

Measurement of I-V Characteristics of a PtSi/p-Si Schottky Barrier Diode at low Temperatures

Somayeh Gholami and Meysam Khakbaz

Abstract—The current-voltage characteristics of a PtSi/p-Si Schottky barrier diode was measured at the temperature of 85 K and from the forward bias region of the I-V curve, the electrical parameters of the diode were measured by three methods. The results obtained from the two methods which considered the series resistance were in close agreement with each other and from them barrier height (ϕ_b), ideality factor (n) and series resistance (R_s) were found to be 0.2045 eV, 2.877 and 14.556 K Ω respectively. By measuring the I-V characteristics in the temperature range of 85-136 K the electrical parameters were observed to have strong dependency on temperature. The increase of barrier height and decrease of ideality factor with increasing temperature is attributed to the existence of barrier height inhomogeneities in the silicide-semiconductor structure.

Keywords—Schottky diode, barrier height, series resistance, I-V, barrier height inhomogeneities.

I. INTRODUCTION

PLATNUM Silicide films are extensively used in silicon devices and ICs to form Schottky barriers and ohmic contacts. Infrared detection is a special application of PtSi/p-Si Schottky barrier. PtSi/p-Si Schottky barrier detector has received a lot of attention as the most promising infrared sensor for large focal plane array applications due to its ease of fabrication, uniformity, compatibility with today's IC technology and low cost [1]. Electrical characteristics of such diodes are often influenced by various non-idealities such as interface states, interfacial oxide layer and series resistance. At low voltages the forward bias current-voltage (I-V) characteristics are linear in the semilogarithmic scale but when the applied voltage is large enough, they deviate considerably from linearity due to the effect of series resistance (R_s), the interfacial layer and interface states. Series resistance (R_s) is the total resistance of bulk of the semiconductor, contact wires and ohmic contacts. Norde [2] was the first who proposed a method to determine R_s from forward bias I/V curves of Schottky diodes. He defined a special function F(V) and showed that for ideal Schottky diode (n=1) R_s can be obtained by finding the minimum of F(V). But Norde's method was not applicable for real diodes with n>1. Cheung and Cheung [3] proposed another model for diodes with n>1 and derived the

diode parameters from only one single I-V measurement. In this work, we have investigated the electrical parameters of PtSi/p-Si Schottky diode obtained from the experimental forward bias current-voltage (I-V) characteristics at the temperature of 85K. We compared the parameters obtained with three different methods which are all based on I-V characteristics of the diode. To investigate the temperature-dependency of electrical parameters, I-V characteristics were measured in the temperature range of 85-136K. Experimental results show that ideality factor, barrier height and series resistance are strong functions of temperature.

II. EXPERIMENTAL PROCEDURE

The diodes were fabricated on p-type (100) Si substrate with resistivity of 4-11 Ω cm. The samples were chemically cleaned using the standard RCA cleaning procedure and rinsed in deionized water and dried. Before ohmic contacts formed on the p-type Si substrates, the samples were dipped in dilute HF:H₂O (1:10) for about 3 min to remove any native oxide layer on the surface, and finally the samples were rinsed with deionized water and dried with high purity nitrogen and inserted into the deposition chamber immediately after cleaning. To form ohmic contacts we thermally evaporated high purity Al with a thickness of 2060 Å on the surface of the samples at the pressure of 10^{-5} mbar and then annealed the evaporated Al at 550 $^{\circ}\text{C}$ for 5 min at the pressure of 7×10^{-6} mbar. All the metal depositions were done through metal shadow masks. To fabricate PtSi layer, Pt film with a thickness of 80 Å was evaporated with an electron gun system on the cleaned Si surfaces and samples were annealed in a vacuum of 7×10^{-6} mbar at 470 $^{\circ}\text{C}$ for 30 min. To form the metal electrodes (rectifier and ohmic contacts), Al usually have been used. But Al has high diffusion ability and can lead to degradation of the contacts therefore in this work to prevent the problem of Al diffusion into Si, we used Ti as a diffusion barrier between PtSi and Al. 800 Å of Ti was evaporated on PtSi layer at the pressure of 10^{-6} mbar and finally, Al films of 3000 Å thickness were evaporated on Ti layer.

