Study of swift heavy ion induced intermixing in metallic thin films (expt. No. SI 1044)

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This is a continuation proposal of our earlier experiment No. SI799. The objective of the work is to study the swift heavy ion induced mixing in metal/Si systems, by making use of the improved depth resolution of x-ray fluorescence technique under x-ray standing wave conditions. In the present experiment x-ray waveguide structure were used in order to further improve the depth resolution in the measurement of concentration profiles as well as XAFS spectra. X-ray waveguides have attracted a great deal of attention in recent years because of their possible application in x-ray optics as well as ataining resonantly enhanced and precisely defined standing wave field distribution inside thin films which in turn can be used for various x-ray based analysis [1]. In the present work, we demonstrate that using a waveguide structure, position of a marker layer can be determined with an accuracy of better than 0.2nm, and a higher depth resolution can be achieved in XAFS measurements too. This improved depth resolution is then used to elucidate the finer details of swift heavy ion induced mixing in Metal-silicon systems, particularly the effects of the type of metal and its thickness on the mixing efficiency.

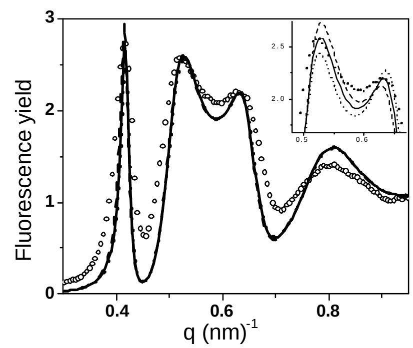

Fig. 1. Fe ka-fluorescence from the waveguide structure: substrate/Cr/Au/Si/Fe/Si/Au.

Figure 1 shows Fe K_α fluorescence measured from a multilayer having structure: substrate/Au70nm/Si 15nm/ Fe 4m/ Si 9nm/ Au 2nm. The layer Si/Fe/Si occupies the cavity formed by the two Au layers. The 4nm thick Fe layer is intentionally kept asymmetrically with respect to the center of the cavity. Three distinct peaks in the fluorescence at q values corresponding to the TE_0, TE_1 and TE_2 modes clearly evidence the excitation of waveguide modes. It may be noted that, had the Fe marker layer been placed at the center of the cavity, one would have observed peaks corresponding to TE_0 and TE_2 modes only. One may note that the relative intensity of the fluorescence peaks corresponding to TE_1 and TE_2 modes depend sensitively on the exact location of the marker layer (since for q values corresponding to TE_1 and TE_2 modes, the depth dependent field at the position of the marker layer has a steep gradient with opposite signs). In order to demonstrate this point, in Fig.1 the continuous curve represent the best theoretical fit to the data, while the dashed and dotted curves represent the simulated fluorescence from Fe layer displaced by ± 0.2nm from the best fit value. From the figure one may note that the accuracy with which position of the marker layer inside the cavity can be determined using this technique is better than 0.2 nm.

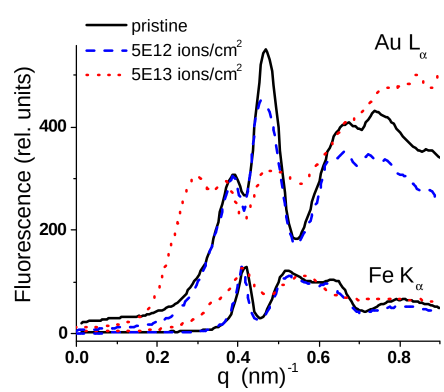

Fig. 2. Fe ka and Au la fluorescence from the waveguide structure after different fluences of 150MeV Au ions

Figure 2 shows the Fe fluorescence as well as Au fluorescence from the above multilayer after a few selected fluences of 150 MeV Au ions. Broadening of the profile of Fe fluorescence with fluence indicates the mixing of Fe layer with Si. It is interesting to note that Au fluorescence also shows significant variation with irradiation fluorescence. A preliminary fitting of the data shows that this variation is primarily due to sputtering of the top 2 nm thick Au layer as a result of irradiation. Thus, the present measurements also yield with high accuracy the swift heavy ion induced sputtering of the top Au layer, confirming our earlier results [2].

