Growth of High-Temperature Superconducting Cuprate Thin Films

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ABSTRACT

Using Molecular Beam Epitaxy, Strontium calcium cuprate is grown on YAO substrates in varying temperatures and cation deficits to hopefully create superconductivity within the thin film that is purely in the orthorhombic phase.

INTRODUCTION

Superconducting thin films plays a abundant role in modern technology, finding applications in diverse areas ranging from MRI machines to microwaves, while also holding promise for efficient and renewable energy solutions. At Kyoto University, Z. Hirioi[1] made a breakthrough by achieving superconductivity in the orthorhombic phase of a strontium calcium cuprate polycrystal. Our endeavor was to replicate and expand upon his achievement by adapting his research to the realm of thin films, departing from the traditional polycrystal approach. The distinctive orthorhombic phase is characterized by unequal dimensions along its three axes, setting it apart from the tetragonal phase, which features two equal axes and one distinct axis. This innovative pursuit contributes to the evolution of superconducting materials with tailored properties for enhanced technological advancement.

METHODS

Strontium calcium cuprate thin film was synthesized through Molecular Beam Epitaxy (MBE) on a Yttrium Aluminum Oxide (YAO) substrate, which had been pre-annealed at 1200°C for a duration of 2 hours. Introducing controlled cation deficiencies of 5%, 10%, and 20% was achieved by modulating flux ratios during film growth. This thin film was cultivated at various temperatures for each deficiency percentage. X-ray diffraction (XRD) emerged as the central method for material characterization, elucidating structural properties. Concurrently, Atomic Force Microscopy (AFM) played a crucial role in quantifying surface roughness, enhancing the comprehensive understanding of the synthesized material's attributes. Additionally, the superconductivity of each film was tested.

RESULTS

Experimentation began being thinly grown on sapphire (Al_2O_3) substrates. YAO substrates were chosen because the lattice parameters aligned closely with the lattice parameters of the material we are growing (Strontium Calcium Copper Oxide). Doing scans such as the XRD scans and AFM Imaging shown in Figures 1-6. Allows us to determine what phase, tetragonal or orthorhombic, the samples are in.

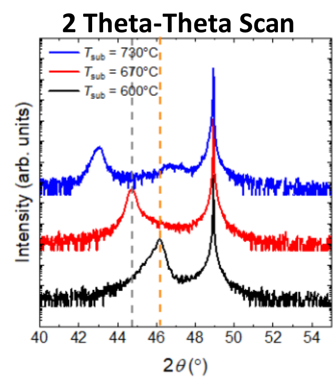

Figure 1: 5% Cation deficiency XRD

The 2 Theta-Theta Scan (Figure 1) reveals distinct temperature-dependent phases. At 730°C, no orthorhombic structure is observed, with a presence of some tetragonal phase. Lowering the temperature to 670°C results in a predominant orthorhombic phase and a minimal tetragonal presence. Upon reaching 600°C, the orthorhombic phase disappears entirely, giving way to an exclusive tetragonal configuration. Atomic Force Microscopy (AFM, Figure 2) analysis indicates minimal surface roughness. However, despite these intriguing

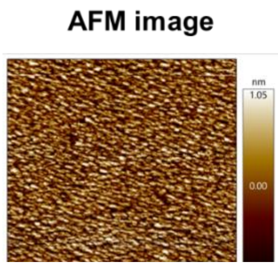

Figure 2: 5% Cation deficiency AFM

findings, no superconductivity is detected within the studied parameters. The 2 Theta-Theta Scan analysis (Figure 3) of the material containing 10% cation deficiencies reveals a

-Theta Scan

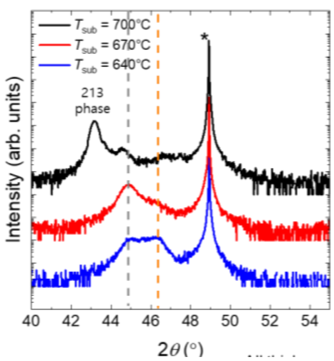

Figure 3: 10 % Cation deficiency XRD

dynamic phase evolution with changing temperatures. At 700°C, there is a minor presence of both orthorhombic and tetragonal phases. Transitioning to 670°C, the majority of the material adopts an orthorhombic structure, accompanied by a smaller tetragonal portion. Further reducing the temperature to 640°C results in an equilibrium between the orthorhombic and tetragonal phases. Atomic Force Microscopy (AFM, Figure 4) measurements exhibit approximately 50% higher surface roughness compared to the 5% sample. Despite these intriguing observations, superconductivity remains absent within the studied parameters.

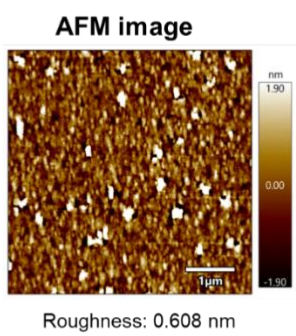

Figure 4: 10% Cation Deficiency AFM

Similar to the 10% cation deficiency samples, the material's phase distinctions became less distinct in the 2 Theta-Theta Scan (Figure 5) as temperature varied. At 680°C, a combination of orthorhombic and tetragonal phases is evident, reflecting a blurred boundary between the two structures.

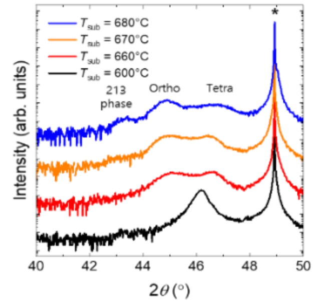

Figure 5: 20% Cation deficiency XRD

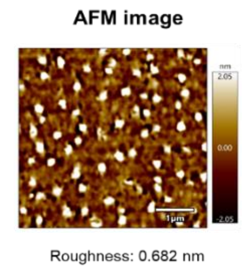

Figure 6: 20% Cation deficiency AFM

This trend continues at 670°C and 660°C, where the coexistence of orthorhombic and tetragonal phases persists. As the temperature drops to 600°C, this mixed-phase characteristic remains. Atomic Force Microscopy (AFM) analysis indicates a slightly rougher surface compared to the 10% sample. Despite these nuanced phase transitions, no superconductivity is detected within the parameters studied.

CONCLUSION

Our endeavor focused on synthesizing superconducting thin films of orthorhombic $(SrCa_{(1-y)})_{(1-x)}CuO2$ (with a critical temperature of 110 K) through Molecular Beam Epitaxy (MBE). We successfully fabricated the desired structure that had superconductivity within polycrystalline samples. However, our thin films, rather than exhibiting superconducting behavior, displayed insulating properties. To address this challenge, we formulated a hypothesis and are currently conducting experiments to ascertain whether an immediate post-growth oxidation process could induce superconductivity. Concurrently, we are exploring various models in our pursuit of fabricating a superconducting thin film with the desired characteristics.

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[1] Z. Hiroi, M. Azuma, M. Takano, Y. Takeda, Structure and superconductivity of the infinite-layer compound $(Ca_{1-y}Sr_y)_{1-x}CuO_{2-z}$, Physica C: Superconductivity,Volume 208. Issues 3–4.1993.Pages 286-296.ISSN 0921-4534.