Modification of the Electrical Properties of Sb/Al Bilayer Irradiated with Low Energy Krypton Ion Beam

Anil K Das

St. John's College, M.G. Road, Agra, Uttar Pradesh-282002, India.

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ABSTRACT

Sb (~50nm) over Al (~50nm) thin films were sequentially deposited on the silicon substrate in the current work using the e-beam evaporation method at a pressure of 2×10^{-5} mbar. Next, a 350 KeV Kr^{+1} beam with a fluence of 3×10^{16} ions/cm^2 was used to irradiate the Sb/Al bilayer. Seebeck coefficient and Resistivity measurements were carried out on Pristine and Irradiated samples and results were compared.

Keywords: Aluminium Antimonide, Ion Beam mixing, Seebeck Coefficient, Resistivity, Power factor.

INTRODUCTION

Researchers globally are actively seeking environmentally friendly, sustainable, and noiseless energy sources. One potential resolution to the current problem at hand is utilising thermoelectric generators to generate power. Thermoelectric devices function based on the Seebeck effect, which states that when two dissimilar metals are joined end to end to create a loop and a temperature difference is maintained at two junctions, an electric current is generated. This current is suitable for powering smaller electrical items. An important factor in this context is the figure of merit, which is a dimensionless quantity. The efficiency of a thermoelectric material can be determined by the ZT value, which is calculated using the formula $ZT = \frac{S^2\sigma T}{k}$ where Seebeck coefficient (S), thermal conductivity (k), electrical conductivity (σ), and temperature (T) in kelvin, certain factors come into play. The value of k is determined by the combination of its electrical component, k_e, and its phonon component, k_p. The equation that represents this relationship is $k = k_e + k_p$. The value of ZT can be increased by either increasing σ or by decreasing k. However, the Weidmann-Fanz law establishes a connection between them: The value of L, known as the Lorentz factor, is 2.44×10^{-8} WΩK^{-2}. Since electrons are the building blocks of all materials and cannot be changed, heat conduction now happens through both electrons and phonons. One possible solution is to construct a phonon scattering centre in order to decrease heat conductivity and increase ZT. The experimental results of the structural properties of pristine and irradiated films of Sb/Al are already reported by me [1]. Ion beam processing is a fascinating technique for generating thin films, and it has recently been utilised to fabricate thermoelectric thin films. These thermoelectric films were discovered to have a nanostructured composition and exhibited an increased Seebeck coefficient following synthesis with an ion beam [2,3,4]. Aluminium Antimonide is a significant material within the III-VI group of the periodic table. The basic components of AlSb are readily available, widely found, and pose no harm to the environment [5,6]. This material, AlSb, is well-suited for high-temperature applications, particularly for transistors and P-N junction diodes, due to its large band gap [7]. This paper utilises the ion beam mixing technique to induce defects at the interface of a bilayer composed of Antimony and Aluminium. These defects act as phonon scattering centres, which in turn enhances the thermoelectric figure of merit of the sample. We conducted a study comparing the Electrical properties of both Pristine and irradiated materials.

Experimental:

Using an electron beam evaporation vacuum coating unit Model BC-300 available at MNIT, Jaipur, the samples were deposited with high purity Antimony (99.99%) over Aluminium (99.999%) on a Silicon substrate. The deposition took place under a pressure of 2×10^{-5} mm Hg. These films underwent irradiation using Kr^{+1} ions with

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an energy of 350 KeV and a fluence of 3×10^{16} ions/cm^2 LEIBF, IUAC, New Delhi. The Seebeck coefficient and Resistivity measurements of the samples were also carried at IUAC, New Delhi.

RESULTS AND DISCUSSION

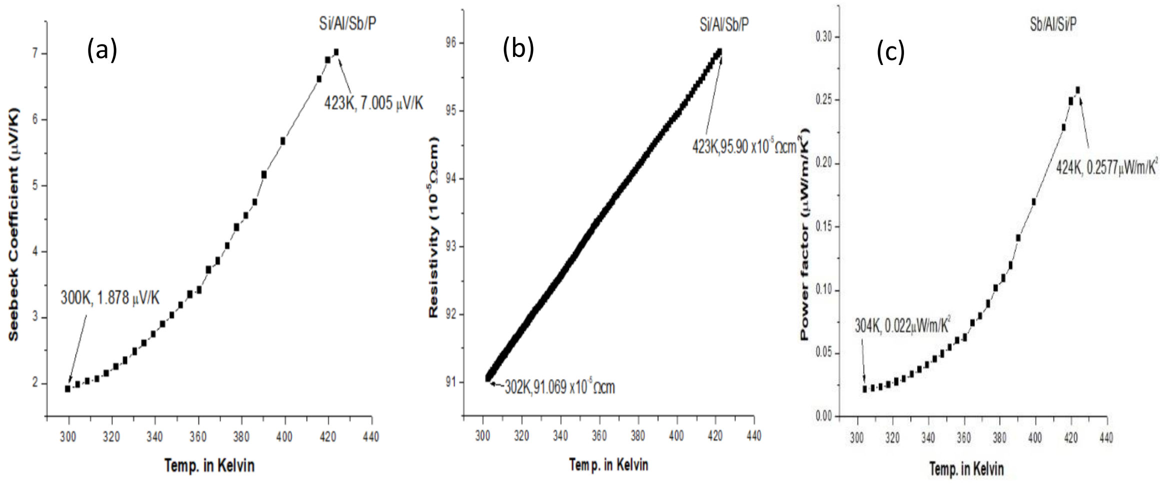

Fig 1. (a) Seebeck Coefficient (b) Resistivity (c) Power factor of Pristine Sb/Al sample with temperature

