Electric Characterization of Gallium Resquitelluride Monocrystals

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Abstract: Electronic transport measurements were made on single crystal samples of Ga_2Te_3. The crystals were prepared by a special design based on Bridgman technique. The influence of temperature on the electrical conductivity, hall effect, hall mobility and carrier concentration was investigated in the temperature range 160K to 440K. The study was carried out with the current following parallel to the c-axis and the magnetic field direction perpendicular to the c-axis. The crystal obtained had n-type conductivity with electron concentration of 3.79×10^{13} cm^{-3} at room temperature. The conductivity and hall mobility at 300K were evaluated as $1.479 \times 10^{-3}\Omega^{-1}cm^{-1}$ and 239.88 cm^2/V. sec, respectively. The energy gap width and the depth of donor centre was found to be 1.588 eV and 0.20 eV respectively. The scattering mechanism of the charge carrier was discussed in the same range of temperature.

1. Introduction

M_2X_3 compounds (where M = Al, Ga or In and X = S, Se or Te) are the simplest examples of materials [1] whose structure is based on the tetrahedral atomic coordination as in the Zinc blende (ZB) structure but in which some atomic sites are empty. In the case of M_2X_3 compounds, one-third of the cation sites of the ZB or wurtzite structures available to group III atoms is vacant. It is apparent from the chemical formula that the valencies are satisfied. In some of these compounds, the vacancies can be ordered to form a superlattice bellow a certain temperature.

Although many recent papers have dealt with $M_2^{III}X_3^{VI}$ – type compounds, their properties remain rather confusing. The reason for this the compounds of this type are defective [2] in respect of their metal atoms : only two-third of all cationic positions are occupied and every third site in the cation sublattice remains vacant. Consequently, the presence of this large number of intrinsic defects strongly affects the motion and scattering of current carriers and phonons, causing their thermal and electrical properties.

Ga_2Te_3 is a member of the above family in the past three decades, significant interest in chalcogenide [3] compounds has been shown by various workers because of their interesting physical properties and well as their wide technological application.

In gallium – tellurium system various stoichiometric compositions have been reported [4-6] three phases are present in the Ga–Te system, $GaTe, Ga_2Te_3$ and Ga_2Te_5 .Among these compounds Ga_2Te_3 seemed to be the less studied [7]. Many investigations have dealt with this compound while results were reported for the resistivity and thermoelectric power of Ga_2Te_3 binary alloy system in the liquid state [8,9]. Some other authors have investigated Ga_2Te_3 in the form of thin films [10]. Few papers have been published dealing with the solid Ga_2Te_3 such as structure[11] , resistivity under high pressures[12], mass spectrometric[13], *Mössbauer* spectroscopy[14], Dielectric and photoconductivity[15,16], optical properties[17], switching effect[18,19], heat capacity[20] ferroelectric properties[21].

2. Sample preparation and measurements:

High quality of Ga_2Te_3 single crystal have been grown from melt by a modification of Bridgman technique. The growth method and the experimental apparatus have been described in detail elsewhere[22]. The purity of the materials used was a follows Ga, 99.9999% and Te, 99.999%. Stoichiometric quantities of the constituent elements, 13.3523 g Ga and 36.6477 g Te, representing 26.705% gallium and 73.295% tellurium were used as starting materials. The appropriate amounts were first sealed in quartz ampoules at a pressure of 10^{-5}Torr. The lower end of the ampoule was trapered in order to favor crystal growth at a single point. The silica ampoule, coated internally with a thin layer of carbon to prevent contamination of the charge the usual precautions were taken throughout this investigation to prevent oxide formation on the ingot material. In the first procedure the tube was placed in a three – stage tube furnace in which a controlled temperature gradient was maintained the mixture was heated above the melting point according to the phase diagram and

maintained for several hours with periodic agitation to ensure through mixing of the constituents. The ampoule was allowed to move slowly from the high temperature zone towards the low temperature zone with a rate of 1.7 mmh^{-1} through the stationary furnace. As the ampoule continuously enters the low temperature zone, crystallization proceeds until all the contents solidify. A prolonged period of time is necessary for the growth of Ga_2Te_3 single crystals. At least two weeks growth are needed to obtain gallium resquitelluride monocrystals. Then, the obtained dark layered silvery crystals were investigated with x-ray analysis. The analysis confirmed the presence of the crystalline phase without any secondary phases.

