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The microelectronic parameters of Al /ZnO/p-Si/Al Schottky diode for solar cell applications

Al/ZnO/p-Si/Al Schottky Diyotunun Güneş Pili Uygulamaları İçin Mikroelektronik Parametreleri

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ABSTRACT

Microelectronics properties of Al/ZnO/p-Si/Al Schottky diode have been investigated. ZnO films have grown onto p type silicon substrate by ultrasonic spray pyrolysis @ 350°C. Al front contacts have been deposited by thermal evaporation process in vacuum at 10-6 Torr. The current-voltage (I-V) characteristics show a good rectifying profile around 1900. The extracted parameters in dark and light (150 mW/cm²) conditions: ideality factor (n), barrier height ΦB, series resistance Rs are respectively found to be 3.5 and 1.6, 0.74 eV and 0.89 eV, 5 kΩ and 1.6 kΩ, respectively. Effect of temperature, varied within the range of 22-107 ° C, on the I-V characteristics was emphasized. Dark and illumination characteristics were also studied. Finally, we accomplished the study by the measurement of capacitance-voltage (C-V) characteristics as a result of frequency.

Keywords: Ultrasonic spray pyrolysis, ZnO film, I-V characteristics, Dark and illumination exposure, Rectifying profile

ÖZET

Al/ ZnO/p -Si/Al Schottky diyodunun mikroelektronik özellikleri araştırıldı . ZnO filmleri 350 ° C de ultrasonik sprey piroliz metodu ile p tipi silikon altlıküzerine büyütüldü. Al kontakları 10-6Torrvakumda termal buharlaştırma ile kaplandı. Akım-gerilim (IV) karakteristikleri yaklaşık 1.9x102değerinde iyi bir doğrultma özelliği gösterdir. Karanlık ve aydınlık (150 mW/cm2) şartlarda hesaplanan, idealite farktörü (n), engel yüksekliği ΦB , seri direnç Rssırasıyla 3.5 ve 1.6 , 0.74 eV ve 0.89 eV , 5k ve 1.6 k olarak bulunmuştur. 22-107 ° C sıcaklık aralığında sıcaklığın I-V karakteristikleri üzerine etkisi araştırıldı. Karanlık ve aydınlık karakteristikleri ayrıca çalışıldı. Sonuçta, çalışmayı frekansın bir sonucu olarak kapasite- voltaj ölçümleriyle başardık.

Anahtar sözcükler: Ultrasonik Püskürtme Proliz, ZnO film, I-V karakteristiği, Karanlık ve Aydınlık Pozlama, Doğrultma özelliği

1. Introduction

Through the last decades, ZnO thin films and devices have been extensively investigated due to their potential applications in optoelectronic devices and photovoltaic cells. ZnO has attracted researchers in films and devices [1-2]. ZnO has intensively grown onto different substrates, like p and n type silicon, InP, graphite, as thin films, Schottky barrier diodes (SBD) and heterostructures (HS) [3-5]. The ZnO devices have been fabricated by various methods like sputtering [6], spin coating and spray pyrolysis [7-8]. The applications of ZnO device are various, like gas sensor and solar cells [9-10]. In the aim to prepare a solar cell, we fabricate a Schottky diode based on a wide band gap semiconductor, Eg > 3 eV with a good rectifying behavior.

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2. Preparation of the Thin Film and Fabrication of Diode

ZnO films were grown by USPD route from zinc acetate ($Zn(CH_3COO)_2$, $2H_2O$) used as precursor. 0.1 mole of zinc acetate was dissolved in 100 ml of methanol. The used substrates were successively cleaned by methanol for 15 min and distilled water for 20 min. We deposited our films at fixed substrate temperature of 350 °C and the time deposition was 5 min and the distance nozzle substrate was around 5 cm. The metallic contacts were made by thermal evaporation in vacuum at 10^{-6} Torr, using a mask. The cross section of Al/ZnO/p-Si/Al structure is sketched in Figure1. The obtained Al contacts are circular with a diameter of 1.5 mm and thickness of 250 nm as indicated in the inset of Figure 2.

