Int. J. Chem. Sci.: 6(2), 2008, 1093-1098

THE A. C. IMPEDANCE STUDY OF POLYCRYSTALLINE ZINC TELLURIDE

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ABSTRACT

The complex impedance of polycrystalline zinc telluride has been measured as a function of frequency ($1.0 \times 10^2 – 1.3 \times 10^7$ Hz) by a two probe technique in the temperature range of 300 – 469 K. The data have been presented in term of complex impedance plane formalism and suitable equivalent circuits have been proposed at different temperatures. The values of resistance and capacitance of grains and grain boundaries have been successfully separated from the total values by employing complex plane analysis. The results have been discussed in the light of contributions of grains and grain boundaries taking part in the overall conduction process.

Key words : Zinc telluride, Impedance analysis, Grain, Grain boundary

INTRODUCTION

Zinc telluride (ZnTe) is an important member of the family of wide band gap semiconductors and has gained prominence in various electronic devices[1] such as photovoltaic detectors, hetero junction solar cells and light emitting diodes. Although there has been greater emphasis on the characterization and development of single crystalline ZnTe as electronic materials, polycrystalline compounds have received considerable attention in recent years because they can be prepared by conventional and very low cost method. However, in polycrystalline materials, grain boundaries play a considerable role in the conduction process. The properties of grain boundaries are different from those of grains and the overall properties of a polycrystalline compound are controlled by both; grains and grain boundaries. Thus, the electrical conduction in polycrystalline compound has contributions from grains, grain boundaries and sample-electrode interface. In this context, impedance analysis offers a valuable and excellent method to separate these contributions in a very simple way. The electrical conductivity of a number of polycrystalline compounds have been successfully discussed in terms of grain and grain boundary contributions by a number investigators[2-8]. Recently, impedance analyses have been thoroughly carried out on compound semiconductors such as CdTe[9-10], PbTe[11] and $CuInS_2$[12]. In the present work the impedance analyses on polycrystalline ZnTe have been performed with the prime objective to measure the values of component resistances (and hence, conductance) and also to judge whether the overall conductivity is dominated by grains or grain boundaries.

EXPERIMENTAL

High purity (99.999 % pure) zinc and tellurium obtained from Johnson Matthey (U.K.) were used in the present investigation. The stoichiometric mixture of component elements corresponding to the composition ZnTe, weighed to an accuracy of 10^{-5} g, was sealed in a silica capsule under a vacuum of better than 1.3×10^{-8} atm. The capsule was heated at a rate of 4 K/min. to 1300 K and held at this temperature for about 40 hours and then at 1425 K for about 5 hours and then finally quenched in cold water. The resultant mass was crushed into fine powder and then compressed (at the pressure of 70 kg/cm^2) to form cylindrical pellet by means of die and punch. The pellet was sintered at 1000 K for about 72 hours in a sealed silica capsule under the vacuum of the same order. The flat surfaces of sintered pellets were polished and coated with thin layer of high temperature silver paint (Eltecks, India).

A two-probe sample holder assembly used in the present investigation was made of piston type silica tubes. The design, construction and operation of the assembly was similar to those described earlier[10,13]. The silver coated ZnTe pellet placed between two silver discs was pressed by two both-end open silica tubes, kept in a piston type other tube, with the aid of nichrome springs. To each of the silver discs one silver electrode wire was welded. The silver electrode lead wires were taken out from the slotted portion of the outer tube. The entire assembly, kept in one-end closed reaction tube, was evacuated to 1.3×10^{-5} atm. and purged with argon repeatedly three times. The impedance parameters were measured as function of frequency (1.0×10^2 to 1.3×10^7 Hz.) in the temperature range of 300-469 K by Impedance Analyzer (Hewlett Packard, USA, Model No. : 4192A LF).

