GROWTH OF HETEROSTRCTURED (BILAYERED) MULTIFERROIC FILMS

Institution: Institution: UAB

Involved researchers: Zengwei Tan, Prof. Jordi Sort, Dr. Enric Menéndez

Manipulation of exchange bias with electric field is of potential technological interest to boost energy efficiency in spintronic devices. Here, this effect is illustrated at room temperature in field-cooled $Fe_{80}Ga_{20}/Ir_{20}Mn_{80}$ bilayers grown on lead magnesium niobite-lead titanate (PMN–32PT) ferroelectric <011> single-crystals.

Ta(10nm)/$Fe_{80}Ga_{20}$(10nm)/$Ir_{20}Mn_{80}$(20nm) thin films were grown by sputtering on $Pb(Mg_{1/3}Nb_{2/3})O_3$–$32PbTiO_3$ (PMN–32PT) ferroelectric <110> single crystals. The thickness of these substrates was 0.25 mm. Sputtering was carried out in a vacuum chamber with a base pressure of 1.2×10^{-7} Torr by using an AJA International magnetron system. During sputtering, the working pressure was kept at 3×10^{-3} Torr. The 10 nm Ta buffer layer inserted between $Fe_{80}Ga_{20}$ and PMN–32PT served as top electrode to apply voltage across the ferroelectric substrate (as shown in Figure 1). The bottom electrode was made by employing silver paste to uniformly cover the back side of PMN–32PT single crystals. By doing so, adjustable electric fields were homogeneously generated perpendicular to the ferroelectric PMN–32PT substrate by varying the strength of the external voltage. Hysteresis loops were recorded by vibrating sample magnetometry (MicroSense VSM) while applying voltage in-situ (converse magnetoelectric effect). From each hysteresis loop, the values of coercivity, H_C (width of the hysteresis loop), exchange bias field, H_{EB} (shift of the hysteresis loop along the magnetic field axis) and remanence-to-saturation ratio (squareness ratio), M_R/M_S (evaluated from centered loops, after correcting for the loop shift) were evaluated. Prior to magnetoelectric measurements, the sample was field cooled to induce the exchange coupling effect between the ferromagnetic ($Fe_{80}Ga_{20}$) and antiferromagnetic ($Ir_{20}Mn_{80}$) layers (i.e., exchange bias). The field-cooling (FC) procedure consisted of first warming the sample to 400 K and then cooling it down to 300 K using H = 5 kOe external magnetic field. Subsequently, different DC voltage values were applied, in the range from -200 V to +200 V, following the ferroelectric hysteresis loop. Magnetic hysteresis loops were measured along the field-cooling direction. This procedure was repeated after FC along the [100] and [01-1] in-plane directions of the PMN-32PT substrate. The ferroelectric properties of the PMN–32PT substrate were assessed using static polarization hysteresis loops measurements. The standard mode of the TFAnalyser 2000 (aixACCT), with an integration time of 1 ms and relaxation time of 1 s, was employed. With this procedure, the displacive current flow through the circuit (I) was measured and the polarization P was obtained from the integrated current with time and normalized to the surface area (A): $P = 1/\mathrm{A} \int I dt + c$. The constant c was selected to obtain equal values of polarization at maximum negative and positive applied electric field.

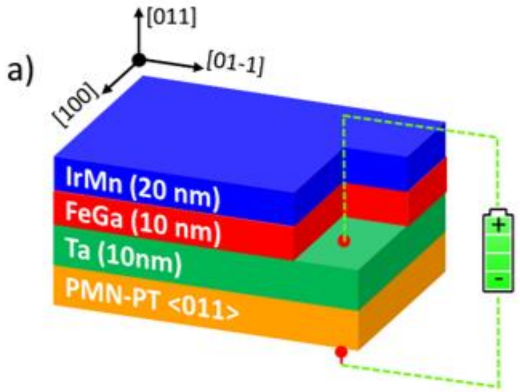

Figure 1: *Schematic representation of the electric configuration used to apply voltage to the PMN–32PT/Ta/*$Fe_{80}Ga_{20}$*/*$Ir_{20}Mn_{80}$ *system.*

After allowing the system to relax through consecutive hysteresis loops (training effect), the strength of the exchange bias field (H_{EB}) was assessed and it was found to increase by applying suitable voltage values across the ferroelectric PMN–32PT substrates. The relative variations of H_{EB} are approximately 24% and 4.5% along the PMN–32PT [01-1] and [100] in-plane directions. These observations are due to strain-mediated magnetoelectric coupling. Further work is nevertheless needed to exactly determine the mechanism underlying the training effect and the variations of exchange bias with voltage for this system.