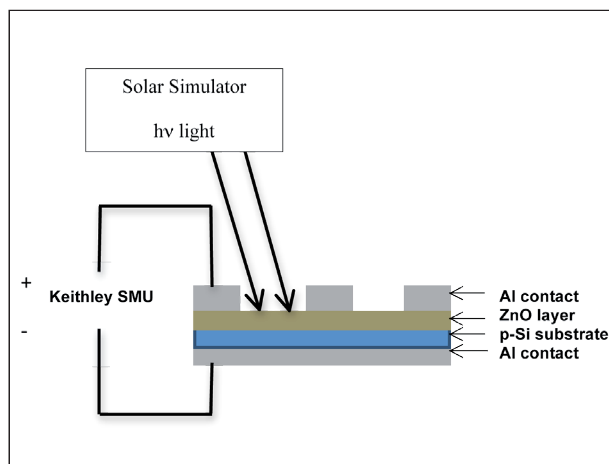

Figure 1: A schematic cross-section of the Al/ZnO/p-Si/Al structure.

3. Results and Discussion

3.1. The Current-Voltage Characteristics of Al/ZnO/p-Si/Al Schottly Diode

The Figure 3 presents the current-voltage measurements in dark and illumination conditions of Al/ZnO/p-Si Schottky diode. The I-V characteristics curve in dark exhibit a good rectifying profile of 1900. The exponential profile of the forward current-voltage characteristics depends strongly on the property of active material used for diode. The *I-V* curve exhibits a slope which depends on two magnitudes like ideality factor (n) and reverse saturation current. From the semilog plot, under condition of V >3kT/q in the forward direction [11], the ideality factor is determined as follows [12];

$$n = \frac{q}{kT} \frac{dV}{d\ln(I)} \quad (1)$$

Where q is the carrier charge, T is the temperature (K), k is the Boltzmann constant, dln(I) /dV is the slope of straight portion of the forward curve I-V. The parameter n gives detail information about the recombination process to be taken place in the diode and the shape of the interfaces. The obtained values of n are varied from 2.49 to 3.02 in dark under heating condition. As found in literature, ideality factor depending on temperature is ranged within 1.7-3.5 [13]. Another parameter that affects the exponential part of *I-V* characteristics is the saturation current I_0 which gives the numbers of charges able to overcome the energetic barrier in reverse

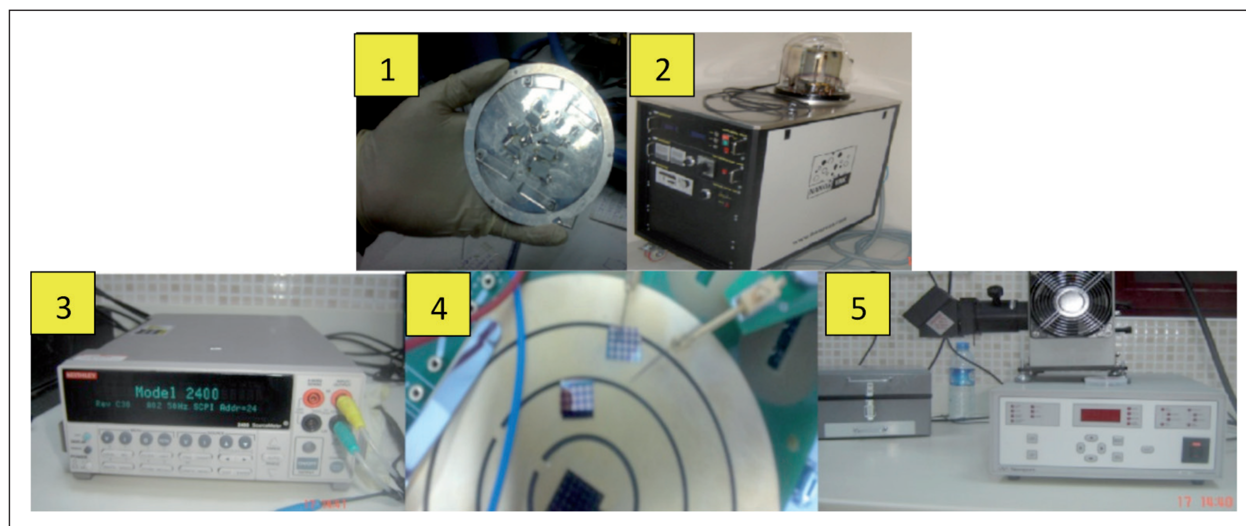

Figure 2: Experimental system for diode fabrication and electrical characterization system (1) Diode with Al contacts are fabricated, (2) Thermal evaporator with vacuum set up, (3) Keithley Model 2400, (4)Electrodes of measurements, (5) Solar simulator with variable light power.