Fig.3 shows an example of depth selective EXAFS analysis for the multilayer irradiated with 150MeV Au ions to a fluence of $1x10^{13}$ ions/cm^2 at two different q values: 0.577 nm^{-1}(**A**), 0.504 nm^{-1}(**B**). Each of these q values correspond to different depth distributions of x-ray intensity inside the film as shows in Fig.4. The EXAFS spectra appear well different as a function of q: the features of A spectrum (maximum SW field intensity at the center of Fe layer) are typical of Fe bcc structure. The Fe bcc features are weaker in the B spectrum (maximum SW field intensity away from the center of Fe layer) and the preliminary data fitting put in evidence the growth of Fe-Si nearest neighbour correlations.

Detailed analysis of the data on Fe and W marker layers of different thicknesses and under different irradiation fluences is in progress. However, the main qualitative results can be summarized as follows: i) In conformity with earlier results [3], Fe is much more sensitive to SHI induced mixing as compared to W, ii) mixing efficiency increases significantly with decrease in film thickness, iii) there is a clear evidence for the shifting of the center of the marker layer towards the surface, iv) large sputtering of the top Au layer (beyond that expected on the basis of the theory of Sigmund) takes place during SHI irradiation. These results in general support the thermal spike model for SHI induced modification, however, there are additional features like shifting of the position of the marker layer which can not be understood in terms of this model alone.

[1] T.Salditt, et al., Physica B 336 (2003)181
[2] Ajay Gupta et al., Phys. Rev. B 64 (2001) 155407
[3] Ajay Gupta et al., Nucl. Instr. Meth. B 212 (2003) 458 .

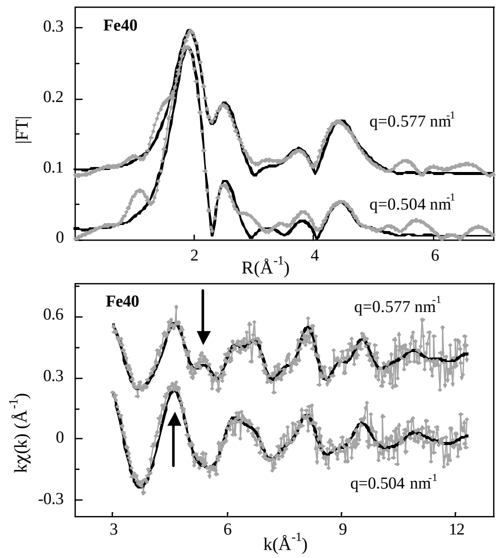

Fig. 3. Experimental (gray) and best fit (black) k-weighted EXAFS spectra (lower panel) and their FT (upper panel) for Fe40 sample collected at different q-values corresponding to different depth distribution of x-ray standing wave intensity within the sample.

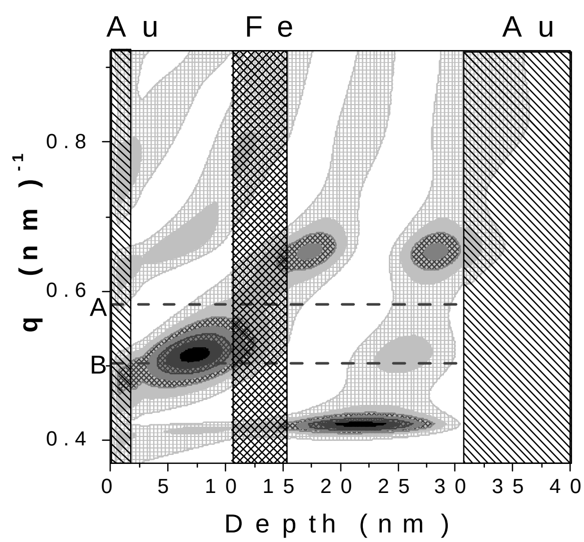

Fig. 4. Contour plot of field intensity distribution inside the multilayer as a function of scattering vector q. Dashed lines represent the q-values at which XAFS measurements have been done