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Temperature dependent electrical properties of n-ZnO/p-Si heterojunction prepared by spray pyrolysis growth of ZnO thin film on p-Si

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Abstract: *Zinc oxide thin film was grown on p-Si substrate by spray pyrolysis method. The X-ray diffraction pattern indicates the hexagonal wurzite structure of the grown ZnO thin films. The FESEM image shows the growth of flower like nanostructured ZnO thin films on p-Si. These n-ZnO film/p-Si substrate heterostructure was characterized by current-voltage (I-V) and capacitance-voltage(C-V) measurements. I-V characteristic of fabricated heterojunction was studied in the temperature range of 103 K to 473 K. The variation of ideality factor and reverse saturation current with temperature was studied. The C-V measurement was carried out in the temperature range of 298 K to 108 K.*

Keywords: *Electrical properties, n-ZnO/p-Si heterojunction, Spray pyrolysis, ZnO thin film.*
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I. Introduction

Zinc oxide (ZnO) is a semiconducting material having direct band gap about 3.37eV at room temperature [1]. It is a promising semiconductor material for optoelectronic applications such as UV-light emitting diodes (LEDs), UV laser and UV photo-detectors [2]. ZnO has also been considered for the applications in solar cells as window material [3]. ZnO is inherently an n-type semiconductors and achieving a stable p-type doping is difficult in ZnO [1]. Therefore, the fabrication of a stable homojunction is hindered in ZnO. Generally, the fabrication of ZnO based junction devices are achieved by forming heterojunctions of n-ZnO with p-type materials such as p-Si, p-NiO, p-Cu_2O_3 etc. [4]. Among the p-type materials, Si has more advantage over other materials due to low cost and availability of large area substrates. The thin film growth methods such as thermal evaporation [5], pulsed laser deposition [6], magnetron sputtering [7], chemical vapor deposition [8], sol-gel process [9] and spray pyrolysis are used for deposition of ZnO thin films on Si. Among these, spray pyrolysis is a simple, low cost technique to deposit ZnO thin films. There are several reports on the n-ZnO/p-Si heterojunction diodes prepared by spray pyrolysis method and their electrical properties at room temperature [10-15]. In the present study, we report on the fabrication of n-ZnO/p-Si heterojunction diode by spray pyrolysis method and study of its electrical behavior in the temperature range of 103 K to 473 K.

II. Experimental details

ZnO thin film was deposited on p-Si (100) substrate by spray pyrolysis method using 0.2 M solution of zinc acetate dihydrate ($Zn(CH_3COO)_2\cdot 2H_2O$) prepared in double distilled water. Prior to the deposition of ZnO thin film, the Si substrate was cleaned ultrasonically using acetone, ethanol, and distilled water, respectively. The cleaned Si substrate was then subjected to HF acid treatment to remove native SiO_2. The HF treated substrate was then thoroughly rinsed in double distilled water to remove HF acid and dried in nitrogen atmosphere. Aluminium film of about 500 nm thickness was deposited using HINDHIVAC thin film coating unit (Model 12A4) on the unpolished side of the Si substrate to form the back Ohmic contact. The ZnO thin film was prepared on polished side of the Si substrate by spraying the prepared 0.2 M ($Zn(CH_3COO)_2\cdot 2H_2O$) solution. The substrate temperature was maintained at around 400 °C using a planar electric heater controlled by a PID temperature controller. Compressed air was used to spray the prepared 0.2 M ($Zn(CH_3COO)_2\cdot 2H_2O$) solution on the Si substrate. The XRD pattern of the as grown sample was studied by Rigaku Miniflex–600 X-ray Diffractometer. The ULTRA 55 Carl Zeiss FESEM was used to study the morphology of grown thin film. The Ohmic contact on ZnO thin film was made by depositing 100 nm thick Al metal film. The schematic diagram of the resulting n-ZnO/p-Si heterojunction diode is shown in the Fig.1. The temperature dependent I-V characteristic of the fabricated n-ZnO/p-Si heterojunction diode was measured in the temperature range 103 K to 473 K using Keithley 2400 Source-Measure Unit (SMU). The C-V characteristic was measured in the temperature range 298 K to 108 K using Agilent 4263B LCR meter at 100 kHz frequency.