For studying electrical conductivity and Hall effect, the sample was prepared in a rectangular shape. The specimens were ground and polished thoroughly with the use of diamond pastes to obtain mirror-like surface. Typical dimensions for the rectangular sample were 9.7 x 3.2 x 2.0 mm^3.In this way the length of the sample was three times of its width to avoid Hall voltage drop.

The d.c Hall measurements were carried out as recommended in ASTM-F 67 and quite similar to those described earlier[23]. Electrical conductivity and Hall effect were measured under vacuum of ~10^{-3}Torr. Measurements above room temperatures were performed with the help of an electrical insulated heater, which was supplied with required voltage, gradually and slowly, from a varic transformer. Liquid nitrogen was used for achieving the low temperature measurements. Calibrated thermocouple, made of copper-constantan, was used for measuring the temperature of the sample. Silver paste contact was used as ohmic contact. The ohmic nature of the contacts was verified by recording the current-voltage characteristics. The conductivity σ and Hall efficient were measured by a compensation method in a special cryostat with a conventional d.c. type measurement system. The designed cryostat allows measurements in a wide range of temperature. For Hall measurements, the magnetic field was perpendicular to the crystallographic c-direction with intensity of 0.5 Tesla. The Hall voltages were measured by reversing the current and the magnetic field directions and taking the appropriate averages.

3. Results and Discussion:

Measurement of the effect of temperature on electric conductivity σ was done from 160K to 440K.**Fig.1** represents the temperature dependence of the electrical conductivity σ of Ga_2Te_3 single crystal.
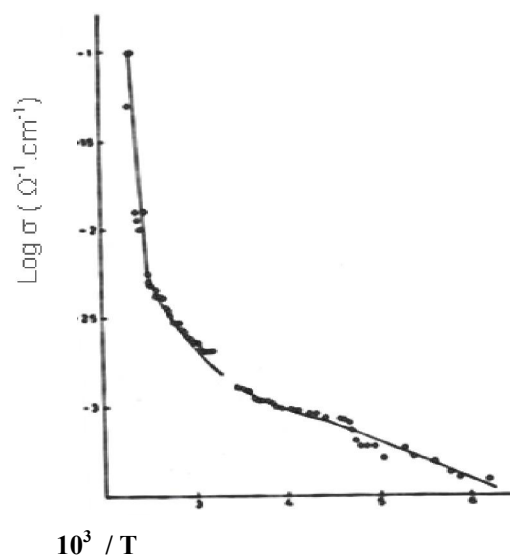

Fig. 1 Electrical conductivity of Ga_2Te_3 single crystal as a function of temperature

The curve shows a typical semiconductor behaviour. As illustrated in the figure, a much less rapid increase in conductivity is observed in the low temperature range with a linear relation up to 240K. After this region the electrical conductivity exponentially increases with a relatively speed rate in the temperature range extending from 240K up to 400K. a rapid increase in the conductivity with linearity is observed in the high temperature range above 400K. It can be stated that the room temperature conductivity reaches a value of σ =1.479 x 10^{-3} Ω^{-1} cm^{-1}. In the extrinsic region σ increases slowly as a result of liberation of the ionized donors and their transition from the impurity level. In the low temperature region the relation between the temperature and electrical conductivity σ can be given as:

$$\sigma = \sigma_o \exp\left(-\Delta E_d / 2KT\right) \tag{1}$$

Where σ_o is the pre-exponential factor and ΔE_d is the ionization energy of donor atoms. This is observed in the temperature interval 160-240K and ΔE_d was found to be 0.20 eV. It is also seen from the curve that as the temperature rises the conductivity rises rapidly because of the increase in the total current density (electrons plus holes). The width of the forbidden gap was evaluated from the high temperature slope of the conductivity curve, to be 1.588 eV. This value contrasts with data of other author[20]. The calculated energy gap width in the present work is larger than that reported in the literature. We may attribute the discrepancy between the values of ΔE_g partially to the presence of the

