposition these wafers were chemically etched in dilute hydrofluoric acid to remove native oxides. The vacuum pressure of the system was kept to be 10<sup>-5</sup> torr during evaporation. Ohmic contact was made on the non-polished surface by depositing 200 nm of aluminum. No antireflection coatings were used in this study.

## 3. Results and Discussion

When the thermoionic emission current being dominating, the expression of the saturation current density ( $J_s$ ) will be described as [5]:

$$J_s = A^* T^2 \exp\left(\frac{-q f_{Bp}}{K_B T}\right) \quad (1)$$

A\*:the modified Richardson constant.  
T: absolute temperature.

The value of  $J_s$  is determined by extrapolating the straight-line region of I-V plot to the point  $V=0$  and the value of  $\Phi_{Bp}$  can be extracted from eq.(1). A semi-log I-V plot under forward bias for Sb-pSi is

presented in Fig.(1).The ideality factor range between (1.5-2), these values reflect that the carriers transport takes place by tunneling and recombination mechanisms associated with thermoionic emission mechanism [8]. Also, it is difficult to obtain the precise extrapolation of the curve to the Y-axis. Thus, employing Norde [9] method is necessary to determine the barrier height.

The variation in  $F(V)$  against the forward bias voltage is presented in Fig (2). $\Phi_{Bp}$  was extracted from the local minimum point of the curve [9]. where  $F(V)$  given by:

$$F(V) = \frac{V}{2} + \frac{KT}{q} \ln \frac{A^* T^2}{I} \quad (2)$$

where:

K= boltzman constant,

T= temperature,

q= charge of electron,

A\* = richardson constant  
(112 for n-Silicon.)

Fig.(3) exhibits the variation in the open-circuit voltage ( $V_{oc}$ ) against the short-circuit current density ( $J_{sc}$ ). The linear variation enables one to determine  $J_0$  and saturation current density can be found from the following eq. [10]:

$$V_{oc} = \frac{n K_B T}{q} \ln J_{sc} - \frac{n K_B T}{q} \ln J_0 \quad (3)$$

The result of these two methods is presented in Table (I).

According to Schottky Model, the barrier height of MS contacts is given by [5] :

$$f_{Bp} = X_s - f_m + E_g \quad (4)$$

where  $X_s$  and  $E_g$  are the electron affinity and the energy gap of the semiconductor respectively, and  $\Phi_m$  is the metal work function. Thus the theoretical barrier height of Sb-pSi is

0.30eV from equation 4. This value is in disagreement with our practical value shown in Table (I). The deviation from Schottky simple theory can be attributed to the effect of surface states of Sb-pSi contact [5-8]. More than one mechanism in addition to thermoionic emission can contribute to transfer the current through the contact. The effect of recombination and tunneling mechanisms at  $V \geq 3kT/q$ , can high deviate the values of the  $n$  and  $\Phi_{Bp}$  of the contact [11]

One of the applications of Schottky barrier is to detect the light .Sb-pSi contact showed a good response to white light under reverse bias mode.

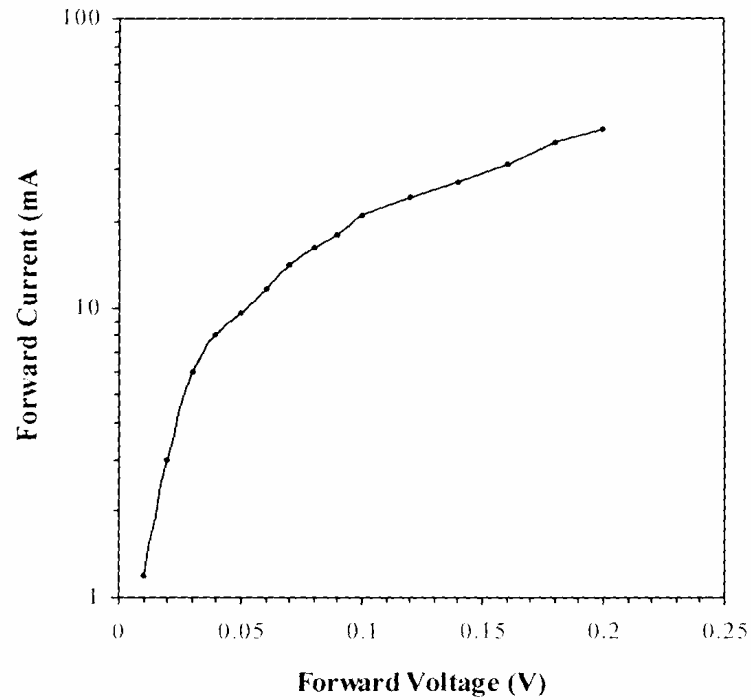
Fig.(4) shows the photocurrent under different levels of incident light. A good linearity can be obtained at low levels of illumination intensity as presented in Fig. (5).