The cross-sectional and top views of the fabricated PtSi/p-Si diode are shown in Figs. 1 and 2 respectively. For the I-V measurement, the device was mounted on the cold work surface of a Dewar at liquid nitrogen temperature. An HP 4145B instrument was used to measure the I-V characteristics at the PtSi SBD.

Somayeh Gholami is with the Electrical Engineering Department, Islamic Azad University, Qaemshahr Branch, Iran (corresponding author to provide phone: +98-911-311-3037; e-mail: so_rudi@yahoo.com).

Meysam Khakbaz is with Islamic Azad University, Qaemshahr Branch, Iran.

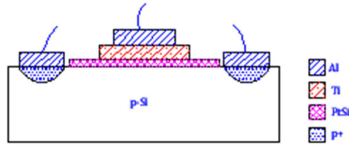


Fig. 1 Cross-sectional view of PtSi/p-Si Schottky diode

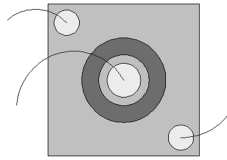


Fig. 2 Top view of PtSi/p-Si Schottky diode

III. RESULTS AND DISCUSSIONS

For a Schottky barrier diode with assumption that the current is due to thermionic emission, the relation between the applied forward bias and current can be expressed as [4]

$$I = I_0 \exp\left(\frac{qV}{nkT}\right) \left[1 - \exp\left(\frac{-qV}{kT}\right)\right] \tag{1}$$

that (1) for $V > 3kT/q$ can be written as

$$I = I_0 \exp\left(\frac{qV}{nkT}\right) \tag{2}$$

where n is the ideality factor, T is the temperature in Kelvin, q the electronic charge, k is the Boltzmann constant and I_0 the reverse saturation current which can be extracted by extrapolating the straight line of $\ln I$ to intercept the axis at zero voltage

$$I_0 = AA^*T^2 \exp\left(\frac{-q\phi_b}{kT}\right) \tag{3}$$

where A is the effective diode area, A^* is the effective Richardson constant which is equal to $32 Acm^{-2}K^{-2}$ for p-Si and ϕ_b is the zero-bias barrier height which can be obtained from (3) as

$$\phi_b = \frac{kT}{q} \ln\left(\frac{AA^*T^2}{I_0}\right) \tag{4}$$

Ideality factor, a parameter which is generally used to measure the deviation of practical diodes from ideal thermionic emission model can be extracted from slope of the linear region of the $\ln I$ - V plot and can be written from (2) a

$$n = \frac{q}{kT} \left(\frac{\partial V}{\partial(\ln I)}\right) \tag{5}$$

Fig. 3 shows the experimental I-V characteristics of our PtSi/p-Si diode at the temperature of 85K in dark. Since the current curve in forward bias quickly becomes dominated by series resistance and deviates from linearity we used the low

forward bias part of I-V characteristics to measure n , ϕ_b . Taking natural logarithm of (2) we have

$$\ln I = \ln I_0 + \frac{q}{nkT} V \tag{6}$$

According to (6) after performing least square fitting on the $\ln I$ - V plot in the linear region of experimental data as in Fig. 4, we determined the value of n , I_0 from the slope and the y-axis intercept of the fitted straight line.

