Magnetic domain quenching in PMN-$_{0.4}$PT/Ni heterostructures via mild annealing cycles

Deepak Dagur[a,b], Hemanita Sharma[b,c], Federico Motti[c], Aleksandr Yu. Petrov[c], Solenn Reguer[d], Giorgio Rossi[c,e], Dominique Thiaudiere[d], Michael Foerster[a], Miguel Angel Niño[a], Piero Torelli[c], and Giovanni Maria Vinai[c]

[a] *ALBA Synchrotron Light Facility, Barcelona, Spain*
[b] *University of Trieste, Trieste, Italy*
[c] *CNR – Istituto Officina dei Materiali (IOM), Trieste, Italy*
[d] *Synchrotron SOLEIL, Paris, France*
[e] *University of Milan, Milan, Italy*

In the framework of multiferroic heterostructures and magnetoelectric coupling, the role of thermal treatments has been up to now rarely explored. Here we report on the structural and magnetic modifications of PMN-PT/Ni heterostructures during mild annealing cycles. Samples were heated up to 200 °C (i.e. PMN-PT Curie temperature, corresponding to the tetragonal to cubic structural transition), monitoring the magnetic behaviour at intermediate steps via XMCD-PEEM images. We observe the stabilization of exotic domain structures at Ni edge before the structural transition, which remain quenched at room temperature. By combining them with XRD 3D maps in temperature, we correlate such structures with the stabilization of intermediate structural phases.

Keywords: magnetostriction; thermal treatments; multiferroic heterostructures.

1. Introduction

Multiferroic heterostructures, coupling ferroelectric/ piezoelectric substrates with magnetic thin films via interfacial magnetoelectric coupling, have gained increasing interest for their fundamental properties and potential applications. Whereas the main coupling mechanisms are considered quite well established,[1] the wide range of levers able to modify the properties of either the ferroelectric or the ferromagnetic component of the heterostructure leave room for further investigations. Here we present the stabilization of exotic magnetic domains in PMN-PT/Ni heterostructures upon mild thermal annealing, up to now rarely explored.[2] PMN-PT (Pb(Mg1/3Nb2/3)O3-xPbTiO3), widely used in multiferroic heterostructure, has been chosen for its complex phase diagram and its high sensitivity to external stimuli[3] whereas Ni for its good magnetostrictive properties and sensitivity to interfacial strain.[4]

2. Results and discussion

Thin Ni films (10 nm) were deposited on PMN-$_{0.4}$PT (001) substrates, with Al_2O_3 as capping layer, via sputtering depositions. The pristine substrates were not heated during the deposition neither before any characterization.

The samples, preliminarily characterized at room temperature via MOKE and laboratory-based XRD, where then demagnetized and measured via XMCD-PEEM at CIRCE, Alba synchrotron, where Ni domain contrast was measured while heating the heterostructure. Twin samples were characterized structurally at Diffabs, Soleil synchrotron, via XRD 3D maps.

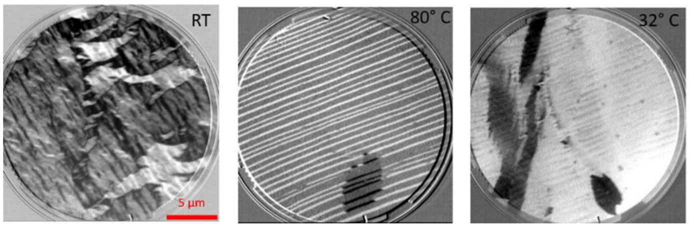

Figure 1: XMCD-PEEM at Ni L3 edge during mild thermal cycle. From left to right, room temperature, 80°C and 32°C.

Structurally, PMN-PT showed the presence of intermediate phases before reaching the tetragonal to cubic transition, which, for selected temperature ranges, could be stabilized at room temperature. Interestingly, a corresponding evolution of the interfacial magnetic properties was observed on the interfacial Ni layer. In the case of pristine unannealed heterostructures, a typical disordered domain distribution is observed (Fig.1). On the other hand, when mild temperatures are reached, highly ordered elongated domains are observed through the whole sample. Interestingly, hints of such domains presist once cooled.

By combining XRD and XMCD-PEEM measures, we can correlate the formation of such exotic domain structure to a highly strained configuration present at mild temperatures. The possibility of quenching such states at room temperature gives interesting perspectives towards technological implementation via local thermal treatments.

References

[1] J.-M. Hu *et al.*, Adv. Mater. **28**, (2016) 15–39
[2] D. Dagur *et al.*, ACS Appl. Electron. Mater. **6**, (2024) 6648−6656
[3] G. Vinai *et al.*, Adv. Electron. Mater. **5**, (2019) 1900150
[4] D. Dagur *et al.*, Adv. Mater. Interfaces **9**, (2022) 2201337

Acknowledgements: This work was performed in the framework of the Nanoscience Foundry and Fine Analysis (NFFA-MUR Italy Progetti Internazionali) project (www.trieste.NFFA.eu).