Towards Superconductivity in Ba-Doped $KTaO_3$ thin films

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Abstract

Superconductivity in $KTaO_3$ (KTO) has been demonstrated in 2 and 3 dimensions. While the superconductivity at the (111) and (110) interface can be induced by different "oxygen hungry" layers (e.g., AlO_x, TiO_x, EuO), in the bulk currently only electrostatic carrier doping has led to superconductivity. Conventional techniques fail to synthesize single crystalline KTO with sufficient carriers to stay metallic at low temperatures. In this work we successfully synthesized Ba:KTO_3 thin films grown by Suboxide Molecular-Beam Epitaxy (SMBE) that stay conductive to 4 K.

Introduction:

Potassium Tantalate ($KTaO_3$) is an ABO_3 cubic perovskite with fascinating physical properties that make it a possible candidate for advanced electronic and spintronic applications[1]. KTO has not been thoroughly studied in bulk, largely due to the volatility of potassium which makes it difficult to synthesize. $SrTiO_3$ (STO), a sister compound with similar physical properties to KTO has been studied in bulk and thin film form. STO shows unconventional superconductivity at the interface[2] as well as in bulk[3] where the transition temperature, T_c, can be manipulated through biaxial strain[4]. In contrast, the transition temperature of KTO varies drastically between bulk (50 mK)[5] and interface (2 K)[6]. With the recent development of KIn_4 as an air stable MBE source, the ability to synthesize Ba:$KTaO_3$ far from thermodynamic equilibrium, pushing the carrier concentration to a region where superconductivity has been observed.

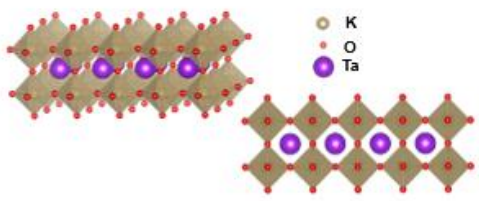

Figure 1: Structure of $KTaO_3$ modeled with Vesta.

Methods:

The process to synthesize barium doped $KTaO_3$ films follows pre-established molecular-beam epitaxy processes [7] with the addition of an elemental barium source. Barium was selected as the dopant due to its Ba^{2+} charge that would replace a K^+ charge in the $KTaO_3$ structure, leading to additional carriers which make KTO metallic rather than insulating. The $GdScO_3$ (GSO) substrate was held at a temperature of 600 ^oC throughout the duration of the growth, an approximate KTO flux of 1.8×10^{13} atoms-cm^{-2}-s^{-1} and barium flux of 5.0×10^{11} atoms-cm^{-2}-s^{-1} were used.

Results:

The synthesized film demonstrates good crystalline quality shown in the XRD and has a sharp interface between KTO and GSO by its Laue Oscillations (Figure 2b). The synthesized film is commensurately strained which can be observed in the reciprocal space mapping (Figure 2c). Upon confirming the quality and strain of the Ba:$KTaO_3$ film, resistance versus temperature measurements were taken from 300 K to 4K – in which the film remains its metallic behavior with a carrier density of 4.36×10^{20} carriers/cm^3 (Figure 3).

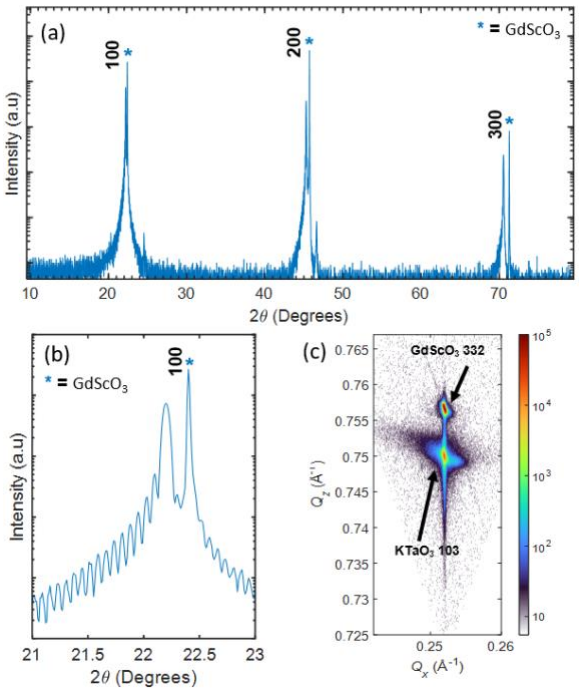

Figure 2: (a) X-Ray Diffraction of Ba-doped $KTaO_3$ thin film (b) Zoomed (100) XRD peak of $KTaO_3$ film on GdScO3 to ensure crystallinity remained intact upon incorporation of Ba^{2+} into the $KTaO_3$ lattice and (c) Reciprocal Space Mapping (RSM) of $KTaO_3$ film on $GdScO_3$

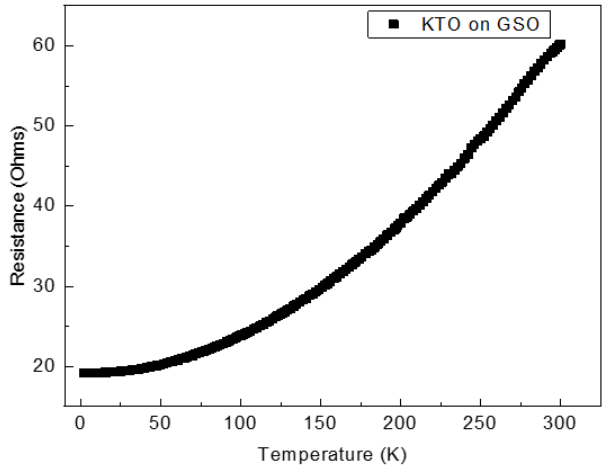

Figure 3: Resistance versus T curve of $KTaO_3$ (100) on $GdScO_3$ (110) indicating metallic behavior in the films down to 4K. The Hall measurement extrapolated a carrier value of approximately 4.36×10^{20} carriers from barium doping.

Conclusions:

This work establishes a minimum barium source temperature that provides sufficient carriers to enable metallic behavior down to 4K in KTO films, while maintaining high crystalline quality.

Future Work:

Further studies on the barium source temperature, effect of strain, and dilution fridge measurements will be crucial to exploring and understanding the superconducting behavior of bulk KTO in addition to SIMS to distinguish shallow and deep donors.

Acknowledgments:

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References:

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