ESRF	**Experiment title:** Strain fields at ferromagnet-semiconductor interface studied by combining versatile AFM setup and high resolution X-ray diffraction	**Experiment number**: HC-1971
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Report:

Rapid progress in spintronics [1] leads to the development of ferromagnet/semiconductor hybrid diode structures, where high efficiency spin injection from ferromagnetic metal into nonmagnetic semiconductor can be achieved [2, 3]. Presence of a thin tunnelling barrier at the interface enhances the spin injection efficiency. The tunnelling barrier is often made of magnesium oxide (MgO), the compound having suitable electrochemical and technological properties [4]. The lattice mismatch between epitaxial layers creates a considerable strain at their interface. The strain directly influences the efficiency of spin injection through an interface [5], being of prime importance for the device performance.

The Atomic Force Microscopy (AFM) is well established tool of surface characterization providing sub-nanometer spatial resolution. Furthermore, the AFM tip can act as a source of external stress applied locally through the tip-to-surface contact area. Thus the elastic properties of individual nanostructures can be investigated [6]. Since the buried layers are hardly accessible by AFM, the use of X-ray scattering methods is beneficial. Combination of synchrotron based high resolution X-ray diffraction (HRXRD) and AFM provides a versatile tool for *in situ* studies of surface and bulk of nanostructured materials. Unlike the existing AFM setups using quartz tuning fork [6], we have implemented a standard AFM system equipped with an optical cantilever feedback. This design ensures stable and controlled force applied to the sample surface, thus avoiding the tip oscillations inherent to tuning fork AFMs.

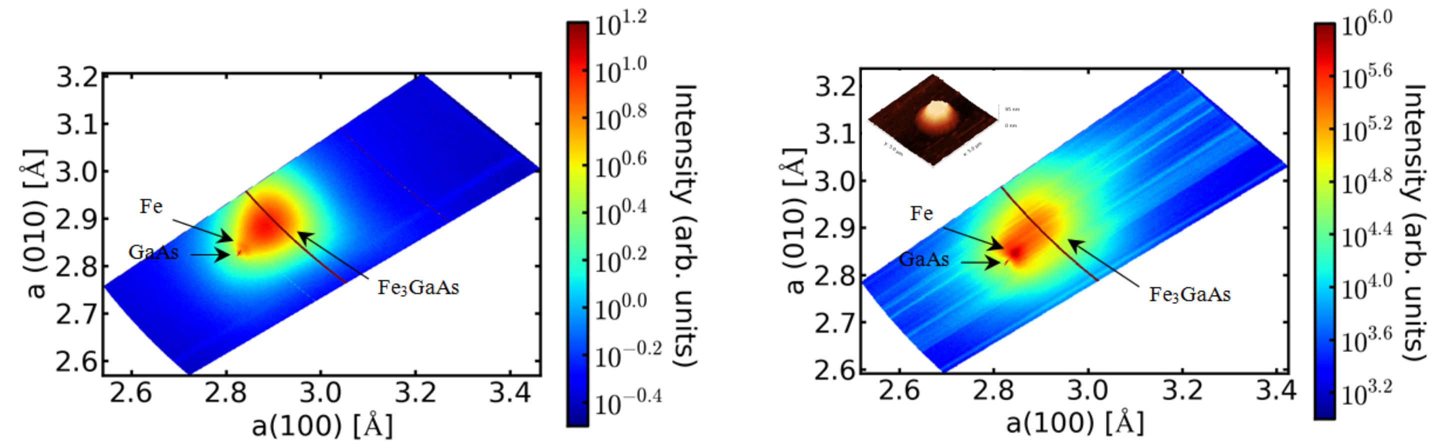

Fig. 1. (a) GID map measured in the vicinity of GaAs (220) diffraction peak plotted in unit cell coordinates. (b) GaAs (220) GID map of an individual nanostructure measured under AFM conditions. AFM image is shown as inset.

The strain distribution in thin epitaxial films is strongly influenced by intermixing and local film thickness. Therefore, it is crucial to study depth distribution of strains locally and non-destructively. In this work we have used the dedicated AFM setup [7] in combination with HRXRD to systematically investigate the strain field distribution at a ferromagnet-semiconductor interface under external stress. Our laboratory measurements of tunnelling resistance variation due to strain induced by an AFM tip show nearly exponential increase of the tunnelling current with increasing strain. However, both the strain variation and the change of surface area of a tip contact contribute to the measured current. To separate these contributions we need a local strain probe.

The measurements were performed at the ID13 beamline of ESRF using using X-ray energy of 14.3 keV. The beam was focused down to 1(h)×0.7(v) μm^2 using Fresnel zone plate optics. We studied individual Fe/MgO/GaAs nanostructures fabricated on a GaAs substrate (AFM image is shown as inset in Fig.1b). Reciprocal space maps (RSMs) measured in grazing incidence diffraction (GID) geometry in the vicinity of GaAs (220) diffraction peak are shown in Fig. 1. Distinct diffuse intensity distribution originating from Fe/GaAs buried interface can be seen in Fig. 1(a). Decrease of the incidence angle leads to higher surface sensitivity and increase in the intensity of the signal originating from the top Fe layer (see Fig1(b)). Application of external load by AFM tip leads to anisotropic change of the lattice constant of the layer identified as Fe_3GaAs located at the interface. Annealing behavior of the lattice constants indicates that the Fe_3GaAs layer is not continuous. Further measurements at ID13 using coherently focused X-ray beam will shed light to the internal strain distribution of spintronic structures as well as evolution of strains uppon applying external load by AFM tip.

References

[1] A. Fert, Rev. Mod. Phys. 80, 1517 (2008).
[2] L. R. Fleet, K. Yoshida, H. Kobayashi, Y. Kaneko, S. Matsuzaka, Y. Ohno, H. Ohno, S. Honda, J. Inoue, and A. Hirohata, Phys. Rev. B 87, 024401 (2013).
[3] R. Farshchi and M. Ramsteiner, J. Appl. Phys. 113, 191101 (2013).
[4] S. S. P. Parkin, Ch. Kaiser, A. Panchula, P. M. Rice, B. Hughes, M. Samant, and S.-H. Yang, Nature Materials 3, 862 (2004).
[5] A. M. Sahadevan, R. K. Tiwari, G. Kalon, C. S. Bhatia1, M. Saeys, and H. Yang, Appl. Phys. Lett. 101, 042407 (2012).
[6] T. Scheler, M. Rodrigues, T. W. Cornelius, C. Mocuta, A. Malachias, R. Magalhães-Paniago, F. Comin, J. Chevrier and T. H. Metzger, Appl. Phys. Lett. 94, 023109 (2009).
[7] T. Slobodskyy, A. V. Zozulya, R. Tholapi, L. Liefeith, M. Fester, M. Sprung, and W. Hansen, Rev. Sci. Instrum. 86, 065104 (2015).