Journal of Nanotechnology & Advanced Materials
An International Journal

http://dx.doi.org/10.18576/jnam/050202

The Change of Series Resistance and Conductance-Voltage-Frequency Characteristics of Cu/N-Si Schottky Diode Exposed To Air

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Received: 29 Jan. 2016, Revised: 10 May 2016, Accepted: 17 May 2016.
Published online: 1 Jul. 2017.

Abstract: Semiconductor surfaces are easily oxidized by exposure to air for extended period of time. In this work we want to examine the change of series resistance and conductance of Cu/n-Si Schottky diode upon being exposed to air. We studied the effects of native oxide layer on current-voltage (I-V), capacitance-voltage (C-V), conductance-voltage (G/w-V) and conductance-frequency (G/w-f) characteristics of Cu/n-Si Schottky diode. For this aim, we fabricated one reference diode and five Cu/n-Si diodes exposed to air for extended period of time. From I-V plot of the Cu/n-Si/Al diodes ideality factor (n), saturation current (I_0) have been calculated. Barrier height ($e\Phi_b$) and series resistance (R_S) have been calculated by using Norde functions. C-V, G/w-V and G/w-f characteristics of diodes have been examined. The obtained results show that native oxide layer have an important effect on the values of series resistance, barrier height, ideality factor and conductance of studied diodes. The value of ideality factor and series resistance increased with time of exposure to air, while the barrier height $e\Phi_b$ values of air-exposed Schottky diode is smaller than that of the reference diode. The differences of series resistances between reference diode and air-exposed diodes are high while within air-exposed group small differences of series resistance are observed.

Keywords: Exposure to air, Schottky barrier diodes, series resistance, conductance-voltage.

1 Introduction

It is well known that the semiconductor surface is easily oxidized by exposure to air for extended period of time [1] and this oxide layer is effective on series resistance of Schottky diodes [2, 3]. During to fabrication process, unless specially processing, some degree of oxidation generate a thin interface oxide layer between the metal and the semiconductor [4]. In the laboratory environment, organic contamination and native oxide layer covers semiconductor crystal surface [5, 6]. The existence of such an insulating layer converts the metal-semiconductor (MS) device into metal-insulator-semiconductor (MIS) device and can have strong effects on the electrical parameters of diode [7-8].

The series resistance, ideality factor and barrier height determines main features of a diode [2, 9]. Gupta and Yakuphanoğlu were examined series resistance and conductance dependent voltage and frequency [2]. Orak *et al*. were studied the effect temperature on Co/n-GaP Schottky diodes. In addition, obtained that values series resistant were nonideal [10]. M. Kumar *et al*. compared MS and MIS diodes and concluded that the native oxide layer at a Schottky rectifying contact play an important role in the electrical parameters of device [8]. Bachir *et al.* studied and plotted Ti/Au/GaAsN Schottky didodes' capacitance-voltage characteristics [11]. Çetinkara *et al*. observed that the non-ideal forward bias I-V behaviors in the Au/n-GaAs Schottky diodes were attributed to change in the MS barrier height due to the interface states and interfacial layer [1]. Ilbilge studied effect thermal growth oxide layer on the Al/p-Si Schottky diode and obtained that the R_S values of the sample without oxide layer had been found to be smaller than those of sample with oxide layer [12]. Ha. *et al*. suggest that the simple post-oxidation processes are suitable for fabrication of high-voltage GaN devices [13]. Kılıçoğlu *et al.* concluded that the values of ideality factor (n), series resistance (R_s) and interface state density with oxide layer have been found to be higher than values of sample without oxide layer [14]. Çetin and Ayyıldız obtained that oxide thicknesses and atomic concentration of oxygen quantity on the surface increased with increasing exposure time to air [6]. When the contact formed on the oxidized surface, air-grown oxide did not cause barrier height enhancement for Cu/n-InP contacts [6]. Çetinkara and Güder obtained that n and $e\Phi_B$ values of the air exposed Pb/p-Si Schottky diodes have reached to saturation after ten days air-exposure and this result have been interpreted as the saturation of the oxide layer thickness [5]. Özdemir *et al.* obtained that Φ_B value for interfacial layer decreased by increasing the exposure time of Au/n-GaAs

