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SHORT COMMUNICATION

Investigation of post-annealing effect on efficient ohmic contact to ZnO thin film using Ti/Al metallization strategy

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Abstract

Ohmic and Schottky contacts are playing a major role in the field of ZnO based electronics device fabrication. It is seen that several works have been reported on metallization scheme, contacts with this semiconducting material. But, the thickness of semiconducting material and the choosing of substrate still remain imperfect and inefficient for advanced IC technology. To estimate contact resistance, the transmission line method (TLM) is found to be more complex. So, Schottky barrier height (SBH) model is considered to obtain at most accuracy to find Ohmic contact parameters. Herein, the investigation of parameters like barrier height, ideality factor and saturation current at room temperature of very low specific resistance Ohmic contact to ZnO using Ti/Al metallization scheme are performed. The thermal evaporation technique is performed for the deposition of ZnO thin film of 200 nm and Ti (100nm) /Al (100nm). Further, using a vacuum furnace, post-annealing treatment is also done at different temperatures (Four samples of 300 ˚C, 450 ˚C, 600 ˚C and 700 ˚C at a time period of 20 minutes for each temperature). Characterization of the contacts are done through current-voltage (I –V) using a semiconductor parameter analyzer. The parameters like barrier height, ideality factor and saturation current of this metallization scheme are extracted from the current-voltage plot. It is considered that the theory of thermionic emission is the fundamental phenomenon behind carrier transport at the interface. After post annealing, a comparative analysis is done and the deviations in the parameters are analyzed from semi-log current versus voltage plot and Richardson plot.

Keywords: *Barrier Height; Ideality Factor; Saturation Current; SBH; ZnO.*

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INTRODUCTION

Zinc oxide is the compound semiconductor belongs to II-VI groups of the periodic Table [1]. It is having a direct bandgap of 3.37eV and high exciton binding energy 60eV which provides a high absorption coefficient. ZnO quite commonly used in household, medical and electronic applications as gas sensors, solid state lasing, drug delivery, anti-bacterial coatings, transistors, diodes, etc [2-3]. ZnO can be modeled into different forms of nanostructures with respect to the process of fabrication [4]. It shows larger adsorption towards different gases and UV light of different wavelengths due to its high surface to volume ratio [5]. There is a wide variety of schemes in metallization performed on ZnO, deposited on various substrates namely silicon, silicon carbide, and sapphire. Deposition of thin films involves pulsed laser deposition (PLD) [6], metal organic chemical vapour deposition (MOCVD) [7], molecular beam epitaxial growth (MBE) [8], radiofrequency sputtering (RF) [9], sol-gel and thermal evaporation method [10]. The thermal coating method is a very simple and low cost fabrication method where film thickness, quality and doping concentration can easily be monitored. Most of the cases, the deposition of the Al substrate can be performed by the study of ohmic contacts of ZnO thin films by the Sol-Gel method [11-15]. It is received that Ohmic contacts on doped ZnO thin film is studied by using the transmission line method (TLM) mechanism. The

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Table 1. Ti/Al on ZnO parameter analysis.

Devices	Ideality Factor (η)	Barrier Height (φ_b)	Saturation Current (I_0)
300	0.53	0.0317	0.031
450	32.289	0.0550	0.0003
600	56.8096	0.0460	0.0028
700	51.745	0.0436	0.0052

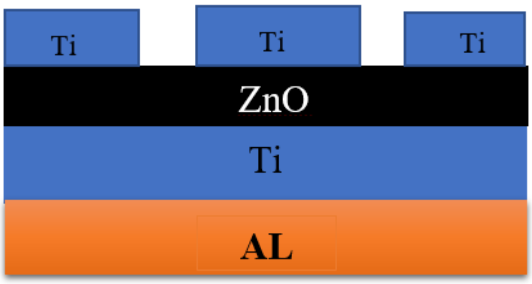

Fig. 1. Schematic representation of the proposed Ti/Al on ZnO thin film-device.

transmission line method is a very complex analysis methodology that needs a complicated structure of the contact [1]. Schottky barrier height method (i.e., the metal to semiconductor which is Ti/ZnO contact having a large barrier height) model considering thermionic emission theory which means by annealing the substrate at the different temperature acquires the emission of particles producing the good Ohmic properties [15-20]. The mask design and corresponding photolithography steps are also very complex. Due to these issues, Schottky barrier [10] height method is undertaken and it identifies the specific contact resistance and ideality factor. So in this work, ZnO thin film is deposited on a glass substrate using the thermal evaporation coating unit, glass is very similar to SiO_2 and will provide the same physical condition as a SiO_2/Si substrate. By using the SBH theory the contact resistance is analyzed.

