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Growth and Electrical Properties of Au Schottky Contact on ZnO/Si Films

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Abstract

Schottky contacts play an important role in determining the performance of semiconductor devices required for various electronic and optoelectronic applications. Barrier heights of Schottky junctions depend strongly on the chemical phases formed by thermal reactions between the metal and semiconductor. In this paper, ZnO (purity: 99.99%) films of thickness 100 nm were deposited on Silicon substrate and observed the results of electrical characterization of Schottky barrier diodes using Gold on ZnO/Si. Structure and composition of the ZnO/Si films have been investigated by X-ray diffraction (XRD), atomic force microscopy (AFM), X-ray photoelectron spectroscopy (XPS) and Rutherford backscattering (RBS).

Key words

ZnO, PL, XRD, Schottky contact, rf magnetron sputtering, Rutherford backscattering (RBS)

1. Introduction

Nowadays, possible solution could be to replace amorphous silicon Diode by ZnO Diode. It is possible to have an optimum working temperature below 100 ^{o}C, which restricts the choice of materials, and processing temperature for flexible electronics. This temperature limitation has its greatest impact on semiconductors, which are the critical material in semiconductor, the basic element in electronic circuitry. Even amorphous silicon, used in most laptop computer displays, may require too high processing temperature to achieve good electronic properties (e.g. adequately high mobility). A broad interest in organic semiconductor, such as pentacene, has evolved because they can be prepared with good semiconductor properties below 100 ^{o}C. However, many organic semiconductor reports indicated its instability if exposed to air. The need for a stable semiconductor with good electronic properties, compatible with low temperature silicon substrates, motivated us to investigate ZnO as a semiconductor applications. ZnO is stable in air and environmentally safe. It has become an attractive wide band gap semiconductor since ultraviolet laser action was demonstrated at room temperature [1-3]. It has potential uses in photo detectors [4], solar cells, and light emitting diodes (LEDs). ZnO is a II-VI compound n-type semiconductor with a wide direct band of 3.37 eV (at room temperature) and has hexagonal wurtzite structure and cell parameters of a=0.3294 nm, c=0.5206 nm [5]. It has large exciton binding energy of 60 meV, this indicates that ZnO is the material with most potential to realize the next generation UV semiconductor laser. Silicon is not only of interest for the integration of opto-electronic devices but is also cheaper and easier to cleave in comparison with sapphire, which is widely used as substrate in the deposition of ZnO film [5]. ZnO thin films have been prepared by a wide variety of techniques, including sputtering, spray-pyrolysis and electrodeposition [6]. In particular, the rf sputter method has advantages over other processes because of its simplicity [7]. The Structure and composition of the ZnO/Si films have been investigated by X-ray diffraction, atomic force microscopy and Rutherford backscattering, X-ray photoelectron spectroscopy for chemical composition.

2. Experiment and Results

In this study, undoped ZnO (100 nm thick) thin films are grown on n-Si (100) at 450 ^{o}C by rf magnetron sputtering technique of sintered commercial 2-inch ZnO target (Purity > 99.99%). Only Ar is introduced as a plasma gas up to 10 mTorr, after standard cleaning (RCA) of the ZnO/Si substrate followed by a dip in 1% HF. The gold metal was deposited through a metal mask of diameter 1.04 mm. The ohomic contact was made by thermal evaporation of Al on the backside of the wafer [8].

Rutherford backscattering (RBS) analysis was carried out to estimate the composition and thickness of the films. The advantages of RBS are the following: (a) speed, (b) ability to perceive depth distribution of atomic species below the surface and (c) the quantitative nature of the results. RBS is used for depth profiling and layer removal of films by sputtering as used in SIMS or AES, is not involved. However, damage or defects are produced in the exposed films during RBS characterization. 2 MeV He^{+2} beam, attained through a charge exchange process with a stripper nitrogen gas, is normally used for the RBS and channeling measurements. The energy momentum of the beam is gained from a 90° analyzing magnet and the beam is directed to the scattering chamber through a switching magnet. The beam is collimated by a pair of collimators of diameter 1 mm separated by a distance of about half a meter. This is done to reduce the divergence of the beam, which is important for channeling measurements. The surface barrier detector (SBD) (resolution 25 keV) can detect scattered particles over a scattering range of 0-170°. The solid angle subtended by the SBD is maintained around 2×10^{-3} steradian with the target. The beam current is in the range of 5-20 nA. The sample holder is a stainless steel vertical holder on which several samples can be mounted. The energy of the beam and the scattering angle of the SBD can be changed without disturbing the vacuum system either in the chamber or in the accelerator. The sample position with respect to the beam can be varied vertically without breaking the vacuum. The data are collected by a MCDWIN (Version-1.0) multichannel analyzer attached to a data acquisition computer.