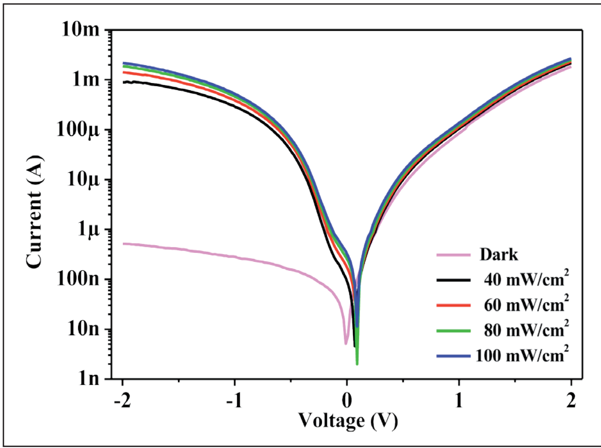

Figure 3: The semilog plotting of the current-voltage characteristics of the as-fabricated Al/ZnO/p-Si diodes measured at several light powers.

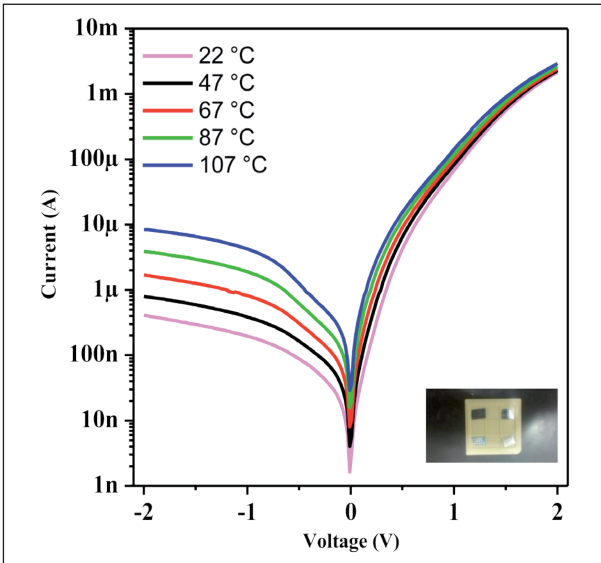

Figure 4: Plotting of I vs. V (semilog scale) measured at various temperatures. Inset shows the as-fabricated Al/ZnO/p-Si diodes.

bias voltage. According to the thermoionic emission mechanism, the current versus voltage depending on I_0 is expressed as follows [6],

$$I = I_0 \exp \frac{q(V - IR_s)}{nkT} \quad (2)$$

V is the applied voltage, R_s is series resistance and I_0 is given by [11],

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

Where A is the diode contact area (0.07cm^2), A^* is the Richardson constant (32 A cm^{-2}K^{-2}) of p-Si and Φ_B is the zero-bias barrier height. The obtained values of I ranged from 1.1 to 42 nA, and from 14 to 450 nA as a result respectively of light power and temperature as listed in table 1.

As observed in Figure 3, the photoresponse I_{ph}/I_{dark} is found to be 1125. The measurement of the current-voltage variation under temperature is shown in Figure 4. The barrier height is expressed as follows [14];

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

Where T is temperature of ambient fixed at 300 K.

The series resistance, $R_s = \Delta V/\Delta I$, is determined from the slope of the linear portion of the I-V characteristics for the high voltage > 1V. The found values, indicated in table 1, a couple of kilo-ohms are a bit higher, which explain the interface occurrence in our as-fabricated devices.

Our SBD presents a barrier height of 0.7-0.9 eV and R_s of 1.5-5.5 kΩ, these obtained values are in good agreement with those found in literature, a barrier height of 0.76 eV and series resistance of 6.69 kΩ are cited previously [6].