EXPERIMENTAL DETAILS

The chemicals used for the fabrication of devices (deposition of film metal, contact formation and cleaning substrates) are purchased from the Sigma-Aldrich and worked without further purification. During the deposition, the substrate is cleaned with soap, acetone and deionized water to remove the contaminate particles like dust or metal particles from the surface of the glass. The substrate is also cleaned with ultra-sonicator which produces the range of 20 to 40 KHz wave to remove the particles. Isopropyl alcohol is used in the ultrasonicator beaker during the cleaning. The glass substrate is dried in vacuum oven at 250 ˚C. Later on, the substrates are transformed to the deposition unit (HIVAC Model BC300) for the deposition of ZnO thin film. A 200nm ZnO thin film is deposited on the glass substrate and the film thickness is measured by the digital thickness monitor. The Ti/Al metallization scheme is performed over the ZnO film by thermal evaporation technique and the shadow mask technique is used during deposition. The thickness of the contact is 100/100 nm and an area of substrates 7.8×10^{-3} cm^2. Inside the deposition chamber vacuum level is fixed at 10^{-5}mbar. After the metallization, contact is formed and it is annealed in a tubular furnace at various temperatures (sample 1 at 300 ˚C, sample 2 at 450 ˚C, sample 3 600 ˚C and sample 4 at 700 ˚C) in air ambient to make contact an alloy type and improve the ZnO thin film surface quality. The electrical properties of the contacts for different substrates are analyzed by using the Key sight B2902A parameter analyzer. The schematic representation of the device is given in the Fig. 1.

I-V RESULTS AND DISCUSSION

The Ti/Al contact on ZnO thin film substrates are analyzed by using the Key sight B2902A semiconductor parameter analyzer and it is measured on a homemade probe station [6]. The

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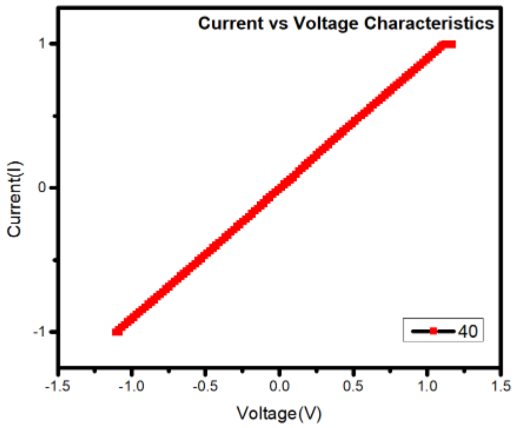

Fig. 2. Current level with respect to the Voltage characteristics at 40⁰Cof the sample 1.

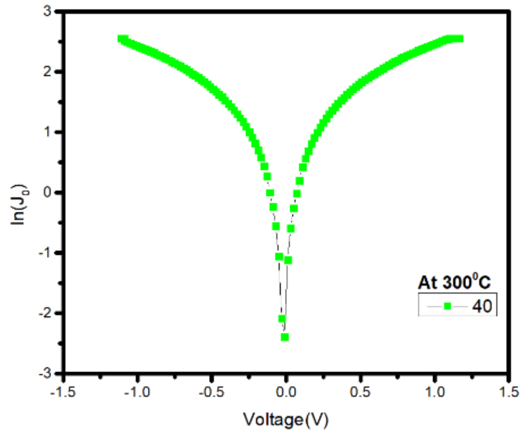

Fig. 3. Logarithmic plot of Current density and the voltage of sample 1 at 40˚C.

current-voltage characteristics of the contact at different temperatures are shown in the following Fig. 2. and Fig. 3. Characteristics are measured at room temperature.

The semi-logarithmic plots for the different temperatures of the substrates are measured and the parameters are calculated by these characteristic graphs. From the I- V characteristics plot, it is found that the current level in the device is 1A which follows the relation of linear path.

Formation of perfect Ohmic contact follows the linear characteristics. Here in Fig. 2 indicates an interface of the Ti and ZnO whereas the Al is used as the following layer. The Figs. (3, 5, 7, and 9) represent the semi-logarithmic plots of the current-voltage characteristics. Here, 40^0C temperature is considered throughout the I-V characterization. The saturation current and current density of the substrates are calculated by each intercept of Fig. 2 by extrapolating the linear region of this curve. Similarly, the ideality factor of the contact is calculated from the slope of the semi-logarithmic plot. The current-voltage characteristics of every substrate are explained in Fig. (2, 4, 6, and 8) can be fitted with equation 1. Schottky barrier height method (i.e., the metal to semiconductor which is Ti/ZnO contact having a large barrier height) model considering thermionic emission theory [15] instead of tunneling but TLM is employed to analyze different parameter for the metallization scheme from where the contact resistance can be measured. The current flowing through the metal to semiconductor interface is mathematically represented by an equation .1 [1].

