Energetic Ion Irradiation and Annealing Effect on Ti/Co System

Nisha Bansal
Department of Physics, FET,
Manav Rachna International Institute of Research and Study,
Faridabad,
Email: nishabansal.fet@mriu.edu.in

Sadhna Shrivastava
Department of Physics,
Dyal Singh College,
Delhi University, Lodi Road, New Delhi
Email: sadhna.093@yahoo.co.in

Abstract: *Energetic ion beams of different elements with high energy of the order of few MeV to GeV are used for the change in material properties, characterization and synthesis of alloys. In the present work the effect of high energy ion irradiation on Ti/Co bilayer system is studied. Specimens were prepared by depositing Ti and Co layers on silicon substrate by sequential electron-beam evaporation technique in the high vacuum deposition system at room temperature. For irradiation of the samples, Au ions (120 MeV), Ag ions (100 MeV) and Ni ions (80 MeV) were used. Depth profile and composition of the pristine and irradiated samples was studied by Rutherford Backscattering Spectroscopy (RBS). Grazing Incidence X-ray Diffraction (GIXRD) patterns were obtained to determine the phase formation. Absence of interface mixing upon irradiation in Ti/Co samples has been discussed. Pristine and irradiated samples were annealed at 400^0C for one hour to study its effect.*

Keywords*: SHI; RBS; GIXRD*

I. INTRODUCTION

Swift heavy ions (SHI) are the high energy ions with velocities higher than or very close to the velocity of orbital electrons. Irradiation of materials by energetic ions results in the highly excited lattice atoms. The interesting changes in the material are seen due to atomic displacements and structural modifications of a lattice [1]. The contributions from elastic collisions with nuclei can be neglected for high energy regime. Various effects of energetic ion irradiation include latent track formation, sputtering and intermixing of the atoms of different materials. Many parameters such as ion energy [2], fluence [3], heat of mixing of the elements [4] and ion velocity [5] are responsible for the irradiation effect. Atomic species of appropriate amount and energy can be introduced into the film which may create lattice defects to promote the phase transformation [6]. When SHI are incident on a material, it creates extensive defects along the ion path after a threshold value of electronic energy loss. These columnar defects along the ion path can be explained by thermal spike model [7]. According to this model, the energy is transferred from the incident radiation to the electronic system of the material. Due to electron- electron interaction, this transferred energy is shared among the electron gas quickly. In a very short span of time it is then transferred to the neighboring atoms by electron-phonon and phonon-phonon interactions. Due to this energy transfer, the temperature of lattice along the ion path exceeds the melting point of the material transiently typically for pico second duration, which may cause atomic displacement and hence mixing.

II. EXPERIMENT

Substrates of 1cm × 1cm were obtained from a silicon wafer. For the cleaning of the substrate, trichloroethylene, acetone and alcohol were used. Finally, before being transferred to the high vacuum evaporator the substrates were washed with de-ionized water. The samples Si/Ti/Co/C were prepared by sequential electron beam evaporation technique at the deposition rate ~ 0.2 Å/s. First Ti layer of 100 nm was deposited on the Si substrate and its thickness was monitored by quartz crystal placed in the vacuum chamber. The vacuum during deposition was ~ $6x10^{-7}$ Torr. Without breaking the vacuum of the deposition system, Co (50 nm) was deposited. To avoid oxidation of the samples, a thin carbon layer of 10 nm was given on top. For irradiation, the deposited samples were mounted on a heavy copper ladder using a thermally conducting adhesive. Au ions, Ag ions and Ni ions were used for irradiation of the prepared samples with fluence of 1×10^{13}, 5×10^{13} and

1×10^{14} ions/cm^2 at room temperature. The energies of the ions used are given in table 1. The samples were irradiated uniformly over an area of 1cm×1cm by scanning the ion beam using an electromagnetic scanner. To avoid sample heating due to irradiation, flux was kept quite low (<10^{10} ions cm^{-2}s^{-1}). The calculated values of electronic energy loss (S_e) and nuclear energy loss (S_n) using simulation program SRIM for different ions and energies in Ti and Co are illustrated in the Table1.

Table1. Ions and energies used for irradiation in Ti/Co bilayer, S_e and S_n values for Au, Ag and Ni ions in Ti and Co

Ions	Energy (MeV)	Material	S_e (keV/nm)	S_n (keV/nm)
Au	120	Ti	23.6	0.35
		Co	36.3	0.67
Ag	100	Ti	18.5	0.96
		Co	29.9	0.18
Ni	80	Ti	11.7	0.02
		Co	19.8	0.05

The threshold value of electronic energy loss $(S_e)_{th}$ for Titanium is <15 keV/nm and for Cobalt it is 30 - 40 keV/nm [7].

The reason for choosing these ions with particular energies is to have S_e values above and below the threshold for creating defects in the material in order to study threshold value of S_e for Ti/Co system. Pristine and all the irradiated samples were annealed at 400^0C lower than the eutectic point of Ti/Co (~ 1020^0C) for one hour in Ar atmosphere to check the annealing effect. To characterize the depth profile and composition of the pristine and irradiated samples, Rutherford Backscattering experiments were performed using 2 MeV He ions with scattering angle of 167^0. Grazing Incidence X-Ray Diffraction (GIXRD) patterns were obtained for the samples using small angle of incidence equal to 3^0 to check for any new phase formation. The deposition, irradiation and characterization of the samples were done at IUAC, New Delhi.

III. RESULTS AND DISSCUSSIONS

Figure1 presents the RBS spectrum of Ti/Co system for pristine and samples irradiated with Au, Ag and Ni ions.