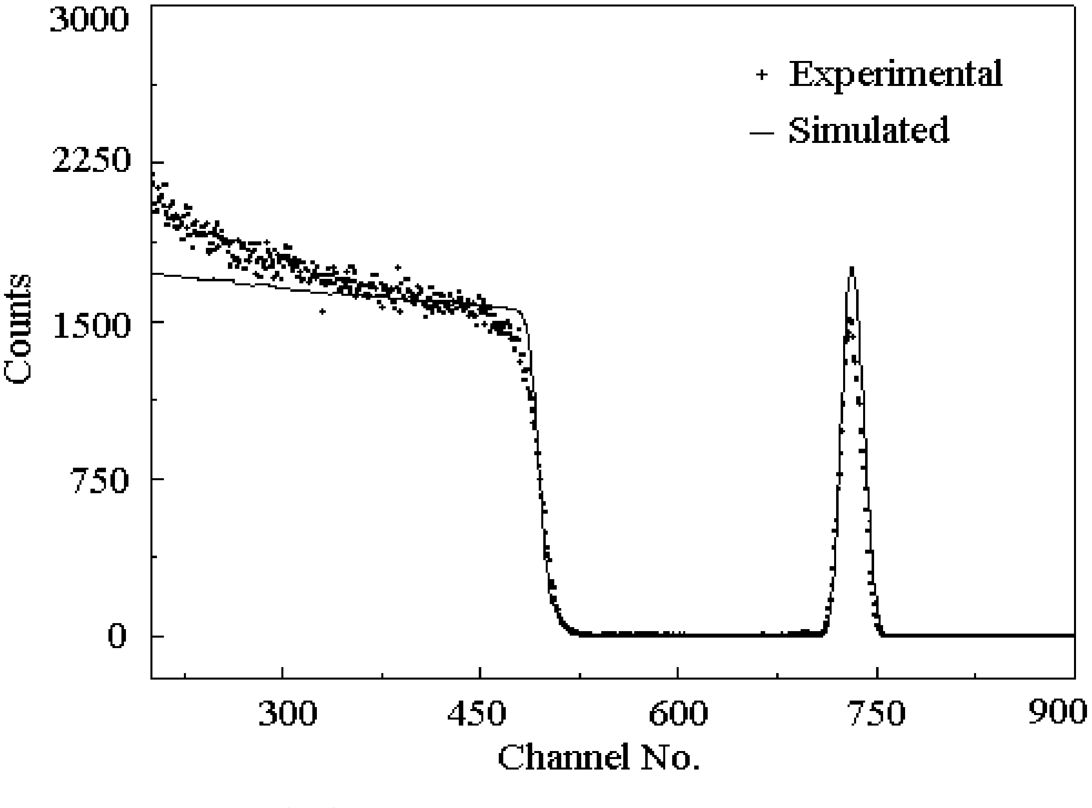


Fig. 1. 2 MeV $^{4}He^{2+}$ Rutherford backscattering spectra of ZnO/Si sample: (+++) experimental and (---) simulation.

