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The barrier height and the series resistance of Ag/SnO_2/Si/Au Schottky diode determined by Cheung and Lien methods

Mostefa Benhaliliba

Material Technology Department, Physics Faculty, USTOMB University, BP1505 Oran, Algeria.

mbenhaliliba@gmail.com

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Abstract

Electronic parameters of Ag/SnO_2 /Si/Au Schottky diode (SD) determined by Cheung and Lien methods are extracted using the current-voltage (I-V) and the capacitance-voltage (C-V) characteristics. Such SD is fabricated by the spray pyrolysis and the metallic contact is achieved by thermal evaporation process in vacuum. To determine more parameters of SD, the quantities like dV/dlnI, H(I) and Ga(V) are introduced. The non-ideal behavior of SD is confirmed, n=4.86 (n>1), the barrier height ΦB and the series resistance Rs are found to be 0.62 V and 585 Ω (by dV/dlnI), 524.5Ω (by H(I). The use of C-V and C^{-2}-V plots allow us to determine the density of acceptor (Na) and diffusion potential (Vd), at a kept frequency of 1MHz, of 7.8 1021 cm-3 and 0.49 V respectively. The profile of C-V, measured at various frequencies, reveals a p type of as fabricated SD where tin oxide layer is doped with 4% indium.

Keywords: Tin oxide; Indium doping; Spray pyrolysis, Schootky diode; Ideality factor; I-V measurement; C-V characteristics.

1. Introduction

Films and devices based on a wide band gap tin oxide semiconductor are largely studied due to its several properties. Such diodes have attracted many researchers and find applications in optoelectronics and sensor devices [1-2]. Lately, researchers have requested that SnO_2 could exhibit many qualities in opto-electrical applications. Further, these properties are improved when it is doped with metallic cations like aluminium, indium, antimony, zinc and iron [3-8]. Hydrothermal method, sputtering and the pray pyrolysis process are among the main used deposition techniques [9-11]. In order to discover the electronic properties of Schottky diode based on tin oxide doped with indium, the Ag/SnO_2 /Si/Au SD is fabricated and the I-V and C-V are measured under dark and room temperature conditions.

2. Fabrication details of Ag/SnO_2/Si/Au Schottky diode

The layers of tin oxide have been grown on n type silicon by ultrasonic spray pyrolysis technique USP at 300 °C. The doping source was indium (3+) chloride (InCl3), the ratio In/Sn was fixed at 4% in the solution. Both precursor and doping compound were dissolved in methanol at room temperature as previously cited [4, 12]. The gold contact, of thickness of 120 nm, was deposited on the film by thermal evaporation at pressure of 1.5 x 10–5 Torr. The I-V and C-V characteristics are achieved by employing Keithley and Agilent impedance analyzer set up respectively as reported previously [4, 12].

3. Results and discussion

In our study, the methods developed by Cheung et al. and Lien et al. have been applied to extract electronic parameters [14-15]. For a Schottky diode with a uniform oxide layer, it is reported that the relation between the applied forward bias and current of the device is due to thermionic emission current and it is given by,

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

As known, the ideality factor is n and the saturation current is I_0 . The figure 1 depicts the I-V (semilog) characteristics of Ag/SnO_2/Si/Au SD in dark and room temperature. The measurement of current is achieved in the {-2V, +2 V} bias range. As shown by the profile, the SD exhibits a slight rectifying behaviour, where the rectifying factor is defined as R= I(2V)/I(-2V), (R >200) while the as-fabricated SD based on SnO_2 doped with 6% In has presented a high rectifying factor (R>420) and ideality factor (n~2.7) was less than that obtained here (4.86), as mentioned in previous work [12]. The forward current increases exponentially with voltage as expressed by eqn.1, but the reverse bias current shows a poor saturation for low reverse applied

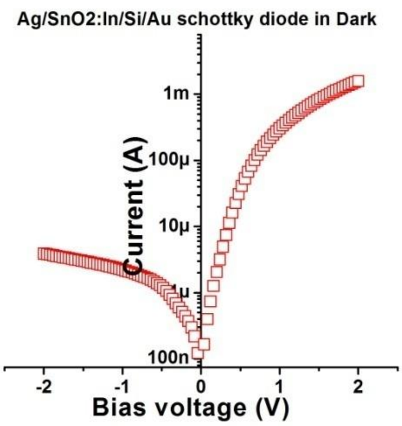

Figure 1. Under dark, the current-voltage characteristics plotting of Ag/SnO_2/Si/Au Schottky diode.

voltages and increases slowly.

