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Low Temperature Electrical Resistivity Studies in Lead Thin Films

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Thin lead films of thickness, 100 nm, 150 nm, 200 nm and 250 nm have been deposited using electron beam evaporation technique at room temperature onto glass substrates under high vacuum conditions. Films were investigated for electrical resistivity at low temperatures from 77 K to 300 K. Resistivity variation with temperature indicates transition from metallic to semiconductor behavior. Transition temperature increased with increasing film thickness. Temperature coefficient of resistance in the metallic region has been determined for all the four films. Using Arrhenius relation, activation energy for conduction in metallic region has been determined. Mott's small polaron hopping model has been employed to determine activation energy in the semiconducting region. In a film of 250 nm thick, deviation from Mott's small polaron hopping model for below 100 K was noted and that has been considered under Mott's variable range hopping model. The complete understanding of electrical properties of Pb films has been necessitated by the fact that the band gap in CdS decreases when Pb is incorporated into it, which in turn can be used to fabricated large efficient solar cells. It is for the first time that lead films of the present thickness have been investigated for low temperature resistivity.

Key words: Thin films, Electrical resistivity, Metal-semiconductor transition, Hopping mechanism.

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1. INTRODUCTION

Thin solid films of thickness few hundred of angstroms to several microns are finding increasing applications in the manufacture of electronic components because of their reliability and decreasing cost. Thin film assembly is an efficient approach to miniaturization, since the integration of many components in a single package and the high achievable pattern density results a great weight and volume savings [1]. The present interest in the investigation of metallic thin films has been motivated by the temperature dependence of electronic transport properties [2]. The temperature dependence of resistivity contains a wealth of information about electronic, magnetic and lattice states [3]. From our extensive literature survey, it was noted that few studies have been published on the thickness and temperature dependence of electronic properties of lead thin films [4-6]. But no much work has been reported on low temperature electrical properties of lead thin films. There are reports that lead has been used as electochromic material in solar energy application [8]. Further, it was reported that incorporation of Pb into CdS films decreases band gap of CdS, which is used to develop high efficiency solar cells, gas sensors etc. [9, 10]. Therefore, it becomes imperative that Pb films needs to be understood completely. We present the low temperature electrical resistivity of lead films of different thickness from 100 nm to 250 nm.

2. EXPERIMENTAL

Lead films of four different thicknesses were deposited using electron beam gun evaporation technique at room temperature onto glass substrates under high vacuum. The low temperature resistivity measurements were carried out in liquid nitrogen cryostat by adopting four probe method. Constant current of 4 mA from Keithley make sourcemeter (Model 2400) was sent through the film and the voltage developed across two points on the surface of the film was measured using Keithley make nanovoltmeter (Model 2182A). The temperature was measured using the sensor Pt-100. Due to nonavailability of temperature controller, the measurement of voltage and current were carried while liquid nitrogen was evaporating naturally. The evaporation of liquid nitrogen in the cryostat was maintained to be steady by keeping outer layer of the cryostat under vacuum.

3. RESULTS AND DISCUSSION

3.1 Resistivity Variation with Temperature

The measured variation of ρ with temperature, T for 250 nm thick film is depicted in Fig. 1. The tempe-rature dependence of resistivity revealed transition from semiconducting like behaviour to metallic like behaviour. For example, T_c was found to be 157 K for 250 nm thick film. The transition temperature, T_c shifted towards higher temperature as the film thickness was increased. The measured T_c values for the films are recorded in Table 1.

Table 1 – Measured transition temperatures (T_c), of the films

Film thickness, t (nm) →	100	150	200	250
T_c (K) →	117 ± 5	137 ± 5	139 ± 5	157 ± 5

The semiconducting region has been analyzed using Mott's small polaron hopping model equation, $\sigma = (\sigma_0/T) \times \times \exp(-\Delta E/K_B T)$, where ΔE is the activation energy for

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conduction. The typical $\ln(\sigma T)$ versus $(1/T)$ for 150 nm film is shown in Fig. 2. From the slope, the activation energy, ΔE, was estimated. Similar analysis was carried out for other films and obtained ΔE values (Table 2).