Different ion beam energies were used for the present study. Using bulk Si did the energy calibration and Au targets and the counting rate was kept 185-500 counts/sec for a particular set of study. In general, RBS is carried out at lower energies using He ions as the scattering cross-section for most of the elements are Rutherford type (Coulomb's law applies). In some cases, slightly higher energy was used for the present observations to estimate the relative composition accurately. However, the advantage of using higher energies lies in the fact that the overlap between the backscattered peaks is reduced and it is particularly important for multi-component films for which the stopping power decreases with increasing incident energy, resulting in narrower spectrum. The disadvantage is that the scattering cross-sections are more likely to become non-Rutherford and the value deviates by 4%. Figure 1 shows a typical RBS spectrum of ZnO/Si sample as described above. The scattered He^{+2} from the ZnO layer appears at higher energies (channel nos. 715-750) while those from the bulk Si substrate appear at lower energies (channel nos. 500-525) [9].

X-ray diffraction pattern (XRD) is an important tool to analyze the crystalline structures for thin films. In other words, the all-physical and chemical characterizations are dependent on the degree of crystalline structure orientation [10, 11]. Figure 2 shows the XRD pattern of ZnO films deposited on Si (100) substrate at 100 W sputtering power with a major peak of the preferential orientation along the (103) and a minor one related to (002), and thus believed to be grown with a polycrystalline structure. The angular peak position of deposited films with (002) orientation is located at $2\theta = 34.1^\circ$.

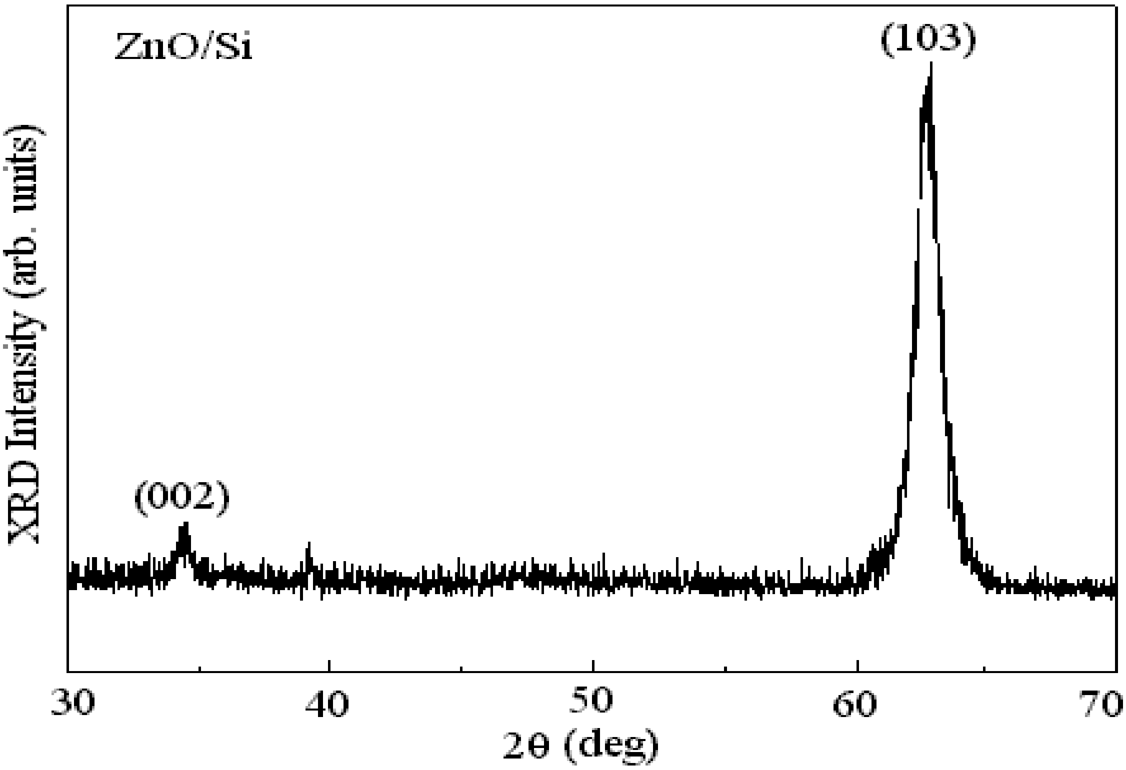


Fig.2. X-ray diffraction pattern of the as-grown ZnO thin film at 450 ºC and rf power 100W

