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# Comparative Electrical Characterization of SnTe Thin Films Grown by Thermal Evaporation and RTA Techniques

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**Abstract**: Semiconducting SnTe thin films were grown by conventional thermal evaporation technique as well as by rapid thermal annealing technique. The stoichiometric SnTe was achieved by starting with the initial Sn:Te ratio as 1:1.2, 1:1.3 and 1:1.4. Variation of hall coefficient, conductivity and mobility were studied as a function of temperatureand were discussed in terms of light and heavy hole valence band, scattering mechanisms, etc. These results were compared with variation in similar electrical parameters observed in the case of SnTe film grown by thermal evaporation technique and shown that RTA grown films possesses comparative electrical properties.

***Index Terms**: SnTe films, RTA Technique, XRD, Hall coefficient, Mobility*

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## I. INTRODUCTION

Tin Telluride (SnTe) is a compound IV–VI semiconductor with a direct narrow band gapof 0.18 eV at room temperature [1,2]. It exhibits many interesting properties and finds numerous applications in various fields like mid-IR photodetectors [3],photovoltaic [3], thermoelectric [5,6],electronic [7]and optoelectronic [8] applications devices.

The study of structural and electrical is important owing to its aforementioned potential uses. It has been reported that SnTe, when prepared from stoichiometric composition, is always deficient in tin [9]. This behavior has been explained by Savage et al.on the basis of phase diagram of SnTe [10]. The deficiency of Sn in SnTe is due to the low chemical diffusion constant of Sn in SnTe below 600 K ,with the result that , in bulk sample, equilibrium tin concentration is frozen and the material therefore is always p-type extrinsic [11]. Several researchers have worked on the carrier concentration in SnTe. Jemal et al. obtained epitaxial thin films with carrier concentration of 2.5 x $10^{20}$ $cm^{-3}$ with Hall mobility 200 $cm^3$/Vs at 300K [12]. Nishiyama has obtained nominal carrier concentration ranging between from 0.35 x $10^{20}$ to 2.9 x $10^{20}$ $cm^{-3}$ at 77K in epitaxial thin films [13].

In the present work SnTe thin films were grown by rapid thermal annealing using with higher Te content as SnTe ratio from 1:1.1 to 1:1.5 and conventional thermal evaporation technique SnTe as 1.1.3 and reported various electrical parameters.

## II. EXPERIMENTAL

Rapid thermal annealing technique was used to grow thin films of semiconducting SnTe. In this process highly pure Sn and Te were deposited onto quartz substrate in the ratio of 1:1.1 to 1:1.5 so that the initial precursor is always Te-rich. The substrate was keptat 150 $^oC$ at a distance of 5 cm from the charge in a platinum boat. After the deposition, the films were subjected to rapid thermal annealing at a temperature of 450 $^oC$ for 30 s in a specially designed set-up in which rate of heating and cooling,along with annealing temperature, can be controlled. Structural characterization was performed by powder XRD technique using $CuK_\alpha$ radiation ($\lambda$= 1.5404 Å). Electrical measurements like Hall coefficient and mobility, conductivity were performed using Vander Pauw technique [14]. The samples were mounted on a copper block provided with electrical contacts and insulation and then kept in a specially designed cryostat. This can be put into a Dewar flask containing liquid nitrogen and can be put between poles of an electromagnet.

## III. RESULTS AND DISCUSSION

### Structural Studies

The SnTe thin films of different compositions were subjected to structural characterization by powder XRD technique using $CuK_\alpha$ radiation ($\lambda$ = 1.54 Å). 2θ spectrum in a range of 20 to 50 degree was recorded. In Fig.1, spectrum A, B and C represent the SnTe films which were prepared with initial Sn:Te ratio as 1:1.2, 1:1;3 and 1:1.4 respectively, and processed with RTA at 450 $^oC$ for 30 sec. Curve D shows the XRD for the SnTe film grown by conventional evaporation technique having a composition 1:1.3. All these films show the occurrence of two peaks at 2θ = 28.3 and 40.4 degrees which correspond to the 200 and 220 planes, respectively, of SnTe.It is worth mentioning that out of various compositions of SnTe in the ratio of 1:1.1

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to 1:1.5 which were tried, the films grown from less than 1:1.2 always resulted in a peak at 23.2 degree. This peak corresponds to additional phase $Sn_xTe_y$ which is presumably rich in Sn, because tellurium has higher vapor pressure as compared to tin. On the other hand, the films grown from composition greater than 1:1.4 always resulted in additional peaks corresponding to Te. Therefore, the only compositional range, which resulted in single phase SnTe was 1:1.2 to 1:1.4.