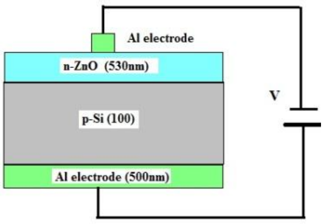

Fig.1 Schematic diagram of n-ZnO/p-Si heterojunction.

III. Results And Discussions

Fig. 2 shows the XRD spectrum of ZnO thin film deposited on p-Si substrate by spray pyrolysis. The XRD spectrum show peaks corresponding wurzite structure of ZnO in accordance with JCPDS No. 36-1451. The sharp diffraction peaks indicated the good crystallinity of the prepared sample. The sample exhibited preferential orientation along the (101) plane. The peaks at 28^o and 68.7^o corresponds to (002) and (511) peaks of Si substrate. The average crystallite size of the ZnO thin film was calculated from (101) peak using scherrer's formula [16]

$$D = \frac{0.9\lambda}{\beta \cos\theta} \tag{1}$$

where β is the FWHM of the XRD peak, λ is the wavelength of the X-ray. The value of average crystallite size of the grown ZnO film was found to be around 38 nm. Fig. 3(a) shows the FESEM image of ZnO thin film deposited on Si substrate. The ZnO thin film exhibits uniform surface with flower type grain structure. The thickness of the film was estimated by FESEM cross-section, shown in Fig. 3(b), which was found to be about 530 nm.

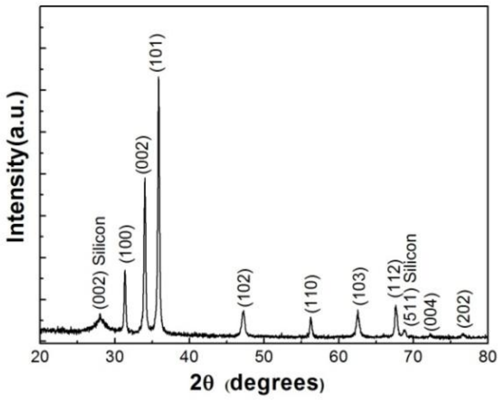

Fig.2 XRD spectrum of ZnO thin film on Si substrate.

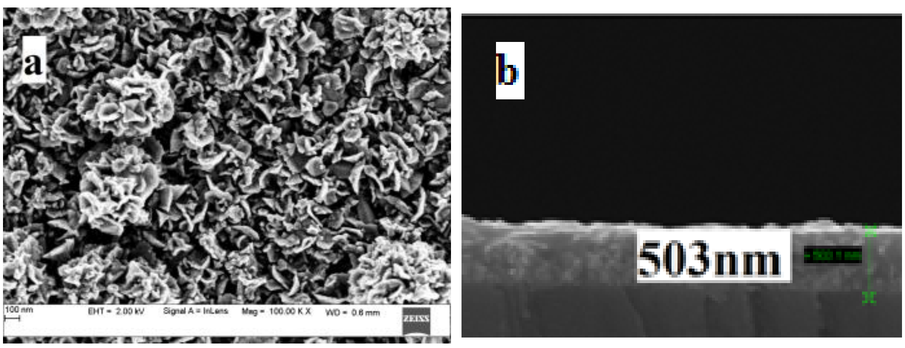

Fig.3 FESEM images of ZnO grown on Si substrate: (a) surface morphology (b) cross-sectional image.

Fig. 4 shows the I-V characteristics of n-ZnO/p-Si heterojunction diode measured at various temperatures in range of 103 K to 298 K. Fig. 5 shows the I-V characteristics of n-ZnO/p-Si heterojunction diode measured in the temperature range 308 K to 473 K. I-V characteristic indicates good rectification property of the prepared n-ZnO/p-Si heterojunction diode in the measured temperature range. The diode rectification ratio (I_R/I_F) at room temperature was found to 13905 at ±10V. The current-voltage relation of the n-ZnO/p-Si heterojunction diode was studied using standard diode equation [17].

