Chapter 4: Electrical Transport Properties

In recent years, semi conducting nanostructures especially one-dimensional nanostructures have drawn a lot of attention due to their potential applications in nano devices. These 1D nanostructures have been found interesting due to their unique optical and electronic properties. Their importance as the building blocks for interconnects of transistors and junctions between metals and semiconductors, and tips of emitters has been recognized. A lot of reports on the whiskers and wires of III-V semiconducting nanostructures as well as the nanostructures of oxide semiconductors are available in the literature. Among the oxide semiconductor nanostructures studied so far, the nanostructures of ZnO have been the focal point of research. ZnO is an n-type material with a wide band gap of 3.3 eV. It emits short wavelength light and shows piezo electric properties. It is also transparent to visible light and electrically conductive with the dopants such as Al, Ga, In, Sn etc. There are some reports on the fabrication of optical and electronic devices of ZnO nanostructures, also available in the literature. [1-4]. Zinc oxide is the semi-conducting material having wide band gap and high transparency. It is also stable for chemical as well as thermal fluctuations. Generally, optical transparent oxides tend to be electrical insulators by virtue of their large optical band gap $E_g = 3.1$ eV, but ZnO is has high transparency and conductivity matching the value for FTO, SnO_2 films Its transparency and conductivity make it a promising candidate for optoelectronic applications like energy windows, liquid crystal displays, solar cells, gas sensors, ultrasonic oscillators, transducers, etc. As is well known there is a strong correlation between structural characteristics of thin films and their electronic transport properties. A heat treatment of the films may modify these structural characteristics [5, 6]. Consequently, in situ measurement of some electrical properties such as the electrical resistivity of thin films during their heat treatment may offer very useful information about possible changes in the film structure determined by the heating process [7]. Keeping in view, the important properties of ZnO nanostructure, we report the electrical transport properties of ZnO nanostructures. Keeping in mind the fact that electrical resistivity has temperature dependence, the ZnO films were investigated in the temperature range 303–573 K.

4.1 Experimental

ZnO nanostructures are fabricated using physical vapour condensation method. In this method, Zn powder (99.999 % pure) has been evaporated in the presence of oxygen and argon gases at a particular partial pressure. Initially, a small quantity of Zn powder has been kept in a molybdenum boat and the chamber has evacuated to a vacuum of the order of 10^{-6} Torr. After attaining this vacuum, the gases (oxygen and argon) are purged in to the chamber. The pressure of these gases is kept fixed at 5 Torr and 1 Torr respectively. The evaporated material is deposited on LN_2 cooled glass substrate. The nanostructures of ZnO are deposited on the glass substrate and also collected in the powder form by scratching from the substrate. Powder X-ray diffraction

(XRD) is performed on a Philips X-ray diffractometer with Cu Kα (l ¼ 1:54178 Å) radiation. The morphology and the microstructure of these nanostructures are studied using a transmission electron microscope (TEM) at 100 kV. For electrical measurements, we have used a four-probe set-up. The contacts are made using silver paste then and an electrometer (Keithley 6517A) is used to measure the current at different temperature, keeping the voltage fixed at 1.5 Volts.

4.2 Results and discussion

4.2.1 Structural studies

The transmission electron microscope (TEM) images of these nanostructures are shown in Figure 4.1. It is observed from the TEM image that nanostructures contain nanorods and nanoparticles of ZnO. The typical diameter of these nanorods is in the range of 80 to 150 nm and the length is of order of several hundreds of nanometers. Some nanoparticles and nanorods of very small diameter can also be seen, but it seems that these nanostructures contain a lot of impurities and defects.

