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STRUCTURAL AND ELECTRICAL PROPERTIES OF LOW ENERGY ION BEAM KR IRRADIATED SB/AL BILAYER

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Abstract
In the present work Sb(~50nm)/Al (~50nm) thin films were deposited successively on the quartz 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. Other electrical properties related experiments like Hall measurement, Resistivity measurement and Seebeck coefficient were also carried out and Pristine sample structural and electrical properties were compared with Kr ion irradiated sample.
Key words: Aluminium Antimonide, ion beam mixing, XRD, RBS, Hall effect, thermoelectric properties

Introduction

The conventional energy sources, such as petrol and diesel, are rapidly running out. In near future we will be left with no Petroleum. The National Petroleum Council, an advisory body to the US secretary of energy, predicted in 2007 that by 2030, global oil demand would increase from 86 million barrels per day to 138 million barrels per day. [1]. We shall therefore be without petroleum in the near future. Second, these petroleum-based energy sources are causing pollution that is harming people's health and changing the earth's climate by depleting ozone and producing more carbon dioxide as a by-product of oxygen combustion, which makes our planet hotter. Our future is bleak if we don't take action to avoid using petroleum-based products. Therefore, researchers worldwide are looking for more environment friendly, sustainable and quiet energy sources. One of the solutions to the issue we are currently facing is the production of power using thermoelectric generators. Thermoelectric devices operate on the Seebeck effect, according to which current begins to flow when two different metals are connected end to end to form a loop and a temperature difference is maintained at two

junctions. Lower scale electrical appliances can be powered by this current. But we need to create for more efficient thermoelectric materials.

A dimensionless quantity known as the figure of merit ZT determines the thermoelectric material's efficiency and given by $ZT = \frac{S^2\sigma T}{k}$Where S is the Seebeck coefficient, k is the material's thermal conductivity, σ is its electrical conductivity, and T is its temperature in kelvin.k is composed of the electrical component ke and the phonon component k_p, and $k=k_e+k_p$. ZT can be raised by either raising σ or by lowering k. But the Weidmann-Fanz law links them together:

$$\frac{k_e}{\sigma} = L \cdot T$$

Where L is known as Lorentz factor having value $2.44\times10^{-8}W\Omega K^{-2}$. Since, electrons are the fundamental components of all materials and cannot be altered, heat conduction now occur both by electrons and phonons. The only remaining option is to build a phonon scattering centre to reduce heat conductivity and raise ZT. Ion beam processing is one of the unique methods for producing thin films, and it has recently been employed to create thermoelectric thin films. These thermoelectric films were found to be nanostructured and to have a higher Seebeck coefficient after being synthesiszed with an ion beam. [2,3]. Aluminium Antimonide is one of the important materials of III-VI group of the periodic table. AlSb's basic components are inexpensive, abundant, and non-toxic. [4,5]. The AlSb is a suitable semiconducting material for high temperature applications especially for transistors and P–N junction diodes because of large band gap [6] . Ion beam mixing technique is used to induce defects at the interface of bilayer of Antimony and Aluminium in this paper. These defects serve as the phonon scattering centres, thereby increases the thermoelectric figure of merit of the sample. In our work, structural and electrical properties of Pristine and irradiated were studied and compared.

Experimental procedure

The samples were deposited Antimony (99.99%) over Aluminium (99.99%) by using electron beam evaporation vacuum coating unit Model-BC-300 available at MNIT, Jaipur on Quartz substrate under the pressure of 2×10^{-5} mm Hg. These films were then irradiated by Kr^{+1} ions of energy 350 KeV with fluence 3×10^{16} ions/cm^2 at LEIBF, IUAC, New Delhi. The samples structural properties were analysed by Panalytical X-Pert Pro diffractometer available at MNIT, Jaipur in the angle from 10^o to 80^o.The Pelletron Accelerator RBS-AMS Systems (PARAS) at IUAC in New Delhi was used to perform RBS on Pristine and irradiated samples. To obtain the RBS spectra, 1.7 MeV He^{2+} ions were employed. RBS data confirms the mixing of Antimony and Aluminium at pristine state. SEM of the samples were carried at IIT Kanpur NOVA NANOSEM 450 facility. Hall measurement of the samples were carried out by using ECOPIA HMS-3000 available at IUAC, New Delhi. Seebeck and resistivity measurement of the samples were done by bridge set up available at IUAC, New Delhi. The experiments were done from room temperature to 420 K.

