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# ELECTRICAL TRANSPORTS IN Al/Bi/Ge ALLOY SYSTEMS

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## ABSTRACT

The electrical transport properties in Al/Bi/Ge alloy systems have been examined in this study at electric field values 0.20 – 0.65 V/m. Powdered samples of the various elements were mixed together in a borosilicate tube which were enclosed in furnace and heated from room temperature to about 700°C to form molten alloy. The melted samples were homogenized at this temperature for about three hours after which the furnace was switched off and the samples allowed to cool down gradually to room temperature. The results of the study showed that the conductivity of the samples increases with increase in temperature and fractional concentration of Ge. An insignificant deviation from the dependence $\alpha(T)\ \alpha\ \exp(1/T)$ within the temperate 303 – 353 K was observed. This indicates that the electrical behavior of the samples followed the Arrhenius relation $\sigma = \sigma_o \exp(-\varepsilon_o/kT)$ typical of semiconductor materials. The variation of conductivity with temperature revealed a wide variation in thermal activation energy sensitive to temperature and concentration of the samples. The values of the calculated activation energies and the general electrical properties exhibited by the system in the study showed that the alloy materials are comparable with most semiconductor materials that are hitherto being studied due to their numerous and attractive applications in solar cell development and thermo electric device applications.

**Key words:** Electrical transport, Al/Bi/Ge alloys, conductivity, activation energy.

## INTRODUCTION

Significant advances have been made over the years in the investigation of efficient alloy materials because of their applications in opto-electronics devices and solar cells[1]. Literature on materials, which are ternary analogue of the II – IV compounds that are noted for thermoelectric devices and applications are at present scarce. According to Villars *et al.,*[2], one has the impression that material scientists have experimentally investigated a major part of all possible binary, ternary and quaternary systems. This is by no means the case, not even for the binary systems. The situation gets worse by looking at the ternary and quaternary systems with just about less than 5 and 0.5% records respectively.

Experimental studies of the transport properties of $Cu_2SnS_3$ alloy thin films[3] revealed that the materials could be prepared to be P-type conducting with an indirect energy band gap of 1.51 eV and a nearly direct one at 1.77 eV for near stoichiometric regions. This edge placement suggests the attractiveness of the material for solar cells development.

Semiconductor alloy systems are also known to attract considerable scientific interest due to their established potential for device applications such as infrared detectors photo resistors, photodiodes, thermoelectric and switching devices, and lasers[4-6]. To this end, various properties, such as fractional concentration, temperature, alloying condition e.t.c had been discovered to affect both the electronic and structural properties of the resulting alloy material [7-12].

The present study therefore investigates the electrical transport properties of Al/Bi/Ge systems, which to the best of the knowledge of the authors had not been studied in both the liquid and solid states. It is believed that finding in this research will complement already established facts on metal-semiconductor alloy materials.

## MATERIALS AND METHOD

Powdered samples of proportions of Al, Bi and Ge (with Ge concentrations ranging between 0.01 – 0.04) were weighed using appropriate weighing balance (Ohaue Triple Beam balance). The constituents; for each Ge concentration, were carefully mixed together and poured into the already cleaned silica tube. The upper end of the tube was sealed off and enclosed in a furnace. The materials in the tube were heated over a range of temperature from room temperature to $700^0$C to form molten alloy. The resulting sample was allowed to homogenize at this temperature for about three hours after which the furnace was switched off and allowed to cool down gradually to room temperature. The sample was polished with fine grain sandpaper and electrical contacts were made to opposite ends of the sample with a flux less solder. Thereafter, the sample with contacts was inserted in a thin- walled test tube. The lower part of the tube was immersed in a lagged heatable water bath while uniformity in temperature was ensured with the aid of a magnetic stirrer immersed in the bath. The insulated electrical leads from the contacts were taken out of the test tube with the aid of ports, which were vacuum-sealed with araldite. The current-voltage characteristics were determined with the aid of a digital electrometer (Keithley 160B) and a digital multivoltmeter (Hewlett-Packard 3465A). The sample temperature and that of the water bath were determined with copper-constantan thermocouple whose cold junction was maintained at $0^o$C. All the measurements were carried out at a number of temperatures between 303 and 353K.

## RESULTS AND DISCUSSION

The experimental results on the Al/Bi/Ge samples with Ge fractional concentrations 0.01, 0.02, 0.03 and 0.04 showed that the current – voltage relationships for all the samples are Ohmic over the electric field value 0.20 – 0.65V/m and temperature range 300 – 363K for the study.

However, the increase in voltage with temperature seems to decrease gradually with increased temperature. This is evident in figures 1, 2, 3 and 4 at relatively high temperature of study, while slight variations exist in the Ohmic behavior of the current-voltage relationships. The conductivities of the samples were found to increase with increase in temperature and Ge fractional concentrations respectively. Recent study [3] for $Cu_2$ Sn $S_3$ samples agree with this finding. It implies therefore, that at low temperatures, the crystallites do not grow sufficiently large, leading to small grain sizes, the intercrystalline regions in the samples are wide, thereby offering a high resistance to the movement of charge carriers. The formation of fewer nucleation centres at higher temperatures results in larger crystallite sizes. During this process, the charge carrier would have to cross-narrower intercrystalline barriers, which results in the observed increase in conductivity.

