Wide-range epitaxial strain control of electrical and magnetic properties in high-quality $SrRuO_3$ films

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There is a strong relationship between the epitaxial strain in 4*d* ferromagnet $SrRuO_3$ films and its physical properties through the strong coupling between lattices, electrons, and spins [1]. It provides a promising way to tune the functionalities of $SrRuO_3$ in oxide electronics and spintronics. However, a comprehensive understanding of the strain effect in $SrRuO_3$ has remained elusive due to the lack of systematic studies.

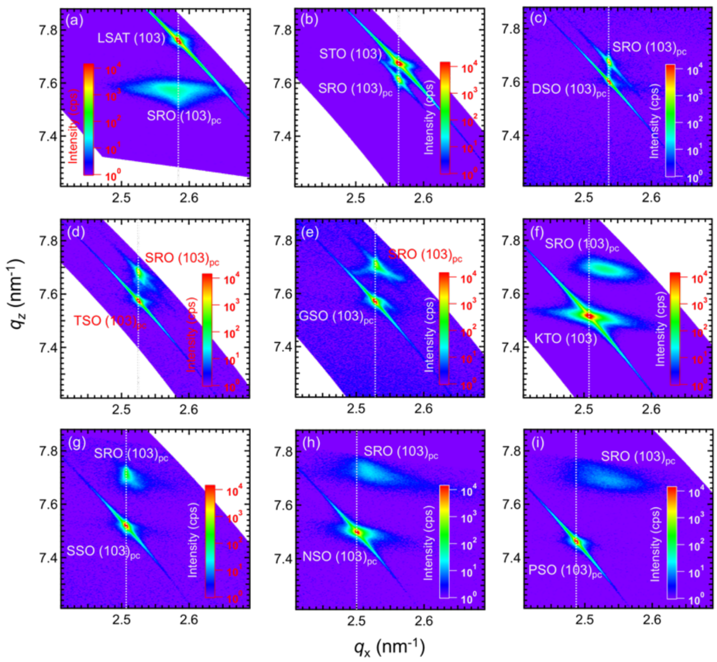

Figure 1 X-ray HRRSM around the $(103)_{pc}$ diffractions of the $SrRuO_3$ films on (a) $(LaAlO_3)_{0.3}(SrAl_{0.5}Ta_{0.5}O_3)_{0.7}$ (001), (b) $SrTiO_3$ (001), (c) $DyScO_3$ (110), (d) $TbScO_3$ (110), (e) $GdScO_3$ (110), (f) $KTaO_3$ (001), (g) $SmScO_3$ (110), (h) $NdScO_3$ (110), and (i) $PrScO_3$ (110) substrates. The white dashed lines indicate the peak positions of the (103) or $(103)_{pc}$ diffractions of the substrates.

In this presentation, we report on the wide-range epitaxial strain control of high quality $SrRuO_3$ thin films and the corresponding electrical and magnetic properties. We grew $SrRuO_3$ films with a thickness of 60 nm by our recently developed machine-learning assisted molecular beam epitaxy technique [2-4]. The epitaxial strain was imposed by cubic or pseudocubic perovskite substrates having a lattice mismatch of -1.6 to 2.3% with reference to bulk $SrRuO_3$ (a_{bulk} = 3.93 Å). We performed high-resolution X-ray reciprocal space mapping (HRRSM) to characterize the crystallographic properties of the films [Fig. 1]. The coherent growth was realized when the in-plane strain ε_a is in the range of -0.7 to 1.5%, corresponding to the in-plane lattice constant a_{film} of 3.901 to 3.988 Å, except for a_{film} = 3.953 Å (on $KTaO_3$). Thus, the epitaxial $SrRuO_3$ films are relaxed when the distance between Ru and O ions [d(Ru-O) = $a_{film}/2$] is out of the range of 1.951 Å < d(Ru-O) < 1.994 Å, reflecting the increase of the strain energy. The Poisson ratio, which represents the two orthogonal distortions owing to the substrate clamping effect, is estimated to be 0.33. The Curie temperature (T_C) and residual resistivity ratios of the series of films are higher than or comparable to the highest reported values for $SrRuO_3$ on each substrate, confirming the high crystalline quality of the films. A T_C of 169 K is achieved in a tensile-strained $SrRuO_3$ film on the $DyScO_3$ (110) substrate, which is the highest value ever reported for $SrRuO_3$. The T_C (146-169 K), magnetic anisotropy (perpendicular or in-plane magnetic easy axis), and metallic conduction (residual resistivity at 2 K of 2.10 - 373 μΩ·cm) of $SrRuO_3$ are controlled widely by epitaxial strain [5]. These results provide guidelines to design $SrRuO_3$-based heterostructures for device applications.

References [1] G. Koster *et al.,* Rev. Mod. Phys. **84**, 253 (2012). [2] Y. K. Wakabayashi, *et al.*, APL Mater. **7**, 101114 (2019). [3] K. Takiguchi, Y. K. Wakabayashi, *et al.*, Nat. Commun. **11**, 4969 (2020). [4] S. Kaneta-Takada, Y. K. Wakabayashi, *et al.*, Appl. Phys. Lett. **118**, 092408 (2021). [5] Y. K. Wakabayashi, *et al.*, arXiv:2101.12376.