#### 4. Conclusions

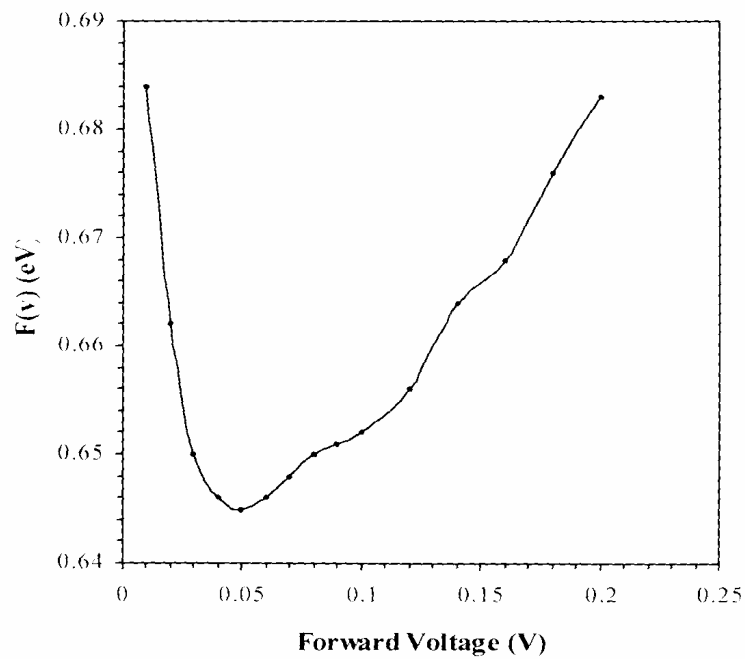
Experimental study for near ideal Sb-pSi contact shows that barrier height does not obey simple theory proposed by Schottky. Because of the effect of series resistance contact, it is necessary to adopt Norde method to extract the precise barrier height. The calculated  $\Phi_{Bp}$  from illuminated  $J_{SC} - V_{OC}$  plot and dark J-V plot is different. The Sb-pSi contact may be used as a detector in the visible region. This kind of detectors can be improved using an antireflection coating [11].

#### 5. References

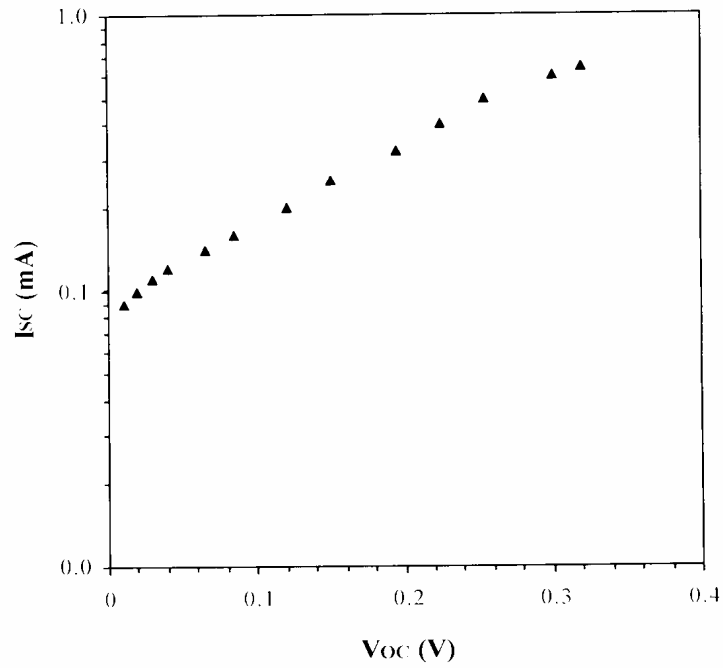
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**Fig. (1). Forward I-V characteristics of Sb-pSi contact.**



