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Extracted Electronic Parameters of a Novel Ag/SnO_2:In/Si/Au Schottky Diode for Solar Cell Application

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The effect of indium on the characteristics of Ag / SnO_2 : In / Si / Au Schottky diode (SD) is studied. The electronic parameters, ideal factor, the effective barrier, flat band barrier height, the series resistance, the saturation current density of the diodes were extracted from the current voltage (*I-V*) and capacitance voltage (*C-V*) characteristics. The series resistance (*Rs*) determined by Cheung method increases (508-534 Ω) with In doping level while the barrier height still constant around 0.57 V. Norde approximation gives a similar barrier height values of 0.69 V but the series resistance reaches higher values of 5500 Ω.

Keywords: Schottky diode, Tin oxide, Current-voltage measurements, Ideality factor.

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1. INTRODUCTION

During the last decades, the researchers in physics and electronics are interested by the performance and the microelectronics reliability of metal-insulator-semiconductor Schottky diodes particularly depend on the formation of an insulator film, active metal / semiconductor interface, and the interface states distribution at the semiconductor, insulator interface, series resistance and inhomogeneous barrier heights. Tin oxide (SnO_2) belongs to the II-VI semiconductor family with a wide band gap of 3.5 eV [1-2]. It has been revealed that SnO_2 is *n*-type direct band semiconductor and lately became a *p*-type material especially when it was doped with aluminum, zinc or indium [3-4]. Several applications of SnO_2 such as light emitting diodes and gas sensors have been mentioned [5-6]. In this research, we studied the electronic properties of indium doped SnO_2 deposited onto a *n*-type silicon substrate by a low cost spray pyrolysis process. Thus, a Schottky diode has been fabricated and the current-voltage measurements have been achieved in dark and room temperature conditions. Besides, the capacitance-voltage were measured at various frequencies and the response has been plotted and several electronic parameters have been extracted such as barrier height, series resistance, interface density and donor concentration. We study the role of indium level (6 and 8 %) as dopant on electronic and electrical properties of Ag / SnO_2 / *n*Si / Au Schottky diode. We expect that this device will be used in optical sensors and solar cell. Our aim is the measurement and to make stronger the knowledge of conduction mechanism in such device based on the wide band gap oxides layers.

2. FABRICATION AND MEASUREMENTS

Sprayed at 300 °C, the films of tin oxide deposited on n type silicon were prepared by ultrasonic spray pyrolysis technique USP. Furthermore, the indium was incorporated at the amount of 6 and 8 % in the solution. The gold contact, of thickness of 120 nm, was deposited on the film by thermal evaporation at pressure of 1.5×10^{-5} Torr. Using Keithley set up, the *I-V* characteristics under dark were measured. A schematic cross-section of the Ag / SnO_2 / *n*Si / Au structure is displayed in figure 1.

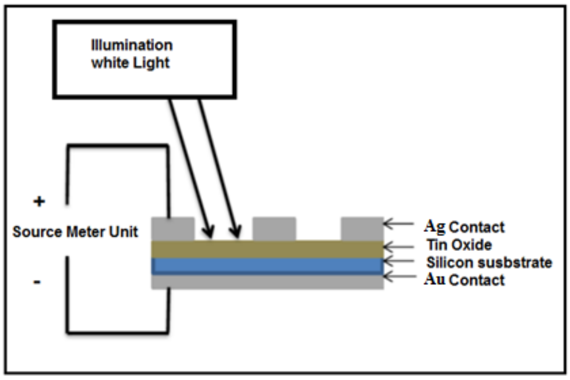

Fig. 1 – A schematic cross-section of the Ag / SnO_2 / *n*Si / Au structure

The electronic parameters, ideal factor, the effective barrier, the saturation current of the diodes were extracted from the current voltage (*I-V*) characteristics. Indium doped SnO_2 films were grown onto *n*-type silicon substrate using ultrasonic spray pyrolysis route that was previously cited [1]. The contacts have diameter of 1 mm and thickness of 110 nm. The Ag / SnO_2 : In / *n*Si / Au characteristics were measured using Keithley equipment. The voltage range varies between 0 and 5 V. The *C-V* data were taken at frequency of 100 kHz.