Theory

The impedance (Z*) is a more general term than the resistance because it takes both resistive (real) and reactive (imaginary) components in to account:

$$Z^* = Z' - j Z'' \quad \ldots(1)$$

In the impedance plane analyses, the imaginary part (Z”) is plotted against real part (Z’) over a wide range of frequencies. The plot gives single or a series of semicircular arcs. Each arc represents the parallel combination of resistance (R) and capacitance (C) of the respective species taking part in the conduction process. The arc of highest frequency range passes through origin represents the contribution due to grains. In the intermediate frequency range, the arc represents the contribution due to grain boundaries, and in the lowest frequency range, it highlights the role of sample electrode-interface or electrode polarization.

RESULTS AND DISCUSSION

The variation of imaginary part with real part of the total impedance measured over a wide range of frequencies is shown in Fig. 1 at three typical temperatures, viz., 300, 325 and 356 K. From the figure, it is clear that two semicircular arcs of almost equal size are obtained at 300 K; thus, the intercepts of the arcs on real axis, which represent the respective values of resistances, are almost equal. The first arc which passes through the origin is due to parallel combination of resistance (R_g) and capacitance (C_g) due to grains, and the second arc is due to the parallel combination of resistance (R_{gb}) and capacitance (C_{gb}) due to grain boundaries. Here we see that the value of resistance (2.9 kΩ) offered by grain boundaries is only little higher than that due to grains (2.7 kΩ). Thus, one can say that the contributions of the grain boundaries and grains to the total resistivity (and hence, conductivity) are almost equal in polycrystalline ZnTe at room temperature. But when the temperature is increased slightly, say to 325 K, the relative size of the arc due to grain boundaries becomes larger (Fig. 1). From this figure, it is evident that at this temperature the resistance offered by the grain boundaries is more than twice to that due to grains. This observation clearly indicates the dominating role of the grains in conductivity of polycrystalline ZnTe at 325 K. However, the contribution of grain boundaries cannot be ignored. Similar dominating trend of grains over grain boundaries has been obtained on further increase of temperature. For example, when temperature is increased to 356 K, resistance due to grain boundaries becomes more than six times than that due to grains. Thus in other words, at this temperature, the conductivity due to grains is more than six times than that due to grain boundaries. At 469 K, the resistance due to grain boundaries becomes about twelve times larger that due to grains. Thus, grains play dominating role in the conduction process.

