Available online at www.sciencedirect.com
SCIENCE DIRECT®
Nuclear Instruments and Methods in Physics Research B 244 (2006) 194–197
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Swift heavy ion induced mixing in metal/metal system

Sarvesh Kumar [a,*], R.S. Chauhan [a], S.A. Khan [b], W. Bolse [c], D.K. Avasthi [b]

[a] Department of Physics, R.B.S. College, Agra 282 002, India
[b] Nuclear Science Centre, Aruna Asaf Ali Marg, New Delhi 110 067, India
[c] Institut füer Strahlenphysik, Allmandring 3, 70569 Stuttgart, Germany

Available online 10 January 2006

Abstract

We performed ion beam mixing in metal/metal systems by swift heavy ions. The irradiation of Ti/Fe system were carried out at room temperature (RT) by 120 and 200 MeV Au ions and at liquid nitrogen temperature (LT) by 350 MeV Au ions. The mixing is found to increase with fluence, electronic stopping power and irradiation temperature, as determined by Rutherford backscattering spectroscopy. We also studied on-line mixing using 135 MeV Au ions by ERDA. Ion beam mixing in Ti/Au system by 120 MeV Au at RT was also performed. In the Ti/Fe system, mixing is found to be higher than Ti/Au system at same energy (120 MeV Au ions) because both Ti and Fe are sensitive to electronic stopping power (S_e) while Au is insensitive material for S_e. However, the energy transfer from S_e sensitive material to the S_e insensitive material will create a thin molten layer leading to interdiffusion at the interface. Explanation of mixing has been proposed on the basis of thermal spike model.

PACS: 61.80.Jh; 68.55.Nq

Keywords: Ion beam mixing; Swift heavy ions

1. Introduction

Swift heavy ions play an important role in materials modifications [1,2] and characterization [3]. High-energy heavy ions with velocities comparable to or higher than the orbital electron velocity are referred to as swift heavy ions (SHI). At such energies (a few tens of keV/nucleon and higher) SHI lose their energy in the target mainly via inelastic collisions leading to the excitation of the target electrons. There are two theoretical models to explain such high local excitation of the lattice by the energy transfer from the highly excited electronic system to the lattice atoms viz. Coulomb explosion [4] and thermal spike model [5]. Both the mechanisms can explain atomic transport across interfaces and the production of defects. In most cases, materials modification by SHI irradiation exhibits threshold behavior in terms of electronic energy loss (S_e) beyond which the defect production efficiency increases to a great extent due to formation of latent ion track. However some materials, termed as S_e insensitive materials, show negligible or no defect production behavior due to S_e. The defect production and atomic motion induced by SHI in insulators [6,7], semiconductors [8] and some metals [9,10] has stimulated great interest to achieve SHI induced mixing at interfaces to produce novels materials and phases. Avasthi et al. [11] have demonstrated atomic mixing in the Fe/Si and the CuO/glass system due to the irradiation with 230 MeV Au ions and 210 MeV I ions, respectively and suggested that mixing increases with the increase in electronic energy loss. Kraft et al. [12] has shown that mixing at the interface of ZnO/SiO_2 is due to interdiffusion during transient melt phase. Mixing in thin films of Ti, Fe, W with Si by 100 MeV Au ions have been studied by Gupta et al. [13] where they observed that metal damage/intermixing occurred at S_e values well below the threshold value in bulk. Wang et al. [14] theoretically

* Corresponding author. Tel./fax: +91 562 2520075.
E-mail address: guptask10@yahoo.com (S. Kumar).

0168-583X/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.nimb.2005.11.054

studied Ni/Ti interface and suggested that GeV Ta or U ion can induce a molten phase both in Ni and Ti at the interface of Ni/Ti bilayers even though bulk Ni is insensitive to SHI irradiation. Kumar et al. [15] studied the ion beam mixing in Cu/Ge bilayer system using 120 and 140 MeV Au ions at RT and found that mixing increases with fluence and with the electronic energy loss. Srivastava et al. [16] recently demonstrated that the SHI induced mixing in Fe/Si system is due to consequence of transient molten state diffusion. In this paper, we investigate mixing in Ti/Fe and Ti/Au system using high energy Au ions and show the dependence of mixing on energy of ions, fluence, irradiation temperature and S_e sensitivity. The two systems are taken in such a way that one common element (Ti) in both is sensitive to S_e whereas the second element is Fe and Au. Out of these two elements (Fe and Au), Fe is sensitive to S_e and Au is insensitive to S_e.

