

Resonant Magnetic Scattering from *fcc* Cu/Fe/Cu Trilayers

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INTRODUCTION

The magnetic properties of artificial structures (thin film, superlattices, etc.) can be tailored to the specific needs of solid state electronic devices by an appropriate choice of parameters (elements, thickness, crystallographic phase). For obvious practical reasons, the integration of such devices into silicon technology is of particular interest. Fe is a natural candidate for growing magnetic objects, and several studies have shown that ordered phases, both *bcc* and *fcc*, can be grown on Si by using a copper thin buffer layer [1]. Moreover, the Fe/Cu/Si structure displays a variety of magnetic behaviors as a function of growth conditions, thickness, presence of a capping layer, etc. [2]. In our work we have addressed the magnetic properties of Fe in the silicon supported trilayer structure Cu₈₅/Fe_x/Cu₃₃ as a function of the iron thickness using soft X-ray resonant magnetic scattering. Resonant scattering of polarized X-rays has been successfully used in the past to determine element specific magnetic moments in thin layers [3] and superlattices [4].

EXPERIMENTAL

Four samples with composition Cu₈₅/Fe_x/Cu₃₃ ($x = 2, 4, 6$ and 20 \AA) were prepared in UHV by electron beam deposition on the same Si(111)7x7 substrate, each sample being about 5 mm wide. In situ Auger analysis showed the formation of oxygen free layers, with an extremely weak and homogeneous C contamination. LEED observation indicated that the first Cu layer grows with a twinned *fcc* (111) orientation. This same growth mode is maintained for Fe and for the second Cu layer when x is small (2, 4 and 6 \AA). On the contrary, the 20 \AA Fe layer exhibits the typical LEED pattern of (110) growth of a *bcc* phase adjusted on an *fcc* (111) substrate (Kurdjumov-Sachs orientation). X-ray scattering measurements were performed using the reflectometer endstation of the 6.3.2 beamline at ALS [5]. Off-plane emission from the bending magnet source was selected in order to achieve a high degree of circular polarization ($\sim 70\%$) and the resolving power was ~ 2000 . We performed both $\theta/2\theta$ scans at fixed photon energy and energy scans at fixed scattering angle. In both cases, we reversed at each point the external magnetic field (~ 800 Gauss, along the intersection between sample surface and scattering plane).

RESULTS

An example of resonant scattering measurement is reported in Fig.1 for the thickest Fe layer ($x = 20 \text{ \AA}$). The value of θ is fixed at 6° and the incoming photon energy is scanned across the Fe 2p resonances. At each energy point, the scattered intensity is recorded for both parallel (Mag.+) and antiparallel (Mag.-) orientation between sample magnetization and photon helicity. Both curves and their difference are reported in the left panel of Fig. 1. The right panel displays the corresponding asymmetry ratio, defined as the difference between the two curves for opposite magnetizations divided by their sum. As a consequence, even though we present the scattered intensity in arbitrary units, the asymmetry ratio is a dimensionless absolute value. In the following we will compare experiments and calculations in terms of this quantity. The thickest $x = 20 \text{ \AA}$ *bcc* Fe layer represents our internal reference in this experiment. To test the validity

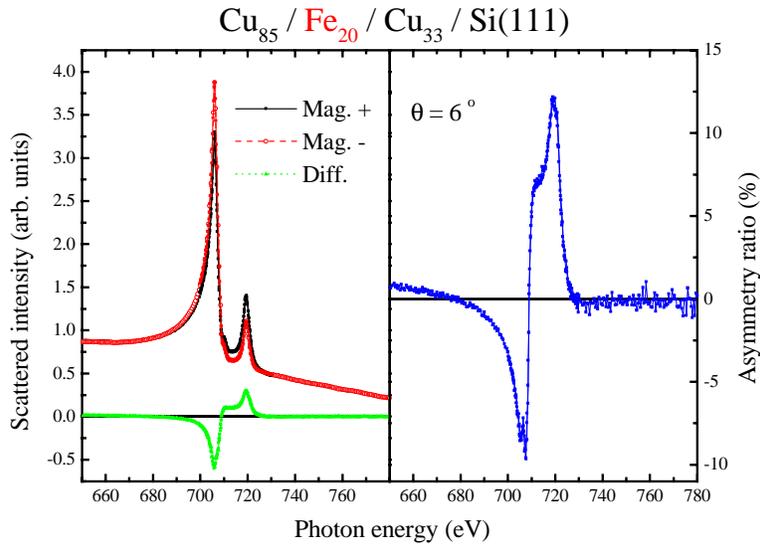


Figure 1. Energy dependence of the scattered intensity for $x = 20 \text{ \AA}$ (left) and corresponding magnetic signal.