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Schottky diodes [15]. Values of barrier heights for Au/n-GaAs Schottky diodes decreased, by increasing exposure time up to ten days. Barrier height value remains unchanged from 10^{th} up to 45^{th} day [15]. Ilbilge concluded that the behavior n and R_s values of Schottky diodes with oxide layer are higher than those of Schottky diode without oxide layer while the $e\Phi_B$ value of the Schottky diode with oxide layer is smaller than those of the diode without oxide layer [12, 16].

At the literature, there are many studied related with different metal- semiconductor interface oxidation. In this paper, we aimed to show effect of the oxidation at the Cu /n-Si Schottky diodes. It is important to know this effect in the experiment, because it is almost impossible to get rid of the oxide layer from interface [1]. If there is a thick oxide layer between interfaces rectifying contact, metal-semiconductor (MS) can be converted to metal-insulator-semiconductor (MIS) devices. Therefore, we want to know the effect exposure to air on the Cu/n-Si contact.

In this work we have intended to understand and to measure the change of series resistance, conductance, barrier height and ideality factor characteristics of Cu /n-Si Schottky diodes with native oxide layer by exposure time to air in the clean room.

2 Experimental procedure

In this work we used n-Si wafers with (100) orientation, 350 μm thickness and ρ=15 Ω.cm resistivity. The samples were chemically cleaned to get rid of chemical and organic contamination [14-17]. For this aim, samples were firstly boiled for 10 minutes in RCA (NH_4H+H_2O_2+6H_2O) and then in (HCl+ H_2O_2+6H_2O). Finally samples were etched in HF:H_2O(1:10) for 30 s. and rinsed in deionised water by ultrasonic vibration [10, 14]. The n-Si wafer was cut into six pieces, then ohmic contact were made to back side of these pieces of samples by evaporating cleaned Al at the 10^{-6} torr pressure and samples were heated 420 ºC for 5 min. in N_2 gas [3]. One of prepared samples was immediately inserted into evaporation chamber by evaporating cleaned Cu at the 10^{-6} torr pressure on the front side to form rectifying contact [6, 7]. That sample was chosen as reference Cu/n-Si Schottky diode and labeled D(ref). Other samples of D(05d.), D(15d.), D(20d.), D(30d.) and D(45d.) were exposed to clean air at the room temperature for 5, 10, 15, 20, 30 and 45 days to obtain the samples with the native oxide layer on the polished n-Si surface and finally Cu was evaporated to front side under 10^{-6} torr pressure to form rectifying Schottky contact formation [6,7].

So samples ready to measurement. ‘’It was measured that different contacts on the same sample that most of them showed the same characteristic electrical properties. One of them was used for the analysis electrical properties of diodes.’’

I-V Measurements were plotted as I-V from which Norde function is calculated and graphs are drawn [3, 18, 19]. From Norde function series resistance (R_S) and barrier height ($e\Phi_B$) were calculated [18, 15]. From I-V plot of the Cu/n-Si diode, ideality factor (n) and saturation current (I_0) have been calculated [2, 8, 17].

C-V, G/w-V and G/w-f measurements of diodes were made at room temperature (300^0K) for 0.5 MHz frequency. We were plotted C-V, G/w-V and G/w-f measurements of diodes characteristics [1, 11, 17, 20, 21].

