Strain in *in Situ* Prepared Magnetoelectric 2-2 Composites Induced by a Magnetic Field

C.T. Koops, M. Abes, S.B. Hrkac, O.M. Magnussen, and B.M. Murphy

Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Leibnizstr. 19, 24118 Kiel, Germany

The development of new highly sensitive magnetic field sensors[1] opens new perspectives in medical applications. Layered magnetoelectric (ME) 2-2 composites, consisting of a piezoelectric phase and a magnetostrictive phase, have shown to be the most promising devices[2] for future applications e.g. in MCG or MEG, because of there extremely high ME coefficient[3]. In these composites, the MS properties are coupled to the PE properties via strain at the interface. Hence, the interface coupling and the decay of magnetically induced strain in the PE component along the interface normal is of central importance for the efficiency of these sensors, as a low mechanical coupling or a rapid decay will decrease the strain transfer from the MS into the PE phase. Thus, a lower ME coefficient will be detected. Up to now only a few direct measurements of the magnetic field induced strain coupling have been reported, using either forbidden reflections[4] or X-ray grazing incidence diffraction (GID)[5] to measure structural properties at the buried interface.

We present our *in situ* GID study of the magnetic field induced strain at a magnetoelectric interface by measuring the lattice deformation in a PE substrate as function of the magnetic field, the penetration depth and the MS layer thickness using the high-resolution X-ray beam provided by P08 at PETRA III. We used a polished PE InP(100) single crystal as a substrate, to grow amorphous MS Ni films *in situ* at the beamline by electron beam evaporation.

We have built a UHV *in situ* growth chamber that can be mounted directly on the sample stage of the LISA diffractometer at beamline P08[6]. The chamber includes an ion gun and an annealing stage for surface cleaning and an electron beam evaporator for rod shaped metal evaporation. A magnetic field of up to 40 mT can be applied with an electromagnet. The (0 -k k) surface reflections

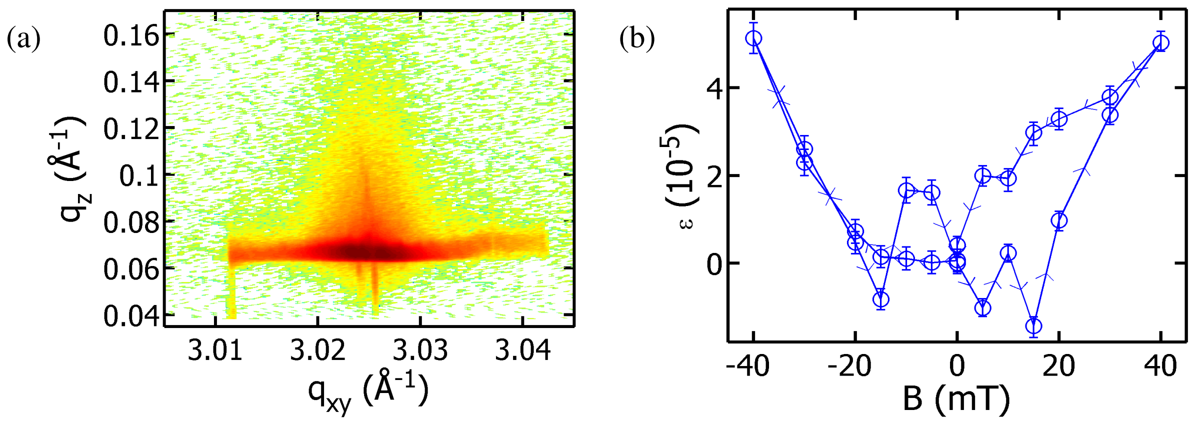

Figure 1: (a) (0 -2 2) Surface reflection of the InP substrate on a logarithmic scale. (b) Magnetic hysteresis from the deposited Ni layer calculated from the position of the (0 -2 2) reflections of the substrate.

are measured horizontally using the sample and the detector rotation. Reflectivities and the (h 0 0) reflections can be measured vertically via tilting the beam on to the surface with the LISA beam tilter. Reflectivities are used to characterize surface and interface roughness and the thickness of the *in situ* grown films. We deposited layer thicknesses of 20, 80, 120 and 160 nm. To determine the strain as a function of the magnetic field, we measured the InP(0 -2 2) reflection (see Fig. 1(a)). The induced strain was determined to go up to 4.5×10^{-5} (see Fig. 1(b)).

Varying the incidence angle and the angle between the surface and the emerging beam changes the penetration depth and allows the investigation of the strain decay parallel to the interface normal. Figure 2(a) shows the field induced strain for 40 mT as a function of the penetration depth for a

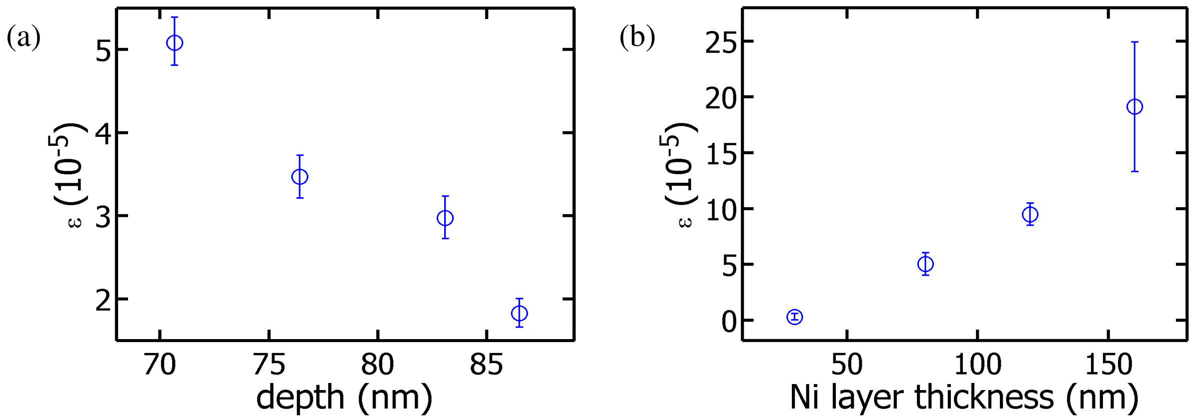

Figure 2: (a) Maximum strain for various penetration depths. The decay of the strain in the bulk is clearly visible. (b) Increasing strain with increasing layer thickness. Measured with a single, *in situ* prepared sample.

Ni layer thickness of 80 nm. The decay of the strain is clearly visible. In a depth of 90 nm half of the strain is already relaxed. The *in situ* deposition of Ni enables us to investigate the influence of the layer thickness, too. Figure 2(b) shows the strain in the substrate in a depth of 70 nm for the maximum field of 40 mT. It is increasing, as a function of the layer thickness.

In conclusion, we are able to measure the small magnetic field induced strain in single crystalline PE substrates of *in situ* prepared ME composites. These studies can determine characteristic length scales for the decay of the strain within the substrate or, the influence of layer thickness on the transferred strain, to improve the efficiency for future applications as a magnetic field sensor.

We thank the DFG for financial support via the SFB 855.

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