ESRF	**Experiment title:** Strain Profile of Magnetoelectric Interfaces by X-ray Diffraction Methods	**Experiment number**: SI-2471
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Report:

In our experiments we investigated $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMNPT) and $CoFe_2O_4$ (CFO) Bragg reflections in the magnetoelectric (ME) CFO/PMNPT epitaxial composites in the presence of an external magnetic field by grazing incidence X-ray diffraction (GID) using the geometry as shown in Figure 1. GID experiments were carried out at the BM28 beamline at an energy of 15 keV. Using a Si (111) single crystal analyzer positioned between the detector and the sample a very high q-resolution was obtained. The incidence beam (q_{in} in Figure 1) impinges on the sample surface at grazing incidence angles of 0.16°, 0.165° and 0.18°, i.e., just below, at and above the critical angle, respectively. The corresponding penetration depth of the X-ray beam into the PMNPT substrate is a few nanometers. Hence, only the PMNPT structure near the interface is probed. In-plane CFO and PMNPT Bragg reflections were measured at a detector angle equal to the grazing incidence angle with respect to the sample surface, i.e., with the scattering vector $q_z = q_{out} - q_{in}$ almost perfectly within the surface plane. The external magnetic field was applied along in-plane [100] direction. A series of X-ray diffraction measurements on the CFO/PMNPT sample at (400) CFO and (200) PMNPT reflections were collected without and during the application of an external magnetic field at grazing incidence angles below (0.16°) at (0.165°) and above (0.18°) the critical angle.

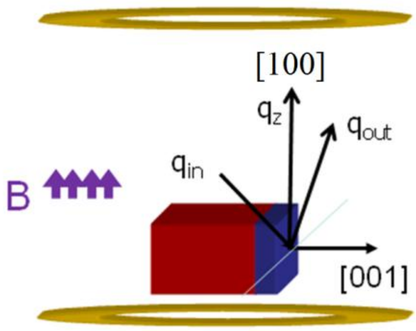

Figure 1: Experimental geometry in the conditions of grazing incidence x-ray diffraction

Figure 2 shows theta-2theta scans through (400) CFO and (200) PMNPT reflections taken without magnetic field (blue curve) and during the application of an external magnetic field (green curve) at a grazing incidence angle just below the critical angle (0.16°). The full width at half maximum of the (200) PMNPT peak is about 0.01° demonstrating the very high crystalline quality of the PMNPT substrate. As clearly visible, the Bragg peak positions shift with the external magnetic field.

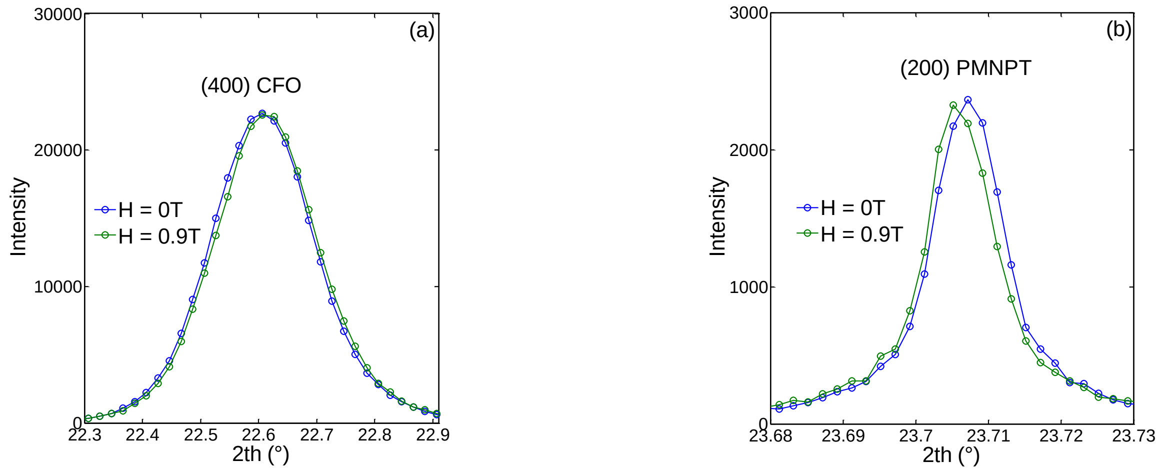

Figure 2: (a) (400) CFO and (b) (200) PMNPT Bragg peaks of the CFO/PMNPT sample, measured just below the critical angle without magnetic field (blue curve) and during the application of an external magnetic field (green curve)

