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Electrical Resistivity of Vacuum Evaporated AgSe Thin Films as a Function of Thickness

***U. P. SHINDE[1], H. P. SHELAR[1], A. B. SURYAWANSHI[1], R. V. DESALE[1], G. V. PAWAR[1], M. B. DEORE[2]**

[1.] Department of Electronic Science M. S. G. College, Malegaon Camp, India
[2.] Department of Physics M. S. G. College, Malegaon Camp, India
***Corresponding author E-mail:** upshinde1965@gmail.com

ABSTRACT

Thin films of AgSe compound of varying thicknesses have been deposited on glass substrates employing three temperature methods, in a vacuum of the order of 10^{-5} *torr. The electrical resistivity of the films has been studied as a function of thickness and annealing temperature. The activation energy has been calculated as a function of thickness and annealing temperature of AgSe thin films. It is found that activation energy increases with increase of thickness and annealing temperature.*

KEYWORDS: AgSe, thin films, thickness, activation energy, resistivity.

INTRODUCTION

Electrical resistivity of vacuum-deposited and vacuum-annealed β-Ag_2Se thin films of thicknesses between 600 and 2000Å has been measured in vacuum [1]. It is found that all the films exhibit semiconducting behavior and the energy band gap is a function of thickness increasing linearly with it. It is also found that the film resistivity and temperature coefficient of resistivity (TCR) are both functions of inverse thickness as expected from the thin-film size-effect theories. The linear dependence of band gap on thickness is thought to be due to the large density of dislocations in thin films and its variation with thickness and the changing stoichiometry of the films. The reciprocal thickness dependence of resistivity and TCR was explained by the effective mean-free-path models. The mean free path (lg) estimated from this model turns out to about 1300 Å and the value estimated from the ρ plot agrees well with that estimated from the β plot. Also, carrier concentration in the films was estimated to be about 6×10^{18} cm−3. Thin films of silver selenide (Ag_2Se) between thicknesses of about 700 and 2200 Å [2] have been prepared on glass substrates at room temperature in a vacuum of 5×10^{-5} torr. After vacuum annealing the films (at about 373 K for 3 h) electrical resistivity measurements on these films have been carried out in vacuum. Electrical resistivity [3] of vacuum evaporated thin layers of Ag-Se has been studied in the temperature range 298 K to 523 K. Films of Ag_xSe_{1-x} (0<x<0.7) show semiconducting to metallic and metallic to semiconducting transformation during heating and cooling respectively. The linear dependence of energy of activation on thickness of these films is attributed to the large density of dislocations and non-stoichiometry of these films.

The study of electrical properties of β-Ag_2Te and β-Ag_2Se [4] has been extended to 4.2 K. The former compound was zone refined without decomposition. Both *n*- type and *p*-type samples of β-Ag_2Te were studied; all samples of β-Ag_2Se prepared were *n* type to 4.2 K. Neither semiconductor showed any indication of extrinsic carrier freeze-out or of impurity banding. The transmission electron microscopy [5] studies show Ag2Se nanowires can be high conducting orthorhombic β-Ag2Se or low conducting cubic α-Ag2Se. It was first time found that α-Ag2Se is stable at room temperature. A threshold switching phenomenon exists in the low conducting α-Ag2Se with on−off ratio up to 7 order magnitudes. These results provide useful new information for exploring solid-state electrolyte nanowires as resistive switching memory devices. The ionic conductivity σi of β-Ag2Te and β-Ag2Se [6] was estimated from the time constant of ionic polarization with the help of galvanic cell Ag|AgI|specimen|Pt showing that σ_i depends on the composition (deviation from the stoichiometric ratio) in contrast with the composition-independent σ_i in their α phase. The chemical potential of Ag ions ζ_i known from the e.m.f. *E*, of the cell is also dependent on the composition in the β-phase, and accordingly *E* does not represent the relative position of the Fermi level as in the α-phase. This composition dependence of ζ_i and σ_i is accounted by a simple theory.

EXPERIMENTAL WORK

Material and Methods

Silver-Selenium binary films have been formed on glass substrates kept at room temperature by evaporation of pure silver and selenium from two different sources, in a vacuum of the order of 10^{-5} torr [7-11]. The silver and selenium both were evaporated from tungsten filament and nichrome windings using mica sheets respectively. Both the elements were simultaneously heated, so as to mix the vapours of Ag and Se gave the required films. The films of same compositions and of different thicknesses have been obtained.