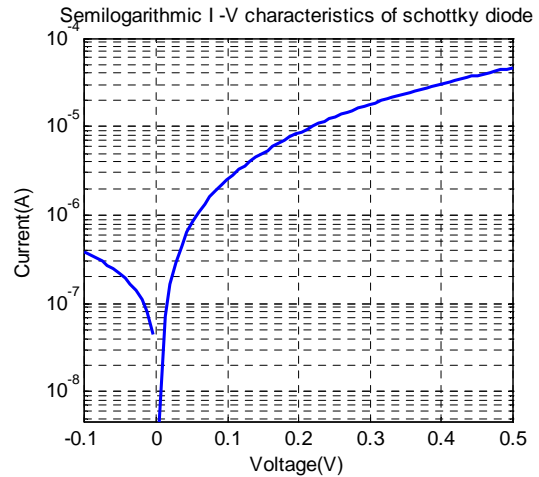


Fig. 3 I-V characteristics of the PtSi/p-Si Schottky diode at the temperature of 85K in dark

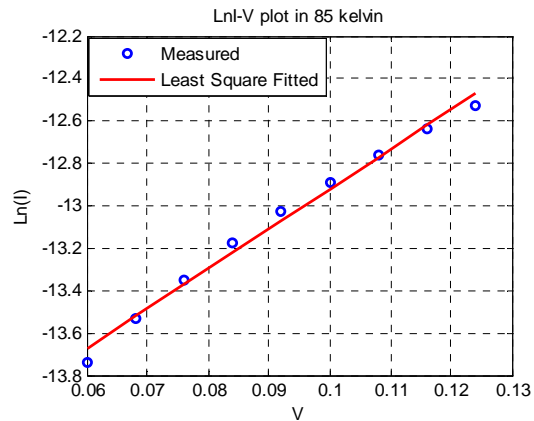


Fig. 4 $\ln I$ - V plot of the PtSi/p-Si Schottky diode at the temperature of 85K in dark

Using (4) n , I_0 , ϕ_b were determined to be 7.27, $3.748 \times 10^{-7}A$ and 0.1971 eV respectively in 85K. But this method only works for diodes with low series resistance which can be neglected in the low forward region of I-V curve which in the case of our diode it seems as if it did not.

Series resistance R_s is an important parameter that influences the electrical characteristics of Schottky diodes so we used Cheung method as an efficient method to evaluate n , ϕ_b and R_s . The forward bias current-voltage characteristics due to thermionic emission of a Schottky barrier diode with series resistance can be expressed as Cheung's functions [3]:

$$\frac{dV}{dLnI} = n \frac{kT}{q} + IR_s \tag{7}$$

$$H(I) = V + n \frac{kT}{q} Ln \left(\frac{I}{AA^*T^2} \right) \tag{8}$$

$$H(I) = n\phi_b + IR_s \tag{9}$$

Experimental $dV/dLnI$ vs. I plot of our PtSi/p-Si Schottky diode at the temperature of 85 K is presented in Fig. 5 After fitting the curve to a straight line and using (7), n and R_s can be determined from the intercept and the slope of the line.

The value of n and the data of I-V characteristics are used to define $H(I)$ from (8). Plotting $H(I)$ vs. I should give a straight line as shown in Fig. 6 which according to (9) its slope and y-axis intercept will give a second determination of R_s and $n\phi_b$. Having two values of R_s we can check the consistency of Cheung's method. The values of R_s obtained from $dV/dLnI$ vs. I and $H(I)$ vs. I plots which are 13.975K Ω and 15.137K Ω respectively are in good agreement with each other. This case shows the consistency of Cheung's approach. The average R_s value for the diode was obtained to be 14.556K Ω .

