Structural and electrical properties of metal contacts on *n*-type ZnO thin film deposited by vacuum coating technique

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The authors report on fabrication and characterization of Al and Pt metal contacts on ZnO thin films grown on ITO coated glass substrates using thermal evaporation technique. The structural and surface properties of ZnO thin film were studied by using x-ray diffraction and atomic force microscopy techniques. Atomic force micrographs revealed that ZnO microparticles have perfect pyramidal shape with small surface roughness (average rms value of 3 nm). The current voltage characteristics of Pt/ZnO and Al/ZnO contacts were studied by scanning tunneling microscopy. The Pt contact on ZnO thin films behaves as a rectifying contact with a barrier height of 0.72 eV, while Al contact on ZnO thin film turns out to be Ohmic in nature. The band gap of ZnO thin film was estimated to be 3.10 eV from absorption spectroscopic measurements. © *2009 American Vacuum Society.* [DOI: 10.1116/1.3196786]

I. INTRODUCTION

ZnO is an important member of II–VI semiconductor family. The material has drawn considerable interest for application in electronic and optoelectronic devices. The attractive features of this material include a wide band gap of 3.37 eV, a strong excitonic feature even (~ 60 meV) at room temperature, and very good optical properties. A considerable amount of work has already been done on the growth of ZnO thin films[1–4] for fabrication of a variety of electronic and optoelectronic devices, such as quantum wires, nanorods, nanotips, thin film transistors, liquid crystal displays, etc.[5–9] However, in order to realize high-performance ZnO-based devices, it is necessary to obtain good metallic contact on high quality ZnO film. Some work has been reported on formation of nanoscale level Schottky metal contacts on ZnO thin films.[10–13] However, improvement in the quality of metal (electrode) contacts on thin film (semiconductor) is still required for enhancement of speed, reduction in contact resistance, and further miniaturization. The faster switching speed and lower turn-on voltages of ZnO based Schottky diodes will make them attractive for high speed detection purpose. The present article reports fabrication and electrical characterization of Pt and Al metal contacts on ZnO thin film grown by thermal evaporation method.

II. EXPERIMENT

Thin films of Zinc oxide (ZnO) were deposited on indium tin oxide (ITO) coated glass substrates by thermal evaporation technique using a vacuum coating system (HIND HI-VAC, India made, and model No. 12A4D). Ultrapure ZnO powder (99.99%) was used as a source material. The details of deposition are listed in Table I. The heating filament used was a conventional molybdenum boat. After deposition, the samples were inserted into a rapid thermal annealing system and postannealed at 600 °C in O_2 atmosphere for 20 min. The film was then left to cool down to room temperature before carrying out the structural and morphological studies.

Pt and Al metal contacts were deposited separately on ZnO thin film samples grown on ITO (surface resistance of $8\ \Omega/\mathrm{cm}^2$) coated glass substrate through shadow masks techniques for preparing two sets of devices, e.g., Pt/ZnO/ITO-glass and Al/ZnO/ITO-glass. The *I-V* characterizations of the fabricated thin film devices (Pt/ZnO/ITO and Al/ZnO/ITO) were carried out by scanning tunneling microscopy (current sensing mode) at room temperature (27 °C). The crystalline structure of annealed ZnO thin films was investigated using Rigku x-ray diffraction (XRD) apparatus in parabolic filter Cu $K\alpha$ radiation mode with a slow scanning speed of 2θ/min. The surface morphology of ZnO thin film was studied using atomic force microscopy (AFM) (NT-MDT; Russia made, model No. SOLVER-PRO 47) in semiconduct mode with a sharpened pyramidal SiN tip fitted with a spring (spring constant of 0.16 N/m). The AFM cantilever spring resonant frequency was set at 256 kHz with a scan rate of 1 Hz. The UV-visible study was carried out using a spectrophotometer (Perkin Elmer, Germany made, and model No. Lamda 25).

III. RESULTS AND DISCUSSION

A. Structural studies

XRD profiles of the ZnO thin films [Fig. 1(a)] reveal the polycrystalline nature ZnO with two peaks. A typical XRD profile shown in Fig. 1(a) confirms that it *C*-axis oriented. The crystallite size was estimated by the Debye–Scherrer relation given by

$$d = \frac{c\lambda}{\beta \cos\theta}, \tag{1}$$

where β is the full width at half maximum of x-ray peak, d is the crystallite size, λ is the x-ray wavelength, and c is the

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TABLE I. Details of ZnO thin film deposition.

Substrates	ITO coated glass
Source material	ZnO 999.99%) powder
Base pressure	5×10^{-3} mbar
Substrate cleaning agents	trichloroethylene methanol and acetone (used sequentially)
Substrate-source separation	18 cm
Film thickness	300 nm
Metal thickness	80 nm
Deposition rate	$2^{\circ}_{A}/\text{min}$

correction factor taken as 0.90 in the calculation. The crystalline size of the deposited film was estimated to be 500 nm.