3 Result and Discussion

According to thermionic emission theory, current-voltage characteristics of a Schottky diode can be expressed as [22-27, 32]. Forward bias current equation for non-ideal condition is given by

$$I = I_0\left[\exp\left(\frac{e(V-IR_s)}{nkT}\right)-1\right] \tag{1}$$

where n is ideality factor, V is forward bias voltage, e is the electronic charge, R_s is series resistance, this represent *resistance of the neutral region on the semiconductor bulk (between the depletion region and ohmic contact)* [28], k is the Boltzmann constant, T is temperature in Kelvin, I_0 is the saturation current derived from the straight line intercept of the *ln*I axis at V=0 and given by,

$$I_0 = AR_n^* T^2 \exp\left(-\frac{e\phi_B}{kT}\right) \tag{2}$$

And where R_n^* is the Richardson constant (112 A/ cm^2 K^2 for n-type Si) [1, 2, 19, 31]. A is the effective diode area (radius is 0.4 mm), and $e\Phi_B$ is the effective barrier height.

The n ideality factor is determined from slope of the linear region of the forward bias in *ln*(I)-V characteristic through the relation [28-32]

$$n = \frac{e}{kT}\frac{dV}{d(\ln I)} \tag{3}$$

Figure 1 represents the forward bias current–voltage characteristics of the Cu/n-Si diodes. It can be seen from Figure1 that value of I-V plots for all diodes except the reference one, for other samples less clustering occurred. This is attributed to after certain days change in properties diodes were little [23]. For ideal diode, ideality factor (n) equals to 1 and it can be greater than unity experimentally [5, 7]. The values ideality factor (n) are obtained from the I-V graphs [4, 18]. The values of ideality factor of Cu/n-Si diode were obtained as in the range from 1.03 to 1.25. High values of the ideality factor imply existence of native oxide layer and diodes obey metal-interface-semiconductor [6, 18]. This implies that the silicon surface is covered with thin oxide layer [1, 6].

To obtain resistant and series resistance (R_s) and barrier height ($e\Phi_B$) Norde function was used [3, 17, 18].

$$F(V) = \frac{V}{2} - \frac{kT}{e}\left(\frac{I(V)}{AR_n^* T^2}\right) \tag{4}$$

Where I(V) is the current obtained from I-V measurements, the barrier height ($e\Phi_B$) determined using the minimum value of F(V)-V plot by means of the relation

$$\varphi_B = F(V_0) + \frac{V_0}{2} - \frac{kT}{e} \tag{5}$$

at which F(V_0) is the minimum F(V) value and V_0 is corresponding voltage value of F(V)-V curve of Cu/n-Si which is drawn in Fig. 2. The series resistance (R_s) of the diodes can be written as

$$R_s = \frac{kT(2-n)}{eI_{\min}} \tag{6}$$

Here, I_{min} is corresponding current value at V_0 [10,13, 19]. The series resistance (R_s) and barrier height ($e\Phi_B$) were calculated using Eqs.(5) and (6) shown as in *Table 1*.

The series resistance (R_s) was obtained to be in range from 136 Ω to 995 Ω while the barrier height ($e\Phi_B$) range is from 0.84 eV to 0.69 eV. All values were inserted in *Table* 1.