Institution: AALTO

Involved researchers: Weijia Zhu, Prof. Sebastiaan van Dijken

Fe films with a thickness of 20-30 nm were grown onto $BaTiO_3$ substrates using molecular beam epitaxy. At room temperature, $BaTiO_3$ is FE and it has a tetragonal crystal structure. Above 120°C, $BaTiO_3$ is paraelectric and exhibits cubic symmetry. The Fe films were epitaxially grown at 300°C. This resulted in (001)-oriented Fe films with a Fe[110]//$BaTiO_3$[100] crystal alignment in the film plane, as inferred from cross-sectional transmission electron microscopy, selected area electron diffraction, and x-ray diffraction (Figures 2 and 3). The strain-coupled FE and FM domains are formed during cooling through the FE Curie temperature at 120°C. Magneto-optical Kerr effect (MOKE) microscopy measurements after growth confirm full imprinting of FE domain patterns into FM film, as indicated in Figure 4.

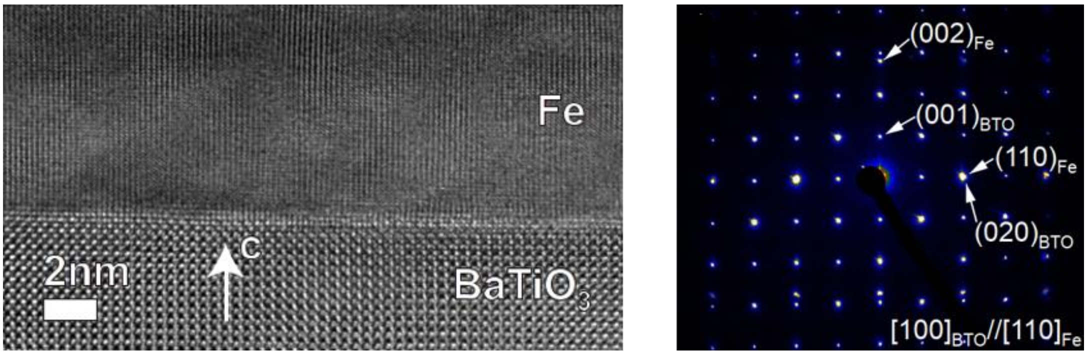

Figure 2: *Transmission electron microscopy image of a Fe film on top of a* $BaTiO_3$ *substrate and a selected area electron diffraction pattern of the sample. The (001) Fe film is epitaxial with a Fe[110]//*$BaTiO_3$*[100] crystal alignment in the film plane.*

