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Analysis of Electrical Parameters Under the Effect of Temperature in Divalent Rare-Earth Chalcogenides

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Abstract :- In the present paper, we have investigated the effect of temperature on electrical parameters of SmS. We have developed a model to calculate electrical parameters such as activation energy, carrier concentration, Hall constant, carrier mobility, electrical conductivity and resistivity under the effect of temperature and these parameters are used to discuss transport mechanism in SmS. Based on this analysis, we have investigated the valence transition in SmS under the effect of temperature.
Keywords : Activation Energy, Carrier Concentration, Electrical Conductivity and Electrical Resistivity.

INTRODUCTION

The rare-earth chalcogenides are of current interest due to their potential applications in the field of non-linear optics, electro optics devices, glass making grinding alloys, composite lasers, phosphor lasers and phosphors [1, 2]. In these compounds, most of the rare – earth ions are trivalent with the exception of Sm, Eu, Tm and Yb.

These compounds are some of the structurally simplest materials and most of crystallize in the Nacl-type structure [3]. For these ions Hund's rule of coupling become important and the divalent state is favoured [4]. Most of electronic and structural properties of rare-earth chalcogenids are governed by the nature of their f-electron state [5]

THEORY –

The divalent rare earth chalcogenides have no conduction electrons in ground state [6-7] and are insulators at T= 0K when in a pure state i.e. free of impurity centers. The occurrence of charge carriers in the conduction band at T > 0 K is the result of two conduction band at T > 0K is the result of two process-thermal activation of the impurity and thermal excilation of the electrons of the local 4f levels [6,7,8], such a mechanism would give n-type conductivity [9] and acoustic scattering. In case of acoustic scattering electrical conductivity σ is given by the following expression [10, 11, 12].

$$\sigma = ne\mu = \frac{1}{\rho} \tag{1}$$

Where n is the carrier concentration, e is the electrical charge, μ is the carrier mobility and ρ is the electrical resistivity.

The study of temperature dependence of Hall emf on rare-earth chalcogenides [13] suggest that Hall mobility of e^-.

The carrier mobility (μ) can also be expressed as [13]

$$\mu = |R_H|\sigma \tag{2}$$

Where R_H is the Hall constant.

Equations (1) and (2) yield.

$$R_H = \left|\frac{1}{ne}\right| \tag{3}$$

Using the values of carrier concentration (n) we have calculated the Hall constant of SmS.

In real materials the number n of thermally excited electrons in the Boltzman approximation given by -

$$n\ \alpha\ \exp\left(-\frac{\Delta E}{kT}\right) \tag{4}$$

Where k is the Boltzmann constant and ΔE is the activation energy. For activation energy, equation (4) can be rewritten as -

$$\Delta E = KT\ln\left(\frac{C}{n}\right) \tag{5}$$

Where C is the constant having the dimension of n.

The value of C= 1.48 x 10^{26} m^{-3} for T < 450K and C= 1.292x$10^{28}$$m^{-3}$ for T> 450K. using these values of C equation (5) can be used for SmS to evaluate the values of activation energy at different temperatures.

Effective mass m* changes significantly with temperature, as

$$m^* = m_0\left[1 + \frac{15.28}{a^2\Delta E}\right]^{-1} \tag{6}$$

With the desumption that lattice parameter (a) of SmS does not vary much with temperature, equation (6) becomes (as a = 5.97A^0)

$$m^* = m_0\left[1 + \frac{0.429}{\Delta E}\right]^{-1} \tag{7}$$

Where m_0 is the rest mass of electron.

We have calculated the value of m* of SmS at different temperatures reported in table 1.

