Structural and Electrical Properties of Dysprosium Barium Copper Oxide ($DyBa_2Cu_3O_{7-\delta}$) Thin Films

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Abstract:

The high critical temperature of cuprate superconductors makes them ideal for many modern applications. In this study, we focus on one of these cuprate superconductors, $DyBa_2Cu_3O_{7-\delta}$ (DBCO). With the goal of creating high-quality DBCO films, we utilize oxide molecular beam epitaxy (MBE). The DBCO films were analyzed via X-ray diffraction (XRD) and X-ray reflection (XRR), followed by transport measurements after each growth. XRD was used to analyze the structure of the films to optimize and improve the film quality. XRR assisted in determining the film thickness to be assessed for precise calibration. Finally, transport measurements depicted the critical temperature of the films. Overall, these methods allowed for the growth of high-quality DBCO thin films.

Summary of Research

Since the discovery of high-temperature superconductivity in La-Ba-Cu-O [1], scientists have continued to discover materials with even higher critical temperatures (T_c). The discovery of a new superconducting material with higher T_c, $YBa_2Cu_3O_{7-\delta}$ (YBCO), made it the first to have a critical temperature higher than the boiling point of liquid nitrogen.[2]

One way to make superconducting materials with precise structural control and design is to fabricate them in thin films.[3] Recent improvements in vacuum technologies and thin film growth systems incentivized revisiting these high-T_c cuprates. Our research project focuses on $DyBa_2Cu_3O_{7-\delta}$ (DBCO) thin films [4], which displays structural similarities with YBCO. We focus on improving their structural and electrical properties utilizing thin films grown by the oxide molecular beam epitaxy (MBE) system.

This project aimed to attain high-quality high-T_c DBCO thin films together with optimizing structural and electrical properties. Oxide MBE has been one of the best methods for high-quality oxide thin film synthesis. The choice of substrate is the first critical step for synthesizing high-quality films, and for our project, we used $LaAlO_3$ substrates for high-quality *c*-axis DBCO growth. Prior to the growth, the MBE effusion cell temperatures were raised to the required growth temperatures and allowed to stabilize. X-ray reflection (XRR) was used to measure the thickness of the calibration samples, with which we can achieve the precise flux values of each source. In particular, the reflectivity oscillations of thin film XRR measurements were used to determine these films' thickness quantitatively. Given that the growth time and growth temperature are known, the thickness information is converted to the flux information of the respective source. After all the sources are calibrated (in some cases using reflection high energy electron diffraction (RHEED) oscillations), the growth of the DBCO thin films is conducted.

Results and Discussion

Once the DBCO thin film growth was finished, the films were examined in the PARADIM four-circle x-ray diffractometer. The X-ray diffraction (XRD) results of the MBE grown thin films were analyzed to determine the phase purity and structural quality, thereby revealing the effects of different growth parameters. These analyses led to the ideal temperatures for *c*-axis growth. Figure 1 shows the 2theta-ω scans of three DBCO thin films. Sample A (red) was grown at 630°C and shows an *a*-axis film with mild *c*-axis contribution, while Sample B (green) (grown at 680°C) shows a good quality *c*-axis film, for which the *a*-axis peaks are no longer present, more *c*-axis peaks appear, and the intensities of the *c*-axis peaks are higher. Sample C (blue), which has the highest growth temperature (750°C), presents the highest structural quality among the samples.

After the structural quality of the samples are examined, temperature-dependent resistivity of DBCO thin films is studied, where apparent differences are observed. The results are presented in Figure 2. While Sample C (blue) shows the highest T_c with a superconducting transition temperature of 87K, Sample B (green) exhibits a wider transition where the T_c is found to be 76K. Lastly, the *a*-axis film (sample A, red) has the lowest T_c (65K) and the highest resistance at room temperature. Our findings reveal that a sample's critical temperature depends on the structural quality, which is tuned by the growth temperature.

Conclusion

In conclusion, we scanned a wide range of growth temperatures for DBCO films, and we obtained high-quality *c*-axis as well as *a*-axis DBCO films as confirmed by XRD measurements. The critical feedback from XRD measurements paved the way for accelerated optimization of the growth parameters and achieving high-quality superconducting films. Our work, including transport measurements for each sample, shows that it is possible to create high quality, high-temperature superconducting *c*-axis DBCO thin films through specific growth temperatures and precise stoichiometry control.

Future Work

In the future, we plan to find optimal growth conditions for *a*-axis DBCO thin films by analyzing the samples with the same methods. One can also utilize the optimal growth conditions for *c*-axis DBCO thin films as reference to grow other kinds of thin films and eventually heterostructures. Heterostructures exhibit interesting properties within the interfaces and are worth researching in the future. For example, integrating our films into Josephson Junction (JJ) devices, where an insulating layer is sandwiched in between two superconducting layers, may be of interest due to the wide range of applications making them a worthwhile pursuit for future work.

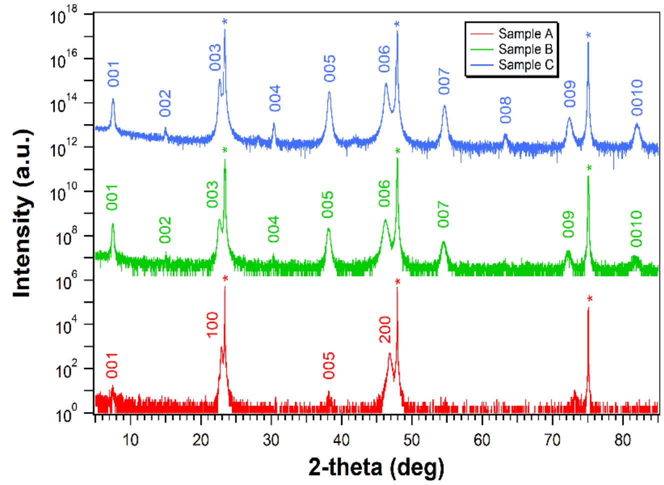

Figure 1. Structural quality. 2theta-ω scans of sample A (red), sample B (green), sample C (blue).

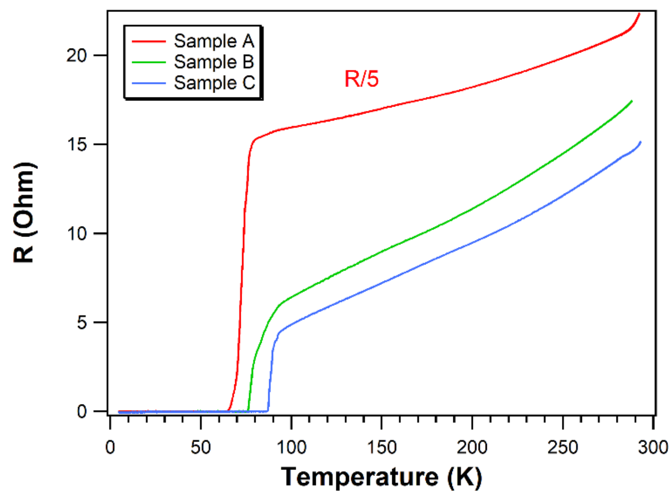

Figure 2. Resistivity vs temperature. Sample A (red), sample B (green), sample C (blue) exhibit the superconducting transition temperatures of 65K, 76K and 87K, respectively.

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