The Pristine sample has p type carriers with avearge Hall coefficeint, Carrier concentration and mobility : 0.03503 cm^3/C, 1.782×10^{20} /cm^3 and 75.85 cm^2/Vs respectivly. The variation of Seebeck coefficient with temperature for Pristine sample is shown in the fig 1a. Seebeck coefficient has value about 1.878 μV/K at 300 K. From 300 K onward there is a gradual and linear increase in value of Seebeck coefficient till 423 K with the value 7.005 μV/K . The resisitivity (fig 1b) of Pristine sample shows metallic behavior as it increases linearly of with rise in temperature. At 302 K, it has resistivity of 91.069×10^{-5} Ωcm and power factor 0.022 μW/m/K^2 at 304 K (fig 1c). With increase in temperature, resistivity and power factor increased. At 423 K resistivity of Pristine sample is 95.90 $\times10^{-5}$ Ωcm and power factor has value 0.2577 μW/m/K^2.

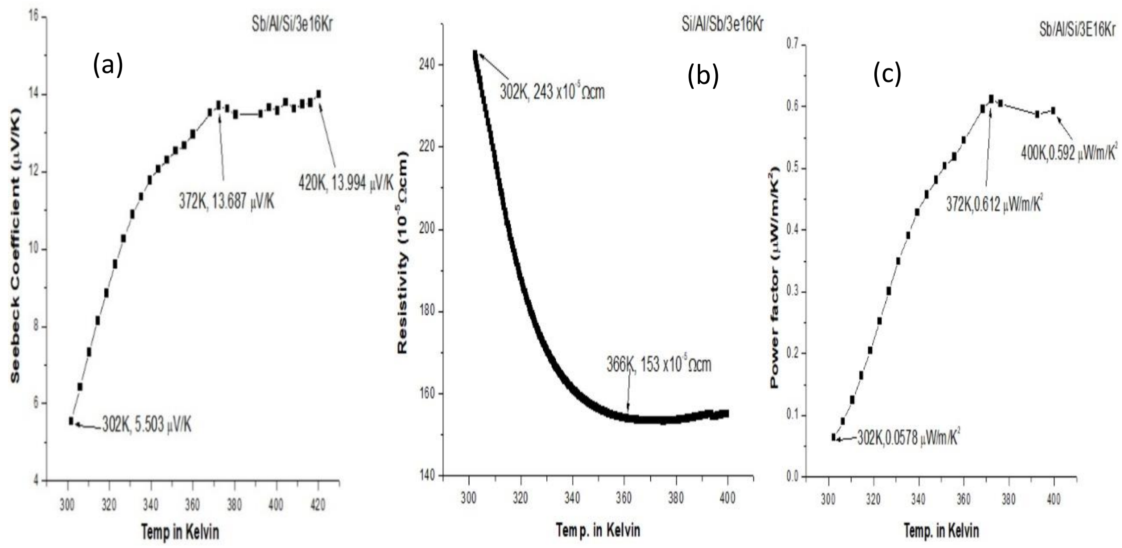

Fig 2. (a) Seebeck Coefficient (b) Resistivity (c) Power factor of Kr irradiated Sb/Al sample with temperature

With irradiation of Pristine sample with Kr ions of 350 KeV at fluence 3×10^{16} ions/cm^2, sample has p type carriers with avearge Hall coefficeint, Carrier concentration and mobility of 0.02791 cm^3/C, 2.236×10^{20} /cm^3

and 14.7 cm^2/Vs respectivly. The value of Seebeck coefficient at 302K is 5.503 μV/K which is nearly 3 times higher than Pristine sample. The resistivity graph (fig 2b) of the Kr irradiated sample is of semiconductor nature. The resistivity of the irradiated sample increased to about 243×10^{-5} Ωcm at 302 K in comparison to Pristine sample. At 300 K, Seebeck coefficient also showed a very high value to about 5.503 μV/K (fig 2a) which is nearly 3 times more than that of Pristine Seebeck coefficient value at same temperature. Moreover, Power factor value also increased from 0.021 $\mu W/m/K^2$ in Pristine to 0.059 $\mu W/m/K^2$ in Kr irradiated sample at 300 K which is nearly also 3 times increment. Power factor increased with increasing temperature and has highest value 0.612 $\mu W/m/K^2$ at 372 K, after which it falls off gradually.

CONCLUSIONS

i. The Pristine sample is good thermoelectric material at temperature from 400 K onward.
ii. Ion beam irradiation can be used to prepare Sb/Al samples, as in our case Kr ion irradiation has increased Seebeck and Power factor values many folds.

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