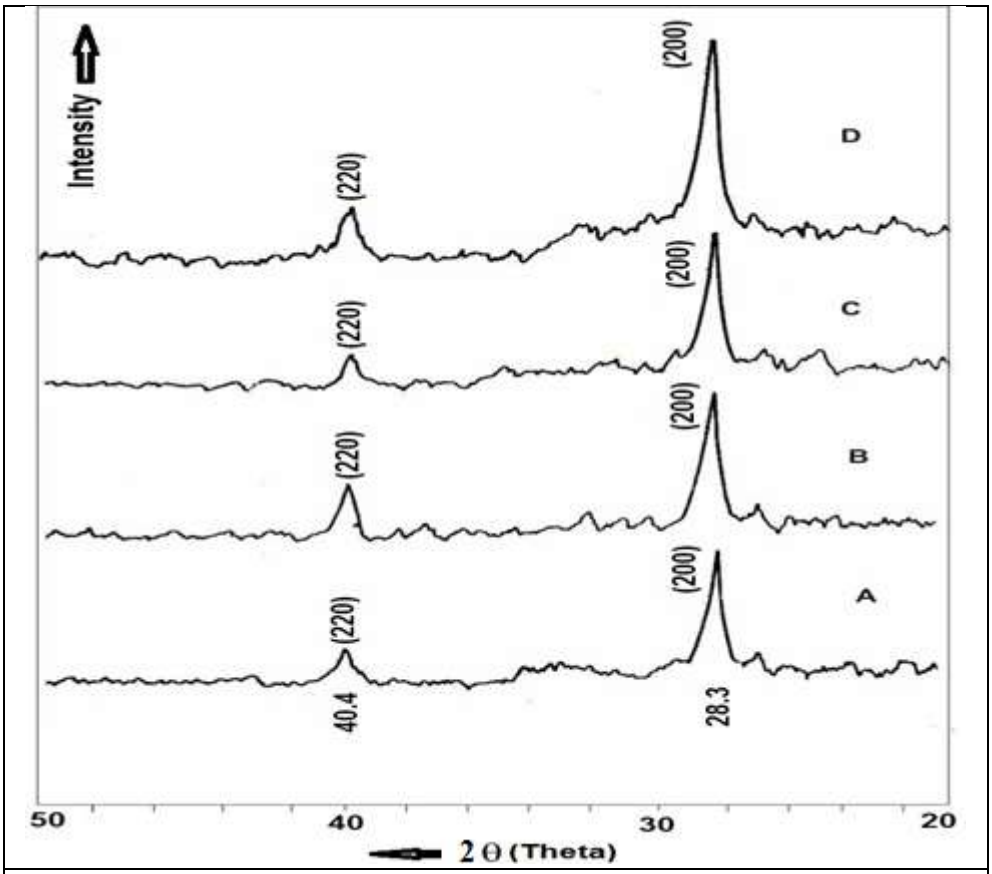


Fig. 1. Powder XRD of Sn:Te thin films. A, B and C represent the films of Sn:Te ratios as 1:1.2, 1:1.3 and 1:1.4, respectively grown by rapid thermal annealing. Curve D is of the SnTe film grown by conventional evaporation technique having a composition Sn:Te ratio as 1:1.3.

**Hall Measurements**

For the measurement of Hall coefficient ($R_H$), a constant current is passed through the samples using any two of the contacts and the voltage drop was measured across other two contacts. The magnetic field was kept at 10 kG and temperature was varied by moving the cryostat above the liquid nitrogen level in the Dewar flask. Any possible error due to thermomagnetic effect on Hall coefficient were eliminated by reverting the current and magnetic field.

In Fig.2, Curves A , B, and C represent variation of Hall coefficient $R_H$ as a function of temperature for SnTe films grown by RTP with the Sn:Te ratios 1:1.2, 1:1.3 and 1:1.4 , respectively. Curve D shows the $R_H$ vs. T for the film grown by conventional evaporation technique having a composition 1:1.3.The increase in $R_H$ at higher temperatures is due to the onset of the hole transfer from the light hole valance band to the heavy hole valence band. Also, $R_H$ increases as the tin content of the film increases. This can be explained on the basis that the film grown from perfect stoichiometric SnTe are always deficient in tin and each tin vacancy provides two holes in the lattice cites which increase the carrier concentration in the films.

