Structure and Transport Relationships of ZrN on MgO (001)

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Combining superconducting metals with semiconductors provides the basis for many solid state devices including Josephson junctions, single electron transistors, and some photon emitters [1]. The interface between the superconductor and semiconductor can be a major source of loss in these devices, and the transport properties are highly intertwined with structural disorder and defects at various length scales. This project focuses on elucidating the role of disorder on superconductivity using thin films fabricated by molecular beam epitaxy, a deposition technique which leverages precise control of stoichiometry, temperature, and substrate preparation. Using molecular beam epitaxy, we employ a method for controlling resulting disorder at the crystalline, structural scale and atomic scale resolutions.

ZrN thin films, a known superconductor, were deposited on various substrates and orientations across a range of growth conditions. Structural disorder is characterized using high-resolution x-ray diffraction. Additionally, 4-point contact schemes are used to analyze the effects of the structural disorder and determine the relationships with electrical transport down to cryogenic temperatures and under magnetic fields. These measurements reveal that the critical temperature of films deposited on MgO are below bulk critical temperature of 10 K, and some show steps indicative of multiple superconducting phases. The transport properties of ZrN on MgO are intimately related to the structural properties, which are found to depend on the nitrogen plasma conditions moreso than variations in substrate temperature. This somewhat contrasts observations on substrates with better lattice matching, which show quite a high dependence on substrate temperature. Disorder at a structural scale and atomic scale both arise, and can be somewhat independently controlled through tailoring the growth parameters. The understanding of disorder in epitaxial semiconductor-superconductor systems will pave the way for thin film based quantum devices.

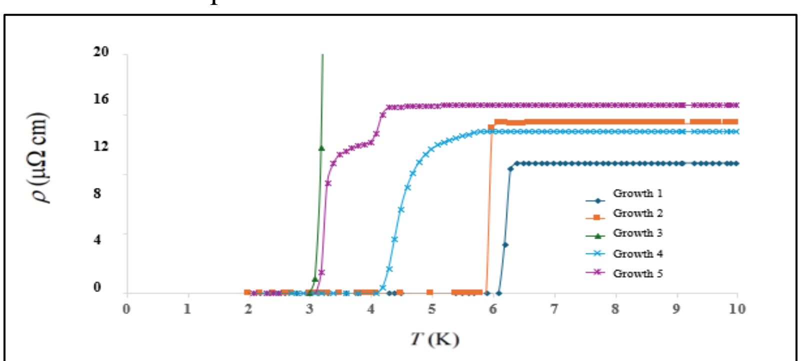

Fig. 1., Critical temperatures of ZrN films across varying growth conditions and substrate orientations.

Refs:

Delfanazari, K. Chip-scale electrically driven superconducting coherent photon sources for quantum information processing. *Nat. Photon.* **19**, 1163–1177 (2025).