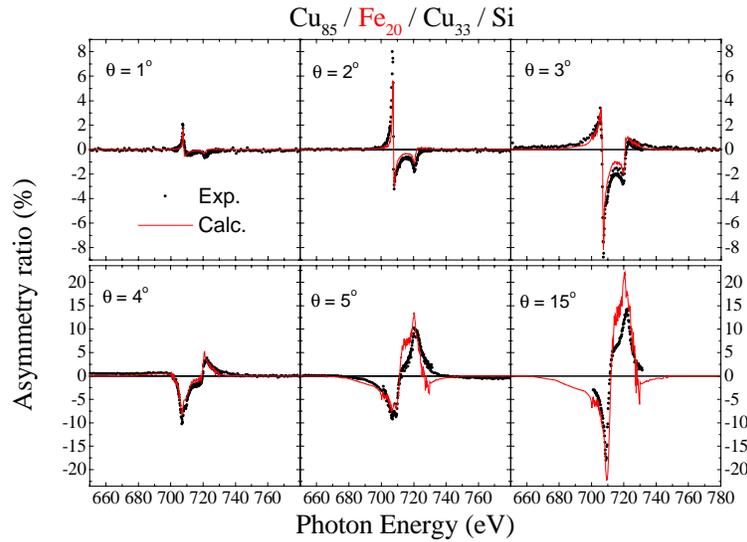


Figure 2. Comparison between experimental and calculated asymmetry ratio curves for $x = 20 \text{ \AA}$.

of our approach to data analysis, we first calculate expected reflectivity curves for the nominal structure of this sample, $\text{Cu}_{85}/\text{Fe}_x/\text{Cu}_{33}/\text{Si}(111)$, without fitting any parameter. The non-resonant optical constants of Cu and Si have been taken from tabulated curves [6], while for Fe we relied on a previous experimental determination [7]. It must be noted that these Fe optical constants contain explicit information about electronic (resonant term) and magnetic (off diagonal elements of the dielectric tensor) properties. In particular, they refer to fully magnetized ($\sim 2.2 \mu_B$ per atom) iron in the *bcc* phase. Fig. 2 compares experimental asymmetry ratio curves for $x = 20 \text{ \AA}$ obtained at six different scattering angles with calculations based on the nominal structure. Since no parameter has been optimized, we consider that our data agree well with the assumption of a fully magnetized *bcc* Fe for $x = 20 \text{ \AA}$. This is also confirmed by Fig. 3, top panel, where we report the angular dependence of the magnetic asymmetry ratio for a fixed photon

energy of 706 eV (Fe L_3 resonance). Fig. 3 also shows that things work out quite differently for thinner *fcc* Fe layers : solid lines are the result of the same calculations performed for $x = 2, 4$ and 6 \AA , and they are in complete disagreement with experiment. From our data we can already obtain an interesting indication about magnetism of thin *fcc* iron films in the trilayer structure, i.e. that Fe carries an in-plane magnetic moment at room temperature down to a thickness of 2 \AA . The next step in our analysis will be to optimize the Fe optical constants in order to correctly reproduce the data (e.g. Fig. 3) within our model calculation. This way we will be able to quantify the magnetic moment carried by Fe in this peculiar *fcc* structure.

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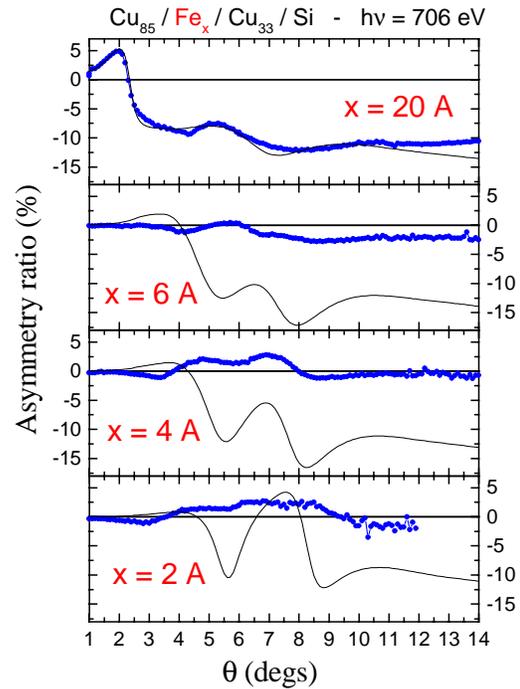


Figure 3. Angular dependence of the asymmetry ratio at 706 eV versus Fe thickness. Lines are calculations performed assuming bulk *bcc* Fe optical constants.