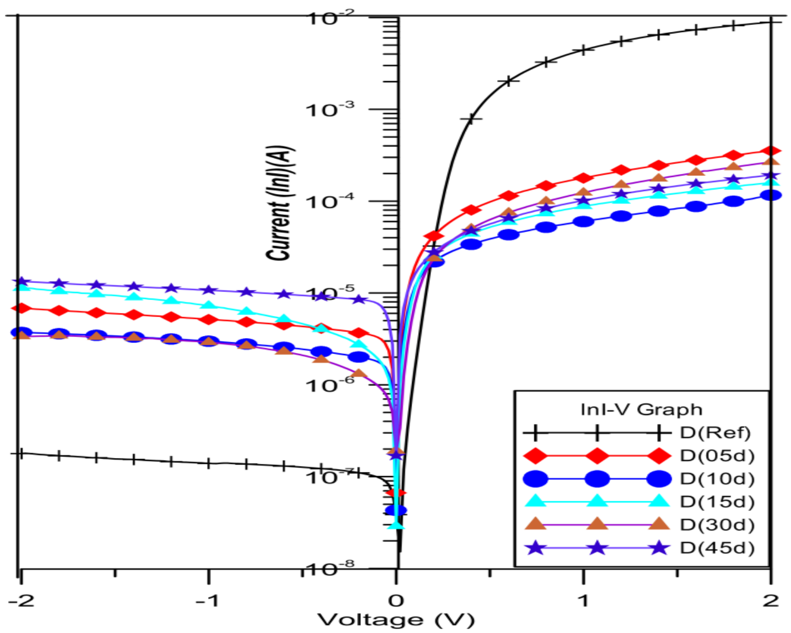

Figure 1. The forward and reverse bias current-voltage (I-V) characteristics of Cu/n-Si Schottky diodes.

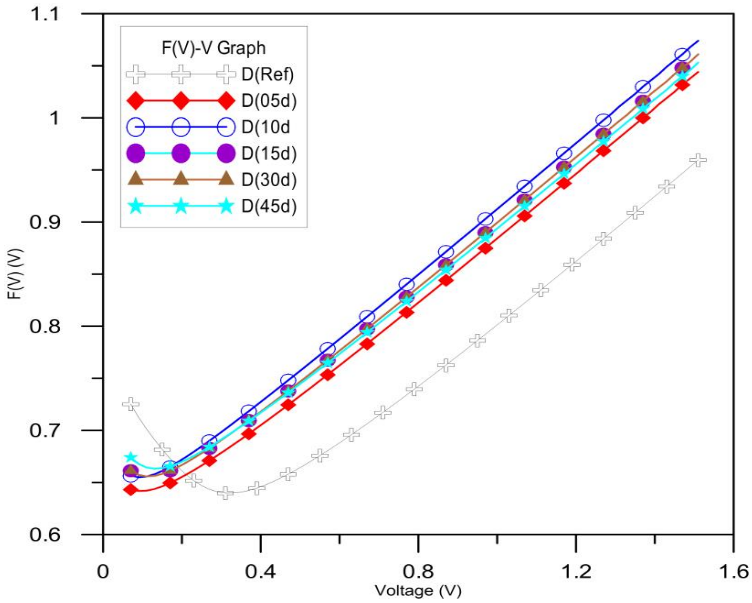

Figure 2. Norde Function versus Voltage [F(V)-V] characteristics of The Cu/n-Si Schottky diodes

It is can be seen from *Figure 3* that series resistance increased with increasing exposure time up to 10 days generally. After 10 days, the value of series resistance remains nearly unchanged between 859 and 995 Ω up to 45 days.

From *Figure 4* it is seen that the value of ideality factor increased with increasing exposure time, in contrary, barrier height eΦ_b values of the Schottky diodes decreased with increasing exposure time to air [5, 6, 14, 23]

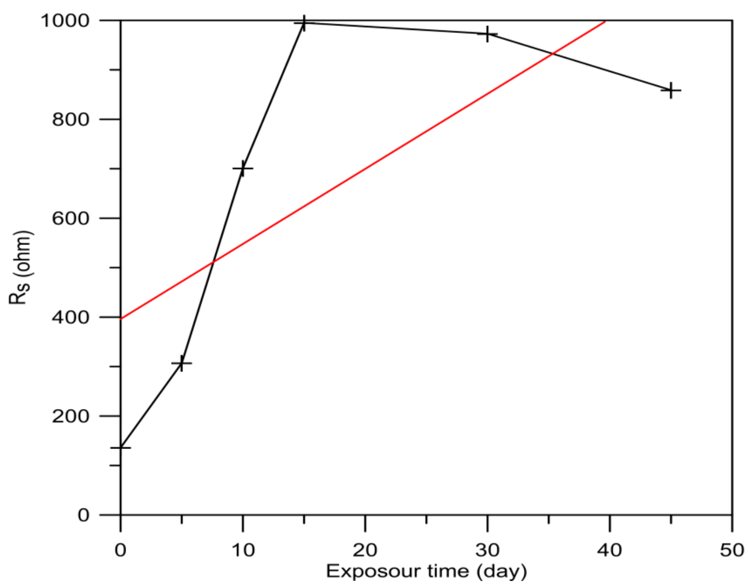

Figure 3. The series resistance versus exposure time to air obtained from F(V)-V characteristics of Cu/n-Si Schottky diodes.

