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The electrical characterization of ZnO/GaAs heterojunction diode

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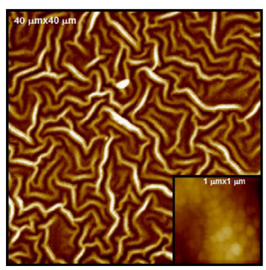
HIGHLIGHTS

- We have fabricated Al/ZnO/p-GaAs heterostructure diode by sol–gel method.
- The current–voltage characteristic of Al/ZnO/p-GaAs shows diode-like behavior.
- AFM images indicate that the ZnO films are formed from the nano-fiber particles.
- It is evaluated that electrical performance of Al/ZnO/p-GaAs can be controlled by ZnO.

GRAPHICAL ABSTRACT



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ABSTRACT

The electrical characteristics of sol–gel synthesized n-ZnO/p-GaAs heterojunction were reported. The values of barrier height and ideality factor for n-ZnO/p-GaAs heterojunction diode were determined to be 0.61 eV and 1.83, respectively. The *I–V* characteristics of the heterojunction diode exhibit a non-ideal behavior. The ideality factor which is greater than unity was attributed to the series resistance, interface states and interfacial layer. The modified Norde's function combined with conventional forward *I–V* method was used to obtain the parameters including the series resistance and barrier height (BH). The capacitance–voltage (*C–V*) measurements were performed in the range of 100 kHz to 1 MHz. The interface distribution profile (D_{it}) as a function of bias voltage was extracted from the *C–V* and G_{adj}–*V* characteristics. The interface state density of n-ZnO/p-GaAs diode is of the order of 10^{13} eV^{-1} cm^{-2}. Also, the *I–V* characteristics of n-ZnO/p-GaAs heterojunction diode were investigated in the temperature range of 293–393 K.

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1. Introduction

The practical semiconductor device applications are based on metal–semiconductor (MS) junction in microelectronic integrated circuits (IC) [1–6]. These applications are consisted of space solar cell, heterojunction bipolar transistors, microwave field effect transistors, phototransistors, photodiodes, radio-frequency detectors, polariton laser, and quantum confinement devices. The interface between the metal and semiconductor affects the reliability and the performance of a Schottky contact. The many efforts have been devoted to understanding the transport mechanism of the Schottky barrier diodes (SBDs). In last few decades, the metal–semiconductor interfaces, particularly in electronic devices have attracted heavy interest. ZnO has an n-type conductivity that can be attributed to the intrinsic defects such as oxygen vacancies [7,8]. Furthermore, ZnO is one of the attracting photonic materials for devices such as ultraviolet (UV)

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photodetectors, laser diodes (LDs) and light emitting diodes (LEDs) due to wide band-gap (3.37 eV) and large exciton binding energy (60 meV) [9–11]. Photodetectors working in the UV range have interesting capabilities for military and commercial applications such as ozone layer monitoring, flame detection and space communications. Si based detectors do not sensitive to the wavelength located in the UV range due to the narrow band-gap energy (only 1.2 eV) of Si. Thus, the performance of Si photodiodes is not satisfactory in the UV range. The photoresponse time of ZnO-based photodetectors has improved with the advent of optoelectronic devices including wide direct-bandgap materials. In the last decade, molecular beam epitaxy (MBE), magnetron sputtering, pulsed-laser deposition (PLD), sol–gel process and metal–organic chemical vapor deposition (MOCVD) are some of methods used to prepare ZnO thin films on various substrates [12–17]. Particularly, the sol–gel method is an alternate way that is extremely low-cost and easy to prepare the large area ZnO thin films [18] and also, spin coating is one of the standard methods for depositing sol–gel, nanocomposite or polymer coatings onto flat substrates (silicon wafers, glass plates for displays, sensor substrates, etc.). The preparation of the new metal–semiconductor contacts based on ZnO semiconductor plays a key role in device applications.

In this work, ZnO/p-GaAs heterojunction structure was obtained by spin coating of ZnO on p type GaAs substrate. The some properties of the ZnO/p-GaAs heterojunction diode were analyzed by the *I–V* and *C–V* measurements.