Results and discussion

3.1 Phase evolution of Pristine and Kr irradiated samples

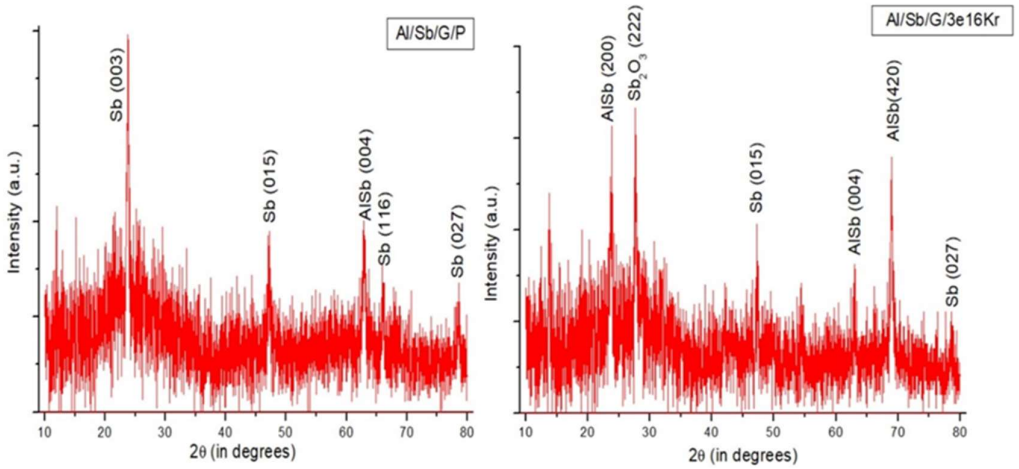

Fig 1 XRD spectra of (a) Pristine and (b) Kr irradiated Sb/Al

The Pristine sample of Sb/Al was marked as Al/Sb/G/P and Kr irradiated sample as Al/Sb/G/3e16Kr. The XRD of the pristine sample (fig.1) indicates minimal mixing and reveals the compound of aluminium antimony AlSb (004), which has an orthorhombic crystal system, along with unreacted antimony along phases Sb (116), Sb (015), Sb (003), and Sb (027), which has a rhombohedral crystal system. New phases such as AlSb (200) and AlSb (420), which are cubic crystal systems, and AlSb (004), which is an orthorhombic crystal system, 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 (116), Sb (015), Sb (003), and Sb (027) (JCPDS 00-005-0562), AlSb (200) (JCPDS 00-006-0233), AlSb (420) (JCPDS 01-071-4037). The size of the nano structures were 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 6.6 nm to 20.04 nm. With the irradiation by Kr ions of energy 350 KeV nano clathrates/ particle size in the Sb/Al sample vary from 13.3 nm to 24.4 nm. The percentage of prominent peaks of each compound of Sb/Al in Pristine sample by using areas under Gaussian curves shows that about 78.20% of Antimony remained unreacted in the Pristine sample and 21.77% of Aluminium-Antimonide is formed. By irradiation with Kr ions of energy 350 KeV, 13.88% of Antimony remained unreacted in the sample. About 68.37% of Aluminium Antimonide is formed. The rest is Antimony oxide along with other impurities.