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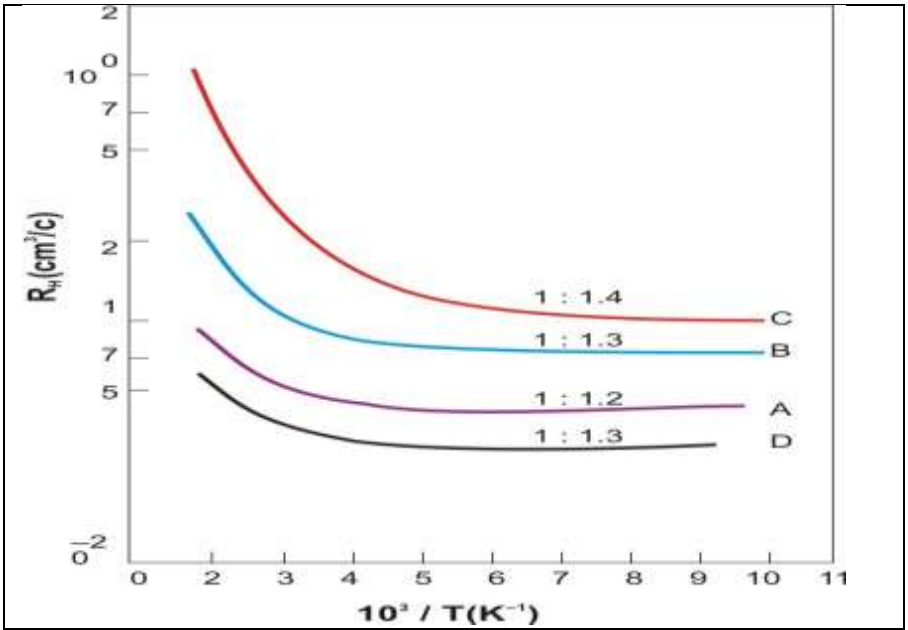


Fig. 2. Variation of Hall coefficient $R_H$with Temperature for SnTe films having different stoichiometric ratios. Curves A, B, C and D represent the same films as described in Fig. 1.

The deficiency of tin is due to freezing of tin vacancies which is the result of low chemical diffusion of tin in SnTe. The excess of tin in the charge, when evaporated,fills up these vacancies thereby reducing the concentration of free holes. This results in the increase of $R_H$ value with temperature. Also, the onset of heavy hole conduction in the films with higher tin content occurs at lower temperature. This is because there are fewer light holes in these films and $R_H$ is therefore higher in accordance with the relation

$R_H = 1/p\ e\ l\ (1\text{-}xb^2)/(1+xb^2)$ (1)

Where, $x = p_h/p_e$, in which $p_h$ and $p_e$ being concentration of heavy and light holes respectively, and $b= (\mu_e/\mu_h)$ is the ratio of the mobilities of the light holes to the heavy holes.

**Hall Mobility**

The Hall mobility of the carriers for different films were calculated using the formula $\mu_H = R_H x\sigma$, where 'σ' is the ac conductivity. For the calculation of Hall mobility, the Hall coefficient as shown in Fig. 2 has been used along with ac conductivity data of in previous report [15]. The curves A, B, C and D in Fig. 3 represent the variation of the Hall mobility $\mu_H$ with temperature, in which A,B,C,D bear the same meanings as above.

The mobility decreases with increase in temperature. However, the rate of decrease in $\mu_H$ in low temperature region follow exponential form, $\mu_H \alpha T^{-\alpha}$. Here, 'α' = 0.22- 0.82. Also, 'α' decreases as the carrier concentration increases. The observed slower decrease in the mobility in the high temperature range is due to the contribution of other scattering mechanisms and due to the presence of various defects such as dislocations, structural disorder, grain boundaries, etc.

The observed mobility data has been analyzed for accounting the scattering mechanism involved in limiting the mobility. According to the Matteheissen's rule, the observed Hall mobility $\mu_H$ can be expressed as $1/\mu_H = 1/\mu_l + 1/\mu_D$, where $\mu_D$ is the mobility limited by all kinds of defects such as grain boundaries, structural disorders, dislocations, etc., and $\mu_l$ is the average lattice mobility corrected by diffuse surface scattering.

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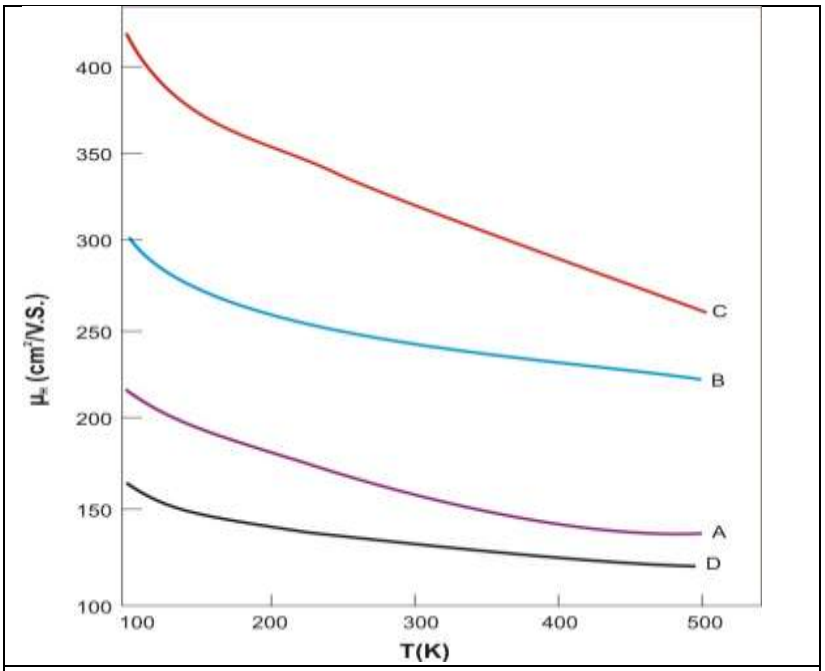