large number of intrinsic defects that affects strongly the motion of scattering of current carriers and phonons. On the other hand it is thought that the technology used to grow these crystals may influence its physical properties. In this paper, we tried to elucidate this confusion but more experimental data were necessary to explain this contradiction. Since Hall effect is important and helpful for the determination of many physical parameter, this work was extended to cover the effect of temperature on the Hall coefficient R_H. This was done in a wide range of temperature (160K-440K). **Fig. 2** shows the dependence of R_H on temperature.
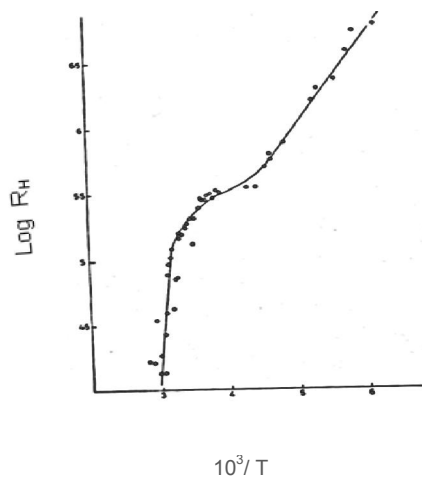

Fig. 2:Effect of temperature the Hall coefficient for Ga$_2$Te$_3$ single crystal

It is obvious that the sign of the Hall coefficient indicates that the compound Ga$_2$Te$_3$ is a brilliant n-type semiconductor which is in reasonable agreement with the results[20] obtained by the other author. The Hall coefficient R_H at room temperature was evaluated as 16 x 10^{4}cm^3/C. Determination of the energy gap and ionization energy from Hall data is possible by plotting the relation between $R_H T^{3/2}$ and $10^3/T$. **Fig.3** was constructed and the relation between $R_H T^3$ and $10^3/T$ is presented on the basis of the following relationship:

$$R_H T^{3/2} \alpha \exp\left(- \Delta E_g / 2KT\right) \qquad (2)$$

In the temperature region in which the conductivity σ is predominantly intrinsic, the forbidden band width was estimated to be 1.588 eV from the above relationship. The depth of the donner level was determined from the region in which the conductivity is predominantly due to impurity atoms and was found to be 0.20 eV. These values are in good agreement with the values obtained from temperature dependence of electrical conductivity the curve shows the following facts.

1-The values of R_H are negative over the entirely temperature range of investigation indicating that Ga$_2$Te$_3$ is a n-type semiconductor.

2-The three regions of the curve support that extrinsic conduction appears from 160 to 240Kand intrinsic one begins from 400 to 440K while the transition region lies between 240K and 400K as observed in fig. 1.As for the importance of the mobility data in the field of solids, especially semiconductors, the present work has dealt with an investigation of the effect of temperature on Hall mobility σ, as shown in **Fig.3**.
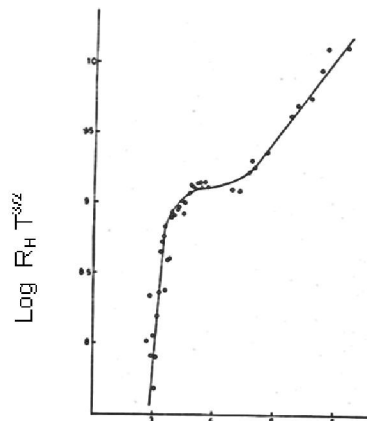

Fig. 3: The relation I $10^3/T$ $T^{3/2}$ and $10^3/T$ of Ga$_2$ Te$_3$monocrystal.

The reason for this is to spot some light on the scattering mechanism of the charge carriers. This was done as a result of availability of both and R_H data.

