Magnetically and Electrically Induced Strain in Magnetoelectric 2-2 Composites: \textit{in Situ} Prepared and Epitaxially Grown

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Magnetoelectric (ME) materials are of great interest for potential applications as highly sensitive magnetic field sensors \cite{1-3}, that can be used e.g. for medical applications. Up to now layered 2-2 composites, consisting of a piezoelectric substrate and a magnetostrictive layer, were used to achieve very high ME coefficients \cite{4}. Of central importance for the operation of these sensors is the mechanical coupling at the interface of the two materials: A weak coupling will decrease the strain, transferred via the interface into the piezoelectric substrate and therefore decrease the ME coefficient. Only a few direct measurements of the field induced strain transfer have been reported, using either forbidden reflections \cite{5} or grazing incidence X-ray diffraction (GIXD) \cite{6}. Thus, the understanding of this coupling and its dependence on the interface structure is still rudimentary.

We report our GIXD study concerning the mechanical coupling at the interface of ME composites by measuring the lattice deformation in the ZnO piezoelectric substrate induced by a magnetostrictive Ni layer, using the high-resolution X-ray beam provided by P08 at PETRA III. The ZnO/Ni samples are prepared \textit{in Situ} at the beamline by electron beam evaporation of amorphous Ni films on the Zn terminated (001) surface of high quality ZnO single crystals. We also investigated the electric field induced strain in epitaxial 0.72\[Pb(Mn_{1/3}Nb_{2/3})O_3]\-0.28\[PbTiO_3]/CoFe$_2$O$_4$ (PMN-PT/CFO) these samples were prepared before the beamtime via pulsed laser deposition.

We have built a UHV \textit{in Situ} growth chamber that can be mounted directly on the sample stage of the LISA diffractometer at beamline P08 \cite{7}. The chamber includes an ion gun for surface cleaning and an electron beam evaporator for rod shaped metal evaporation. A magnetic field of 50 mT can be applied with a new electromagnet. The surface reflections can be measured horizontally and reflectivities vertically up to the (002) Bragg reflection via tilting the beam on to the surface with the LISA beam tilter. Reflectivities collected before and after the deposition process are used to determine surface and interface roughness and the thickness of the deposited layer for \textit{in Situ}

Figure 1: (a) Reflectivity measurement after the deposition of a 230 nm Ni layer. The exact layer thickness can be calculated directly at the beamline from the oscillations. (b) Magnetic field induced strain in the piezoelectric ZnO substrate as a function of the magnetic field.
growth of Ni on top of a ZnO substrate. A Ni layer of 230 nm thickness, as determined by the reflectivity (fig. 1 (a)), was used for the diffraction experiment. To determine the strain induced as a function of applied magnetic field we measured the ZnO(330) surface reflection. The directly measured induced strain $-1.3 \times 10^{-5}$ (fig. 1 (b)) occurs in response to the corresponding strain induced in the Ni.

In composites with amorphous magnetic layers GIXD can reveal the induced strain in the substrate directly, but the missing information from the top layer prevents a direct calculation of the coupling. Thus, measuring both crystalline materials in epitaxial systems can reveal the coupling directly.

To measure this experimentally we investigated both the PMN-PT(200) reflection and the CFO(400) reflection in parallel as a function of the applied electric field. Figure 2 (a) shows the ferroelectric hysteresis, induced in the magnetic CFO top layer. Figure 2 (b) shows the strain in both materials in the linear range for a decreasing electric field. It is visible, that the coupling is not perfect and plays an important role for the efficiency of such materials.

In conclusion, we are able to prepare ME composites \textit{in Situ} in UHV to investigate the interface properties. The data show very high resolution to reveal even very small changes in the lattice parameters, required to observe the induced strain from a Ni layer into a ZnO substrate. Moreover, epitaxial systems were measured and the imperfect coupling was determined directly from the linear range of the ferroelectric hysteresis.

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References