Table 1: Ideality factor, saturation current, barrier height and series resistance with several powers and temperatures.

Parameters of measurements		n	I_0 (nA)	Φ_B (V)	Rs (kΩ)
P (mW/cm^2)	0	3.5	32	0.74	5.4
	40	1.9	42	0.79	2.1
	60	1.5	16	0.89	2.8
	80	1.1	2	0.86	1.4
	100	1.6	1.1	0.90	1.6
T (°C)	22	3.02	34	0.74	2.5
	47	2.55	73	0.79	2.5
	67	2.49	14	0.89	1.6
	88	2.51	260	0.86	1.0
	107	2.67	450	0.89	1.2

3.2. The Capacitance-Voltage Characteristics of Schottky Diode

The capacitance-voltage at several frequencies of Al/ZnO/p-Si diode is studied. The measurement was carried out at frequencies range within 50kz-5MHz. It is seen in Figure 5 that the capacitance of the as fabricated diode increases with a decrease in frequency, and the high point is of 16 nF at 50 kHz. Using the C^{-2} against voltage (see Figure 6), we determine the carrier concentration N_D according to the following relation [14];

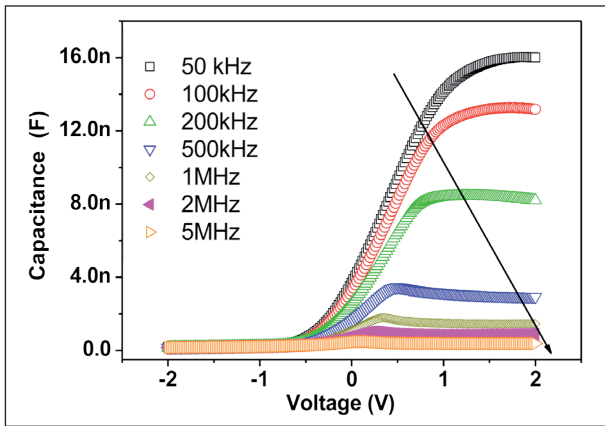

Figure 5: C-V plot of Al/ZnO/p-Si/Al Schottky diode at several frequencies 50kz-5MHz.

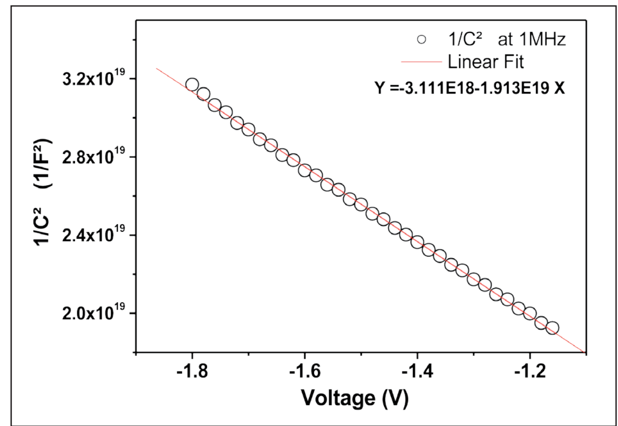

Figure 6: Plot of $1/C^2$ vs. V of the Al/ZnO/p-Si/Al Schottky diode at 1 MHz, red solid line is a linear fit.

$$\frac{1}{C^2} = \frac{2(\Phi_B + V)}{q\varepsilon A^2 N_D} \qquad (5)$$

Where ε is a dielectric constant of ZnO and N_D is a donor carrier concentration.

The obtained value of the carrier concentration N_D, calculated at 1 MHz, is about 10^{16} cm^{-3} as depicted in Figure 6.

Conclusion

The Al/ZnO/p-Si/Al diode Schottky was fabricated by a facile technique controlling parameters like film and contacts thickness, vacuum pressure and temperature. Our device exhibits a good rectifying profile and a lower ideality factor <3.5. The barrier height is around 0.7 eV and the photocurrent is evaluated at 2 mA. Effect of light power and temperature on microelectronic parameters was clearly observed. The carrier concentration N_D, calculated at 1 MHz, is about 10^{16} cm^{-3}. Such device can be used in solar cells, photoconductor and photodiode applications.

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