Surface Properties and Thermal Behavior of Epitaxial $SrRuO_3$ Thin Films

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Metallic strontium ruthenium oxide $SrRuO_3$ has recently attracted significant attention as a prominent material for oxide electronics. To elucidate the qualities of this material, which make it a good electrode for ferroelectric capacitors, we have studied the surface properties of $SrRuO_3$ using a combination of electron spectroscopies, low energy electron diffraction (LEED) and scanning probe microscopy. Epitaxial $SrRuO_3$ thin films were grown by pulsed laser deposition using a stoichiometric target on (001) $SrTiO_3$ substrates. Atomic force microscopy (AFM) images taken in air confirm the high quality of grown films, showing uniformly spaced terraces with single steps on the film surface, which closely imitate those of the $SrTiO_3$ substrate. After reinsertion into vacuum, a (1x1) LEED pattern has been observed from the as-inserted sample at room temperature without thermal treatment, revealing an excellent chemical stability in air. Corresponding vacuum scanning tunneling microscopy (STM) imaging and spectroscopy show some evidence of an inhomogeneous surface with insulating regions. The LEED pattern disappears after a brief anneal at 200 ºC, indicating surface disordering. To quantitatively investigate this behavior, $SrRuO_3$ thin films have been annealed in high vacuum in steps of 100ºC up to 800ºC and studied after cooling by LEED, x-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES) and STM. The evolution of the surface topography, atomic and electronic structure, and valence state of ruthenium was characterized and compared with results of thermodynamic calculations. The implications of these results for perovskite oxide electronic devices are discussed.

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