Semiconductor surface roughness is one of the most important parameters, which can adversely affect the performance and reliability of the devices [12]. Surface morphology of buffer layers is dependent on the processing conditions such as grading rate and growth temperature. While it has been shown that high growth temperature is desirable for dislocation propagation, it also leads to a 3-D growth and eventually a rough surface morphology that may affect lithography steps in subsequent device processing. Atomic force microscopy (AFM) yields information about the surface morphology of a layer. An atomic force micrograph of ZnO film is shown in figure 3. The scan was taken on an area of 25 μm^2. The rms surface roughness (Zrms), and average roughness (Zav) were found to be 50.9 Å and 30.4 Å, respectively.

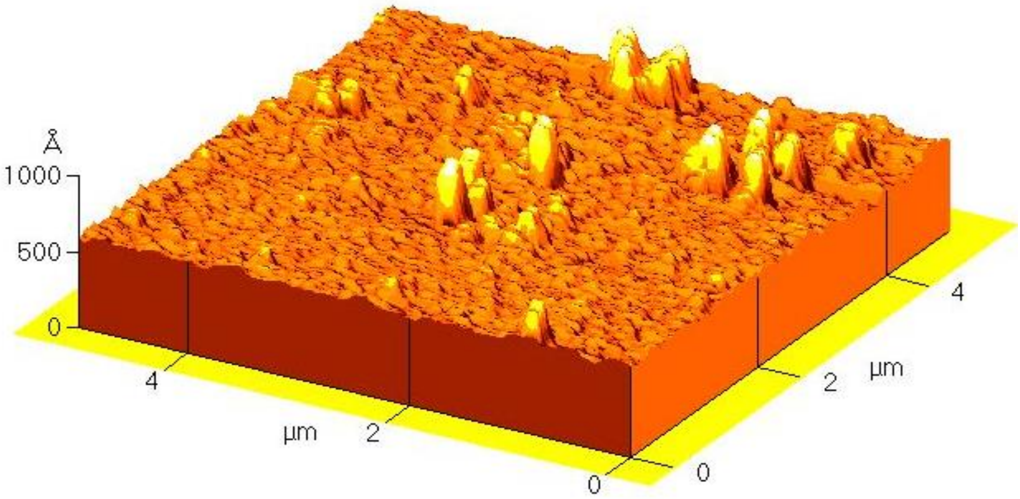
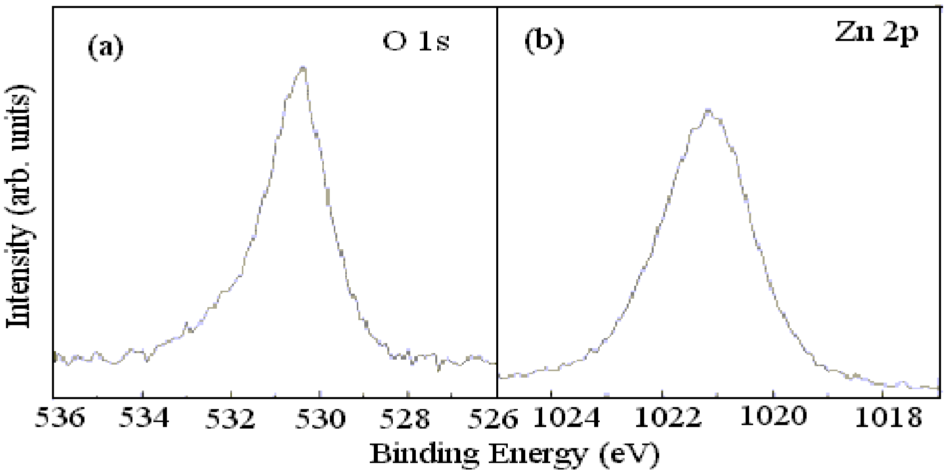


Fig. 3. Two-dimensional AFM image of ZnO Film with scan area of 5 μm × 5 μm.