The dielectric constant (ε) of SmS at different temperatures is calculated by using the equation.

$$\varepsilon = \left[\frac{13.53}{\Delta E} \frac{m^*}{m_0} \right]^{1/2} \tag{8}$$

and reported in table-1

The carrier mobility at different temperatures is calculated by using the equation.

$$\mu = \frac{1.353 \times 10^{-45} \times \varepsilon^2}{m^* \left[\ln(1+x) - \frac{x}{1+x} \right]} \tag{9}$$

Where

$$x = \frac{13.54 \times 10^{-49} \times (n)^{1/3}}{m^*}$$

and $$N = \frac{4.24 \times 10^{-36} \times n^2}{(m^*)^{3/4} \exp\left(\frac{\Delta E}{2KT} \right)}$$

RESULT AND DISCUSSION

To study the effect of temperature on electrical parameters, we have selected SmS for which exponential study of the Hall emf has been carried out in the temperature range from 295K to 870 K. The experimental values of Hall constant of SmS as a function of temperature are listed in table 1. Using these values of Hall constant in equation (3) We have calculated the values of carrier concentration at different temperatures. The variation of Hall constant and carrier concentration of SmS are shown in figures 1 and 2 respectively. These figures revealed that beginning at about T=450K the Hall coefficient decreases exponentially, while the carrier concentration increases exponentially.

We have calculated the value of effective mass m* of SmS at different temperatures and reported in table 1. it is observed that m* increases significantly with the rises in temperature.

The value of dielectric constant (ε) first increases slightly with temperature and than decreases more slowly. The variation of carrier mobility with temperature is shown in figure 3 which revealed that carrier mobility first increases rapidly with the increase in temperature and than decreases exponentially at about T=550K, which is same as observed experimentally [14]. The electrical conductivity and resistivity of SmS at different temperatures is calculated by using equation (1) and reported in table-1. The order of electrical conductivity calculated by us is found same at T=295k as reported experimentally in the literature [14]. The variation of electrical conductivity and resistivity are shown in figures 4 and 5 respectively these figures revealed that electrical conductivity increases exponentially with the rise in temperature, while electrical resistivity decreases exponentially.

Table 1 : The values of electrical parameters of SmS at different temperatures

T /K	R_H /10^{-7}(m^3C^{-1})	n /10^{25}(m^{-3})	ΔE /eV	m* /10^{-31}(kg)	ε	N /10^{39}(m^{-3})	μ /10^{-4}($m^2v^{-1}sec^{-1}$)	σ /10^2($\Omega^{-1}m^{-1}$)	ρ /10^{-4}(Ωm)
295	3	2.08	0.18	2.69	4.71	2.0	5.9	19.6	5.10
375	2.7	2.31	0.17	2.58	4.75	0.94	9.5	35.3	2.83
455	1.7	3.68	0.23	3.18	4.53	1.63	7.3	43.4	2.30
525	1.3	4.81	0.25	3.35	4.46	1.71	7.3	56.2	1.78
540	1.2	5.21	0.26	3.44	4.43	1.86	7.0	58.3	1.72
625	0.7	8.93	0.27	3.52	4.40	2.34	6.1	86.6	1.15
6.90	0.52	12.0	0.28	3.60	4.37	2.64	5.6	107.5	0.93
770	0.35	17.9	0.38	0.60	4.37	3.0	5.1	145.6	0.69
830	0.30	20.8	0.30	3.75	4.31	3.40	4.8	160.8	0.62
870	0.25	25.0	0.30	3.78	4.31	3.71	4.6	182.4	0.55