3.2 RBS analysis of Pristine and Kr irradiated samples

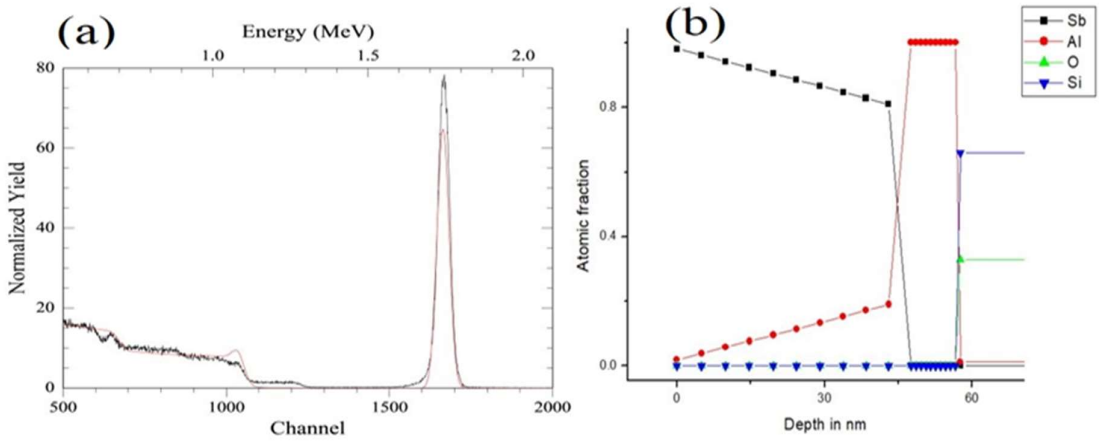

Fig 2 (a) RBS Spectra and (b) Depth profile of Pristine Sb/Al sample

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 50 nm wide and contains only a little amount of aluminium. As AlSb is formed in the Pristine sample, XRD spectra (fig. 1a) show that this mixing has occurred. The depth profile of the Pristine sample and XRUMP simulations indicate that the second layer has a thickness of 10 nm aluminium (fig.2 a, b). Some of the aluminium from the second layer is present in the third layer.

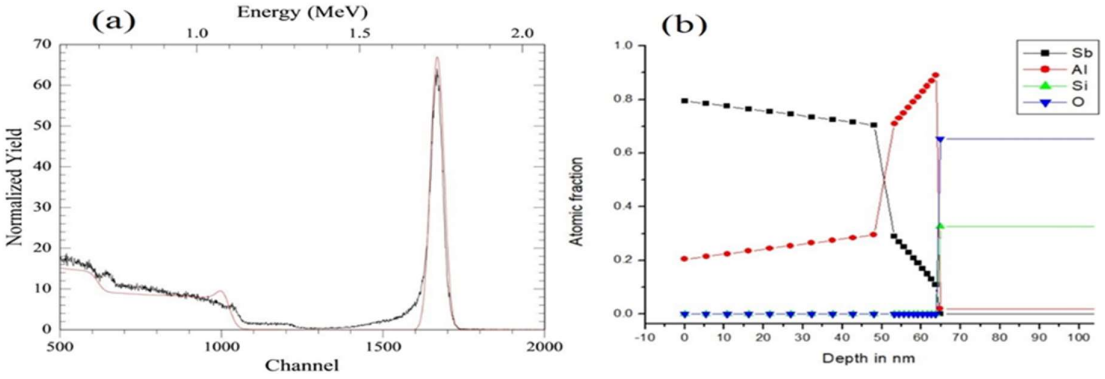

Fig 3 (a) RBS Spectra and (b) Depth profile of kr irradiated Sb/Al sample

The depth profile of the Kr-irradiated sample's XRUMP analysis indicates that layer 1 has a width of 50 nm and is mixed with antimony and aluminium. As more AlSb is generated in the Kr irradiation sample, XRD spectra (fig. 1b) confirm this mixing. According to XRUMP simulations and the depth profile of the Pristine sample (fig. 3 a, b), which includes antimony from the first layer, the second layer has a thickness of 10 nm aluminium. Some of the aluminium from the second layer is reacted in the third layer.