**Table - 1: Temperature (K), and the conductivity $(Wm)^{-1}$ values at different concentrations**

| Ge fractional concentration (0.01) | | | Ge fractional concentration ( 0.02) | | Ge fractional concentration ( 0.03) | | Ge fractional concentration ( 0.04) | |
|---|---|---|---|---|---|---|---|---|
| T (K) | $\sigma$ $(\Omega m)^{-1}$ | $\varepsilon$ (eV) | $\sigma$ $(\Omega m)^{-1}$ | $\varepsilon$ (eV) | $\sigma$ $(\Omega m)^{-1}$ | $\varepsilon$ (eV) | $\sigma$ $(\Omega m)^{-1}$ | $\varepsilon$ (eV) |
| 303 | 1.553 | 0.21 | 1.712 | 0.19 | 1.729 | 0.20 | 1.801 | 0.19 |
| 313 | 1.592 | | 1.759 | | 1.778 | | 1.855 | |
| 323 | 1.618 | | 1.766 | | 1.798 | | 1.872 | |
| 333 | 1.640 | | 1.799 | | 1.828 | | 1.897 | |
| 343 | 1.765 | | 1.800 | | 1.836 | | 1.96 | |
| 353 | 1.790 | | 1.855 | | 1.859 | | 1.967 | |

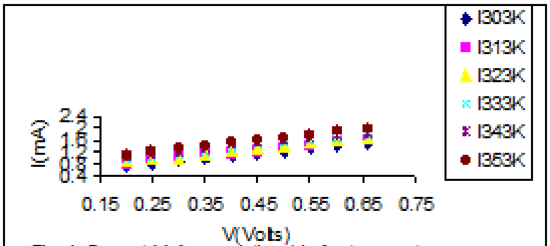


Fig. 1: Current-Voltage relationship for temperatures 303K-353K at Ge fractional concentration 0.01

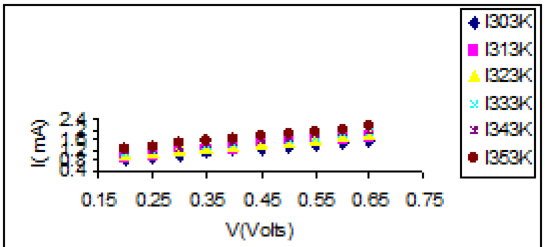


Fig. 2: Current-Voltage relationship at temperatures 303K-353K for Ge fractional concentration 0.02

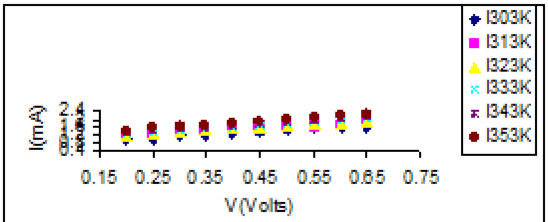


Fig. 3: Current-Voltage relationship at temperatures 303K-353K for Ge fractional concentration 0.03

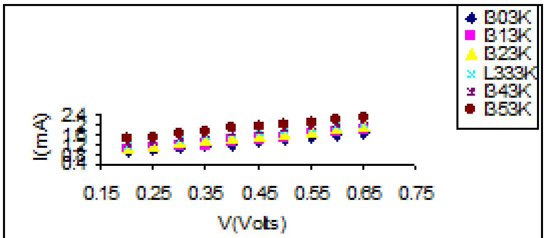


Fig. 4: Current-Voltage relationship at temperatures 303K-353K for Ge fractional concentration 0.04

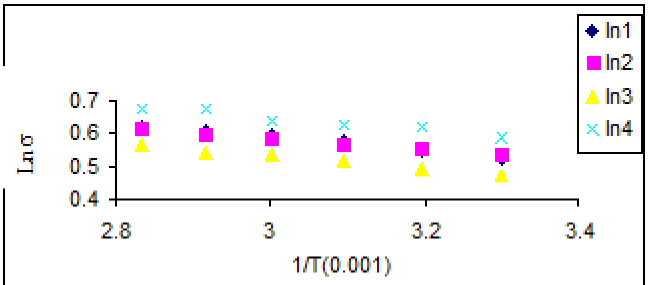


Fig. 5. Ln σ - 1/T plots for the samples

Figure 5 shows the temperature dependence on the conductivity of the samples. The activation energy ($e_o$) calculated from the experimental s(T) data showed an insignificant deviation from the dependence s(T) a exp (I/T) within the temperature range 303 – 353K. The temperature dependence of the conductivity of the samples showed/revealed that the samples obey the Arrhenius relation $s = s_o \exp(-e_o/kT)$, where $s_o$ is a constant, $e_o$ is the activation energy, k is the Boltzman's constant and T is the absolute temperature. This type of relationship is typical of semiconductor materials [3, 8, 13]. This variation of conductivity with temperature indicates a thermal activation energy $e_o$, which is found to be sensitive to temperature, and concentration of the samples (See figures 1 – 4 and table 1). e(o) is found to fluctuate between 0.19 and 0.21eV at temperatures 300 – 353K

The conductivity was calculated from the microscopic form of Ohm's law [4, 5]. This involves measurement of current when a voltage is placed across a finite specimen of conducting material, which has total resistance R. Such that the current density J = 1/rE where r is the resistivity and E is the electric field. The microscopic form of Ohm's law then becomes J = sE, where s is the conductivity given by the reciprocal of the resistivity.

## Conclusion

Alloy mixtures of Al/Bi/Ge materials have been prepared by heating powdered samples of the material in a furnace over a temperature range of 700°C. Measurements of the current-voltage relationships were obtained at different temperature range 303 – 353K in an airtight heatable measuring device. The electrical properties observed indicated that the samples can be comparable to the II – VI and ternary semiconductor materials useful in solar cell development and thermoelectric devices. In addition, the conductivity of the samples were found to be temperature and concentration dependent while the activation energies for the samples varies between 0.19 and 0.21eV. The conductivity was found to increase with temperature as in the relation r = s = $s_o$ exp ($-e_o$/kT) typical of semiconductor materials. The values of the activation energies suggest that the alloy materials are semiconducting in nature. They also seem to exhibit narrow energy gap conduction.

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