Fig. 3. Variation of Hall mobility ($\mu_H$) with temperature. Curves A, B, C and D bear the same meaning as described in Fig. 1.

In the present case r >> 1, which yields $\mu_I > \mu_i$ . The use of Matteheissen's rule for the additivity of inverse mobility is justified because the Hall scattering parameter is close to unity in the temperature range under consideration.

**Defect Limited Mobility**

The value of the defect limited mobility ( ln $\mu_D$ vs lnT) thus calculated as a function of temperature for various tin concentration are shown in the Fig.4. The value of $\mu_D$ at any temperature increases with the increase in the stoichiometric excess of Sn in the film. They show that the contribution of the defects in limiting the overall mobility of films decreases with the increase of Sn content in the films. However, the temperature variation of $\mu_D$ shows that for films with low tin contents, the values of $\mu_D$ are almost constant in the low temperature region while in the higher temperature region, the mobility due to defects starts increasing.

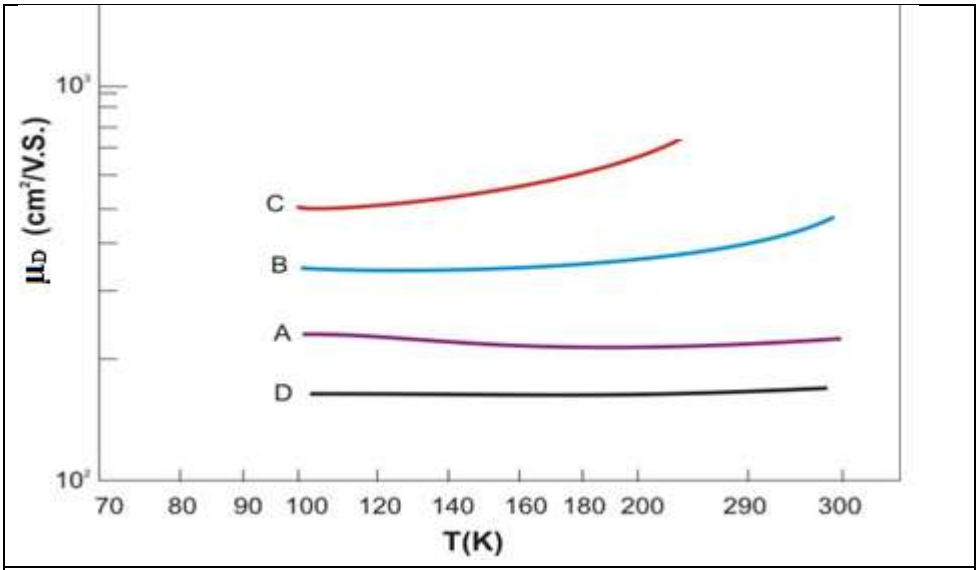


Fig.4. Variation of defect limited mobilities ($\mu_D$) with temperature. Curves A, B, C and D bear the same meaning as given in Fig. 1.

This behavior of $\mu_D$ vs T curves suggests that the excess Sn is accommodated in the structure as (i) substitutional, to fill up the Sn vacancies which cause the decrease in the carrier concentration thus improves the mobility and (ii) to create more boundary regions. The second process should decrease the overall mobility but this

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decrease may not be as large as the improvement in its value due to process (i). Hence the net effect of Sn excess is the improvement in mobility

## Conclusion

1. Thin films of SnTe was prepared by two methods: (a) Rapid Thermal Annealing (RTA) process and (b) conventional thermal evaporation technique in different SnTe ratio in the range 1:1.2 to 1:1.4.
2. The condition of Sn and Te ratio, the annealing temperature & duration, etc were optimized to get SnTe films of comparative properties.
3. Thin films were characterized for structural and electrical properties. Variation of Hall coefficient, Hall mobility, conductivity, etc. as a function of temperature were reported and explained in terms of relative volatility of Sn & Te during deposition, band gap, defects mechanism, etc.
4. It has been demonstrated that a simple RTA technique can be used to grow SnTe film.

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