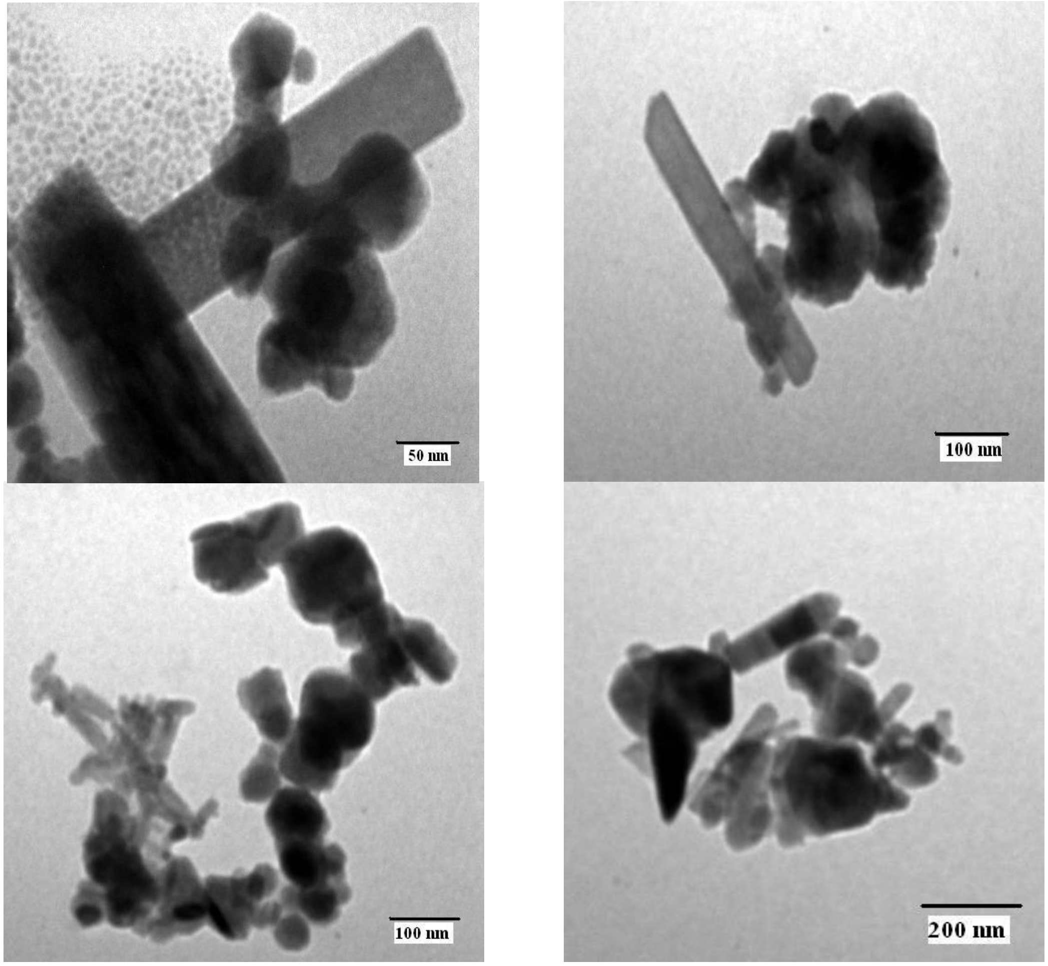

Figure 4.1: *TEM images of the grown nanostructures*

4.2.2 XRD Studies

The crystallinity and phase identification of ZnO nano structures grown have ascertained by X-ray diffraction (XRD) and result is shown in figure 4.2. As can be seen, sharp diffraction peaks corresponding to wurtzite (hexagonal) structure of ZnO have been observed. The obtained diffraction peaks in all spectra correspond to the single crystallinity with wurtzite hexagonal phase for the grown ZnO nano structures as shown in figure 4.2.