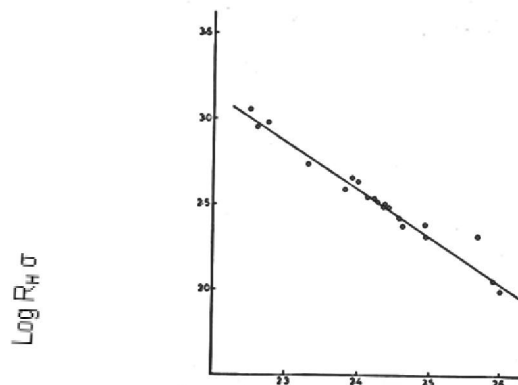**Fig.4** illustrates this dependence for Ga$_2$Te$_3$ sample.

Fig. 4: Temperature dependence of charge carrier mobility's of Ga$_2$ Te$_3$.

This plot results in a straight line, the slope of which allows the determination of the

exponent. In the temperature range of investigation it was found that the exponent n in the relation $\mu_H \sim T^n$ is − 1.46, which is closely near to the − 3/2 power law. It may be concluded that the charge carriers are scattered by acoustic lattice vibration. The most striking feature of the Hall mobility σ is its temperature dependence as illustrated in fig 4. The mobility is always seen to decrease with increasing temperature and appears to be unaffected by impurity scattering effects. At room temperature the electron mobility of 239.88 cm²/V. sec, was obtained in these measurements for Ga_2Te_3 sample. Calculation of the diffusion coefficient for electrons gave a value of 6.15 cm²/sec. Assuming that the effective mass for electrons m^*_n is equal to the rest mass and using the value for the electron mobility at room temperature, the mean free time could be determined and its value was equal to 1.365 x10⁻¹³ sec. Also the diffusion length of electrons in the Ga_2Te_3specimen was evaluated as 0.916 x 10⁻⁶ cm. The electron concentration for our investigated sample plotted as a function of inverse temperature is shown in fig.5.
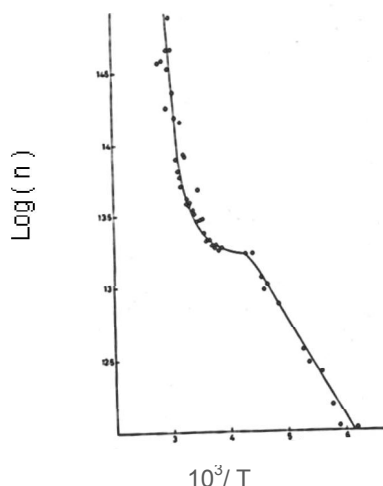

Fig.5: Dependence of carrier concentration of gallium sesquitelluride on temperature

It can be stated that at room temperature the concentration reaches a value of 3.79x10¹³ cm⁻³. The variation of the carrier density with temperature appears to be nearly linear, except in the temperature range 235-320K which represents the region of transition to intrinsic conduction. At low temperature and indeed (160-235K) in Ga_2Te_3 the carrier concentration is determined by the number of ionized donors. The variation of the carrier concentration is quite slow in the transition region. Since Ga_2Te_3 sample is exhibiting an intrinsic behavior above 400K, then the expected value for the intrinsic concentration n_i will be given as:

$$n_i = 2\left(\frac{2\pi K}{h^2}\right)^{3/2}\left(m^*_n m^*_p\right)^{3/4} T^{3/2} \exp(-\Delta Eg / 2KT)................(3)$$

Where "m^*_n and m^*_p :the effective mass for electrons and holes" and another symbol refers to their usual significance and the energy gap width as deduced from this relation is 1.588 eV.

4. Conclusion:

In the present paper, measurements of the electrical conductivity and Hall coefficient in a wide range of temperature extending from 160– 440K was reported. The main conclusions were:-

Ga_2Te_3 crystal is a promising n-type semiconductor.

The energy gap for the compound is 1.588 eV, while the activation energy of donors is 0.20 eV.

The scattering mechanism for Ga_2Te_3 was checked.

The diffusion coefficient for majority carrier and free time between collision as well as the diffusion length was determined.

The conductivity σ , Hall mobility μ_H and carrier concentration n_i at room temperature was evaluated to be $1.479 \times 10^{-3}\Omega^{-1}$ cm⁻¹, 239.88 cm²/V.sec , and 3.79×1013 cm⁻³ respectively.

This study is a timely one in view of the recent interest in this compound. The important parameters deduced from this study leads to better application in electronic devices and techniques.

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