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Structure Domains Tuning Magnetic Anisotropy and Motivating Novel Electric Behaviors in $LaCoO_3$ Films

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Abstract : Great efforts have been taken to reveal the intrinsic origins of emerging ferromagnetism (FM) in strained $LaCoO_3$ (LCO) films. However, some macro magnetic performances of LCO are still not well understood and even controversial, such as magnetic anisotropy. Determining and understanding magnetic anisotropy might help to find the true causes of FM in turn. Perpendicular magnetic anisotropy (PMA) was the first time to be directly observed in high-quality LCO films with different thickness. The in-plane (IP) and out of plane (OOP) remnant magnetic moment ratio of 30 unit cell (u.c.) films is as large as 20. The easy axis lays in the OOP direction with an IP/OOP coercive field ratio of 10. What's more, the PMA could be simply tuned by changing the thickness. With the thickness increases, the IP/OOP magnetic moment ratio remarkably decrease with magnetic easy axis changing from OOP to IP. Such a huge and tunable PMA performance exhibit strong potentials in fundamental researches or applications. What causes PMA is the first concern. More OOP orbitals occupation may be one of the micro reasons of PMA. A cluster-like magnetic domain pattern was found in 30 u.c. with no obvious color contrasts, similar to that of $LaAlO_3/SrTiO_3$ films. And the nanosize domains could not be totally switched even at a large OOP magnetic field of 23 T. It indicates strong IP characters or none OOP magnetism of some clusters. The IP magnetic domains might influence the magnetic performance and help to form PMA. Meanwhile some possible nonmagnetic clusters might be the reason why the measured moments of LCO films are smaller than the calculated values 2 μB/Co, one of the biggest confusions in LCO films.What tunes PMA seems much more interesting. Totally different magnetic domain patterns were found in 180 u.c. films with cluster magnetic domains surrounded by < 110 > cross-hatch lines. These lines were regarded as structure domain walls (DWs) determined by 3D reciprocal space mapping (RSM). Two groups of in-plane features with fourfold symmetry were observed near the film diffraction peaks in (002) 3D-RSM. One is along < 110 > directions with a larger intensity, which is well match the lines on the surfaces. The other is much weaker and along < 100 > directions, which is from the normal lattice titling of films deposited on cubic substrates. The < 110 > domain features obtained from (103) and (113) 3D-RSMs exhibit similar evolution of the DWs percentages and magnetic behavior. Structure domains and domain walls are believed to tune PMA performances by transform more IP magnetic moments to OOP. Last but not the least, thick films with lots of structure domains exhibit different electrical transport behaviors. A metal-to-insulator transition (MIT) and an angular dependent negative magnetic resistivity were observed near 150 K, higher than FM transition temperature but similar to that of spin-orbital coupling related 1/4 order diffraction peaks.

Keywords : structure domain, magnetic anisotropy, magnetic domain, domain wall, 3D-RSM, strain
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