$$I = I_0[\exp(\frac{qv}{\eta kT}) - 1] \tag{1}$$

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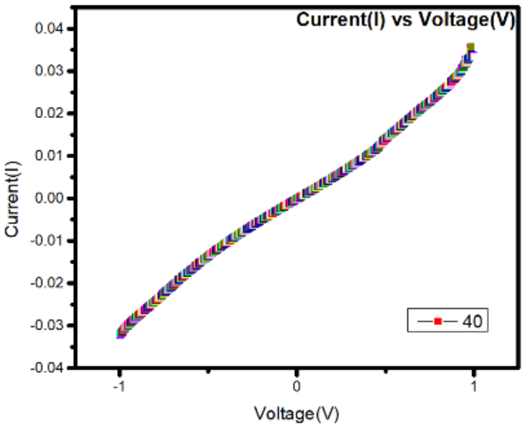

Fig. 4. Current level with respect to the Voltage characteristics of Sample 2 at 40˚C.

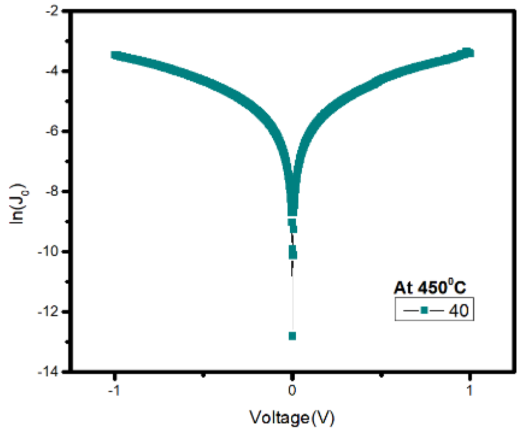

Fig. 5. Logarithmic plot of Current density with respect to the voltage of sample 2 at 40˚C.

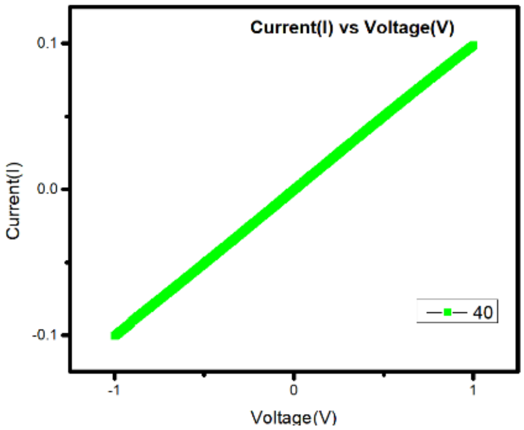

Fig. 6. Current level with respect to the Voltage characteristics of sample 3 at 40˚C.

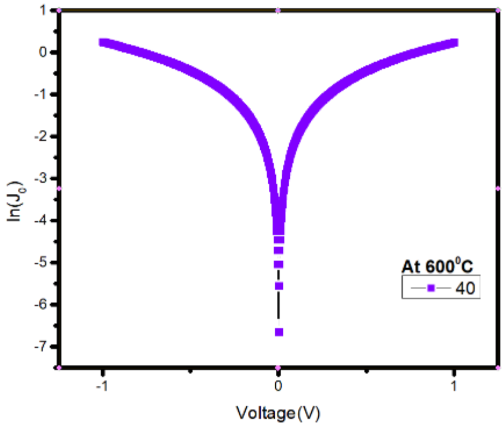

Fig.7. Logarithmic plot of Current density with respect to the voltage of sample 3 at 40˚C.

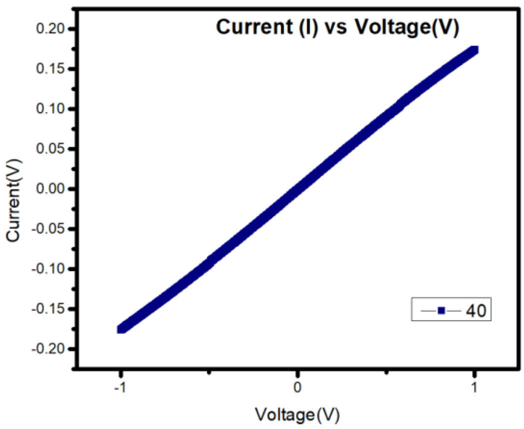

Fig. 8. Current level with respect to the Voltage characteristics of sample 4 at 40˚C.

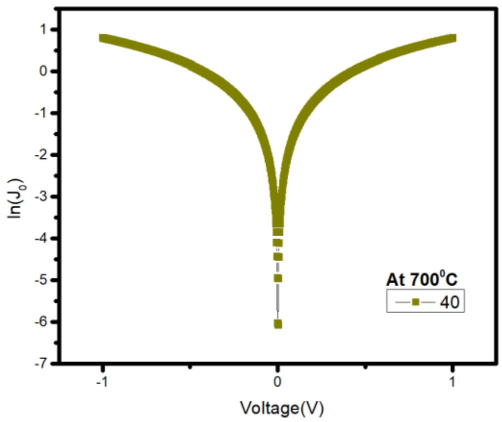

Fig. 9. Logarithmic plot of Current density with respect to the voltage of sample 4 at 40˚C.