3.3 SEM analysis of Pristine sample

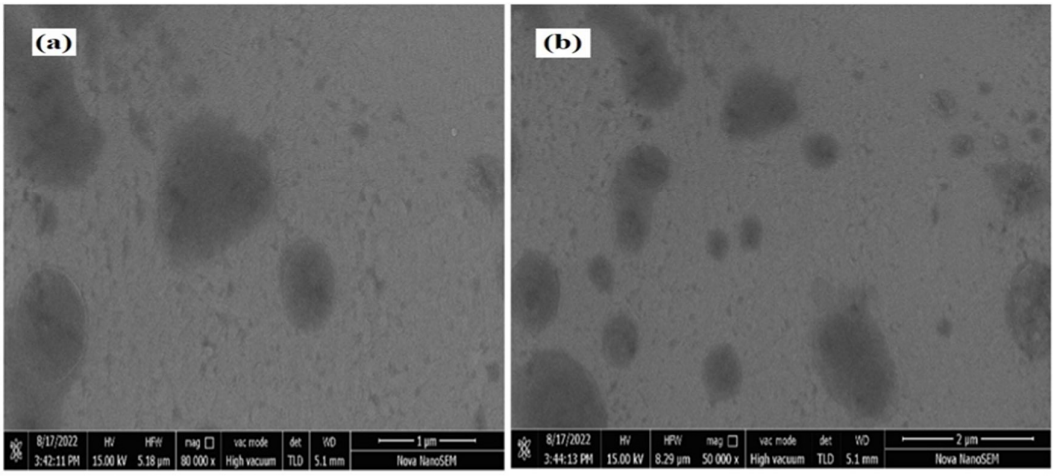

Fig 4 SEM of the Sb/Al Pristine sample with magnification (a) 80Kx (b) 50Kx

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 remains unreacted.

3.4 SEM analysis of Kr irradiated sample

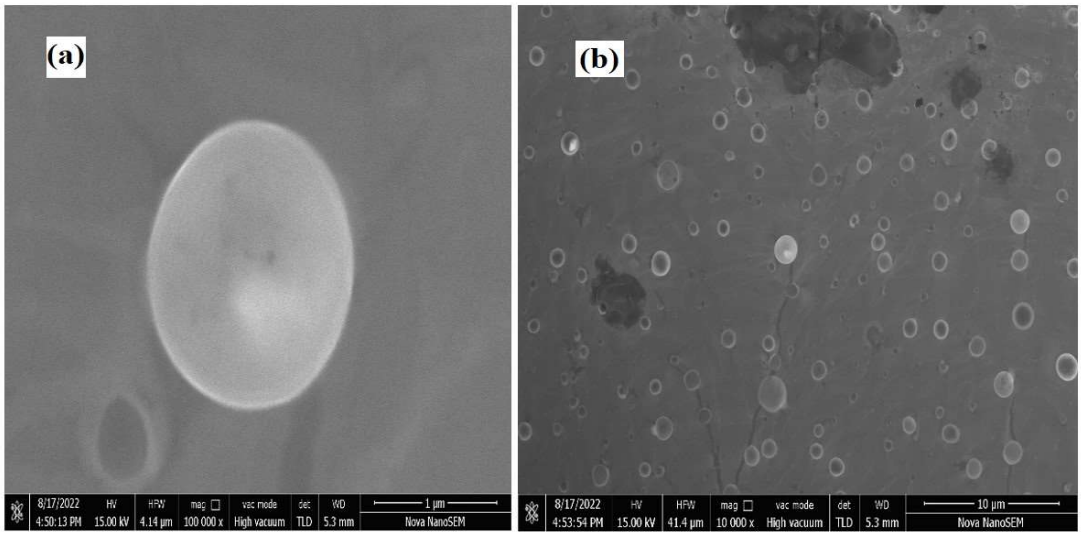

Fig 5 SEM of the Sb/Al Kr irradited sample with magnification (a) 100 Kx (b)10Kx

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 accounts for the thermoelectric module's exceptional performance.