2. Experimental

The Ti(42 nm)/Fe(32 nm) and Ti(96 nm)/Au(17 nm) bilayer samples were prepared by electron beam evaporation of Ti and Fe (top layer), Ti and Au (top layer) on Si(1 0 0) substrate at room temperature in an ultra-high vacuum deposition system. The deposition was performed at a pressure of $\sim 4 \times 10^{-8}$ Torr. The Si wafers were properly cleaned and etched chemically prior to deposition. The samples were irradiated by 120 and 200 MeV Au ions with different fluences at room temperature (RT) using the 15 UD Pelletron at Nuclear Science Centre (NSC), New Delhi and with 350 MeV Au ions at liquid nitrogen temperature (LT) at Hahn-Meitner-Institut (HMI), Berlin. The irradiation flux was kept low to avoid sample heating during irradiation. Table 1 shows the nuclear and electronic energy loss of the projectile ion as calculated using TRIM program [17]. In SHI–solid interactions, the nuclear energy loss may be neglected as compared to the electronic energy loss [5]. The threshold of S_e for Ti and Fe are ~15 keV/nm and ~40 keV/nm, respectively [18]. The thickness and the composition of the pristine and irradiated samples were studied by Rutherford backscattering spectrometry (RBS) using 1 MeV He ions with scattering angle 165° (for 120 and 200 MeV Au ion irradiated samples) and 171° (for 350 MeV Au ion irradiated sample). The concentration profiles were extracted from the RBS spectra with the help of the RUMP simulation code [19]. The on-line mixing in Ti/Fe bilayer sample was studied by elastic recoils detection analysis (ERDA) experimental set up at NSC, New Delhi using 135 MeV Au ions. The sample was kept tilted at an angle of 30°. The recoils from the sample were detected in a large area gaseous telescope detector at an angle of 45°. The data were collected event by event in list mode in the computer so that the fluence dependent study can be performed off-line. From the two-dimensional $\Delta E - E$ spectra, events corresponding to Ti recoils were selected and projected onto the E-axis to obtain the Ti recoil energy spectra.

Table 1
Au ion energies E, electronic stopping power S_e and mixing rate k at the interface

System	E (MeV)	S_e (keV/nm)	S_n (keV/nm)	Irradiation temperature	k (nm^4)
Ti/Fe	120	23.2/33.9	0.35/0.62	RT	60 ± 2
	135	24.4/36.2	0.32/0.51	RT	147 ± 9
	200	27.7/44.0	0.23/0.41	RT	155 ± 5
	350	31.8/51.1	0.15/0.26	LT	56 ± 4
Ti/Au	120	23.2/38.2	0.35/1.02	RT	15 ± 7

3. Results and discussions

Fig. 1 shows the RBS spectra of pristine and irradiated samples of Ti/Fe bilayer. Samples were irradiated with 120 MeV Au ions at fluences of 1×10^{13} and 1.5×10^{14} ions/cm^2 and 200 MeV Au ions at fluences of 1×10^{13} and 6×10^{13} ions/cm^2 at room temperature (RT). The decrease in the slope of the lower edge of the Fe peak and front edge of Ti peak indicate that the mixing occurred at this interface which also increases with the fluence. Fig. 2 shows the RBS spectra of the pristine and samples irradiated with 350 MeV Au ions at liquid nitrogen temperature (LT) at fluences of 4.4×10^{13}, 8.8×10^{13} and 1.33×10^{14} ions/cm^2. In this case also, mixing increases with the fluence. There is some reduction in the RBS yield at Fe surface. This is attributed to transient enhanced diffusion of oxygen [20]. This oxidation does not affect the processes taking place at the interfaces.

The concentration profiles of Ti were extracted from the RBS spectra with the help of the RUMP simulation code. The concentration profiles of Ti were fitted with a Gaussian error function and the variances were determined. The

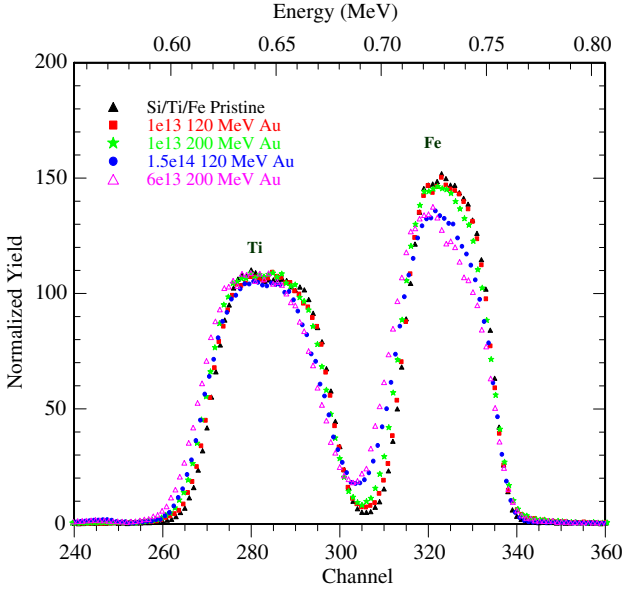

Fig. 1. RBS spectra of Ti/Fe film on Si(1 0 0) substrate after being irradiated with 120 and 200 MeV Au ions of different fluences at RT.