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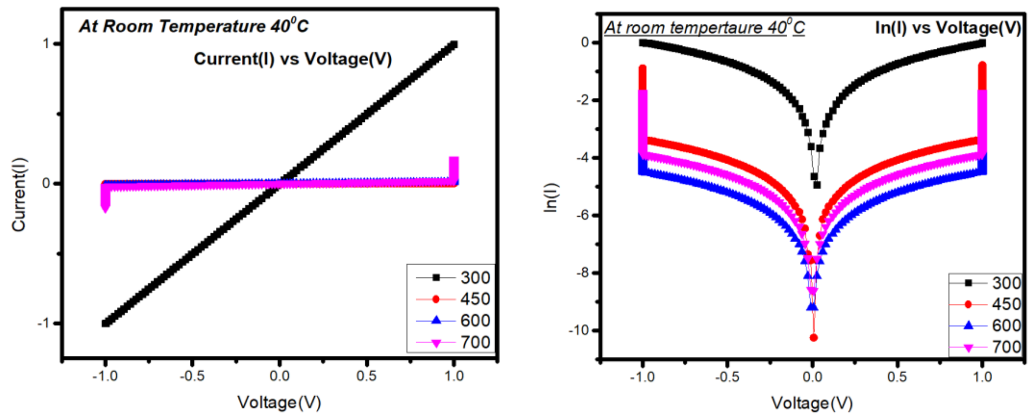

(a) (b)

Fig. 10. (a) Richardson plot and (b) Logarithmic plot of the current level after volatge axis correction and annealing treatment of different samples (sample 1 at 300 ̊C, sample 2 at 450 ̊C, sample 3 600 ̊C and sample 4 at 700 ̊C).

Where I is the total current andthe reverse saturation current is

In the above equation, the parameters A defines area of a contact, A* Richardson constant (~32 $Acm^{-2}K^{-2}$ for m_e =0.27m) [6], q is the elementary charge, K implies the Boltzmann's constant. φ_b is the barrier height.

The logarithmic plot are attained by the current density of the current characteristics between the ZnO and the layer of the shadow mask of the Ti layer which exhibits the ohmic properties with better resistivity.

The 'η', the ideality factor is calculated by the fitting the graph in Fig. 3 with equation 2 [1] given below

$$\ln(I) = \ln(I_0) + \left[\frac{qv}{\eta kT}\right] \quad (2)$$

Ideality factor can be obtained by the deriving the equation 2 and can be written as the equation 4

$$\eta = \frac{qv}{kT}\left[\frac{\partial v}{\partial(\ln I)}\right] \quad (3)$$

The experimental values of the ideality factor for different substrates are estimated as 1.5. By rearranging the relation between the saturation current and the barrier height, the following equation4 [1] is formed.

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

Small deviation may occur in the reported value with respect to the estimated value of the barrier height [8]. The deviation is caused by the series resistance, contact barrier inhomogeneity and other such anomalies at the contact. Using the barrier height estimation and contact resistance (equation 5) the contact resistance value6×10^{-3} ohm.cm^2 is obtained. The contact resistance may get decreased if the barrier inhomogeneity series resistance and actual area effect are nullified [10].

$$\rho_C = \left[\frac{\partial J}{\partial V}\right]^{-1}$$

$$\rho_C = \frac{k}{qA^*T}\exp\left[\frac{q\phi_b}{kT}\right] \quad (5)$$

The overall characteristics of a room temperature from above devices perform at one plot are shown in below Fig. 10. (a) and Fig. 10. (b).

ANALYSIS REPORT

The fabricated devices are measured by the key sight measuring unit and the parameters are calculated at the room temperature. Then the results are given in Table 1.

CONCLUSION

By the thermal evaporation method the Ti/Al contact on the ZnO thin film is deposited and furthermore, characterized by I-V analyzer. The devices (sample 1, sample 2, sample 3 and sample 4) are measured thoroughly to investigate the

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ohmic contact properties. The characterized substrate involves the heat treatment to increase the structural, optical and electrical properties of the ZnO thin film. The contacts exhibit the linear characteristics to analyse the parameters like ideality factor, barrier height and saturation Current. The device characterizations are performed at 40˚C. SBH approach is considered for the specific contact resistance avoiding complex TLM method. Finally, this work ensures a reliable way to optimize the contact by following this unique way and improves the constraint related to doping and conquers the TLM complexity.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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