3.5 Electrical and Transport measurement of Pristine and Kr irradiated samples.

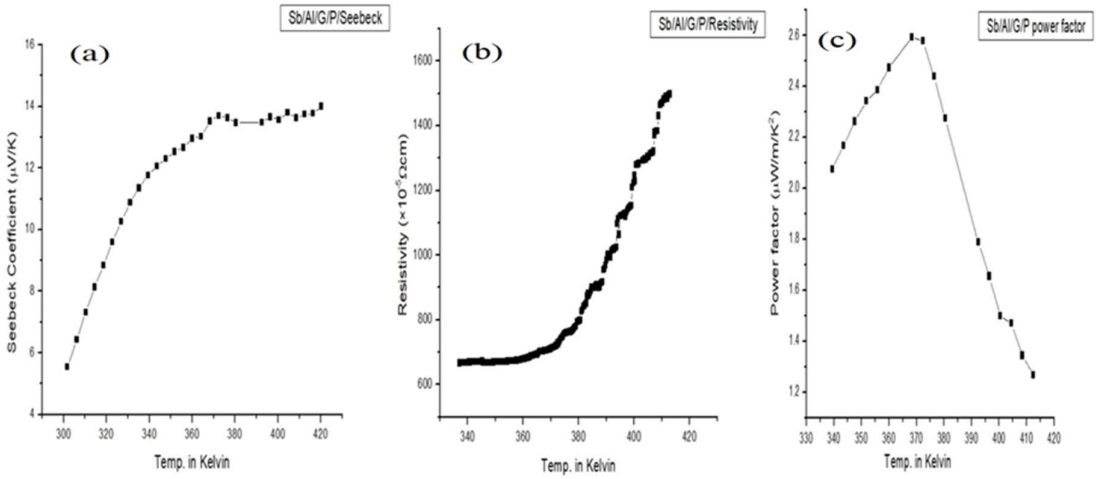

Fig 6 Graph of (a) Seebeck co-efficient, (b) Resistivity and (c) Power factor verses temperature for Pristine sample

Figure 6 (a) depicts the Seebeck coefficient (thermopower) vs. temperature plot for the Pristine sample . Its Seebeck coefficient, which is 5.5 μV/K at 300 K and rises linearly and gradually with temperature, reaches saturation at 367 K and beyond (13.69 μV/K). At 336 K, the resistivity value is around 6.67×10^{-3} Ωcm. The resistivity value rises with temperature, confirming the Pristine Sb/Al sample's metallic behaviour. At 413 K its value is about 15.04×10^{-3} Ωcm. Power factor ($S^2\sigma$) is also minimal at 339 K, with a value of 2.06 μW/m/K^2, but it increases linearly and gradually until it reaches its maximum value at 368 K, with a value of 2.59 μW/m/K^2. After 368 K, its value decreases drastically. Its value is 1.27 μW/m/K^2 at 412 K. Pristine sample reveals a p type charge carrier with a bulk concentration of 3.132×10^{20}/cc, a mobility of 4.131×10^{1} cm^2/Vs, and an average Hall coefficient of 1.993×10^{-2} cc/C.

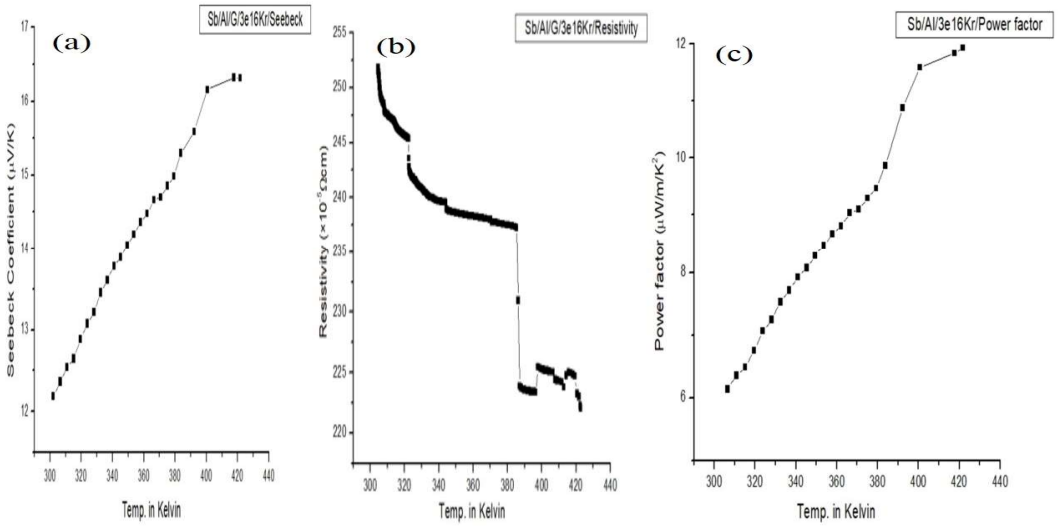

Fig 7 Graph of (a) Seebeck co-efficient, (b) Resistivity and (c) Power factor verses temperature for Kr irradiated sample