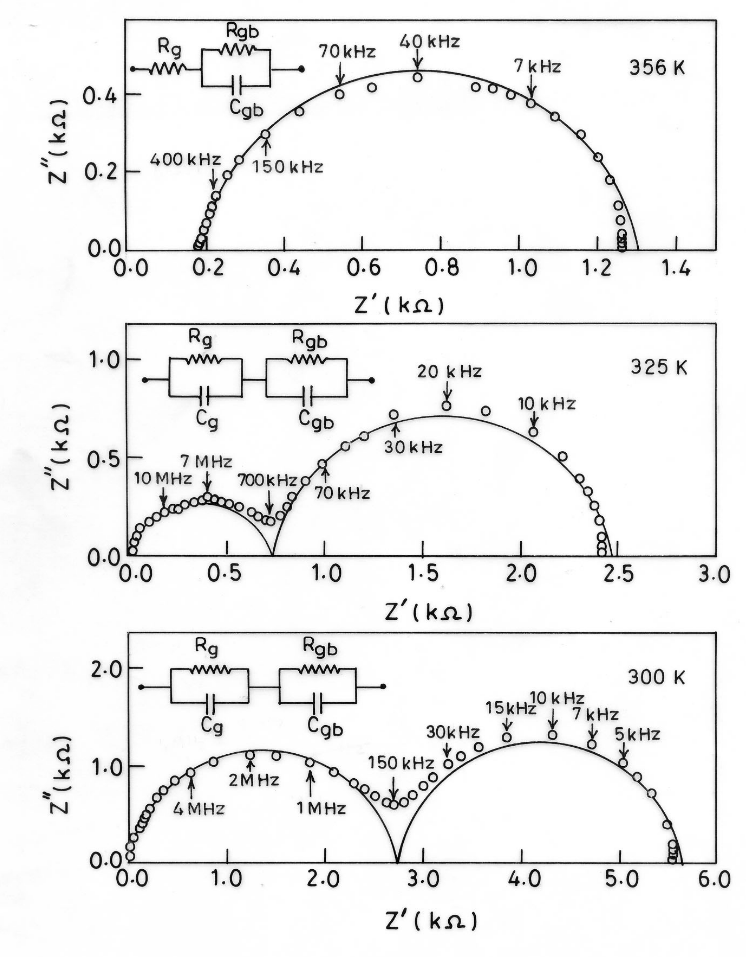

Fig. 1: Complex impedance plot at different temperatures

It is interesting to note that the size of high frequency arc showing the contribution of grains in the conduction process, decreases with the increase of temperature and disappears at 356 K and only one semicircular arc corresponding to grain boundary effects shifted from origin is obtained in the temperature range of 356-469 K. This indicates the absence of capacitive behaviour of the grains of polycrystalline ZnTe beyond 356 K.

From the values of resistance due to grains and grain boundaries the respective values of capacitance have been calculated using the following relationship:

$$2 \pi f_{max} RC = 1 \qquad \dots(2)$$

where, f_{max} is frequency of the peak maxima. The values of grain capacitance (C_g = 3.70 x 10^{-11} F) and grain boundary capacitance (C_{gb} = 5.21 x 10^{-9} F) so obtained confirm that the arcs of high and low frequencies regions are due to grain and grain boundary effects, respectively[7].

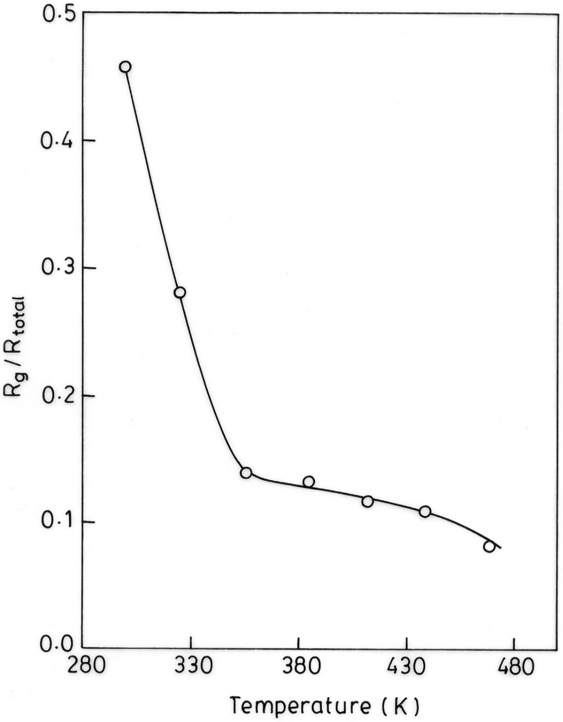

Fig. 2: Contribution of grains to the total resistance of polycrystalline ZnTe at different temperatures

The contributions of grains to the total resistance has been analysed in Fig. 2 as function of temperatures. Fig. 2 shows that the contribution of resistance due to grains to the total resistance (i.e. the factor R_g/R_{total}) decreases with increase of temperature and becomes about 8 % at 469 K. However, the decrease of R_g/R_{total} is more pronounced in the lower temperature range (300-356 K). The decrease of grains contribution to the total resistance clearly suggests that the role of grains in the conduction process increases with increase of temperature. Obviously, at high temperature, e.g., at 469 K, the electrical conductivity of the polycrystalline ZnTe is mainly due to grains and grain boundaries, which play negligible role in the conduction process.

ACKNOWLEDGEMENTS

The authors are thankful to the Head, Department of Metallurgical Engineering, Banaras Hindu University for providing necessary laboratory facilities.

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Accepted : 04.08.2007