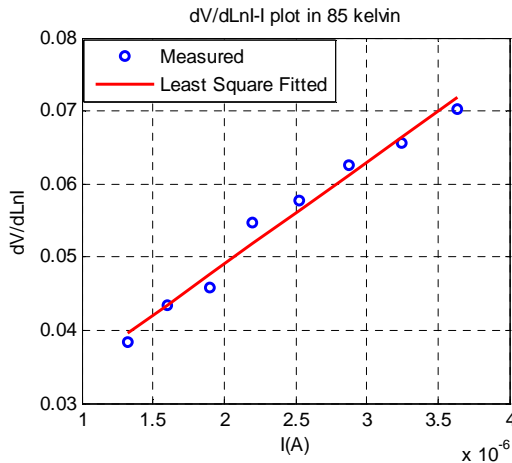


Fig. 5 The $dV/dLnI$ vs. I plot of PtSi/p-Si Schottky diode at the temperature of 85 K

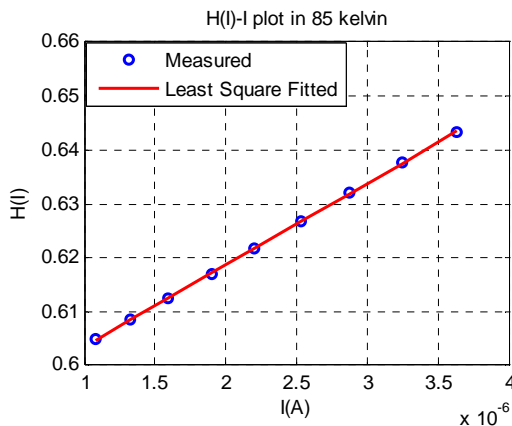


Fig. 6 The $H(I)$ vs. I plot of PtSi/p-Si Schottky diode at the temperature of 85 K.

The values of R_s and n from $dV/dLnI$ vs. I plot and R_s and ϕ_b from $H(I)$ vs. I plot are all given in Table I.

As a third approach to determine n , ϕ_b and R_s , we modeled the real Schottky diode with an ideal diode in series with a resistance R_s . According to thermionic emission theory the forward bias I-V characteristic of the diode can be described by

$$I = AA^*T^2 \exp \left(\frac{-q\phi_b}{kT} \right) \exp \left(\frac{qV_D}{nkT} \right) \tag{10}$$

and V_D which is the voltage across the metal-semiconductor interface in the Schottky diode can be written as

$$V_D = \frac{nkT}{q} Ln \left(\frac{I}{AA^*T^2} \right) + n\phi_b \tag{11}$$

V which is the applied or experimentally measured voltage in the Schottky diode circuit considering the equation $V = V_D + R_s I$ can be expressed as

$$V = \frac{nkT}{q} Ln \left(\frac{I}{AA^*T^2} \right) + n\phi_b + IR_s \tag{12}$$

This equation has three unknown parameters which are n , ϕ_b and R_s . Using (I, V) experimental data we can solve this equation. Since we have 3 unknowns and more than three (I, V) or simultaneous equations we cannot expect to get values for n , ϕ_b and R_s that would exactly satisfy all equations. For this reason we used the least square fitting approach which gives us the opportunity of using more data points and hence increasing the accuracy of the solution. The values of n , ϕ_b and R_s obtained by this method are also given in Table I. Comparing the values of n , ϕ_b and R_s derived from three methods described above, it can be seen that the values obtained from the last two methods which consider series resistance are in close agreement with each other. This consistency is a good reason for proving the efficiency of these methods but the first method (basic I-V method) which neglects the series resistance leads to a large ideality factor that does not seem reasonable. So neglecting the series resistance especially when it is large can cause errors in calculating electrical parameters of the Schottky diode.

TABLE I
THE EXPERIMENTAL VALUES OF SOME PARAMETERS OBTAINED FROM I-V CHARACTERISTICS IN THREE METHODS

Electrical parameter	Barrier height (eV)	Ideality factor	Series resistance (K Ω)
First method	0.1971	7.27	-
Second method	0.2045	2.8774	14.556
Third method	0.2044	2.9082	15.033

I-V characteristics of diode have been measured in the temperature range of 85-136 K. It was observed that values of n , ϕ_b and R_s are strong functions of temperature. With increasing temperature, barrier height is increased while ideality factor decreased. As can be seen from Table II the value of barrier height is measured to vary from 0.2045 eV in 85K

to 0.3019 eV in 136K and the value of ideality factor decrease from 2.9082 in 85K to 2.158 in 136K.