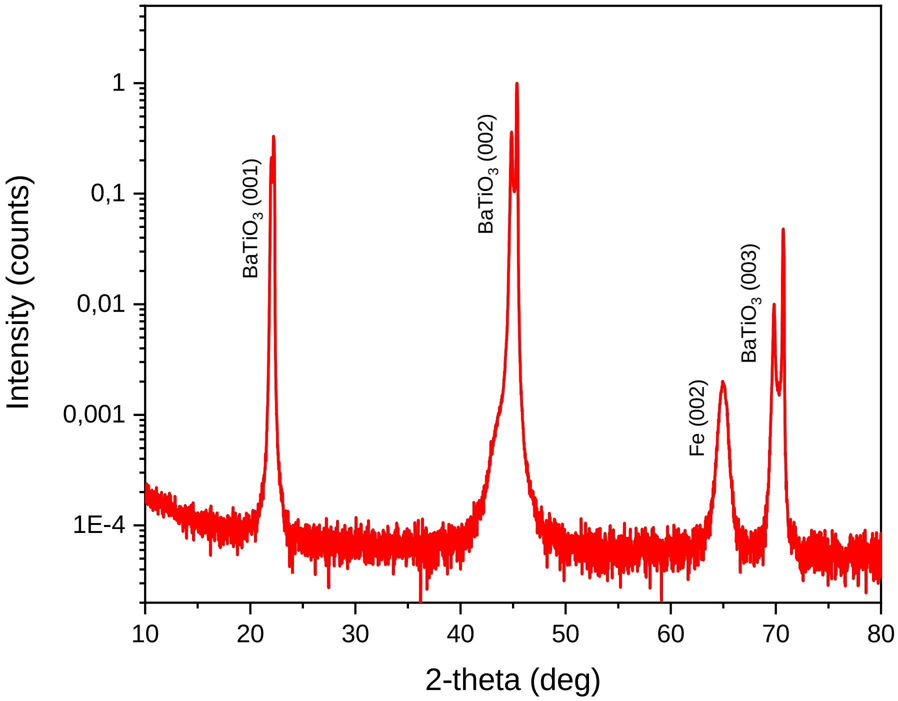

Figure 3: *X-ray diffraction* θ - 2θ *scan of the Fe/*$BaTiO_3$ *sample. The diffraction peaks illustrate (001)-oriented film growth on the (001)-oriented substrate.*

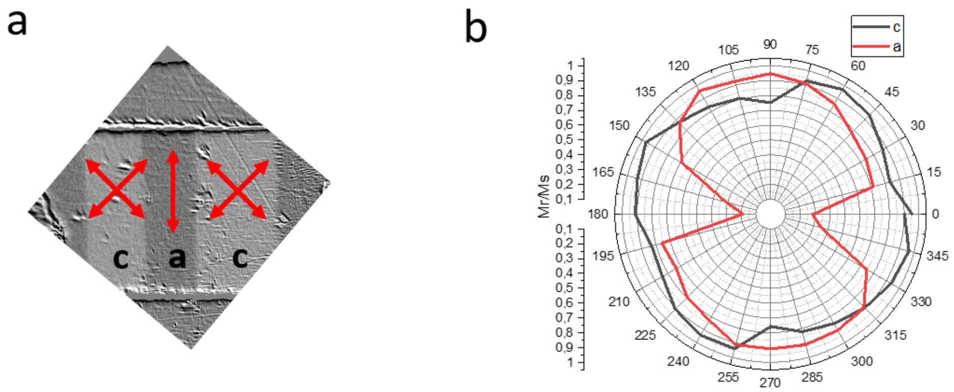

Figure 4: a MOKE microscopy image of the FM domain structure in the Fe film in zero magnetic field. Alternating FM stripe domains are observed (hereafter, I label them as *a* and *c* domains). The orientation of magnetic anisotropy of *a* and *c* domains is labeled by double-headed arrows. **b** Polar plot of the normalized remnant magnetization (M_r/M_s) for the *a* and *c* magnetic domains shows uniaxial and biaxial magnetic anisotropy properties.

References

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Institution: TTS

Involved researchers: Eleftherios Niapos, Ing. Lenka Mikulickova

We deposited the thin films presented in the Table 1. The deposition was made with the method of Triode Sputtering. Before the deposition, the base pressure was $8.5x10^{-6}$ Torr and during the deposition the working pressure was $5.1x10^{-4}$ Torr. The temperature was 100°C-120°C. Previous attempts of fabricating samples with smaller thickness of the ferromagnetic layer (2nm) led to the formation of small clusters with superparamagnetic properties and not continuous films.

Samples	Thickness (nm)		
Ta/Fe/BaTiO	**Ta**	**Fe**	**BaTiO3**
	50	5	10
	50	10	10
	50	15	10
	50	20	10
	50	5	20
	50	10	20
	50	15	20
	50	20	20
Ta/Co/BaTiO3	**Ta**	**Co**	**BaTiO3**
	50	5	10
	50	10	10
	50	15	10
	50	20	10
	50	5	20
	50	10	20
	50	15	20
	50	20	20
Ta/Ni/BaTiO3	**Ta**	**Ni**	**BaTiO3**
	50	5	10
	50	10	10
	50	15	10
	50	20	10
	50	5	20
	50	10	20
	50	15	20
	50	20	20

Table 1

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