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Structural Properties of Low Energy Ion Beam Kr Irradiated Sb/Al Bilayers Deposited on Silicon Substrate.

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Abstract - In the present work, Sb(~50nm)/Al (~50nm) thin films were deposited successively on the silicon substrate by e-beam evaporation method under 2×10^{-5} mbar pressure. The Sb/Al bilayer was then irradiated with beam of 350 KeV Kr^{+1} with fluence 3×10^{16} ions/cm^2. The sample was then characterised by XRD and Rutherford backscattering spectrometry (RBS). The XRD study reveals AlSb phase formation in Pristine sample. RBS also confirms mixing in Pristine sample.

Keywords- Aluminium Antimonide, ion beam mixing, XRD, RBS (Rutherford Backscattering Spectrometry).

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 by $ZT = \frac{S^2\sigma T}{k}$ When considering the 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, ke, and its phonon component, kp. The equation that represents this relationship is k = ke + kp. 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. 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 [1,2]. 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 [3,4]. This material, AlSb, is well-suited for high-temperature applications, particularly for transistors and P-N junction diodes, due to its large band gap [5]. 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 structural properties of both Pristine and irradiated materials.

Experimental procedure

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 an energy of 350 KeV and a fluence of 3×10^{16} ions/cm^2 at LEIBF, IUAC, New Delhi. The chemical composition of the samples was analysed using the Panalytical X-Pert Pro diffractometer, which is available at MNIT, Jaipur. The analysis was conducted in the angle range of 10º to 80º. At IUAC in New Delhi, the Pelletron Accelerator RBS-AMS Systems (PARAS) were utilised to conduct RBS analysis on both pristine and irradiated samples. 1.7 MeV He^{2+} ions were used to obtain the RBS spectra. The RBS data confirms the successful mixing of Antimony and Aluminium in their pristine state. The samples were analysed for SEM at IUAC in New Delhi.

Results and discussion

Phase evolution of Pristine and Kr irradiated samples

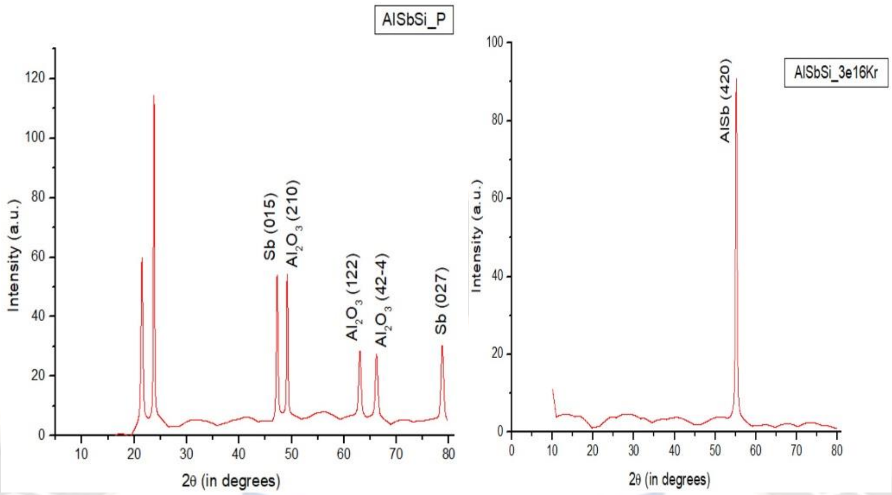

Fig 1 ***XRD spectra of (a) Pristine and (b) Kr irradiated Sb/Al***

The Pristine sample of Sb/Al was marked as AlSbSi_P and Kr irradiated sample as AlSbSi3e16Kr. The XRD of the pristine sample (fig.1) indicates minimal mixing and reveals the compound of aluminium oxide (210), (122) and $(42\overline{4})$ which has an orthorhombic crystal system, along with unreacted antimony along phases Sb (015) and Sb (027), which has a rhombohedral crystal system. New phases AlSb (420), which are cubic crystal systems are evolved when the pristine sample is irradiated with Kr^{+1} ions at a fluence of 3×10^{16} ions/cm^2 and energy of 350 KeV. The JCPDS lists for the observed peaks in the pristine and Kr irradiated samples are as follows: AlSb (004) *(JCPDS 00-043-0992),* Sb (015) and Sb (027) *(JCPDS 00-005-0562),* AlSb (420) (*JCPDS 01-071-4037)*. The size of the nano structures was calculated by using Scherrer equation:

$$\tau = \frac{0.9\lambda}{FWHM \cdot \cos\theta}$$

where τ is the mean size of crystallites domain, λ is wavelength of X-rays used, FWHM= Full Width at half Maxima and θ is the Bragg's angle of the corresponding peak. Calculations shows nano clathrates/ particle size in the Pristine Sb/Al sample vary from 6.9 nm to 20 nm. With the irradiation by Kr ions of energy 350 KeV nano clathrates/ particle size in the Sb/Al sample vary from 13.9 nm to 24.8 nm.