3. RESULTS AND DISCUSSIONS

Figure 2 depicts the semilog plotting versus bias voltage which varies within (– 2, + 2) V for the Ag / SnO_2 / Si / Au Schottky diodes. The measurements are achieved in dark conditions and at room temperature.

The exponential profile of the forward current-voltage characteristics depends strongly on the property of active material used for diode. It is given in terms of voltage and temperature as follows;

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

Where V is the applied voltage, n is the ideality factor is a quantity how the diode closes the ideal behavior, k is the Boltzmann constant, q is elementary charge, T is absolute temperature of 300 K and I_0 is reverse saturation current. This latter goes from 227 to 748 nA.

The ideality factor of the as-fabricated diode is then given from

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

Where $dV/\mathrm{dln}I$ is the derivative of voltage versus ln$I$, q is free carrier charge; T is the absolute temperature, $k = 8.625\ 10^{-5}$ eV/K is the Boltzmann constant. The ideality factor is found to be 2.7 and 3.6 respectively for 6 and 8 % indium doped SnO_2 films, which confirms the non-ideal behavior of the as-fabricated diodes. A rectifying parameter is greater than 425 for the 6 % In doping level, but it is slighter for 8 % In doped tin oxide film.

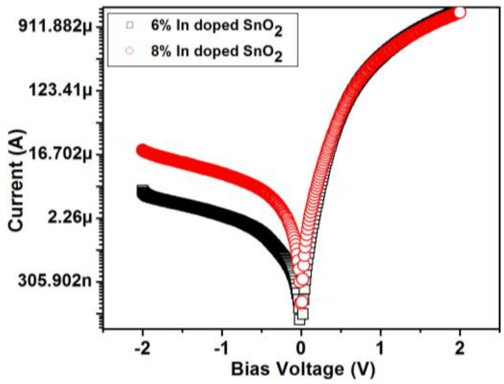

Fig. 2 – Semilog Plot of current-voltage characteristics of Ag / SnO_2 / nSi / Au Schottky diode for 6 and 8 % In doping level

I_0 can be obtained from the extrapolation of the linear portion of semi-log I-V and is given by,

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

Where A is the effective diode area, A^* is the Richardson constant and ϕ_{B0} the zero bias barrier height of the diode. A^* is the Richardson constant (112 Acm^{-2} K^{-2} for n-type Si), [7], we calculated the value of $AA^*T^2 =$ 80640.

The height barrier dependent on temperature and I_0 is expressed as follows [14];

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

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

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

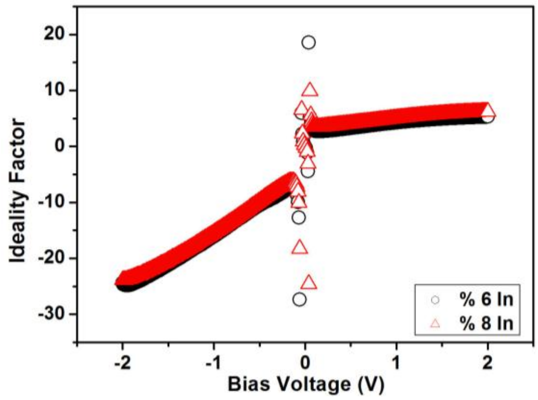

Fig. 3 – The ideality factor dependence on bias voltage of Ag / SnO_2 / nSi / Au Schottky diode without R_s for 6 and 8 % In doping level

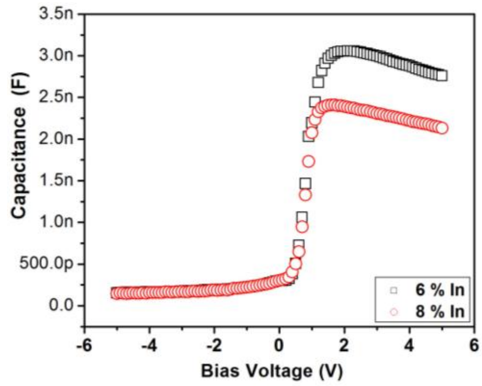

Fig. 4 – The capacitance-voltage plots of Ag / SnO_2 / nSi / Au Schottky diode for 6 and 8 % indium doping level