$$I = I_0\left[\exp\left(\frac{qV}{nkT}\right)-1\right] \tag{2}$$

where I_0 is the saturation current, q is the electronic charge, V is the applied voltage, k is the Boltzmann's constant, and T is the temperature in Kelvin and 'n' is the ideality factor. The ideality factor is given by equation (2) as

$$n = \frac{q}{kT}\left(\frac{\partial V}{\partial \ln(I)}\right) \tag{3}$$

The ideality factor can be calculated from the slope of the straight line region of the forward bias ln(I) versus V plot. Fig. 6 shows the ln(I) versus V plot in the temperature range 298 K to 103 K. Fig. 7 shows the ln(I) versus V plot in the temperature range 308 K to 473 K. Fig. 8 (a) shows the variation of the n-ZnO/p-Si heterojunction diode ideality factor with temperature. Fig. 8 (b) shows the variation of the saturation current of the n-ZnO/p-Si heterojunction diode with temperature. The value of ideality factor at 103 K was found to be about 14.5 which decreased to 6.13 as increase in temperature up to 300 K and above 300 K value of ideality factor remains in between 5 and 6. The reason for higher value of ideality factor may be due to the high concentration of interface defect states in the n-ZnO/p-Si heterojunction [18].

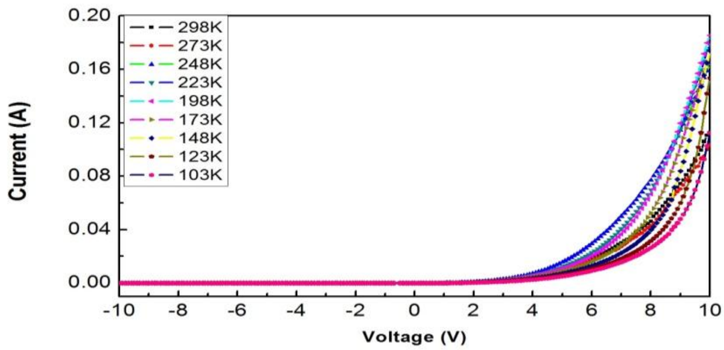

Fig.4 I-V characteristics in the temperature range 298 K to 103 K.

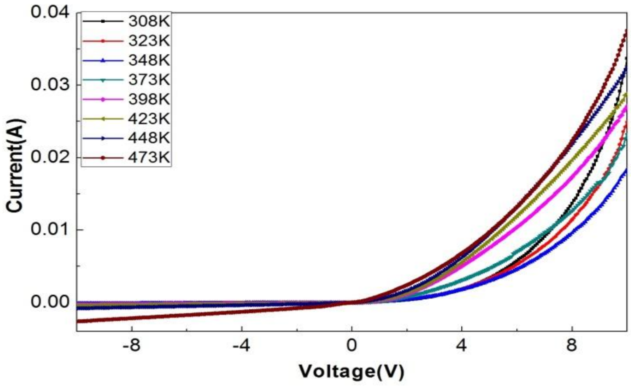

Fig.5 I-V characteristics in the temperature range 308 K to 473 K.

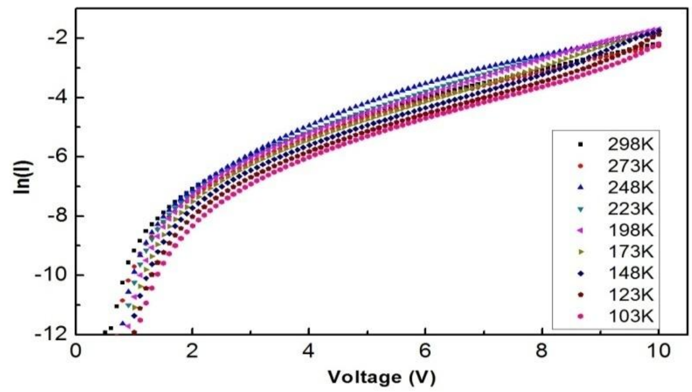

Fig. 6 ln(I) versus V plot in the temperature range 298 K to 103 K.