Figure 4 shows core levels of O 1s and Zn 2p of the ZnO films measured by X-ray photoelectron spectroscopy (PHI-5800). For a comparison,



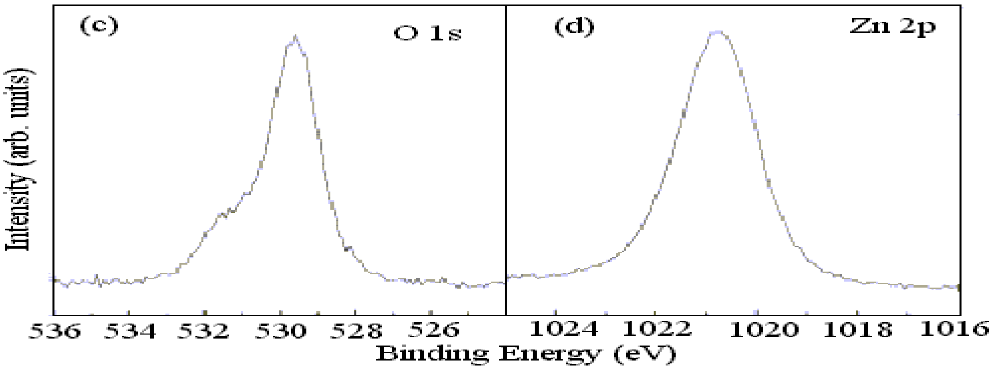


Fig. 4. XPS core-level of (a) O 1s, (b) Zn 2p of ZnO single crystal, and (c) O 1s and (d) Zn 2p of the as-grown ZnO thin film.

XPS spectra from both a standard ZnO crystal grown by a seed chemical vapor transport (SCVT) and as-grown ZnO thin film are taken. In case of O 1s, it consisted of two peaks at the binding energies of 531.5 eV and 529.7 eV corresponding to -OH and Zn-O bonding, respectively. The N_o/N_{Zn} was computed by correction of I_o/I_{Zn} with the observed peak area ratio of O 1s to Zn 2p in the standard ZnO crystal as a reference and it was 0.95 [13].

The current density vs. applied voltage characteristics at different temperature (300 K, 275 K, 250 K, 225 K, 200 K, 175 K, 150 K, 125 K) of Au/ZnO/Si Schottky diode is shown in figure 5.

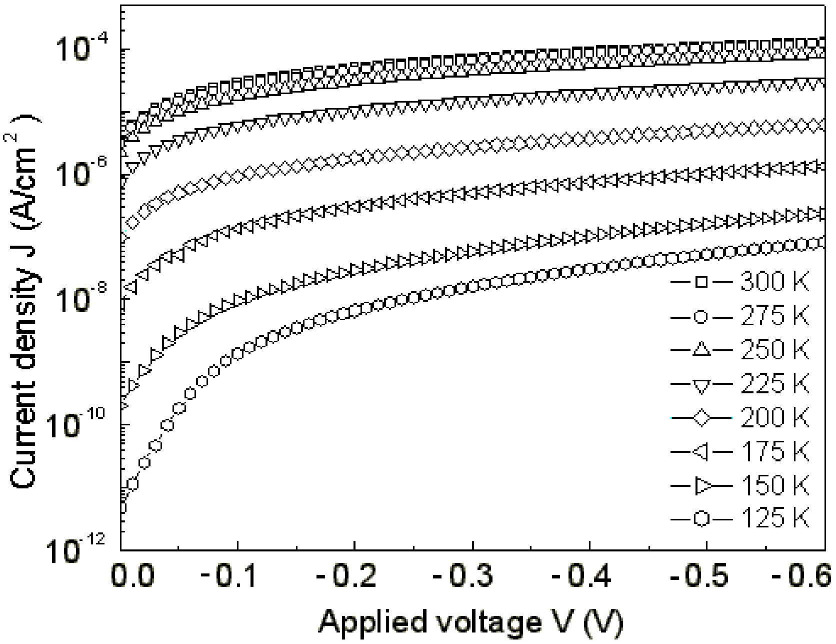


Fig. 5. Forward current density vs. voltage characteristics at different temperature.