C-V measurements of Cu/n-Si diodes were carried out for 500 kHz frequencies at room temperature in darkness, and presented in *Figure 5* from which one can see that capacitance at negative voltages capacity curves are close together and small, but at positive voltages capacitance peaks change with increasing series resistance [2]. Average values of peaks of plot for higher series resistance are smaller than values peaks of low series resistance. The effect of series resistance on measured capacitance is important [4, 11].

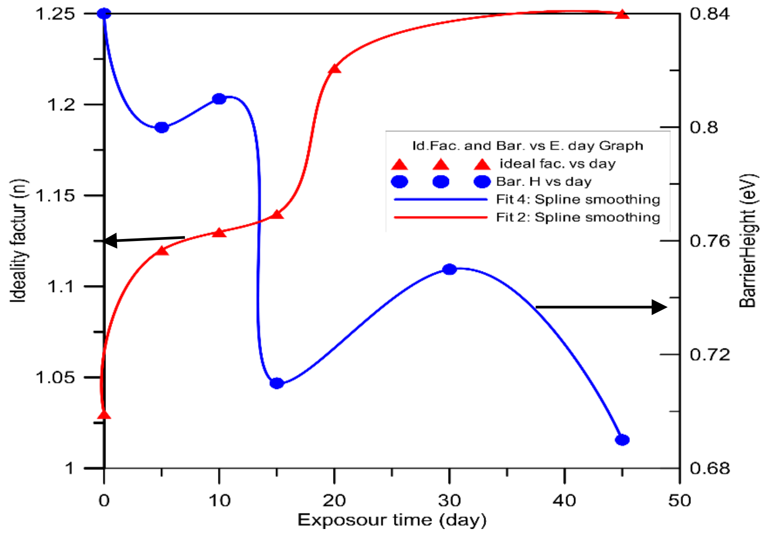

Figure 4. Ideality factor versus exposure time to air obtained from (I-V) characteristics and barrier height versus exposure time to air obtained from F(V)-V characteristics of Cu/n-Si Schottky diodes.

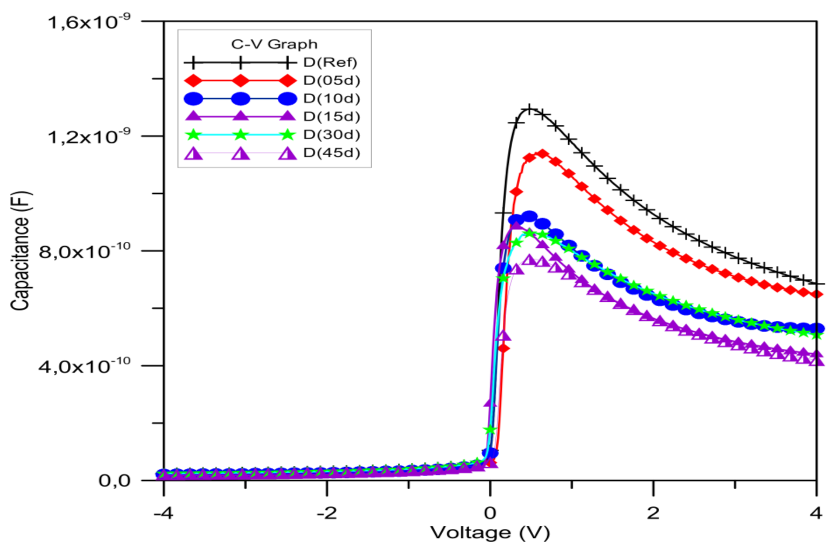

Figure 5. Current-voltage (C-V) characteristics of the Cu/n-Si Schottky diodes.