B. Surface morphology study by AFM

The two-dimensional (2D) and three-dimensional (3D) views of the surface morphology of ZnO thin film (scale of $5\times 5\ \mu\text{m}^2$) are shown in Figs. 1(b) and 1(c), respectively. It is observed that the grains grow uniformly with homogenous distribution. The AFM images also show that a good quality homogenous film over a large region can be grown by vacuum thermal evaporation technique. The roughness and other statistically derived parameters of ZnO thin film were obtaining by using "STATISTICS" tool of AFM software.[14] The values of grain size, rms roughness, standard deviation, aspect ratio, and average grain height of ZnO thin film are estimated to be 500 nm, 3 nm, 9.60, 21.8 nm, and 395 nm, respectively.

C. Optical properties

The absorbance and optical transmittance spectra of a sample ZnO thin films are shown in Figs. 2(a) and 2(b), respectively. The thickness of the film was estimated to be 300 nm from AFM measurement. From Fig. 2(a) it is seen that strong absorption occurs in UV wavelength range of 350–375 nm with the peak occurring at 365 nm. This optical property of the ZnO thin film can be exploited for the detection of optical signal in UV region. The weak absorption area covers almost the whole of the visible field ranging between 400 and 650 nm. The transmittance spectrum of the ZnO thin film shown in Fig. 2(b) reveals that the transmittance of the film is above 77% in this visible region. The optical band gap of ZnO thin film is evaluated from the absorbance spectra of ZnO thin film on ITO coated glass. The substrate absorbance was corrected by introducing an uncoated ITO glass sub-

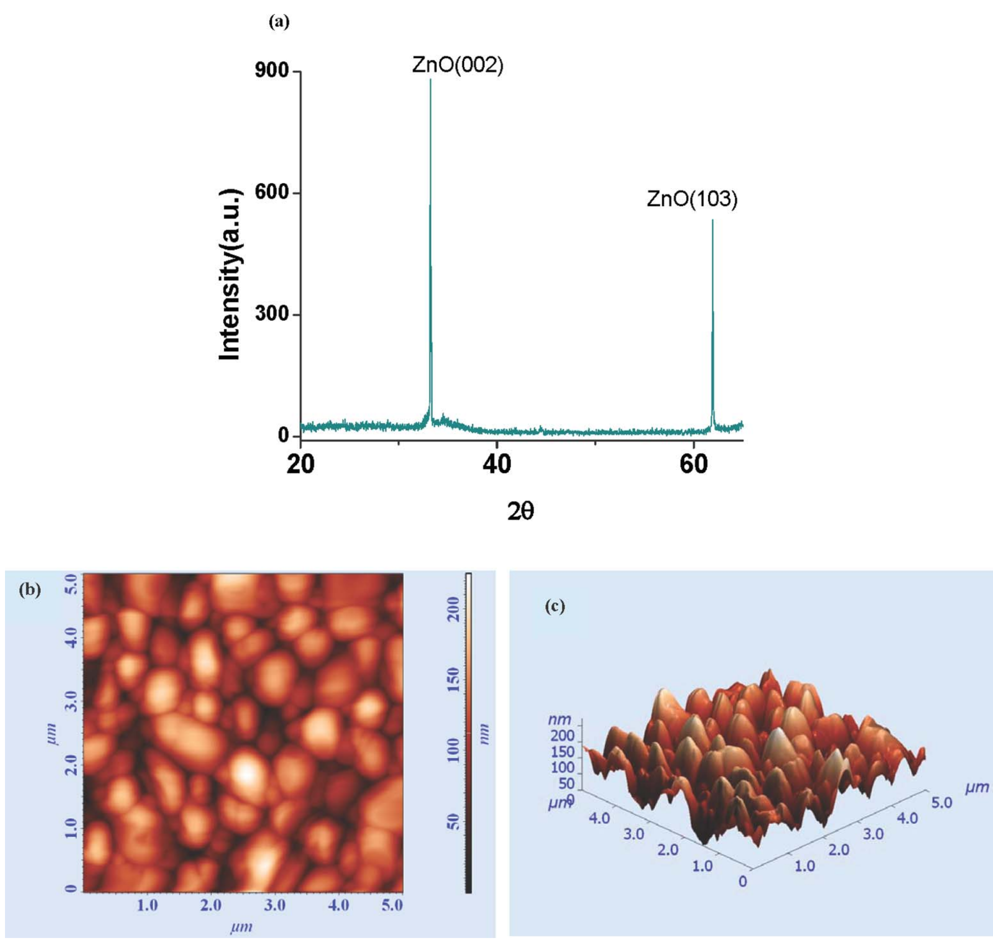

FIG. 1. (Color online) XRD and AFM images of ZnO film: (a) typical XRD pattern, (b) AFM 2D image, and (c) Corresponding 3D image of (b).

