Thin films of orthorhombic YbMnO$_3$

D. Rubi and B. Noheda

Zernike Institute for Advanced Materials, University of Groningen,

Nijenborgh 4, 9747AG-Groningen, The Netherlands

Multiferroic materials, those which can order ferromagnetically and ferroelectrically, are attracting a lot of attention from the fundamental point of view. Moreover, thin films of multiferroics have a great potential in applications and some of them, such as tunnel junctions driven by voltage or four-stage memories, have already been demonstrated [1,2]. One of the big advantages of thin film research is the possibility of tuning the magnetic and electrical interactions, as well as the coupling between them, by means of the strain imposed by a well chosen substrate.

The rare earth manganites are among the most popular multiferroics due to the large coupling observed between the dielectric and magnetic properties. For some of these compounds the reason for this large coupling is well understood now. In particular, in those that present spiral magnetic ordering, such as TbMnO$_3$ and DyMnO$_3$ (see Figure 1), it has been shown that the spin spiral itself breaks the inversion symmetry, creating ferroelectricity [3].

![Figure 1: Magnetic phase diagram for rare earth manganites[4].](image)

The ground state of bulk YbMnO$_3$ has the hexagonal structure but under high pressure, the metastable orthorhombic phase can also be obtained. Orthorhombic YbMnO$_3$ displays an antiferromagnetic (AF) transition at 40K, followed by a spin re-ordering at 35K, in which the sinusoidal AF arrangement switches to an E-type AF ordering. This, according to recent theoretical work, should trigger the appearance of ferroelectricity[5]. So, o-YbMnO$_3$ is likely to be a good multiferroic. However, reports on o-YbMnO$_3$ are scarce, specially in thin film form. Therefore, we have grown thin films of o-YbMnO$_3$ on (111)-oriented SrTiO$_3$ substrates in order to investigate their magnetic and ferroelectric properties, and the effect of epitaxial strain on these. The structure and strain state of the films was investigated by x-ray diffraction in standard and grazing angle geometry at W1.1 (HASYLAB).

Films with thicknesses ranging between 10 and 70 nm were grown by RHEED-assisted Pulsed Laser Deposition. The epitaxial relationship between the films and the substrate (111) surface is sketched in Figure 2a. The three-fold symmetry expected in this case was observed by means of
azimuthal scans. The evolution of the out-of-plane lattice parameter with thickness confirmed that the thinnest films are subjected to compressive strain, as expected from the mismatch between the in-plane lattices of the two crystals, and that the strain relaxes with increasing thickness. Atomic force microscopy showed that the strained films, with thicknesses below 20nm, were atomically flat with RMS roughness lower than one unit cell. For t> 20nm, the roughness was found to increase with increasing thickness, typical of 3D-type of growth. All the films show crystallographic domains with a clear evolution as thickness increases. In all cases, the main reflection in the x-ray diffractograms cannot be indexed with a bulk-like orthorhombic cell; indeed, grazing incidence diffraction experiments reflect an in-plane tilting of these domains, suggesting a lower symmetry that the orthorhombic bulk structure. The in-plane component of this contribution is fully coherent with the substrate for t< 20 nm and relaxes for thicker films, in agreement with the behavior of the out-of-plane component. Orthorhombic (101)-oriented and (011)-oriented domains can be observed in the relaxed films, while in the thinnest strained films only a very weak contribution of (101)-oriented domains can be seen next to the main peak. Work is in progress to elucidate the microscopic relationship between the film and the substrate and its effect on the magnetoelectric coupling.

Figure 2. Left: Epitaxial relationship between orthorhombic YbMnO₃ (yellow rectangle) and the (111)-oriented SrTiO₃ substrate. Center: Reciprocal space map around the (112)c reflection of the substrate of a relaxed film showing three different types of domains. Right: 2θ-ω scan around the (111)c reflection of a fully strained film.

We would like to gratefully acknowledge Wolfgang Caliebe for his continuous support and help at the beamline.

References