3.2 RBS analysis of Pristine and Kr irradiated samples

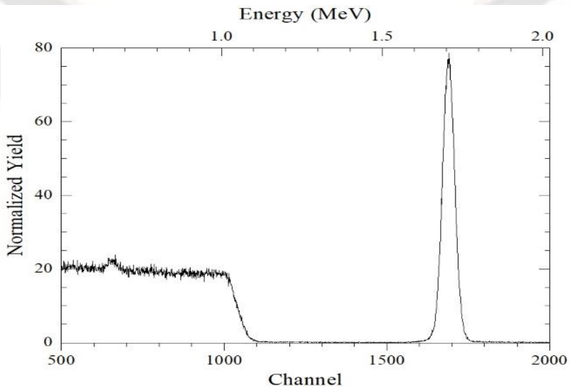

Fig 2 (a) RBS Spectra of Pristine Sb/Al sample

Pristine and Kr irradiated samples were both subjected to RBS in the Pelletron Accelerator RBS-AMS Systems (PARAS) at IUAC, NEW DELHI. The RBS spectra were generated by 1.7 MeV He^{2+} ions. The top layer is 75 nm wide and contains only a little amount of aluminium with antimony. The rest is aluminium, and silicon mixed at great depth.

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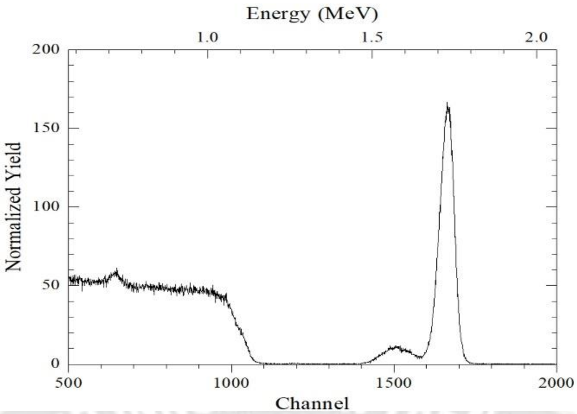

Fig 3 (a) RBS Spectra of kr irradiated Sb/Al sample

The thickness of the first layer is reduced to 54 nm on Kr irradiation. The new layer is emerged which has thickness of about 20 nm with antimony- aluminium- silicon intermixed.

SEM analysis of Pristine sample

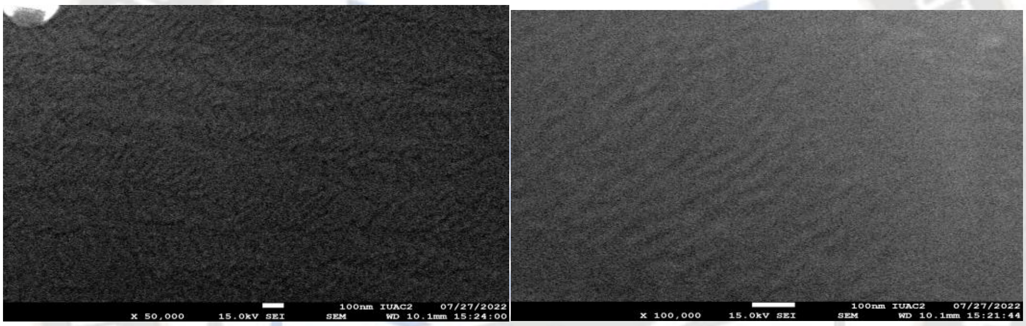

Fig 4 SEM of the Sb/Al Pristine sample with magnification (a) 80Kx (b) 100Kx

The majority of the area is smooth, according to SEM photographs of the pristine sample given above (fig. 4). According to XRD analysis, the majority of the antimony in the uppermost layer is aluminium oxide which forms a protective layer for preventing further oxidation of the system.

SEM analysis of Kr irradiated sample

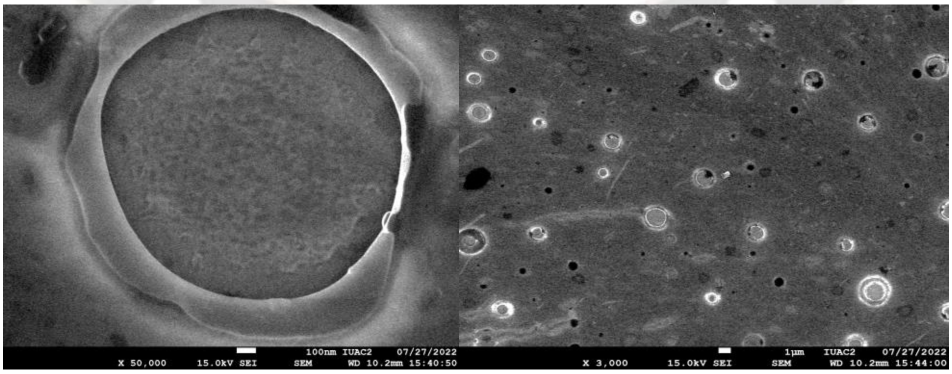

Fig 5 SEM of the Sb/Al Kr irradiated sample with magnification (a) 50 Kx (b)3Kx

The nanostructures in the form of circles are created after exposure to Kr ions, as depicted in fig 5. According to XRD studies, these nanostructures consist of aluminium antimonide. These nanostructures serve as phonon scattering centres without impairing the sample's electrical conductivity, which is expected to enhance the thermoelectric module's exceptional performance.

Conclusions:

Most of the Sb is reacted with Al in the pristine sample. As Al is deposited on Si, it is reacted with Si. So, a hump is observed on the substrate side. With the irradiation with Kr ions, there are no appreciable changes in the third layer. However, the first layer is damaged by the ions with the formation of vacuoles which can act as the phonon scattering centres.

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