The capacitance-voltage plots of Ag / SnO_2 / nSi / Au Schottky diode for 6 and 8 % indium doping level is shown in figure 4. This profile confirms the n type of the tin oxide layer. At the frequency of 100 KHz, 3.1 and 2.4 nF are the highest obtained value of the capacitance for the 6 and 8 % In doping level detected in the forward C-V characteristics. Capacitance increases rapidly with the bias voltage in the forward bias 0-5 V range. The $1/C^2$ versus bias voltage (0.2-0.7 V) is plotted as seen in figure 5. A straight line fitting of equation, 1.5E19-2.1 E19 V and 1.3E19-1.76 V respectively for 6 and 8 % In doping level, permits to determine the donor concentration and the buit-in potential.

$$\frac{1}{C^2} = \frac{2(V_{bi} + V)}{q\varepsilon A^2 N_d} \tag{6}$$

And function H can be expressed in terms of barrier height and series resistance R_s by eqn. 5, and in terms of barrier height and series resistance by the following relation;

$$H(I) = n\Phi_B + R_s I \tag{7}$$

A is the effective diode area of 8×10^{-3} cm^2, A^* is the Richardson constant and ϕ_{B0} the zero bias barrier height of the diode. A^* is the Richardson constant (112 Acm^{-2} K^{-2} for n-type Si) [7]. The Norde function $F(V)$ under the $V > 3kT/q$ condition [8] is expressed as follows;

$$F(V) = \frac{V}{\gamma} - \frac{kT}{q}\ln\left(\frac{I(V)}{AA^*T^2}\right) \quad (8)$$

Where γ is the first integer greater than ideality factor. $F(V)$ allows to determine R_s and Φ_B as listed below using the minimum voltage V_0 and $F(V_0)$ (not shown here). The barrier height is then given by,

$$\varphi_B = F(V_0) + \frac{V_0}{\gamma} - \frac{kT}{q} \quad (9)$$

The series resistance of the contact can be defined through the relation [8],

$$R_S = \frac{kT(\gamma - n)}{qI_{\min}} \quad (10)$$

The log*I*-log*V* curves identify two distinct current regions I and II (not shown here). Current obeys the power law of $I \approx kV^m$ [7] where k is a constant and m is the constant that describes the dominant conduction mechanism of the diode, Current-voltage characteristics and the power-law dependency were found to be ruled by a space charge-limited currents SCLC (slope $m > 2$) because log*I*-log*V* plots give roughly the power laws as $I\alpha V^{2.5}$ for the region II while the relation is modified as $I\alpha V^{1.3}$ for the region I which confirms the ohmic regime. To explain the conduction mechanism of the Ag / SnO_2 : In / Si / Au SD under high voltages;

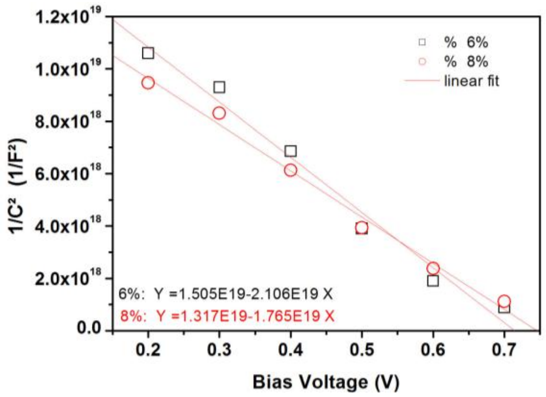

Fig. 5 – $1/C^2$ vs. bias voltage plot of Ag / SnO_2 / nSi / Au Schottky diode for 6 and 8 % In doping level

The ideality factor versus bias voltage is given by [9-10],

$$n(V) = 1 + \frac{\delta}{\varepsilon_i}\left(\frac{\varepsilon_s}{d} + qN_{ss}\right) \quad (11)$$

