Spectroscopy in STEM/TEM

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Atomic scale investigation of a $PbTiO_3/SrRuO_3/DyScO_3$ heterostructure

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Ferroelectric thin films have recently received a lot of attention because of the outstanding properties making them highly useful for applications in ferroelectric devices [1,2]. An essential component to create a contact to ferroelectric thin films is a metallic conductive $SrRuO_3$ oxide layer. Structural, physical properties and applications of $SrRuO_3$ have recently been extensively reviewed by Koster et.al. [3]. Particularly interesting is the self-organized formation of epitaxial $SrRuO_3$ ribbon-like structures on $SrTiO_3$ substrate steps. $SrRuO_3$ nanostructures are reported to nucleate on substrate steps followed by a 3D island growth [4]. Recent work reported on self-assembled $SrRuO_3$ nanowires, grow preferentially only on one type of $DyScO_3$ surface termination. A diffusion model was proposed where a difference in surface diffusion between DyO and ScO_2 was responsible for the formation of the $SrRuO_3$ nanowires [5]. Here we provide a thorough structural and chemical characterization at the atomic scale, leading to a comprehensive understanding of the detailed growth of $SrRuO_3$ in heterostructures. An epitaxial $PbTiO_3$ thin film grown on self-organized crystalline $SrRuO_3$ nanowires deposited on a $DyScO_3$ substrate with ordered DyO and ScO_2 chemical terminations is investigated by transmission electron microscopy. In this $PbTiO_3/SrRuO_3/DyScO_3$ heterostructure the $SrRuO_3$ nanowires are assumed to grow on only one type of substrate termination. Here we report on the structure, morphology and chemical composition analysis of this heterostructure. Electron energy loss spectroscopy reveals the exact termination sequence in this complex structure. The energy loss near edge structure (ELNES) of the Ti-$L_{2,3}$, Sc-$L_{2,3}$ and O K edges show intrinsic interfacial electronic reconstruction. Furthermore, $PbTiO_3$ domain walls are observed to start at the end of the nanowires resulting in atomic steps on the film surface [6].

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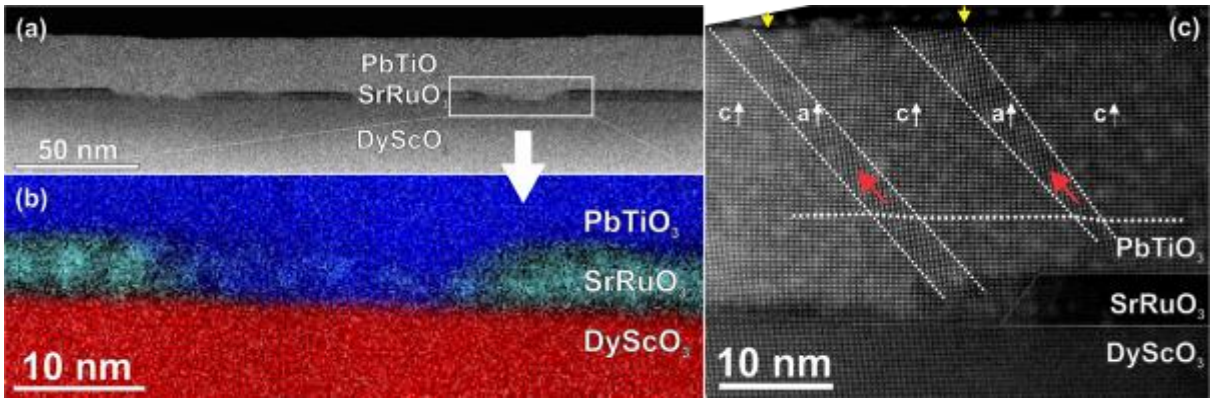

Figure 1. (a) HAADF-STEM overview image of the sample. The surface structure of the $PbTiO_3$ film and the $SrRuO_3$ nanowires of ~5x120nm size are distinct. (b) Colored elemental map with Ti (blue), Ru (light-blue) and Sc (red). (c) Magnified image of a nanowire ending showing the a and c domains. Domain walls in the film (white dashed-lines) occur (mostly) at the end of the nanowires.