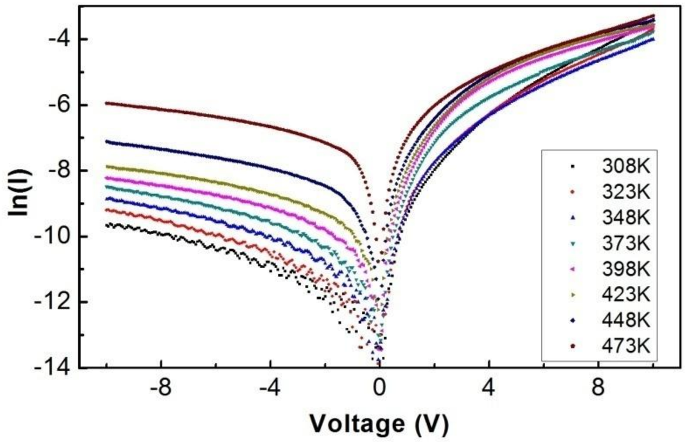

Fig.7 ln(I) versus V plot in the temperature range 308 K to 473 K.

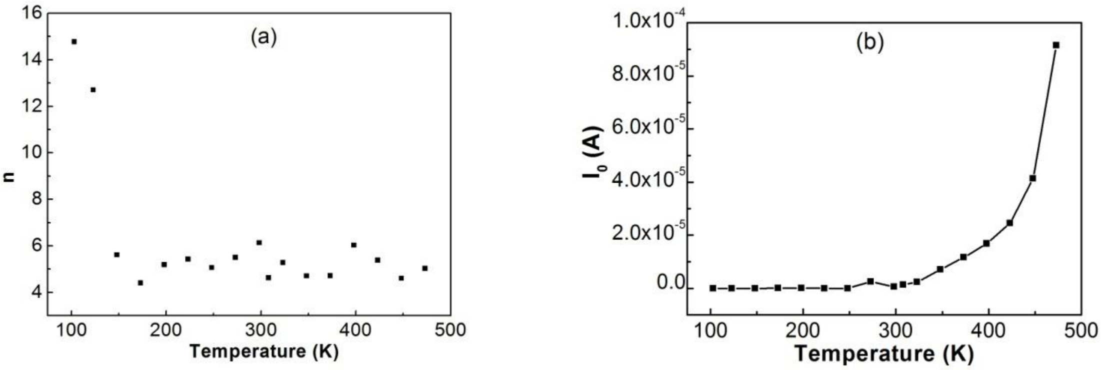

Fig.8 Variation of (a) ideality factor (b) saturation current in the temperature range 103 K - 473 K.

Fig. 9 shows the C-V characteristic of the n-ZnO/p-Si heterojunction in the temperature range 298 K to 108 K. The capacitance shows the typical characteristic of a p-n junction, i.e. the nonlinear decrease of capacitance with increase in the reverse bias voltage.

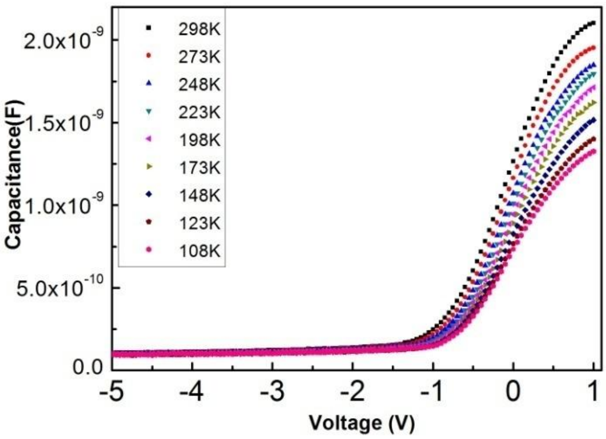

Fig.9 C-V plot of n-ZnO/p-Si heterojunction in the temperature range 298 K to 103 K.

IV. Conclusion

ZnO thin film was grown on p-Si substrates by spray pyrolysis method. The XRD spectrum confirms that the grown ZnO thin film has hexagonal wurzite structure. The as grown ZnO thin film on p-Si was used to fabricate n-ZnO/p-Si heterojunction diode. I-V characteristic in the temperature range 103 K to 473 K shows that heterojunction was found to stable and has good rectification property. The high value of ideality factor may be due to the high concentration of interface defect states in the n-ZnO/p-Si heterojunction. The C-V measurement was conducted in the temperature range 298 K to 108 K.

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