$$n = \frac{q}{kT}\frac{dV}{d\ln(I)} \quad (2)$$

I_0 is easily extracted from the extrapolation of the linear portion of semi-log I-V and is given by,

$$I_0 = AA^*T^2\exp\left(-\frac{q\phi_{B0}}{kT}\right) \quad (3)$$

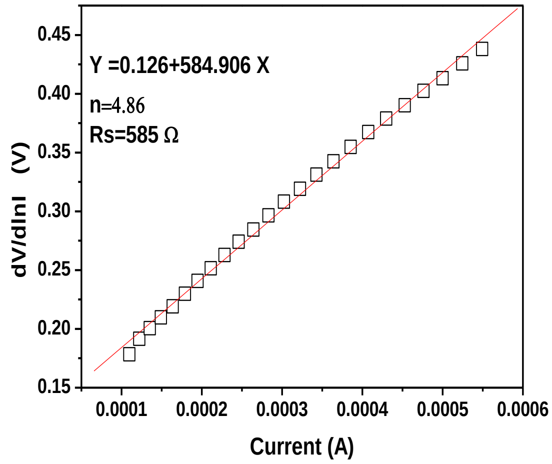

Figure 2. Sketch of dV/dlnI vs. current of Ag/SnO_2 /Si/Au Schottky diode fabricated by spray pyrolysis process (the red solid line indicates the linear fit).

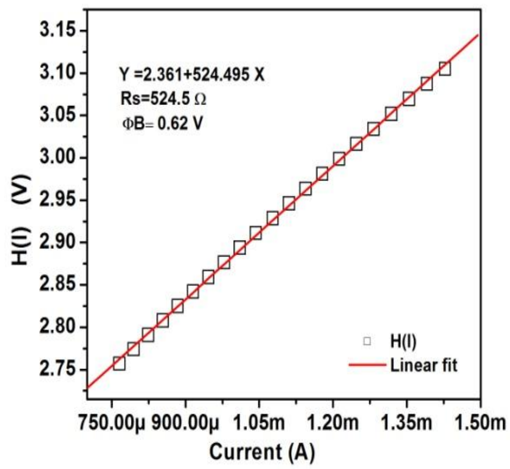

Figure 3. Plot of H vs. current of Ag/SnO_2/Si/Au Schottky diode fabricated by spray pyrolysis process (linear fit is displayed by a red solid line).

For the voltage greater than V> 3kT/q, the ideality factor and the saturation current, which are extracted from the linear fitting of LogI-V curve, are found to be 3.34 and 0.4 μA. Based on these results, our fabricated SD exhibits a non-ideal behavior due to n>1 due to presence of series resistance and interface states which are present between the SnO_2 layer and the silicon substrate. As shown in figures 2 and 3, the linear fit of the forward I-V permit us to know accurately the value of ideality factor, series resistance and barrier height for the large measured currents. It is explained by the non-ideal behavior of the SD which is caused by the interface existence in the metal-semiconductor junction. In this behavior of our SD, n increases a little (n=4.86), Rs= 585 Ω by (dV/dlnI method) and 524.5 Ω by (H(I) method) and a barrier height of 0.62 V.

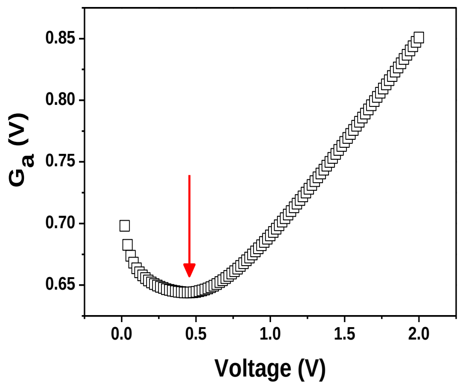

Figure 4. The plotting of the quantity G_a vs. bias voltage of Ag/SnO_2/Si/Au Schottky diode in dark condition and room temperature (the minimum $G_a(V_0)$ is indicated by red arrow).

Whereas, the respective obtained values of Rs and Φ_B are found to be 508 Ω and 0.58 V for the case of 6% In as reported earlier [12]. The Cheung-Cheung method is employed to determine some parameters in the non-ideal behavior of the diode [15];

$$\frac{dV}{d\ln I} = R_s I + n(\frac{kT}{q}) \tag{4}$$

The H(I) function versus current is expressed as follows [13],

$$H(I) = V - (\frac{nkT}{q})\ln(\frac{I}{AA^*T^2}) \tag{5}$$

The plotting of Ga vs. bias voltage is sketched in figure 4. Furthermore the function H is given by,

$$H(I) = n\Phi_B + R_s I \tag{6}$$

The figure 5 shows the capacitance-voltage of as fabricated SD within the -5V, +5V voltage range for several frequencies100kHz- 1MHz.