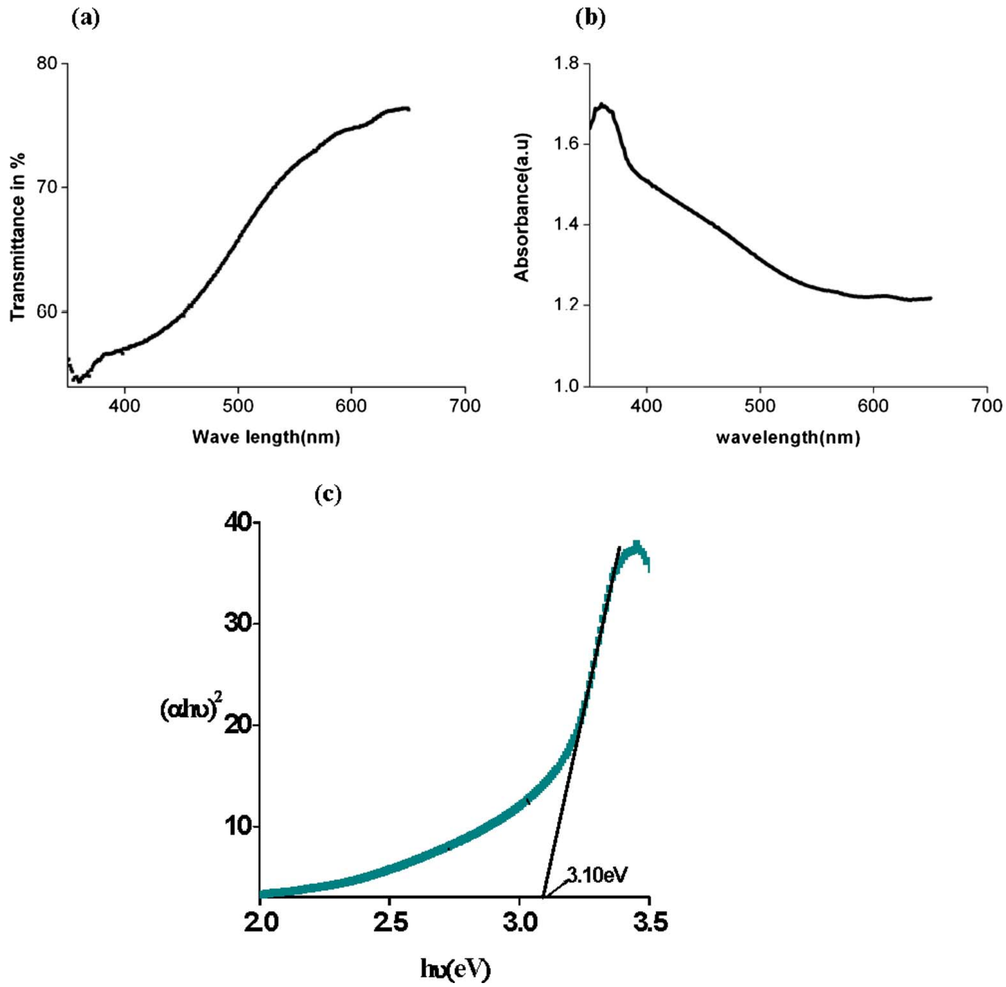

FIG. 2. (Color online) UV-vis spectrum of ZnO thin film: (a) Absorption spectra, (b) optical transmittance spectra, and (c) $(\alpha h\nu)^2$ vs $h\nu$ plot for estimation of band gap.

strate of the same size as the reference. The optical band gap of ZnO thin film was calculated by the standard relation given by

$$\alpha h\nu = B(h\nu - E_g)^n, \quad (2)$$

where α is the absorption coefficient, $h\nu$ the energy of absorbed photon, $n=1/2$ for direct allowed transition, and B is the proportionality constant. Energy gap E_g was obtained by plotting $(\alpha h\nu)^2$ versus $h\nu$ and extrapolating the linear portion of $(\alpha h\nu)^2$ versus $h\nu$ to intersect the $h\nu$ axis as shown in Fig. 2(c). The band gap of ZnO thin film was estimated to be 3.10 eV by using the above method.