From the Bragg peak positions we determined the interplanar spacings in the CFO and PMNPT materials and the corresponding strains. The study revealed magnetic field induced strains in the magnetostrictive CFO and PMNPT piezoelectric materials as shown in Figure 3a and b, respectively. The CFO film is under compressive strain along [100] direction with a maximum value of $-2.9 \cdot 10^{-4}$ close to those found in the literature [1]. The PMNPT substrate displayed a tensile strain in the [100] direction with a maximum value of one smaller magnitude order than those found in the CFO film. Figure 3c shows the strain profiles in the both CFO and PMNPT components as a function of the grazing incidence angle. As shown in Figure 3c the results revealed a strong magnetic field induced strain in the CFO film only at a grazing angle below the critical angle (0.16°), i.e., within a few nanometers from the surface of the magnetostrictive CFO film. Then this shows that the magnetic field induced strain coupling is weak at the CFO/PMNPT interface. This is likely to be to the clamping of the film by the substrate.

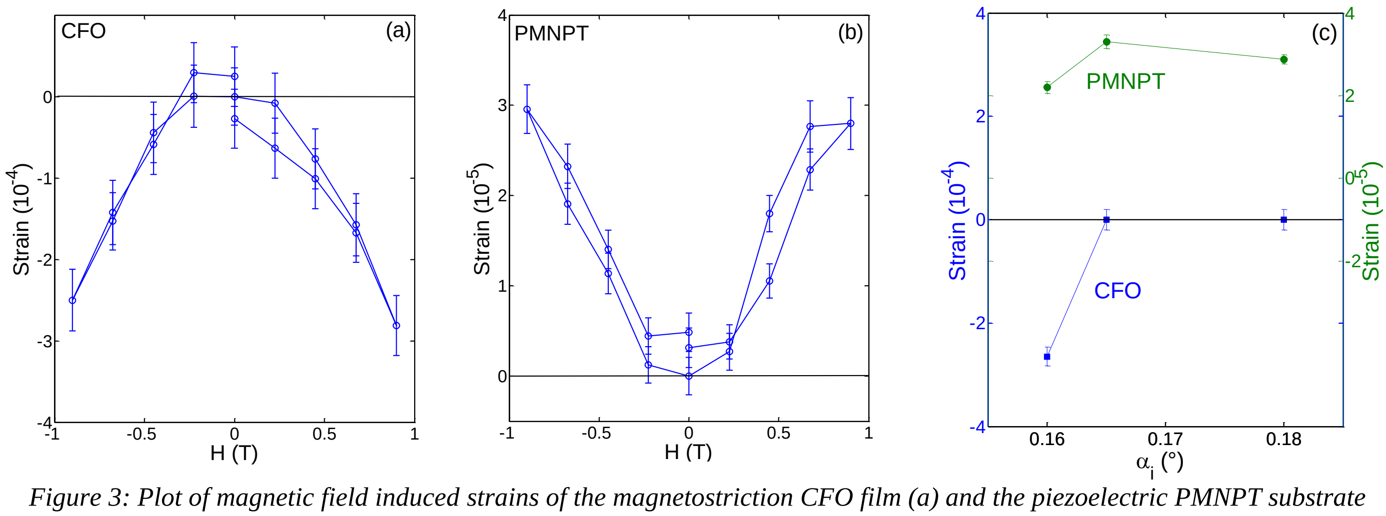

Figure 3: Plot of magnetic field induced strains of the magnetostriction CFO film (a) and the piezoelectric PMNPT substrate (b)Strain profile as a function of the grazing incidence angle (c)

In conclusion, to investigate the ME coupling at the CFO/PMNPT interface, we performed the magnetic field induced strain coupling in the CFO/PMNPT epitaxial composites at BM28. The study revealed that the magnetic field induced strain coupling is weak at the CFO/PMNPT interface due to the clamping of the film by the substrate. This observation demonstrates that the coupling at magnetoelectric epitaxial interfaces can be directly measured by X-ray diffraction.

In future work we plan to reproduce these promising results and perform systematic studies of related systems by this method.

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References:

[1] R. M. Bozorth, E. F. Tilden and A. J. Williams, Phys. Rev. **99** 1788 (1955)