Mechanical Coupling in Magnetoelectric Composites

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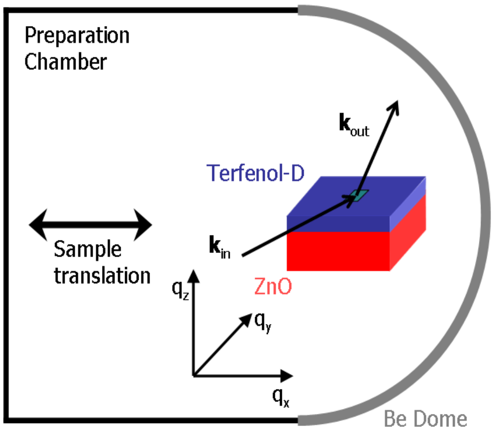
Magnetoelectric (ME) composites, consisting of a piezoelectric and a magnetostrictive material, are of great interest for potential applications as highly sensitive magnetoelectric sensors [1, 2, 3], that can be used e.g. for medical applications. Of central importance for the operation of these sensors is the mechanical coupling at the interface of the two material components: A large ME response is only obtained if the lattice deformation, induced by an external magnetic field in the magnetostrictive material, can be transferred efficiently to the piezoelectric material. Up to now, only a few measurements of the mechanical interface coupling have been reported, for example in the case of $La_{0.67}Sr_{0.33}MnO_3/BaTiO_3$ composites induced by an electric field [4]. In general, the understanding of this coupling and its dependence on the interface structure is still very rudimentary, in particular for magnetic field induced ME effects in such composites.

We report the experimental work of our 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 layer using the high-resolution X-ray beam provided by P08 at PETRA III. The ME samples are prepared directly at the beamline by electron beam evaporation of amorphous Terfenol-D ($Tb_{0.3}Dy_{0.7}Fe_{1.92}$) films of various thicknesses on the Zn terminated (0 0 1) surface of high quality ZnO single crystals. We investigate surface reflections via grazing incidence diffraction (GID).

To achieve the aims proposed, we have built a UHV chamber that can be mounted directly on the sample stage of the LISA diffractometer at beamline P08. The 120 kg chamber includes an ion gun for surface cleaning and an electron beam evaporator for rod shaped metal evaporation. The sample can be translated in situ into a beryllium dome for the X-ray experiment. During the measurements a magnetic field of up to 47 mT can be applied. It is possible to measure surface reflections horizontally with a scattering angle of more than 90° and reflectivities vertically up to the (0 0 2) peak via tilting the beam on to the surface with the LISA beam tilter (figure 1(a)).

(a)



(b)

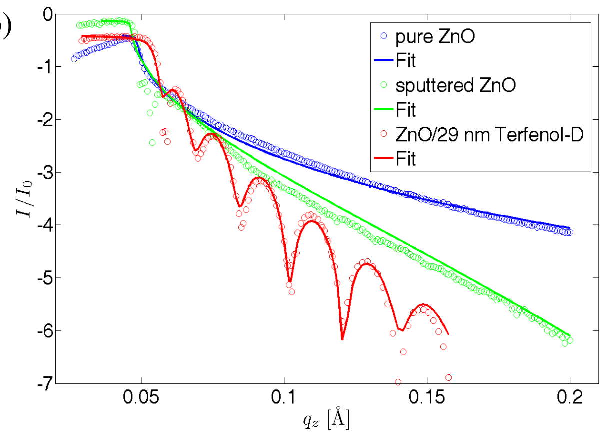


Figure 1: (a) The sample is horizontally oriented in the beryllium dome. The LISA beam tilter controls the angle between surface and incident beam. The sample stage allows rotation around the surface normal for measuring grazing incidence reflections. (b) X-ray reflectivity curves for the pure and the sputtered ZnO substrate show increasing roughness. The red curve shows the fringes from the 29 nm Terfenol-D layer.

In first experiments with this setup we collect reflectivities of the pure ZnO substrate before and after the cleaning process and after every deposition to determine the surface roughness and the

layer thicknesses (figure 1(b)). The data shows that the surface roughness of the substrate increases after Ar sputtering from 2 Å to 12 Å. After the cleaning process we deposit Terfenol-D layers with a thickness of 6 nm and 29 nm. The roughness of the metallic surface is comparable to the values of the clean ZnO substrate before.
To determine the mechanical coupling at the interface, we carry out a series of X-ray diffraction measurements on the four samples described above. We measure the (4 -4 0) grazing incidence surface reflection in the presence of various magnetic fields between 0 and 47 mT.

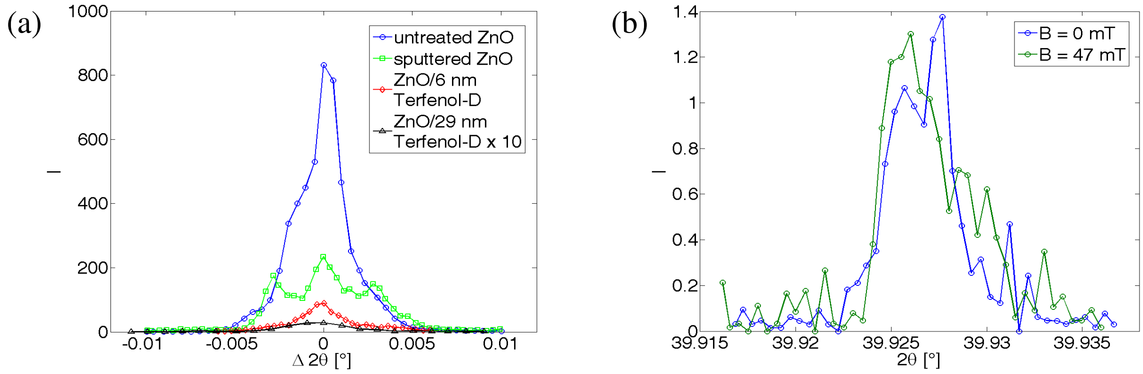


Figure 2: (a) Absolute intensity of the (4 -4 0) surface reflection decreases with the preparation steps. The Intensity of the peak from the ZnO/29 nm Terfenol-D interface is multiplied by 10. (b) Effect of the magnetic field on the (4 -4 0) reflection of the ZnO/29 nm Terfenol-D composite.

Figure 2(a) shows the (4 -4 0) surface reflection without magnetic field for the four samples. It is clearly visible that the absolute intensity is decreasing. The increasing roughness during sputtering is responsible for the lower intensity after the cleaning process. As we are probing the buried interface the peak height is decreasing with growth of the amorphous top layer. The FWHM of the peaks is 0.003° at a 2θ value of 39.926°. Hence the resolution of the setup is sufficient to show lattice strain of less than 7.0 x 10^{-5}. Figure 2(b) shows the (4 -4 0) peak for the 29 nm thick layer with a magnetic field of 0 mT and 47 mT. Rod shaped Terfenol-D shows a magnetostriction of up to 1.2 x 10^{-3} at 47 mT, but the effect decreases in pre stressed rods. In our measurements the effect is very small in comparison with the resolution and is much smaller than expected for stress free Terfenol-D layers.
In conclusion, we are able to prepare ME composites at the beamline and apply a magnetic field in situ to investigate the interface properties without breaking the vacuum. The X-ray diffraction data are of good quality and show very high resolution to reveal even very small changes in the lattice parameters. Moreover, the intensity is sufficiently high to investigate even deeply buried interfaces. In future studies we plan to increase the applicable magnetic field and implement a heating stage to improve the properties of the surface and the top layer.
We thank the DFG for financial support via the SFB 855.

References

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