TABLE II

TEMPERATURE DEPENDENT VALUES OF VARIOUS EXPERIMENTAL PARAMETERS OBTAINED FROM I-V MEASUREMENTS OF PtSi/p-Si SCHOTTKY DIODE

Temperature(Kelvin)	Barrier height (eV)	Ideality factor	Series resistance (K Ω)
85	0.2044	2.9082	15.033
90	0.2163	2.8613	14.629
95	0.2296	2.7195	14.519
100	0.2412	2.702	14.023
105	0.2451	2.6743	10.426
110	0.2576	2.6401	10.426
115	0.2702	2.6278	10.426
120	0.2772	2.5945	8.129
125	0.2869	2.5626	7.455
128	0.2907	2.5171	6.343
133	0.2971	2.1903	5.115
136	0.3019	2.158	5.115

These temperature dependencies can be explained satisfactorily by assuming the existence of barrier inhomogeneities and describing them with Gaussian distribution of BHs. Since current transport across metal-semiconductor interface is a temperature-activated process, at low temperatures electrons are able to surmount the low barriers and therefore current transport will be dominated by current flowing through patches of lower SBH and a larger ideality factor. In other words, as the temperature increases more electrons have sufficient energy to overcome the higher barrier. Therefore the dominant barrier height will increase with the rise of temperature [5]. It is also seen that the value of R_s strongly varies with temperature and falls from 14.556 K Ω in 85K to 5.1 K Ω in 136K. The increase of series resistance with the fall of temperature is believed to result from lack of free charge carriers at low temperatures [6]. In our case the large values of R_s at low temperature can also be attributed to the nonideality of the ohmic contact.

IV. CONCLUSION

In this paper the I-V characteristics of a PtSi/p-Si Schottky barrier diode was measured at the temperature of 85K. We compared the parameters obtained with three different methods which are all based on I-V characteristics of the diode. It was observed that the results of the two modified methods (second and third methods) which considered series resistance were in close agreement with each other but the basic I-V method which neglected the series resistance gave a large ideality factor which did not seem reasonable. We concluded that the basic I-V method does not work properly for diodes with large series resistance like our diode. By measuring the I-V characteristics in the temperature range of 85-136 K the electrical parameters were observed to have strong dependency on temperature. The increase of barrier height and decrease of ideality factor with increasing temperature is attributed to the existence of barrier height inhomogeneities in the silicide-semiconductor structure.

REFERENCES

- [1] M.C. Li, L.C. Zhao, X.H. Zhen, X.K. Chen, "Effects of annealing processing on morphological, compositional and Schottky characterization of PtSi/Si diodes," *Materials Letters*, vol. 57, 2003, pp. 3735-3740.
- [2] H. Norde, "A modified forward I-V plot for Schottky diodes with high series resistance," *J. Appl. Phys.*, vol. 50, no. 7, 1979, pp. 5052-5053.
- [3] S.K. Cheung, N.W. Cheung, "Extraction of Schottky Diode Parameters from Forward Current- Voltage Characteristics," *Appl. Phys. Lett.*, vol. 49, 1986, pp. 85-87.
- [4] E.H. Rhoderick, *Metal- Semiconductor Contacts*, Clarendon, Oxford, 1988.
- [5] Ş. Karataş, Ş. Altındal, A.Türüt, A. Özmen, "Temperature dependence of characteristics parameters of the terminated Sn/p-Si(1 0 0) Schottky contacts," *Appl. Surf. Sci.*, vol. 217, 2003, pp. 250-260.
- [6] D. Donoval, M. Barus and M. Zdimal, "Analysis of I-V measurements on PtSi-Si Schottky structures in a wide temperature range," *Solid-State Electron.*, vol. 34, 1991, pp. 1365-1373.