The set of films thus formed were annealed at different temperatures from 373 K to 573 K with temperature difference of 50 K for 8 hrs each, for the purpose of observing the temperature dependent electrical characteristics as well as uniform distribution of the components in the deposits. After annealing the films were used for temperature and thickness dependent resistance measurement.

Film thickness measurement

The film thickness (d) of AgSe thin films was measured by gravimetric method [7-11] using the relation,

$$d = \frac{M}{g \times A} cm \qquad \text{------------------------------------} \quad (1)$$

Where

A = surface area of the film
M = Mass of the film
g = the density of the film material = $x_1 g_1 + x_2 g_2$

where g_1, g_2 and x_1, x_2 are densities and atomic fractions of Ag and Se elements respectively.

RESULTS AND DISCUSSION

Fig.1and 2 show the variation of resistance with temperature for AgSe films of nearly same thicknesses with different annealing temperatures, both during heating and cooling. It is seen from the figs., during heating the electrical resistance decreases with increase in temperature upto phase transition point then increases slowly with further rise in temperature. The effect of annealing temperature changes the position of phase transition point. During cooling the resistance decreases continuously as the temperature decreased, and after the transition point there is sharp increase in resistance. In both cases the films show semiconducting to metallic behaviour.

Fig.1: Plot of resistance versus temperature with annealing temperature 373 K and thickness d~1650Å.

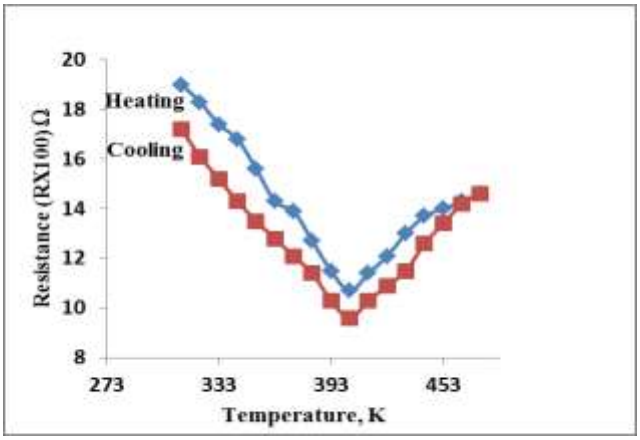

Fig.2: Plot of resistance versus temperature with annealing temperature 573 K and thickness d~1950Å.

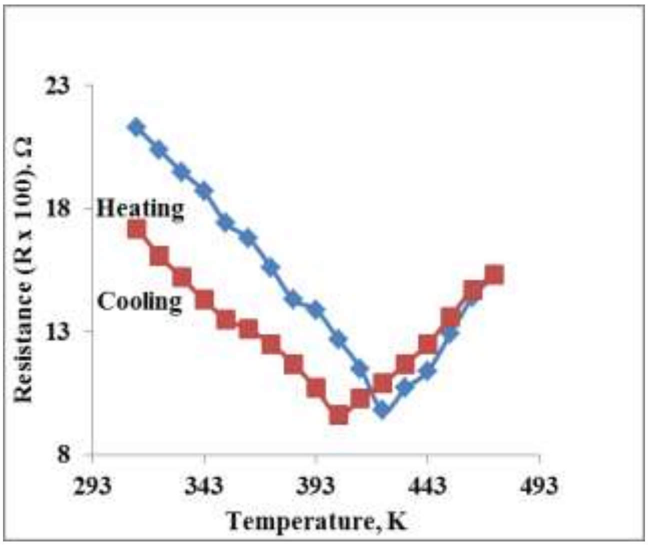

Fig. 3 shows activation energy (ΔE) versus thickness (d) of the films, the activation energy (ΔE) is thickness dependent. From fig. it is seen that (ΔE) increases with increase of film thickness it is due to the films studied were nonstoichiometric [3] and increase in (ΔE) with increase in thickness may possibly be due to the combined effect of varying dislocation density and stoichiometry in the film.

