Strategies for the characterization of epitaxial thin films as Röntgen Materials

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About 50 years ago, Fisher [1] proposed the utilization of single crystals as distributed feedback resonators for compact X-ray lasers. However, the realization of a compact X-ray laser has been hindered by challenges associated with the usage of single crystals. In our previous work [2], we classified a new class of Röntgen materials and detailed their gain parameters for X-ray laser on a chip. We found that the quality of single crystals, particularly in terms of their stoichiometry and geometry, plays a crucial role in achieving the desired results. Moreover, we determined that only 100 nm^3 crystals are required for our purposes, leading us to propose the use of pulsed laser deposition (PLD) for their fabrication.

PLD is renowned for its epitaxial growth with stoichiometry transfer. We demonstrated the growth of a complex oxide, $La_{0.5}Sr_{0.5}CoO_3$, epitaxial thin film using a homemade compact PLD system. Extensive analysis of the crystal quality was performed through X-ray studies. Atomic force microscopy (AFM) was utilized to analyze the topography of the grown thin film, with the roughness estimated to be approximately 3.5 nm.

Resonance nuclear elastic scattering (RENS), a specialized technique akin to Rutherford backscattering spectroscopy (RBS), was employed to probe lighter elements within a heavier matrix. In our case, the thin film was grown on a strontium titanate substrate. RENS was employed to accurately estimate the oxygen content in the grown thin film. Furthermore, the thickness and stoichiometry of the grown film were analyzed using RENS. The thickness of the film was calculated to be 100 nm, assuming a theoretical density of 6.5 g/cm^3.

[1] Fisher, Robert A, Applied Physics Letters 24, **1974**, 12, 598-599.
[2] Rameshbabu, Sharath, and Bleiner, Davide, SPIE, **2023**, 12582, 95-103.