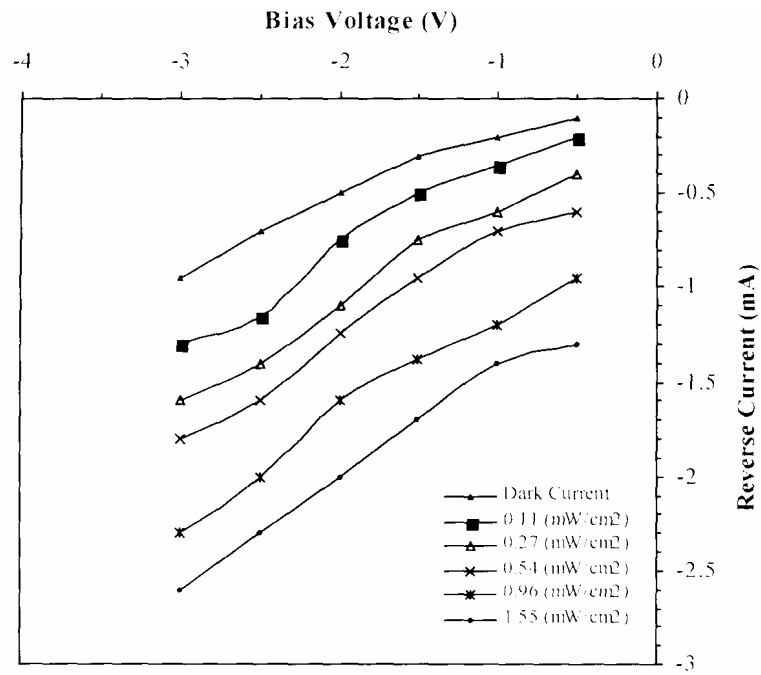
**Fig.(2).Calculated F(V) vs. the forward voltage through Sb-pSi contact.**



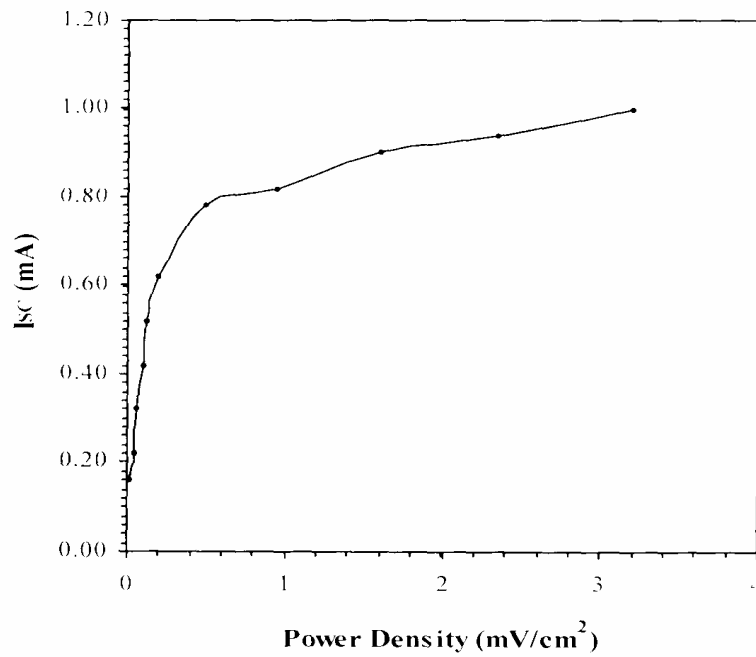
**Fig. (3). JSC - VOC characteristics of Sb-pSi contact**

**Table (I). Results of  $\Phi_{Bp}$  and n for as -deposited Sb-pSi contact.**

	J-V	$J_{SC}$ - $V_{OC}$	Norde Method
$\Phi_{Bp}$ (eV)	0.64	0.62	0.645
n	1.5	2	-



**Fig. (4).** Reverse photocurrent as a function of bias voltage.



**Fig.(5).** Short – circuit current versus illumination power density