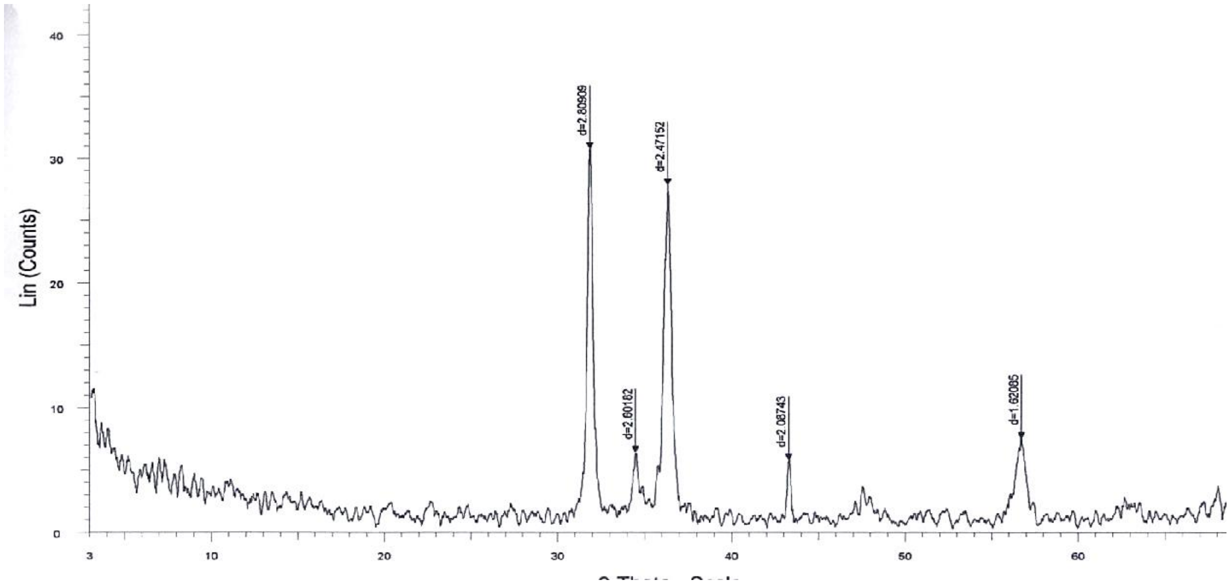

Figure 4.2: *X-ray diffraction pattern of the grown film*

4.2.3 Electrical Transport Studies

The dc conductivity of semiconductor at temperature T is given by

$$\sigma_{dc} = \sigma_0 \exp (E/kT) \qquad (4.1)$$

where σ_0 is pre exponential factor, E is activation energy for the generation process and k is Boltzmann constant. We may write

$$\ln \sigma_{dc} = \ln \sigma_0 - (E/kT) \qquad (4.2)$$

or

$$\ln \sigma_{dc} = -(E/1000k)(1000/T) + \ln \sigma_0 \qquad (4.3)$$

When we plot a graph between ln σ_{dc} & 1000/T, a straight line is obtained having slope (E/1000K) and intercept ln σ_0 is given in Figure 4.3. Thus, the activation energy can be calculated by using the slope of a straight line.

The dc electrical conductivities of the sample in dark, in the range of temperature from 303-573K were measured. The temperature dependence of the dark conductivity is shown in figure 4.3 The plot of ln σ_{dc} against 1000/T is a straight line indicating that conduction is through thermal activation process [8]. The resistivity of ZnO has been determined from current voltage curve measured for different temperatures. For all studies a linear dependence typical of ohm's behavior has been observed (the conductivity as a function of the temperature). The conductivity is directly proportional to temperature. Curve exhibits a minimum of conductivity at room temperature [9]. The conductivity increases with increase in the temperature and the increase in the conductivity by a factor of 10 in comparisons to the previous estimated values are given in table 4.1. The electrical conductivity changes in ZnO and other n type semiconductor under photo reduction in subsequent exposure in oxidizing gas atmosphere are in general explained by the formation and annihilation of oxygen vacancies at the metal oxide surface [10, 11].

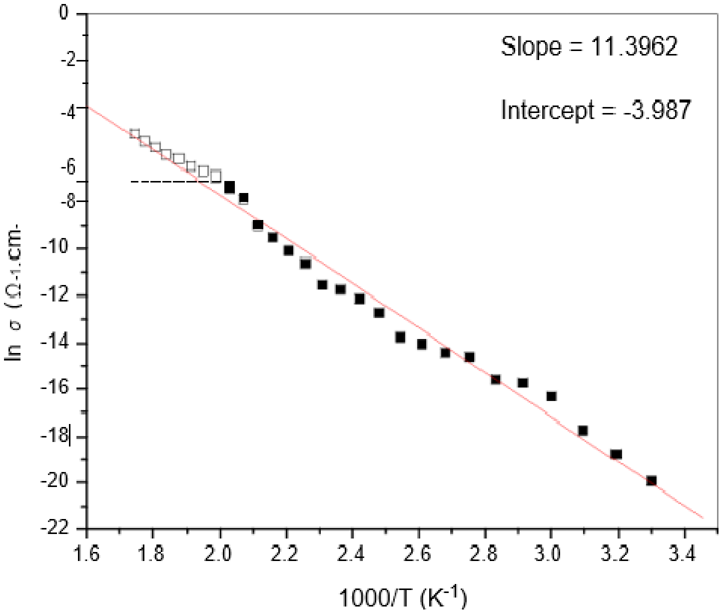

Figure 4.3: *Plot of lnσ vs 1000/T*

Table 4.1: *Variation of conductivity with temperature*

Temperature(T) K	312	357	416	455	500	555
Conductivity(σ)	$2.52 \cdot 10^{-18}$	$2.52 \cdot 10^{-16}$	$2.38 \cdot 10^{-14}$	$2.45 \cdot 10^{-13}$	$2.33 \cdot 10^{-12}$	$2.23 \cdot 10^{-11}$

4.3 Conclusion

ZnO nanosructures are fabricated using physical vapour condensation method. Powder X-ray diffraction (XRD) is performed on a Philips X-ray diffractometer. The morphology and the microstructure of these nanostructures are studied using a transmission electron microscope (TEM) performed at 100 kV. For electrical measurements, we have used a four-probe set-up. The conductivity increases with increase in temperature.

4.4 References

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