

DC Conductivity Study of Cadmium Sulfide Nanoparticles

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Abstract- The dc conductivity of consolidated nanoparticle of CdS has been studied over the temperature range from 303 K to 523 K and the conductivity has been found to be much larger than that of single crystals.

Keywords- CdS, Nanoparticles, DC Conductivity

1.1 INTRODUCTION

Encapsulation of metal atoms and nanosize clusters in organic media lead to formation of materials with the properties, different from ones of bulk substance. Such materials can be used in microelectronics, catalysis, optics, as very sensitive chemical sensors and in other fields of science and industry [1]. The physics of materials in the nano-size regime has been the subject of considerable theoretical and experimental studies during the last decade [2, 3, 4, 5, 6, 7, 8, 9, 10, 11] The interest in this topic has mainly arose because of the general expectation and experimental evidence in a few cases that nano-particles may exhibit interesting and technologically important properties which are not possessed by bulk materials [12, 13, 14, 15, 5]. It has already been accepted that small clusters of atoms of metals have intriguing physical and electronic properties, [16, 17] each atom on its own has a well-defined set of electronic states. The N-atoms cluster of non-interacting atoms must have N-fold degeneracy for each electronic energy level. The interatomic electron interactions of the cluster remove this degeneracy and the allowed energy states spread into a band. In the case of small particles, the statistics of the electron-level distribution in addition to the density of energy states is important while, in bulk material, it is concerned only with the density of energy states.

The electronic properties of polycrystalline materials and thin films consisting of small crystallites have been investigated in semiconductor [18, 19, 20, 21, 22] like CdS, the study of electrical conduction in systems consisting of nano-particles is very limited; [23, 24, 25, 26] particularly such studies in bulk samples obtained by consolidating nano-particles of important semiconductors is altogether

lacking. It was felt that the study of electrical properties of pellets of nano-particles of semiconductors would be interesting. The results of such studies are expected to reflect the effect of finite size on the electrical conduction of small particles. Quantum size effects on the electronic properties have been investigated by many workers in the case of nanoparticles of CdS [3, 27, and 28].

1.2 Fabrication and Preconditioning Of CdS Pellets

Nano-particles of CdS were prepared by solution growth method. The prepared particles of CdS were washed repeatedly using distilled water. The water in the suspension was then removed by evaporation first and then heating in an oven at about 100°C. Pellets of nano-particles of CdS of diameter 1×10^{-2} m and thickness 766.5 μ m were made by applying a pressure of 4 tonnes/cm² in a hand operated hydraulic press at Government Pharmacy College, Amravati.

1.3 I-V Characteristics of CdS Sample

Resistivity measurements of sample (pellets of CdS) can be calculated by using the formula

$$P = \frac{V}{I} \frac{2HS}{\rho}$$

Where, V = Voltage

I = Current

S = Point Spacing

$$\text{From this } \sigma = \frac{1}{\rho}$$

Figure 1.3 (a) shows the plot of current vs. applied voltage of CdS nanoparticles at room temperature. Initially

at room temperature by varying voltage, current through the sample was noted.

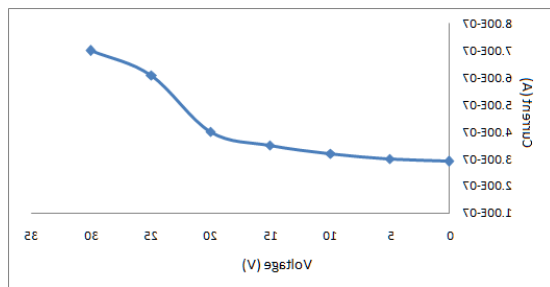


Figure 1.3 (a): I-V characteristic curve for CdS.

At lower voltages the slope of the current-voltage characteristics curve was approximately equal to 5.02 whereas the slope increases to approximately 5.09 as the voltage increases to 30 volts. The linear relation between current and voltage indicates the good ohmic behavior [29]. Therefore it can be concluded that at lower voltages ohmic conduction exists and the conduction mechanism tends to change at higher voltages [30]. It can also be expected that at still higher voltages the slope may be approximately corresponds to space charge limited conduction mechanism. Similar mechanism has been reported earlier by Mahmoud S A *et al* (2000) for CdS sample.