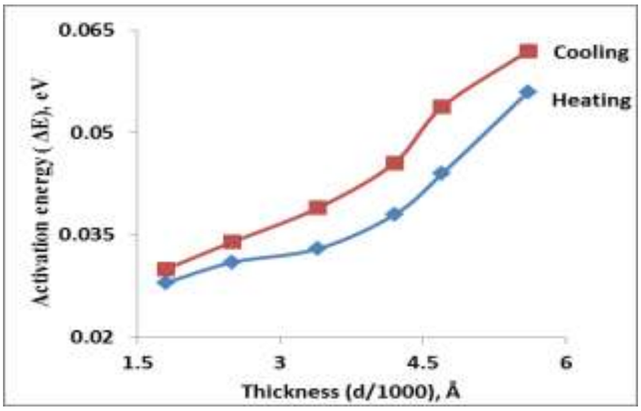

Fig.3: Plot of activation energy (ΔE) versus thickness (d) of AgSe thin films.

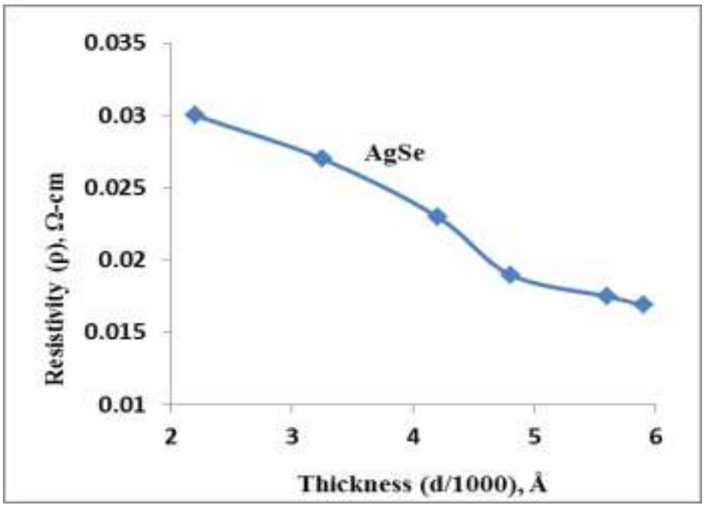

Fig.4: Plot of resistivity (ρ) versus thickness (d) at room temperature.

Fig. 4 shows variation of resistivity (ρ) with thickness (d) of AgSe thin films. It is seen that resistivity decreases with increase of thickness of the deposits. The sharp decrease of ρ, for thinner films may be due to island structure and higher defect density in the films. The effect of thickness (d) on resistivity (ρ) of film can be explained by Mathiessen rule.

$$\rho_{total} = \rho_{ideal} + \rho_{residual} + \rho_{thickness} \text{ ------------------------------ } (2)$$

Where ρ_{ideal} depends on amplitude of thermal motion of ions [7], $\rho_{residual}$ is the component strongly dependent on the lattice defects, but independent of temperature as long as these lattice defects are not affected by temperature change and $\rho_{thickness\ the}$ component of ρ_{total} that depends on thickness of the film.

Now as the thickness of the film increases, effect of island structure, quantum size effect and effect like grain size are diminished, thus reducing the contribution of $\rho_{thickness}$ on ρ_{total}, contribution to ρ_{total} by ρ_{ideal} and $\rho_{residual}$ being characteristics of material may be taken as same for all film thicknesses . Thus ρ_{total} of the film decreases with increasing film thickness.

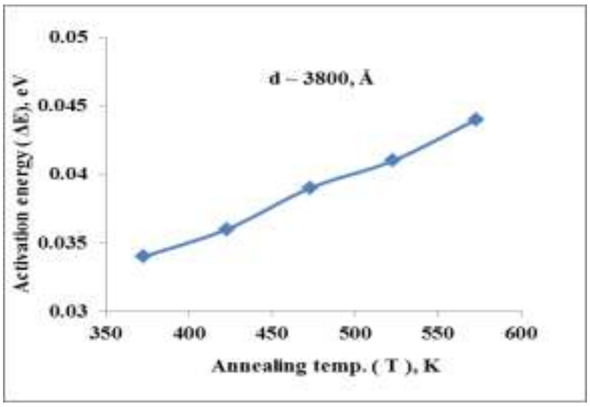

Fig.5: Plot of activation energy (ΔE) versus annealing temperature of AgSe thin films.

From fig.5, it is observed that activation energy (ΔE) of AgSe thin films increases with increase of annealing temperature. Due to increase of annealing temperature, the components of the film material uniformly distributed over the entire area of the film and there by removal of defects.

CONCLUSIONS

AgSe thin films have been well prepared by three temperature method. These films showed temperature dependent semiconducting and metallic behavior. Activation energy increases with increase of film thickness and annealing temperature of the films. Resistivity decreases with increase of film thickness can be well explained.

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