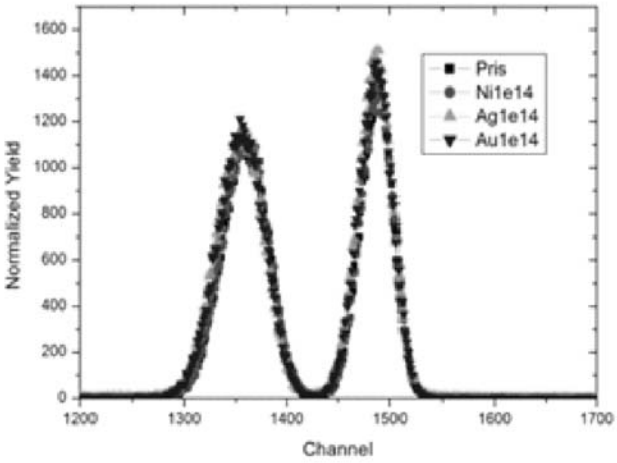

Fig. 1. RBS spectra of Si/Ti/Co/C samples pristine and irradiated using 120 MeV Au ions, 100 MeV Ag ions and 80 MeV Ni ions at the fluence of 1 × 10^{14} ions/cm^2

It is clear from the Fig. 1 that there is no appreciable change in the spectrum obtained for the samples irradiated using different ions with different electronic loss value even at the highest fluence.

The interface mixing was expected since both the elements Ti and Co are S_e sensitive materials and the ion and energy used for irradiation were sufficient to create molten phase in both the materials according to thermal spike model. Further both Ti and Co have high value of electron-phonon coupling ~ 92.8 × 10^{11} (W cm^{-3}K^{-1}) and 34.5 × 10^{11} (W cm^{-3}K^{-1}) respectively [7] and have negative heat of mixing.

As the irradiation could not induce mixing at the interface, the pristine and post irradiated samples were annealed at 400^0C for one hour in Ar atmosphere to check the mixing of the two elements and any new phase formation. RBS spectra of the pristine and irradiated samples after annealing are shown in Fig. 2. No intermixing at the interface is seen in the spectra of post annealed samples also.

Fig. 3 shows GIXRD pattern of pristine and irradiated annealed samples. No new peak is seen in the pattern which indicates no crystalline phase formation in the post irradiated annealed samples.

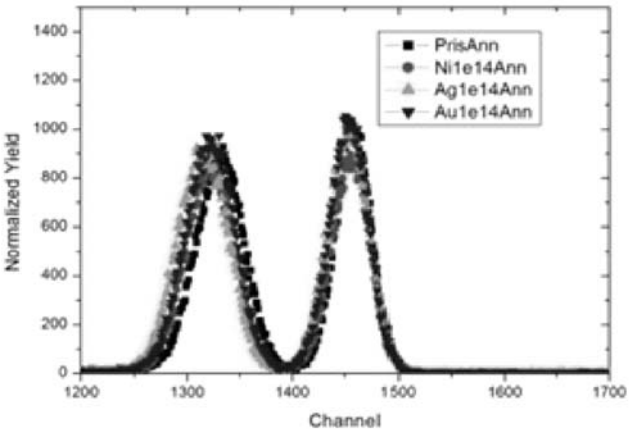

Fig. 2. RBS spectra of Si/Ti/Co/C samples pristine, irradiated using Au, Ag and Ni ions after annealing

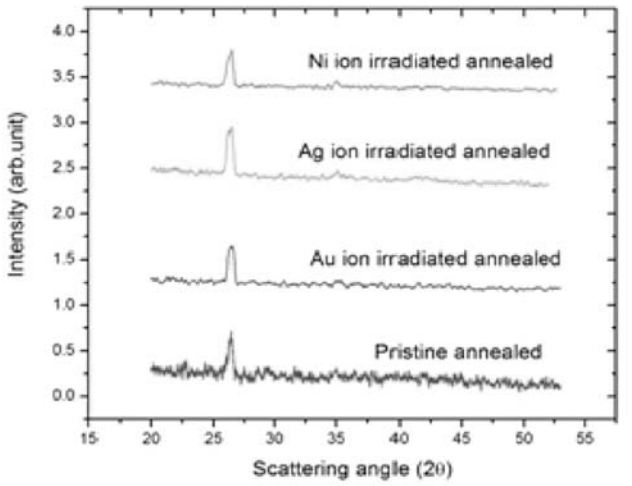

Fig. 3. GIXRD patterns of pristine and irradiated Si/Ti/Co/C samples after annealing

Although bulk Co is known to have a $(S_e)_{th}$ value of 30-40 keV/nm above which significant damage is created [8], to the best of our knowledge there is no report on the $(S_e)_{th}$ value of Co in the form of a thin film.

The complex nature of SHI induced modification of metals has also been studied in case of bulk [11] and thin films of Fe [12].

For metallic thin films, increased interface scattering may result in a decreased mobility of the conduction electrons causing a reduction in the smearing out of the deposited energy [9]. Perhaps, it induces modification in a thin metallic layer well below the $(S_e)_{th}$ value for the bulk metal [10]. The present S_e value 36.3 keV/nm may not be sufficient for inducing large degree of modification in thin Co film even though it is comparable to the $(S_e)_{th}$ value of bulk Co.

IV. CONCLUSIONS

Interface mixing in Ti/Co samples has not been observed even for the ion having electronic stopping power above the threshold. Possibly this can be attributed to the complex nature of SHI induced modification of metals observed in case of bulk [11] and thin Fe films [10,12]. Annealing of the pristine and irradiated samples at 400^0C for one hour could not contribute to new crystalline phase formation.

ACKNOWLEDGEMENTS

We are thankful to the target lab for providing their help in sample deposition, Pelletron group for irradiation and the facility provided for the characterization of the samples at IUAC, New Delhi.

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