D. Electronic properties

The Hall effect measurement of the ZnO thin film was carried out using OMEGA Hall effect experimental setup (model No. CCPHM −3/4) connected with digital gauss meter (OMEGA, model No. DGM-020). Hall effect measurements in the van der Pauw techniques were used to determine the mobility and carrier concentration of the ZnO sample. From Hall effect measurement of the ZnO thin film sample, the values of free electron concentration and mobility are found to be 1.31×10^{18} cm^{-3} and ~42 cm^2/V s, respectively, at room temperature (300 K). The values of electron concentration and mobility are found to be in the order with the results reported by Seong Jun Kang.[15]

E. Electrical characteristics

The STM setup for *I-V* measurement is shown in Fig. 3(a). Experimentally measured *I-V* characteristics of Pt/ZnO and Al/ZnO contacts are shown in Figs. 3(b) and 3(c), respectively. The *I-V* characteristic [Fig. 3(b)] demonstrates that the Pt contact is rectifying in nature. The Schottky diode current was measured at various bias voltages applied (through STM tip) between the Pt metal contact and ZnO thin film layer. The STM was operated in the current sensing mode. All measurements were performed at room temperature (300 K). The nature of *I-V* characteristics depends on surface morphology of ZnO thin film (such as surface roughness) as well as other measurement parameters such as contact force of the tip. The turn-on voltage of the Pt/ZnO Schottky contact is estimated to be 0.4 V. We used the conventional thermionic emission model for the analysis Pt/ZnO Schottky contact.[16] The barrier height and ideality

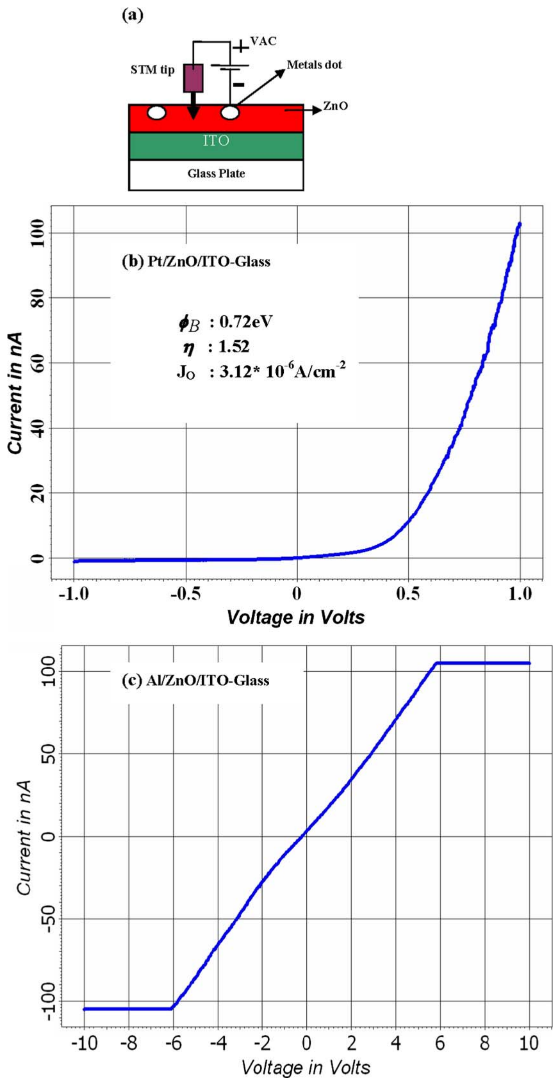

FIG. 3. (Color online) I-V characterization: (a) Measurement setup, (b) rectifying characteristics of Pt contact, and (c) Ohmic I-V plot of Al/ZnO contact.

factor of Pt/ZnO contact have been estimated from the study of $\ln(J)$ versus V (not shown here). The measured value of J_0 is 2.12×10^{-6} A/cm^2. Assuming the effective Richardson constant $A^*=32$ A cm^{-2} K^{-2} (for $m_e^*=0.27m_0$),[16] the barrier height has been estimated to be 0.72 eV. The ideality factor was calculated to be 1.52. The value of barrier height is in order with the result reported by Sang-HoKim.[17] The Al/ZnO contact on the other hand exhibits a linear I-V variation over the voltage region ranging from −10 to 10 V [Fig. 3(c)] indicating the Ohmic in nature of the contact. The current and voltage characteristics of the Pt/ZnO device studied 5 weeks after the date of fabrication exhibited consistent result (1% variation of current for given voltage) demonstrating long term stability of the devices.

IV. CONCLUSIONS

In this article we report fabrication of Al/ZnO and Pt/ZnO devices using a simple low-cost vacuum deposition unit. Hall effect measurements showed that the electron mobility and n-type carrier concentration of the ZnO thin film are 42 cm^2/V s and 1.31×10^{18} cm^{-3}, respectively. The I-V measurements with Pt/ZnO and Al/ZnO contacts revealed that Pt/ZnO contact is rectifying in nature having a barrier height of 0.72 eV at 27 °C and an ideality factor of 1.52 with saturation current density of 3.12×10^{-6} A/cm^{-2} while Al/ZnO contact is Ohmic. It is conclude that the Pt/ZnO Schottky contact fabricated by a fairly simple technique can be used as a substitute of conventional Schottky diode for electronic and optoelectronic applications.

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