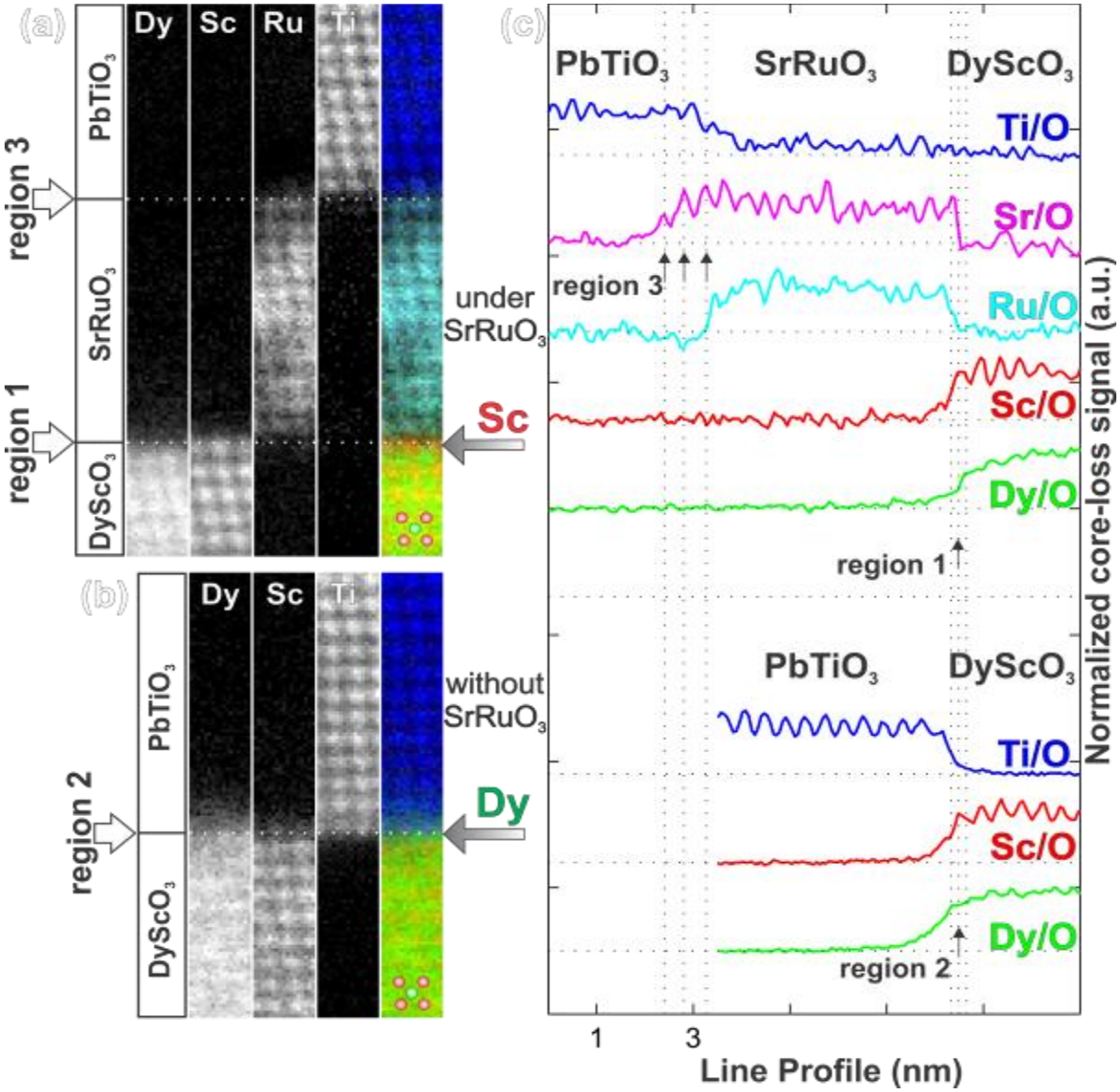

Figure 2. (a,b-left) EELS elemental maps of Dy-$L_{2,3}$, Sc-$L_{2,3}$, Ru-$M_{4,5}$, Ti-$L_{2,3}$ and O K edges (gray scaled) together with the corresponding color map with Dy (green), Sc (red), Ru (light-blue) and Ti (blue). (c) EELS elemental line profiles with Dy (green), Sc (red), Ru (light-blue), Ti (blue), Sr (pink) and O (black).