Low temperature deposition of superconducting aluminum films for quantum information applications

Wilson J. Yánez-Parreño[1], Teun A. J. van Schijndel[1], Anthony P. McFadden[2], Raymond W. Simmonds[2], Christopher Palmstrøm[1,3]
[1]Electrical and Computer Engineering Department, University of California Santa Barbara, Santa Barbara, California 93106, USA
[2] National Institute of Standards and Technology, Boulder, Colorado 80305, USA
[3] Materials Department, University of California Santa Barbara, Santa Barbara, California 93106, USA

Aluminum is one of the most widely adopted superconductors for quantum information applications [1, 2]. It has well understood superconducting properties and a self-limiting oxide that is an ideal barrier in Josephson junction devices [1]. This together with the ability to grow it in a clean manner on low dielectric loss substrates like sapphire and silicon makes it the material of choice to make quantum information devices like transmon qubits [2], Nevertheless, a big disadvantage of superconducting aluminum is its low critical field of around Hc=100 Oe and critical temperature of Tc=1.2K which makes it non ideal in quantum applications that require higher temperatures or an applied magnetic field.

In this context, we explore the growth of superconducting aluminum films on c-plane sapphire and silicon (111) at room temperature and cryogenic temperatures of < 20 K during deposition. The films are synthesized in state of the art low-temperature molecular beam epitaxy equipment with in-situ reflection high energy electron diffraction (RHEED) characterization and a base pressure of $< 5 \times 10^{-11}$ mbar. We characterize the structure and crystallinity of the films, the substrate and the interface using x-ray diffraction, RHEED, atomic force microscopy and X-ray photoelectron spectroscopy. We measure electrical transport in these films under perpendicular magnetic fields and temperatures as low as 70 mK and correlate the superconducting properties of aluminum with its structure. We find that low temperature deposition increases the degree of structural disorder which enhances the critical temperature and critical field of aluminum to Tc=1.5K and Hc = 690 Oe. We then fabricate superconducting microwave resonators on these films and study the loss in aluminum grown at cryogenic temperatures.

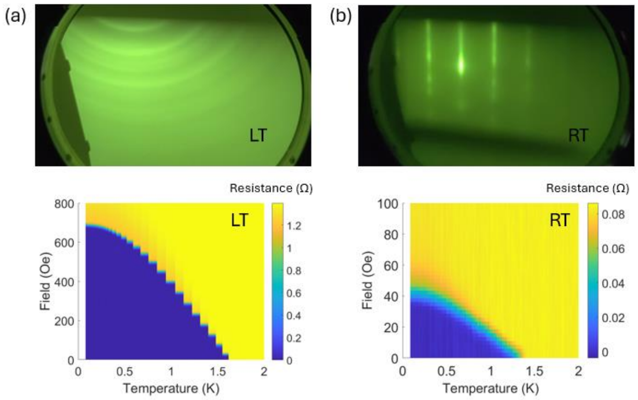

Figure 1: Reflection high energy electron diffraction patterns and resistance as a function of temperature and perpendicular magnetic field of aluminum grown on c-plane sapphire at (a) low temperature (LT) and (b) room temperature (RT).

[1] C. R. H. McRae, et al. Review of Scientific Instruments **91** (2020).

[2] Aute, F., et al. Nature **574**, 505-510 (2019).

Author for correspondence: cjpalm@ucsb.edu