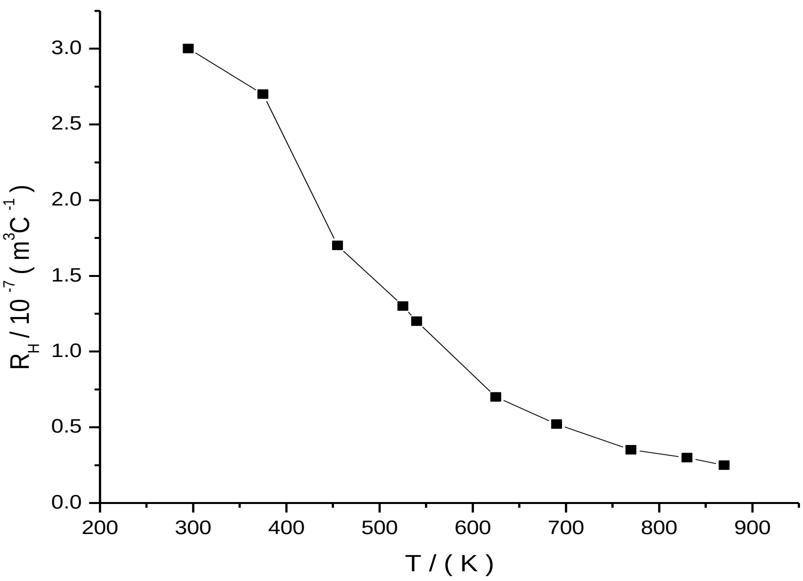

Figure :1
Variation of Hall constant of SmS with Temperature

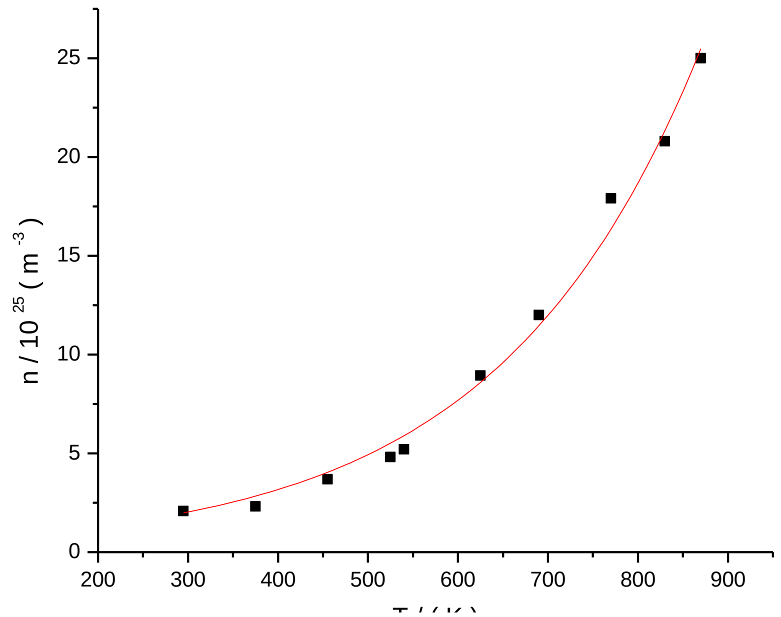

Figure :2

Variation of Carrier Concentration of SmS with Temperature

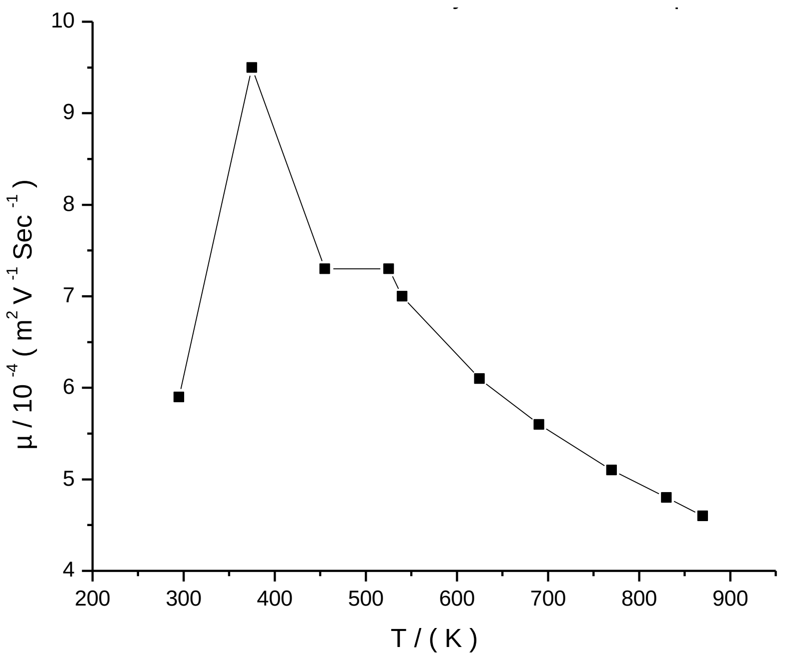

Figure :3

Variation of Carrier mobility of SmS with Temperature

