ESRF	**Experiment title:** Uniaxial magnetic anisotropy of ferromagnetic / semiconductor interfaces	**Experiment number**: HE-1113
Beamline: ID08	**Date of experiment**: from: 16/11/01 to: 20/11/01	**Date of report**: 19/02/02
Shifts: 12	**Local contact**: S.S. Dhesi	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

*G. van der Laan, Daresbury Laboratory, Warrington WA4 4AD, UK.

*C.M. Teodorescu, Daresbury Laboratory, Warrington WA4 4AD, UK.
*Y. Huttel, Instituto de Microelectr nica de Madrid, CNM-CSIC, Madrid, Spain.
*Y.B. Xu, Department of Electronics, University of York, York YO1 5DD, UK.

Ferromagnetic metal/semiconductor heterostructures, such as Fe thin films grown epitaxially on GaAs(001), have served as a model system to study the possibility of injecting spin-polarized electrons into a semiconductor, thereby creating novel devices in the framework of the emerging *spin electronics*. A huge in-plane uniaxial magnetic anisotropy (UMA), quite unexpected from the crystal symmetry of bcc Fe on GaAs, was observed over a decade ago [*1*] but its microscopic origin still remains an open issue. X-ray magnetic circular dichroism (XMCD) and the novel technique of x-ray magnetic linear dichroism (XMLD) [*2-4*] have shown to be valuable tools to extract the element-specific magnetocrystalline anisotropy energy (MAE) of thin films and interfaces. XMCD measurements at SRS Daresbury under an applied field of +/-4 T showed strongly enhanced orbital moments along the hard axis (the out-of-plane direction) [*5*] in agreement with recent theoretical studies [*6*]. The in-plane UMA is difficult to obtain with XMCD, since the beam cannot strike parallel to the surface, however this geometry is ideal for XMLD. Here, we present the results of our XMLD measurements done at the ESRF on Fe/GaAs(100) structures for different Fe coverages in two different geometries: (i) by aliging the linear polarization vector (**E**) of the x-rays parallel and perpendicular to the easy-magnetization direction (ε) of the film; and (ii) by aligning the magnetization (**M**) of the sample parallel and perpendicular to ε.

Fe/GaAs(100) samples, with Fe coverages of 5, 8, 12, 16, and 40 monolayers (ML), were prepared by molecular beam epitaxy (MBE) at the University of York. MOKE gave confirmation that ε was parallel to [1(-1)0]. The samples were covered with a thin Cu capping layer to prevent surface contamination in transit to the ESRF. A new dedicated vacuum chamber was prepared equipped with a revolving +/-0.5 T electromagnet capable of saturating **M** parallel and perpendicular to ε, whilst keeping **E** fixed in the geometry. The APPLE II undulator on beamline ID08 was used to align **E** parallel and perpendicular to ε, whilst keeping **M** fixed. The x-rays always strike the sample at normal incidence. X-ray absorption spectra (XAS) and the resulting XMLD were measured at room temperature in total-electron yield mode.

Figure 1 shows the experimental results for the different Fe film thicknesses. The XMLD signal is very strong and exceeds that of Fe metallic thin films reported in Refs. [*5*] and [*6*].

Figure 2 shows the integral ratios, $(\Delta L_3 - 2\Delta L_2) / (L_3 + L_2)$, proportional to the MAE, that clearly increase with the Fe coverage (for the range of thicknesses investigated). Applying the sum rules [*2,3*] the MAE is obtained from the integral ratio times a proportionality factor $\zeta n_h / 2A$, where n_h is the number of 3*d* holes, which can be different in Fe/GaAs compared to metallic Fe; ζ is the radial part of the spin-orbit interaction, and A is the geometrical coefficient [*4*]. Assuming n_h(Fe) = 3.39; ζ(Fe) = 40 meV; and A = 8/5 ˆ3

[*3*] this gives a proportionality factor of 24.5 meV/atom between the integral ratios plotted in Fig. 2 and the MAE.

The MAE derived from the presented XMLD data ranges between ~122 μeV/atom for the 8 ML film to ~441 μeV/atom for the 40 ML film. These values exceed those reported for Fe [*4*] and Co [*3*] films grown on stepped Cu, which are 181 and 138 μeV/atom, respectively. If the number of 3*d* holes for these films is larger than for metallic Fe, owing to charge transfer from Fe to the semiconductor substrate, the derived MAE values could be even larger. A futher observation that can be made from Fig. 2 is that rotating **E** or **M** does not make a large difference in the derived values of the MAE (the two points shown for the 12 ML sample).