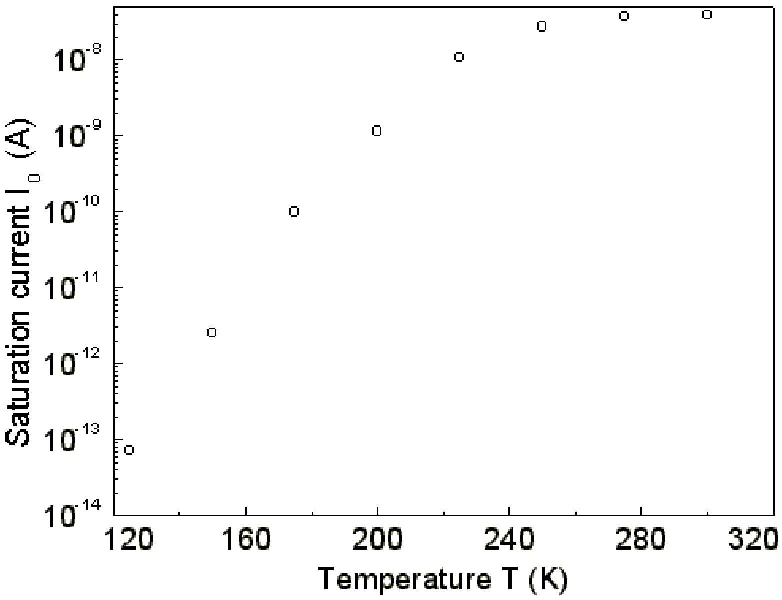


Fig. 6. Saturation current vs. measuring temperature plot.

The saturation current density (J_0) at zero bias of Schottky diode is usually obtained by extrapolating the linear portion of the forward current-voltage characteristics to zero applied bias. The saturation current vs. temperature characteristics is shown in figure 6. Using the saturation current, important parameters such as barrier height and ideality factor for a Schottky diode can be determined. However, it is difficult to apply at large biases where the voltage drop across the series resistance of the diode may become a significant proportion of the applied voltage. To avoid this difficulty, saturation current is calculated by using least square fitting method [14, 15]. Barrier height and ideality factor have been calculated using standard equations [16]. The variation of barrier height with temperature is show in figure 7 and also, the variation of ideality factor with temperature is show in figure 8.

