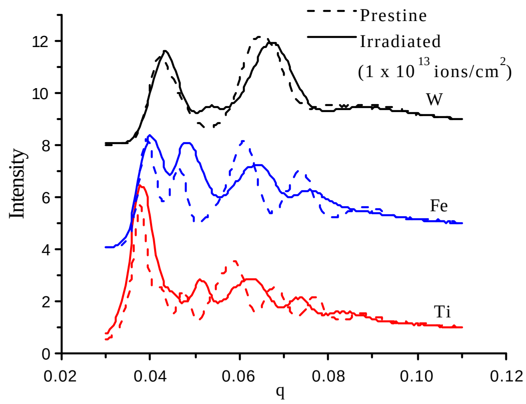
Report on proposal No. SI799

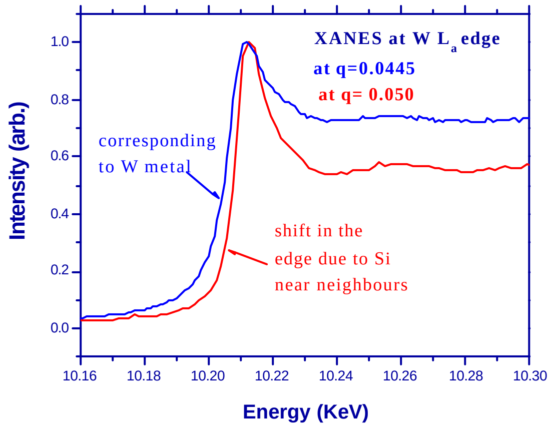
STUDY OF SWIFT HEAVY ION INDUCED INTERMIXING IN METALLIC THINFILMS

This is a preliminary report of the proposal on the study of swift heavy ion induced mixing of different metals with silicon. 18 shifts of the beam time were allotted for the experiment during the period 24th April to 30th April, 2002. The objective of work was to study the swift heavy ion induced mixing in W/Si, Fe/Si and Ti/Si systems under identical conditions. For this purpose thin layers (3nm) of W, Fe, Ti were embedded in a Si film at different depths and the film was irradiated with swift heavy ion so that all the three systems undergo the same irradiation fluence under identical conditions (ambient temperature, beam current, etc.). The system was analysed using x-ray standing wave (XSW) analysis and XANES.

Another objective of the proposal was to explore the feasibility of doing depth selective XANES across the thickness of a single layer using x-ray standing wave. It may be noted that depth selective XANES under standing wave conditions has been done in literature in periodic multilayers, where by varying the angle of incidence an antinode of standing wave can be scanned across the period of the multilayer. In contrast to this, the objective of present experiment was to explore depth selective XANES in a single layer of W, Fe, or Ti. Interfaced with Si.

A multilayer having the structure substrate/Cr10nm/Au70nm/Si12.5nm/W3nm/ Si12.5nm/Fe3nm/ Si12.5nm/Ti3nm/Si12.5nm was used in the experiment. Different pieces of the multilayer from the same batch were irradiated with 100 MeV gold ions of different fluences ranging from $5x10^{11}$ ion/cm^2 to $5x10^{13}$ ion/cm^2. Information about the intermixing induced by swift heavy ions was obtained using x-ray reflectivity, x-ray standing wave analysis and XANES measurements. For x-ray reflectivity and x-ray standing wave analysis a photon energy of 10.2 keV (just about the absorption edge of W was used). The X-ray standing wave pattern was formed in the multilayer as a result of the total reflection of x-rays from the gold surface. The fluorescence from the metal layers was measured using a Rontec detector. A thin Cr foil was kept in the path of incidence x-ray and the fluorescence coming out of this foil was also detected simultaneously in order to make correction for the deadtime of the detector. Fig.1 gives the fluorescence yield of different metals as a function of the angle of incidence. Peaks in the fluorescence yield are obtained as one of the antinodes passes through the corresponding layer. It can be seen that heavy ion irradiation results of broadening of all the three profiles. The analysis of the data would give a detailed depth distribution of elemental concentration as a function of depth.





For XANES measurements, the x-ray energy was scanned across the absorption edge of the corresponding elements up to an energy of 200 eV above the absorption edge. For each element two sets of measurements were done with q kept equal to a value corresponding to the: (*i*) first peak in the fluorescence yield of that element and (*ii*) subsequent minimum in the fluorescence yield. In case (*i*) the antinode of the x-ray standing wave coincides with the center of the layer and thus the measurement would give information about the atomic structure in the center, while in case (*ii*) the position of antinode is away from the layer and therefore, the information will be obtained from the metal atoms residing at the interface. During the measurements, the x-ray energy and angle of incidence were scanned in a coupled manner so as to keep the scattering vector fixed. Fig. 2 gives the x-ray absorption spectrum of the W layer in a pristine sample corresponding to the two cases above. There is a significant difference in the two absorption spectra. While absorption spectrum of the centre of the layer is typical of metallic W, a shift of the absorption edge towards high energy is clearly observed in the absorption spectrum of the interface layer, indicating the presence of Si near-neighbours. It is interesting to observe that, after irradiation with swift heavy ions the absorption spectrum from the interface layer became closer to that of metallic W. Thus, a combination of the results of x-ray standing wave analysis and XANES results suggests that irradiation causes migration of W atoms into Si layer but these atoms segregate together to form nanoparticles. Such long range migration of atoms under the influence of heavy ions has been predicted in several theoretical works. In case of Fe/Si interface formation of amorphous silicide is observed. XSW and XANES measurements were also done at W/Si and Fe/Si layers

Main findings of the present experiment can be summarized as follows:

- These experiments clearly demonstrated the possibility of doing depth selective XANES in a single layer using x-ray standing wave field,
- broadening of the depth profiles of different metals after the same irradiation fluence is, in the order: Ti>Fe>W. This confirms the theoretical predictions of thermal spike model [1], that sensitivity to swift heavy ion irradiation varies as Ti>Fe>W.
- Combination of x-ray standing wave analysis and depth selective XANES measurements suggests that irradiation results in long range migration of W atoms into Si to form nanoparticles.
- In case of Fe, amorphous Fe silicide is formed upon irradiation.

Detalied analysis of the XSW and XANES data is under way.

[1] Z.G. Wang et al., J Phys. Condens. Matter 7 (1995) 2525; A. Meftah et al., Mater. Sci. Forum 248-249 (1997) 53.