As it is seen from *Figure 6* that capacitance at negative voltages remains constant. Peak of reference diode is bigger than that of all diodes' peak and peak of diodes of long time exposure to air are smaller than that of diodes with low time exposure. The effect of series resistance on measured conductance and capacitance values is important [11].

When plot of conductance-frequency in *Figure 7* is examined, it can be seen that an excess conductance occurs at low frequencies in diodes, which have high series resistance. In G/w-V plots for all diodes conductance value peak occur and dropped for certain frequencies [2, 8].

Table 1. The experimental values of parameters obtained lnI-V characteristics of Cu/n-Si Schottky diode.

Air exposure time (Days)	**Samples Name**	**Ideality factor n**	**Barrier height eϕ_B (eV)**	**Series resistant R_s (Ω)**
Reference diod	D(Ref.)	1.03	0.85	136
5 day	D(05d.)	1.12	0.80	307
10 day	D(10d.)	1.13	0.81	701
15 day	D(15d.)	1.14	0.71	995
30 day	D(30d.)	1.22	0.75	973
45 day	D(45d.)	1.25	0.69	859

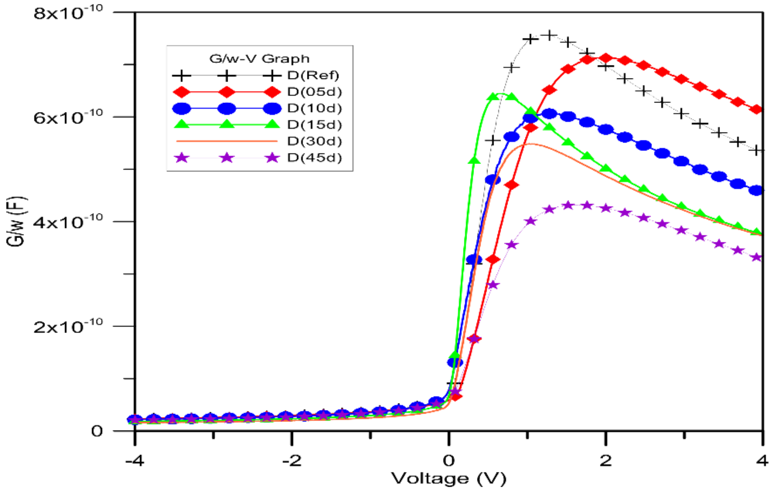

Figure 6. Conductance-voltage (G/w-V) characteristics of the Cu/n-Si Schottky diodes

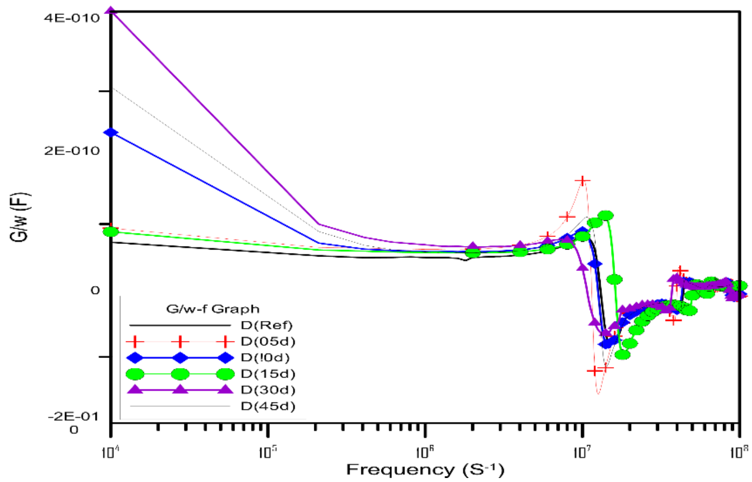

Figure 7. Conductance-frequency (G/w-f) characteristics of the Cu/n-Si Schottky diodes.

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