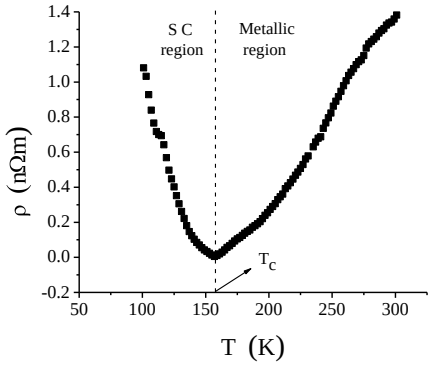

Fig. 1 – The plot of resistivity, ρ versus T for film of 250 nm thickness

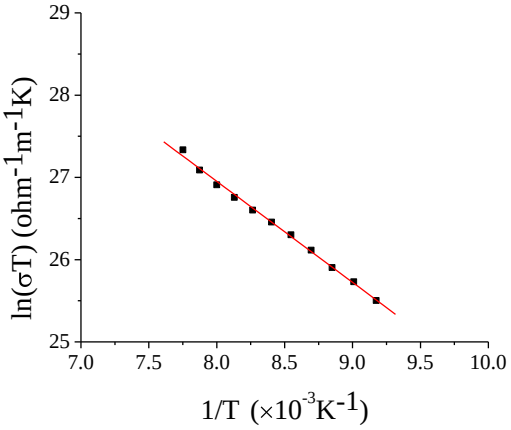

Fig. 2 – The plot $\ln(\sigma T)$ versus $(1 / T)$ for a film of thickness 150 nm in the semiconducting region

It was found that for a film of thickness 250 nm data deviates from linearity in the low temperature region and that has been considered under Mott's variable range hopping model.

Table 2 – Activation energy, ΔE for films of different thickness, t in the semiconducting region

t (nm)	100	150	200	250
ΔE (eV)	0.33 ± 0.03	0.11 ± 0.01	0.08 ± 0.01	0.16 ± 0.01

The temperature coefficient of resistance for all the films in the metallic region were determined to be in the order of $10^{-3}\,K^{-1}$ and were positive. TCR increased with increasing film thickness. The increase of TCR with film thickness can be attributed to diffusive scattering processes which get enhanced with increasing thickness. Similar conclusion was drawn in the case of Pb and Al films [4, 7]. These values of TCR were compared with the reported values for lead films [4] and were found to be of the same order. Using Arhenius expression, $\rho = \rho_0 \exp(-\Delta E/K_B T)$ activation energy for conduction in the metallic region was determined (Table 3). A plot of $\ln(\rho)$ versus $(1 / T)$ for 100 nm thick film is shown in Fig. 3. The activation energy increased with increase of film thickness and their magnitudes are comparable with similar films [4]. The variation of activation energy with film thickness indicates that the thermal activation was decreased with increasing film thickness.

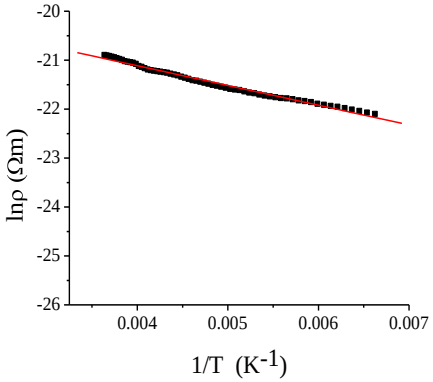

Fig. 3 – The plot of $\ln(\rho)$ versus $(1 / T)$ for 100 nm thick film in the metallic region

Table 3 – Activation energy, ΔE for films of different thickness, t in the metallic region

t (nm)	100	150	200	250
ΔE (meV)	34.75 ± 0.58	61.18 ± 0.64	84.09 ± 0.88	98.64 ± 0.80

4. CONCLUSIONS

At room temperature, lead films of different thickness have been deposited under high vacuum using electron beam evaporation technique. Electrical resistivity of the films in the temperature range from 77 K to 300 K has been measured. The resistivity increased with increasing film thickness.

Resistivity variation with temperature indicated transition from metallic to semiconductor behaviour. Activation energy and temperature coefficient of resistance were determined for metallic region and found that they increased with increase of film thickness. By employing Mott's SPH model, activation energy for conduction in the semiconducting region has been determined. For a film of 250 nm thickness, the data deviated from Mott's SPH model below 100 K and that has been considered under Mott's VRH model.

The understanding of electrical properties of Pb films is essential as many researchers have used Pb as an additive element to reduce the band gap in CdS films and there by improve the efficiency of the solar cells made of CdS.

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