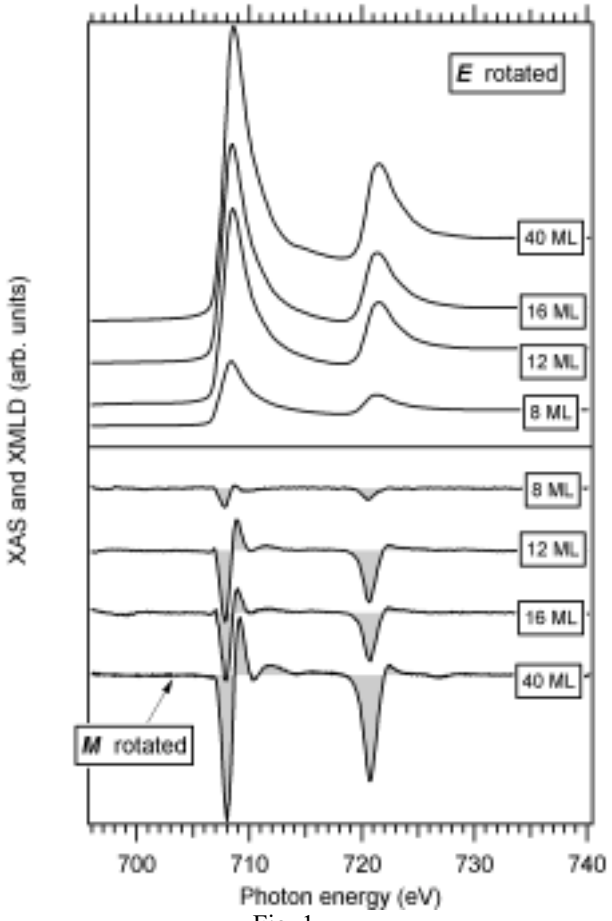

Fig. 1

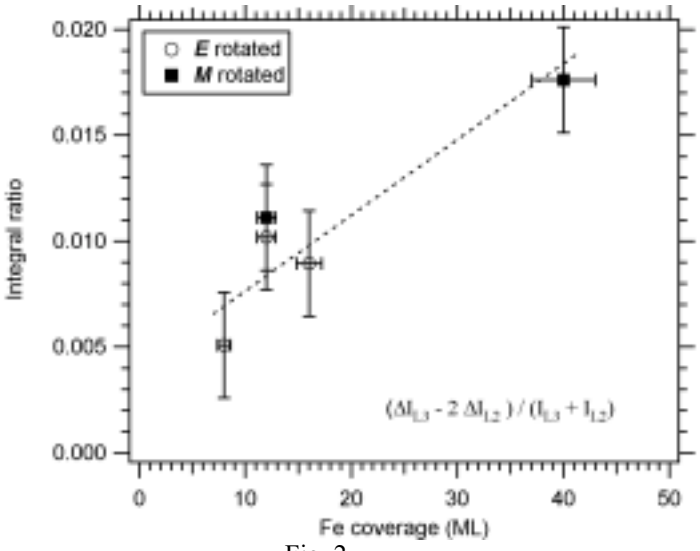

Fig. 2

Fig. 1: XAS (top panel) and XMLD (bottom panel) of Fe/GaAs(100) as a function of Fe coverage. The 5 ML sample, which showed no XMLD, has been omitted. All spectra were obtained in a fixed magnetic field whilst rotating **E**, with the exception of the 40 ML sample, where **M** was rotated.

Fig. 2: Integral ratios, proportional to the magnetocrystalline anisotropy energy, extracted from the XMLD spectra presented in Fig. 1. The straight line serve as a guide to the eye.

References

1. J.J. Krebs, B.T. Jonker, G.A. Prinz, *J. Appl. Phys.* **61**, 3744 (1987).
2. G. van der Laan, *Magnetic linear x-ray dichroism as a probe of the magnetocrystalline anisotropy*, Phys. Rev. Lett. **82**, 640 (1999).
3. S.S. Dhesi, G. van der Laan, E. Dudzik, A.B. Shick, *Anisotropic spin-orbit coupling and magnetocrystalline anisotropy in vicinal Co films*, Phys. Rev. Lett. **87**, 067201 (2001).
4. S.S. Dhesi, G. van der Laan, E. Dudzik, *Determining element-specific magnetocrystalline anisotropies using x-ray magnetic linear dichroism*, Appl. Phys. Lett. **80** (2002), *in press*.
5. Y.B. Xu, M. Tselepi, C.M. Guertler, C.A.F. Vaz, G. Wastlbauer, J.A.C. Bland, E. Dudzik, G. van der Laan, *J. Appl. Phys.* **89**, 7156 (2001); *J. Magn. Magn. Mat*. **226 - 230**, 1643 (2001).
6. I. Cabria, A.Ya. Perlov, H. Ebert, *Phys. Rev. B* **63**, 104424 (2001).