1.4 Variation of Conductivity with Temperature

The variation of surface conductivity with temperature in the temperature range 303 K to 523 K by four probe method. Figure 1.4 (a) gives the plot ($\log \sigma$ vs $10^3/T$) of CdS nanoparticles. It is observed that the dc conductivity increases with temperature at a very slow rate upto a temperature of about 375 K and there after the conductivity increases very rapidly.

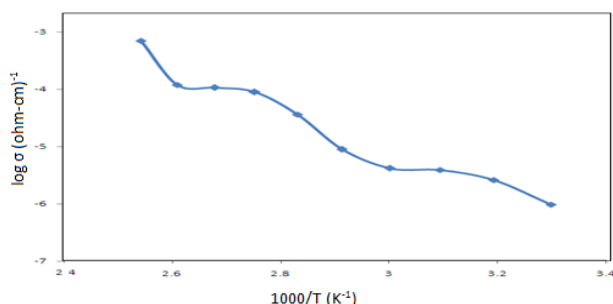


Figure 1.4 (a): The Arrhenius plot of bulk CdS.

The $\log \sigma$ and $1000/T$ plot shows two distinct regions, the first region indicating a slow increase of conductivity with temperature upto about 375 K and the second one indicating a rapid increase beyond 375 K since increase in dc conductivity with increase in temperature

indicates the semiconducting nature of the CdSnanoparticles [31]. The linear characteristics of the plot indicate the presence of only one type of conduction mechanism [30]. Since the plot fit to the relation

$$\sigma = \sigma_0 \exp[E_a/KT]$$

High temperature conductivity is attributed due to the thermal excitation of charge carriers from grain boundaries to the neutral region of the grains. Similar characteristics have been reported by other workers [32].

RESULT AND DISCUSSION

In the present study, the observed increase in conductivity is explained as follows. In case of pellets of small particles, the boundary between the particles must play an important role in determining conductivity as in the case of polycrystalline semiconductor films [33, 34, 35, 36, and 22]. According to grain-boundary trapping theory, free carriers are trapped by trapping states at the boundary causing a depletion of charges in the grain region nearest to the boundary [34]. Therefore the region near the surface of the particle becomes depleted of charges causing a space charge which should establish an energy barrier between adjacent particles. In this case assuming the voltage drop in the particles to be negligible compared with the voltage drop in the barrier, the electrical conductivity may be assumed to be completely dependent on the voltage drop in the barrier. If thermionic emission of carriers over the barrier is the predominant transport mechanism, then the conductivity should exhibit Arrhenius behavior. In the case of indium doped CdS films Garcia-Cuenca M V and Morenza J L (1985) have reported that conductivity due to a tunneling transport of carriers through the potential barrier could be comparable or larger than thermionic emission, when the barrier width is low enough, which depends on the doping level and on the trap density. Also the reported results of [38,17] reveal the same in small particles. The confinement of charge carrier does perturb the band structure resulting in a series of discrete states in the conduction and valence bands and an increase of the effective band gap.

Due to the small size of the particles, the charge carriers reach the surface of the particles more easily enabling easy electron transfer by thermionic emission, or tunneling or both, enhancing the conductivity. Experimental evidence strongly indicate that in small particles the confinement of charge carriers perturb the band structure resulting in a series of discrete states in the conduction and valence bands and in an increase of the effective band gap.

In the case of nano-particles the high surface stress causes a lattice contraction [39, 40] which may not be symmetrical. This may result in a lattice disorder which may be equivalent to a plastic deformation causing dislocations. But it is not reasonable to argue that these dislocations may be considered to be one dimensional or get aligned so at a particular temperature enhancing conductivity. Also the conductivity in the present study is found to increase continuously from a high temperature upwards unlike the reported enhancement due to plastic deformation in CdS [41]. Hence enhancement of conductivity in the present study cannot be accounted for on the basis of dislocation

energy bands.

From the linear part of $\log \sigma$ vs. $1000/T$ it is possible to calculate the activation energy. From activation energy of CdS nanoparticles in region I and region II has been calculated from the slope of the linear part of the curve and found to be 1 eV and 1.22 eV respectively. The minimum activation energy proves the semiconducting nature of the CdS nanoparticles. It also suggests that the grain boundary scattering contribution reduces significantly. Similar results have been reported by other workers [32].

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