2. Experimental details

In this study, p-GaAs (1 0 0)-doped with Zinc (Zn) was used as substrate. The GaAs wafer was cleaned with methanol, acetone and trichloroethylene. After, the wafer was thoroughly washed with de-ionized water (> 18Mohm.cm), followed by drying under high purity (99.9%) dry N_2 gas. The native oxide on the wafer was removed by etching in sequence with acid solutions (H_2SO_4:H_2O_2:H_2O=3:1:1) for 60 s, and (HCl:H_2O=1:1) for another 60 s. Again, the wafer was thoroughly washed with de-ionized water (> 18Mohm.cm), followed by drying under high purity (99.9%) dry N_2 gas. The ohmic contact to the p-type GaAs wafer backside was deposited by thermal evaporation of high purity (99.999%) indium metal in the pressure of 2×10^{-5} Torr. The GaAs wafer with indium back contact was thermally treated at 370 °C for 6 min in N_2 atmosphere. Sol–gel method was employed for preparation of undoped ZnO sample. Zinc acetate hexahydrate, deionized water and monoethanolamine were used as the starting material, the solvent and stabilizer, respectively. Zn^{2+} and monoethanolamine were used in equal concentrations. In order to a homogeneous sol, the solution was mixed with a magnetic stirrer at 65 °C for 2.5 h and then remained in air for 24 h aging. The thin film of ZnO was formed on the front surface of the GaAs by spinning (non-vacuum process) at 1000 rpm, for 1 min. The ZnO thin film was heated to 470 °C for 3 min in a tube furnace. Contacts with a diameter of approximately 2 mm of Al were formed on undoped ZnO films by thermal evaporation method through a molybdenum mask at vacuum ambience of $\approx 3.4\times10^{-5}$ mbar pressure. A diagram of the diode structure is shown in Fig. 1.

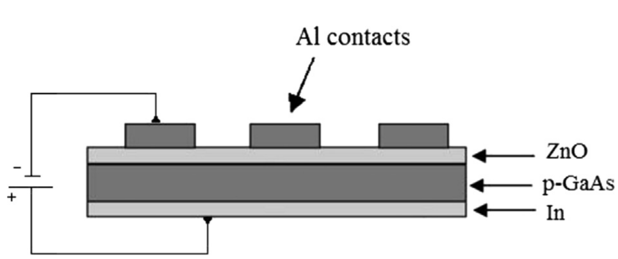

Fig. 1. A schematic cross-section of the Al/ZnO/p-GaAs structure.

The measurements were performed using KEITHLEY 4200 semiconductor characterization system. The two terminal cables of Source Measure Unit1 (SMU-1) and Source Measure Unit2 (SMU-2) were united to a home made specially designed holder for a point contact. The temperature dependent measurements were controlled by means of a temperature controller (Lakeshore 331) with sensitivity better than ±0.1 K.

3. Results and discussion

3.1. The current–voltage characteristics of the Al/ZnO/p-GaAs heterojunction diode

In order to investigate the morphology of the ZnO film, atomic force microscopy (AFM) (Park System XE-100E) was used. Fig. 2 shows two (2D) dimensional and inset: three (3D) dimensional AFM images of the ZnO film. The AFM results show that the ZnO films are formed from the nanofibers. The surface roughness of undoped ZnO film by means of a PARK system AFM XEI software programming was determined to be approximately 42.32 nm.

The current–voltage (*I–V*) characteristics were measured to obtain the effective values of the diode parameters. Fig. 3 shows the current–voltage characteristics of ZnO/GaAs/In heterojunction diode. As seen in Fig. 3, the diode shows a rectifying characteristic with relatively low reverse current of 9.15×10^{-6} A at reverse bias of $V_R=-1.0$ V. The current increases exponentially in low applied voltages. The current flow for $V-IR_s>3kT/q$, can be analyzed by the following relation [1,19,20]:

$$I=I_o\exp\left(\frac{q(V-IR_s)}{nkT}\right) \quad (1)$$

where, I_0 is the reverse saturation current given by:

$$I_0=AA^*T^2\exp\left(-\frac{q\Phi_b^{I-V}}{kT}\right) \quad (2)$$

where q is the electronic charge, V the definite forward biasing voltage, A the contact area, A^* the effective Richardson constant, k the Boltzmann's constant, T the absolute temperature, Φ_b^{I-V} the barrier height and n is the ideality factor. The values of Φ_b^{I-V} and n

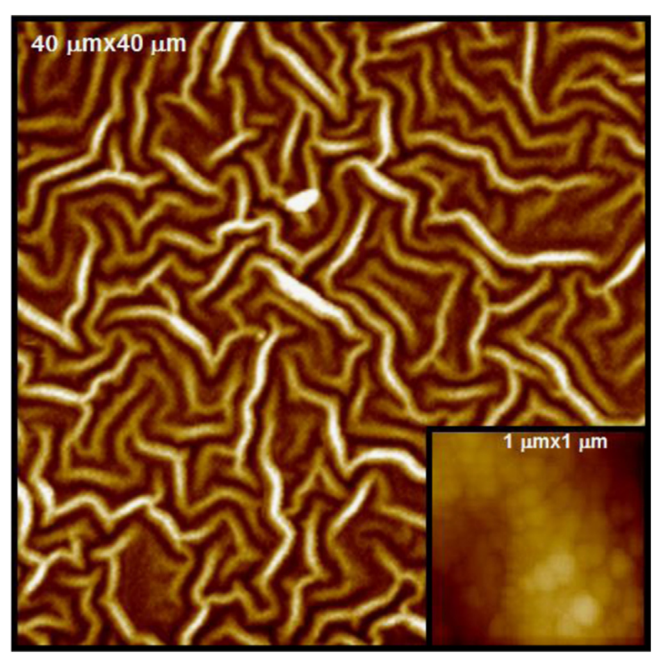

Fig. 2. AFM images of nano fiber ZnO thin film.

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