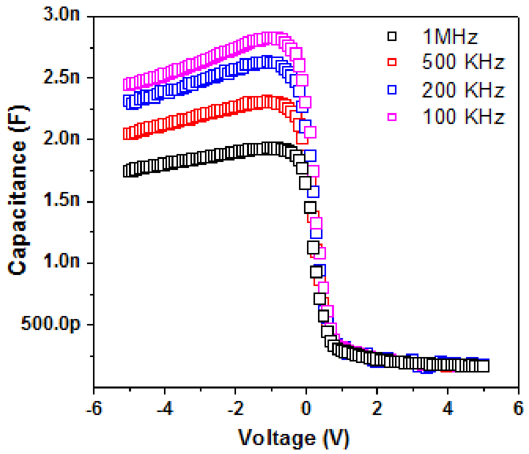

Figure 5. The capacitance-voltage profile of Ag/SnO_2/Si/Au Schottky diode at various frequencies 100kHz-1MHz.

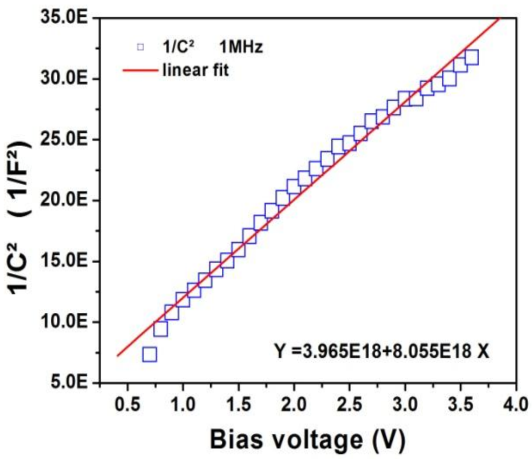

Figure 6. The variation plot of C^{-2}-V of Ag/SnO_2/Si/Au Schottky diode in dark and room temperature condition. Red solid line indicates the linear fit and its equation is written in the bottom ($E=10^{18}$ in y-axis).

The Lien method is based on the plotting of G function defined [14] by;

$$G_a = \frac{V}{a} - \frac{1}{\beta}\ln(\frac{I}{AA^*T^2}) \tag{7}$$

Where the barrier height and series resistance are defined as follows;

$$\phi_B = G(V_0) + \frac{V_0}{a} - \frac{kT}{q} \tag{8}$$

$$R_s = \frac{kT(a-n)}{qI_{\min}} \qquad (9)$$

Where the constant β=q/kT and a is integer parameter greater that n. Here, n is found to be 4.86, as indicated above and in the inset of figure 2, a is taken equal to 5 and the area value (A) of contact is found to be 0.018 cm^2. The constant (AA^*T^2) is of 80640 and the Richardson constant of n type silicon is 112 A /Kxcm^2. Thus, the following magnitudes V0=0.44 V, its corresponding current (Imin) is of 3.77 µA and G (V0) =0.64 V are determined from the figure 4. From eqn.8, the barrier height is then found to be 0.70 V and Rs, from eqn.9, is evaluated at 960.87 Ω[14].

$$\frac{1}{C^2} = \frac{2(V_d + V)}{q\varepsilon A^2 N_a} \qquad (10)$$

The two values of Rs found by dV/dlnI and H(I) are close and different from that found by Lien method. This discrepancy might due to following reason that Cheung's methods are only applied for the non-linear part of the forward bias I-V characteristics and Norde functions (F-V) are applied for the full forward region of I-V curve of the diode. From the linear fit of C^{-2}-V throughout the equation displayed inside of figure 6, the concentration is easily determined using the eqn.10 [13]. It is found that N_a=7.8 10^{21} cm^{-3} and V_d =0.49 V.

Conclusion

The series resistance and barrier height of Ag/SnO_2/Si/Au Schottky diode in dark and room temperature condition have been measured and extracted using Cheung and Lien approximation methods. The non-ideal behaviour of Ag/SnO_2/Si/Au Schottky diode is confirmed n>1. Such situation of the non-ideal behavior, leads to think to the presence of the series resistance and the interface states. Cheung and Lien approximation techniques permit to confirm this statement by calculating the parameters cited above and found to be 524.5 Ω and 0.62 V. A p type of as fabricated SD where tin oxide layer is doped with 4% idium. The density of acceptor is found to be 7.8 10^{21} cm^{-3} and the diffusion potential is of 0.49V. A p type of as fabricated SD, with 4% In doping level, is revealed.

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