

SELF-ORGANIZATION IN COMPLEX OXIDE THIN FILMS: FROM 2-D TO 0-D NANOSTRUCTURES OF SrRuO₃ AND CoCr₂O₄

F. Sánchez, U. Lüders, G. Herranz, I.C. Infante, J. Fontcuberta
Institut de Ciència de Materials de Barcelona, CSIC, Campus UAB, Bellaterra 08193 (Barcelona),
Spain

M.V. García-Cuenca, C. Ferrater, M. Varela
Departament de Física Aplicada i Òptica, Universitat de Barcelona, Diagonal 647, Barcelona
08028 (Barcelona), Spain
E-mail: fsanchez@icmab.es

The extremely rich variety of functional properties of complex oxides, and the excellent crystal matching they can present, allows the design of a new electronics involving only oxides. The new devices could be revolutionary compared to the silicon-based ones, in part because the much superior behavior of some physical properties, but also due to the fact that some of these properties can be coupled, which can result in new functionalities. The development of these promises requires a precise control of multilayer architectures at atomic and mesoscopic scales, since the properties of the involved films can depend greatly on the lattice strain, and the complexity of the crystal structures favors the formation of defects that condition the functional properties. Therefore, it becomes essential the knowledge and control of the peculiar thin film growth phenomena in these materials and to correlate the resulting nanostructure with the final properties.

Some of the interesting physical properties of complex oxides are associated to very short characteristic length scales. However, defining geometries at such level can be not attainable with standard lithographic processes. For such purposes, self-assembly techniques are alternatives to be considered. On the other hand, in hybrid systems fabricated by self-assembly, the interfaces can be the result of a lateral coalescence and not of a bottom-to-up growth progression. Then, lattice strain state and defects associated to the interfaces could be of more easy control. New behaviors can be obtained with these new technologies, and this is exemplified with the recent findings of Zheng et al. [1]. The authors fabricated arrays of ferrimagnetic CoFe₂O₄ nanopillars embedded in a ferroelectric BaTiO₃ matrix by a self-assembly technique, and observed a remarkable coupling of magnetic and ferroelectric properties not found in ordinary multilayer structures.

In this presentation we shall overview our recent research on the heteroepitaxial growth of some functional oxides, namely the conductive ferromagnetic perovskite SrRuO₃ (SRO) on SrTiO₃(001) and of the insulating ferrimagnetic spinel CoCr₂O₄ (CCO) on MgAl₂O₄(001). We will show an extremely rich variety of growth modes of complex oxides, which allows the design and controlled fabrication of atomically smooth surfaces as well as nanostructured objects of varied reduced dimensionality with a high potential for new concept device applications.

Self-organized finger-like SRO structures of nanometric size form after an initial 3D growth of island that nucleated along the substrate steps. [2] With additional growth, there is a transition to 2D growth mechanism since after the coalescence of the finger-like structures an extremely smooth surface of terraces and steps forms and growth proceeds by step flow (Figure 1). The coalescence of the finger-like structures origins an oriented pattern of disordered regions that lead to an in-plane anisotropy of the electrical transport (Figure 2) [3-4]. We demonstrate that the self-organized quasi 1D fingers (and in turn the transport properties) can be controlled with the miscut angle of the SrTiO₃ substrates.

In the epitaxial growth of (001)-oriented CCO films, self-organized {111}-faceted pyramids and hut clusters appear (Figure 3) [6]. Contrarily to the well-known semiconductor dots, the CCO objects do not undergo shape transitions, even after having lateral dimensions above a micrometer. Since the {111} facets form an angle of 54.7° with the surface, the CCO pyramids can be considered true 3D structures. We prove that varying the deposition conditions the size and number of the objects can be tuned, and we demonstrate that arrays of elastically strained pyramids with narrow size distributions (peaked around a few tens of nanometers) can be fabricated (Figure 4). [7]

We discuss on the driving forces that originate the peculiar SRO and CCO nanostructures. These findings illustrate that the growth of complex oxides can promote a variety of novel self-organized morphologies, and suggest original strategies to fabricate templates or hybrid structures of oxides combining varied functionalities.

References:

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Figures:

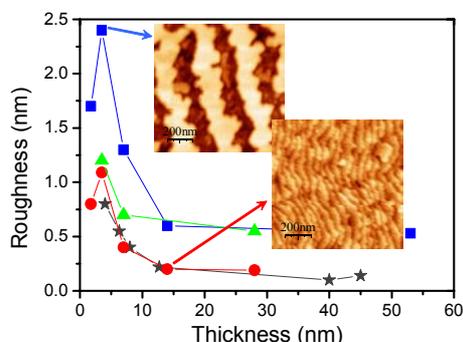


Figure 1: Surface roughness of SRO films against the thickness. The different symbols correspond to substrates with different miscut angle

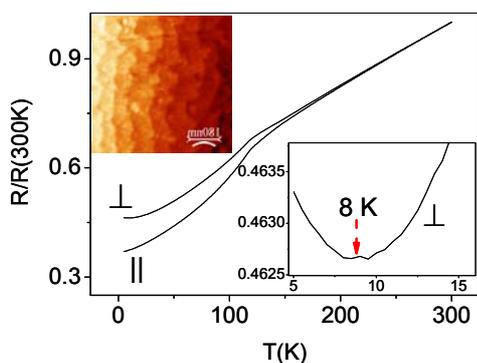


Figure 2: Normalized resistance measured perpendicular and parallel to the steps. The AFM image in the upper left corner illustrates the smooth morphology.

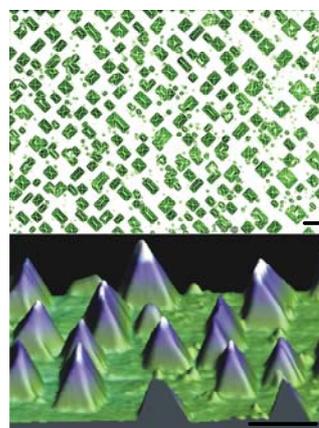


Figure 3: Morphology of a CCO film. Top panel: SEM view (derivative mode). Bottom panel: AFM view. The scale bar in both images corresponds to 1 μm.

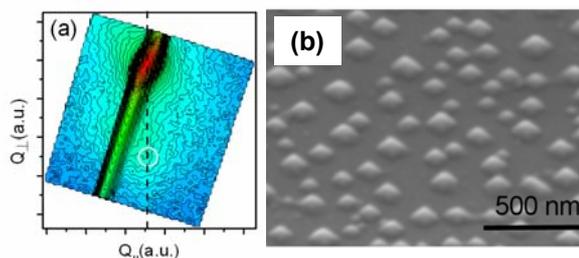


Figure 4: (a) XRD reciprocal space map of an asymmetrical reflection showing coherent growth of a film around 40 nm thick. (b) SEM view of the same film.