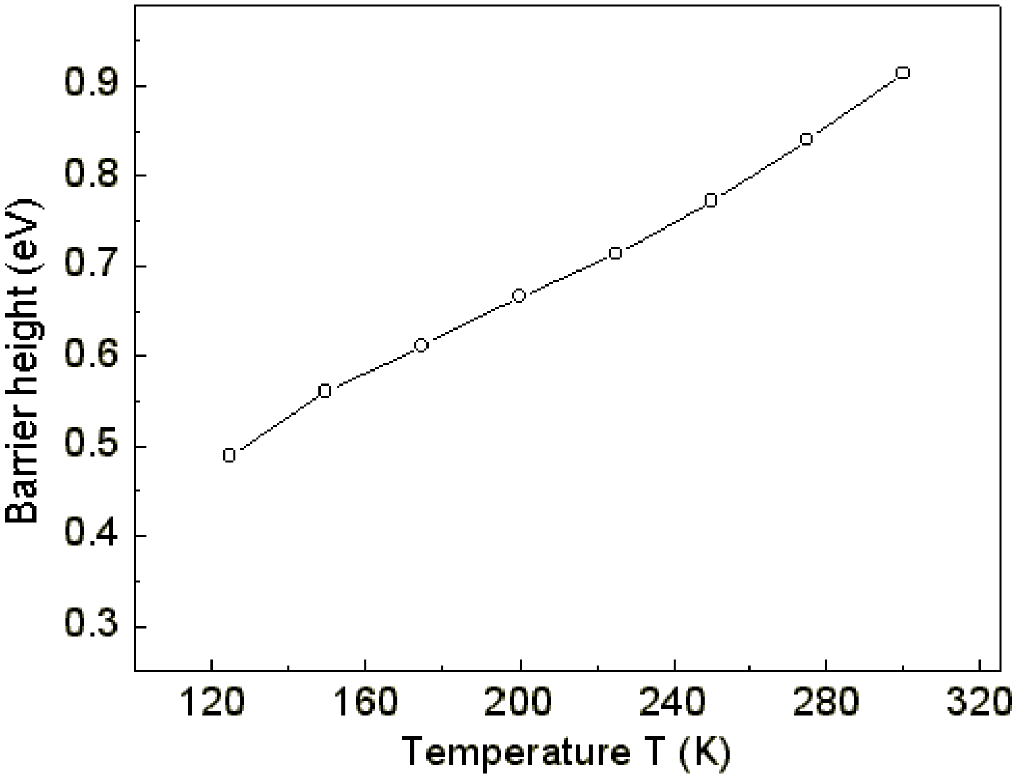


Fig. 7. Variation of barrier height (ϕ_b) of Al/ZnO/Si Schottky diodes as a function of temperature.

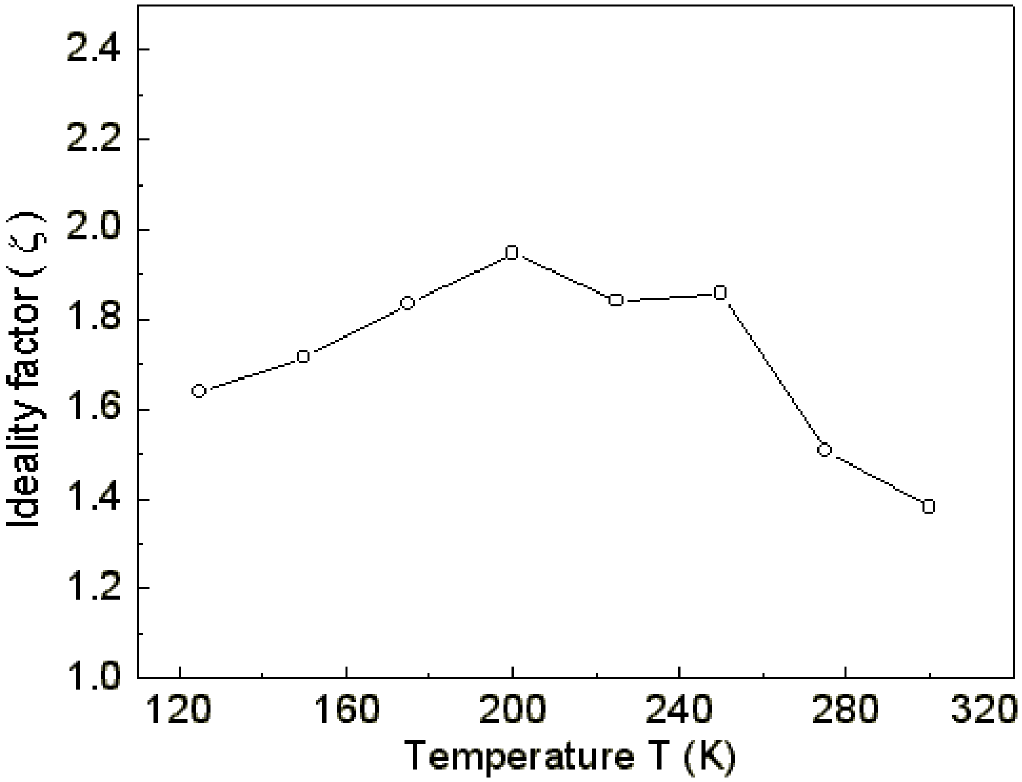


Fig. 8. Ideality factor vs. temperature plot.

3. Conclusion

In this paper, we have investigated the electrical properties of Au-ZnO/Si Schottky diode with the help of current-voltage characteristics in the temperature range of 125-300K. The Au-ZnO/Si films have been studied. The Physical, chemical characterizations of ZnO/Si films were investigated using RBS, AFM, XRD and XPS. So this Au-ZnO/Si film may have attracted much interest of potential commercial application in electronic devices.

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