Its Seebeck coefficient after being exposed to 350 KeV Kr is 12.18 μV/K at 300 K, which is roughly 2.2 times more than that of the Pristine sample at the same temperature. As the temperature rises, the Seebeck coefficient linearly and gradually rises. It begins to saturate about 417 K. At 418K, it reaches its maximum value of 16.33 μV/K. To understand the phase evolution with rise in temperature, in-situ XRD examination of Kr irradiation sample is required. The resistivity of the Kr irradiated sample has value at 300 K which is nearly 2.6 times less than that of Pristine sample at same temperature. At 300 K, the resistivity of the Kr-irradiated sample is 2.52×10^{-3} Ωcm, which is roughly 2.6 times lower than the resistivity of the pristine sample. The resistivity value at 385K abruptly decreases. Hao et al. [7] report this abrupt decrease in its resistivity. Its resistivity value falls with temperature and reaches a value of 2.22×10^{-3} Ωcm at 420 K, which is roughly 6.7 times less than the Pristine sample. This decrease in resistivity as a function of temperature further supports the sample's semiconductor behaviour after Kr irradiation. At 300 K, the power factor ($S^2\sigma$) is 6.1 μW/m/K^2, and it rises linearly as the temperature rises. It reaches its highest value of 11.9 μW/m/K^2 at 420 K and does not saturate as the temperature rises. Kr irradiated sample shows n type charge carrier with bulk concentration, mobility and Average Hall coefficient 2.588×10^{20}/cc,1.634×10^{1} cm^2/Vs and 2.412×10^{-2} cc/C respectively.

4. Conclusion

(1) Thermoelectric power can be produced using a Pristine sample of the p type semiconductor Sb/Al bilayer, which exhibits good thermoelectric performance at higher temperatures.
(2) The Sb/Al sample irradiated to Kr ions is a n type semiconductor with good thermoelectric properties at 385K.
(3) The creation of nanostructures that serve as phonon scattering centres is responsible for the Sb/Al sample's excellent thermoelectric performance after Kr radiation.

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References

(1) source: Encyclopaedia Britannica, status of the world oil supply. https://www.britannica.com/science/petroleum/Status-of-the-world-oil-supply
(2) Srashti Gupta, D.C. Agarwal, S.K. Tripathi, A. Tripathi, S. Neeleshwar , D.K. Avasthi ,

App. Surf. Sci. 265 (2013) 124.
(3) Manju Bala, Anuradha Bhogra, Saif A. Khan, Tripurari S. Tripathi, Surya K. Tripathi, Devesh K. Avasthi and Kandasami Asokan RSC Advances 5 (2015) 25887.
(4) S. Das, B. Ghosh, S. Hussain, R. Bhar, A.K. Pal, Pulsed laser deposition: a viable route for the growth of aluminum antimonide film, J. Cryst. Growth 419 (2015) 12e19.
(5) Z. Huang, L. Wu, B. Li, X. Hao, J. He, L. Feng, W. Li, J. Zhang, Y. Cai , 2010 Chinese Phys. B 19 127204
(6) A. Herczog, R. R. Hebercut, A. E. Middelton, J. Electrochemistry soc. 105,533 (1958).
(7) X. Hao, L. Wu, Z. Huang, J. He, L. Feng, J. Zhang, W. Li, Y. Cai, B. Li, Studyon AlSb films deposited by Co-sputtering, in: Asia-Pacific Power and EnergyEngineering Conference (APPEEC 2010), Chengdu, China, 2010, p. 3.