Where ε is a dielectric constant of SnO_2 and silicon ($\varepsilon_I = 7\varepsilon_0$, $\varepsilon_s = 11.8\varepsilon_0$, where $\varepsilon_0 = 8.84 \times 10^{-12}$ F/m). Based on the $1/C^2$ vs. V plots, the as-fabricated diode presents p-type conductivity. Acceptor density N_A is assessed at 3.5×10^{14} cm^{-3}. Ideality factor dependence of interface states densities were obtained using eqn. 12 [10]. We determine the energy distribution of the interface states in equilibrium with semiconductor using the equation 12 and 13 by taking into account the forward bias current-voltage characteristics. The obtained values of electronic parameters as a result of In doping level are gathered in Table 1.

$$N_{ss} = \frac{1}{q}\left[\frac{\varepsilon_i}{\delta}(n(V) - 1) - \frac{\varepsilon_s}{d}\right] \quad (12)$$

Where $n(V)$ is the ideality factor expressed by the eqn. 14 can be calculated with and without the series resistance R_s.

$$E_{ss} - E_V = q(\varphi_B - V) \quad (13)$$

$$n(V) = \frac{q}{kT}\left(\frac{V - IR_s}{\ln(\frac{I}{I_0})}\right) \quad (14)$$

The ideality factor dependent on current and bias voltage $n(V)$ without R_s for 6 and 8 % In doping level is sketched in figure 3. The interfacial layer thickness is deduced from the relation $C_i = \varepsilon_i\varepsilon_0 A/\delta$ [7]. The interface state energy density N_{ss}, expressed by eqn. 12, is plotted with and without series resistance for the 4, 6 and 8 % In-doped tin oxide as shown in figure 6.

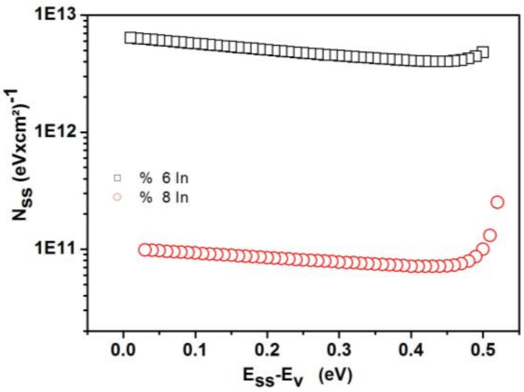

Fig. 6 – The energy distribution profile of the interface state densities N_{ss} obtained from forward I-V characteristics of Ag / SnO_2 / nSi / Au Schottky diode for 6 and 8 % In doping level without R_s

Table 1 – Microelectronic parameters of Ag / SnO_2 / nSi / Au Schottky diode for 6 and 8 % In doping level

In %	n	R	γ	I_0 (10^{-7} A)	Cheung method using dV/dln$I$		Cheung method using $H(I)$		Norde method $F(V)$			
					n	R_s (Ω)	R_s (Ω)	Φ_B (V)	V_0 (V)	$F(V_0)$ (V)	R_s (Ω)	Φ_B (V)
6	2.73	425	3	2.27	10.46	508	510	0.58	0.16	0.70	5549	0.72
8	3.57	72	4	7.48	11.46	534	538	0.57	0.18	0.65	2148	0.67

4. CONCLUSION

The layer of indium doped tin oxide, as a part in the Ag / SnO_2 : In / Si / Au Schottky diode, properties are completely studied.

Further, the effect of indium level on the electronic extracted parameters like ideality factor, saturation current, barrier height, series resistance is fully emphasized. Based on *I-V* plots, we determine series resistance by Cheung and Norde methods and it is revealed that a non-ideal behavior of SD is observed (n is greater than unity). The obtained value of the saturation current I_0 ranged within 220-750 nA. In doping level arises the series resistance in the diode in the ratio of 1.5 while the barrier height stills the same around 0.57 V according to Cheung model. The energy distribution profile of the interface state densities decreases with an increase in In doping level.

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