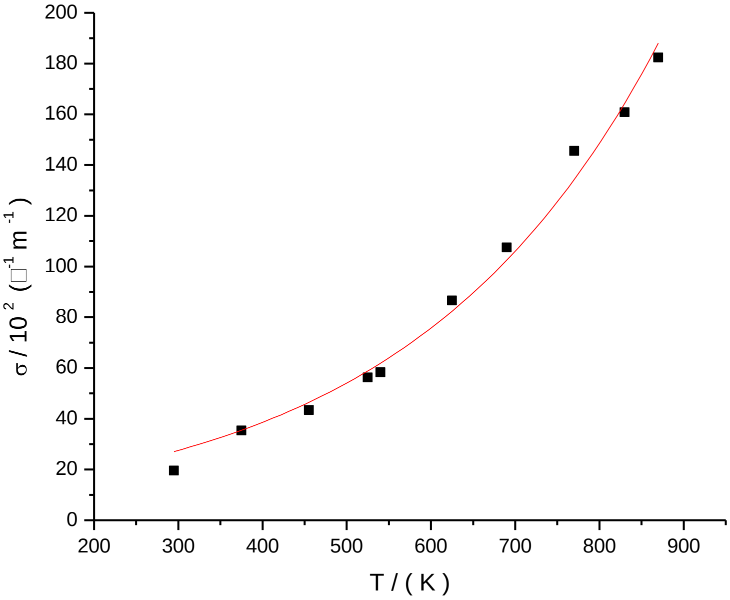

Figure :4

Variation of Electrical Conductivity of SmS with Temperature

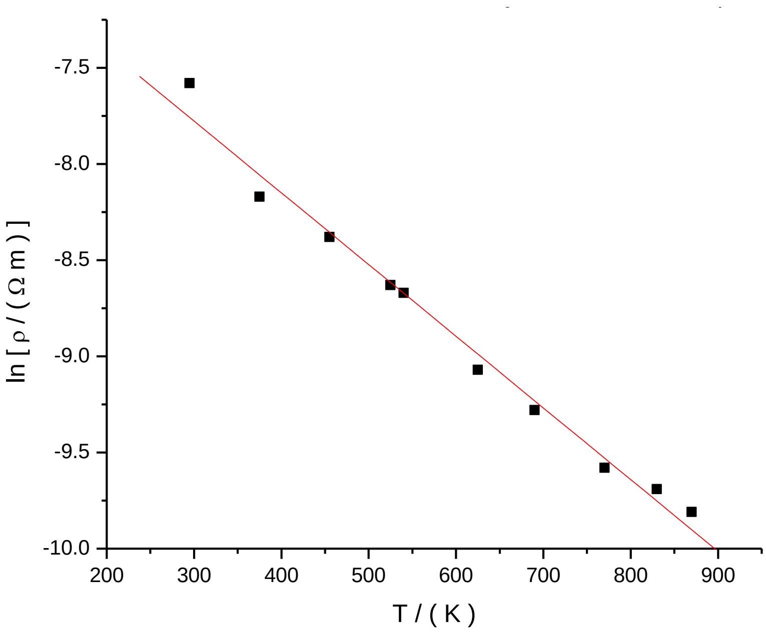

Figure :5

Variation of electrical resistivity of SmS with Temperature

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