Overall, this study offers a theoretical foundation for designing and using rare-earth phosphor materials, focusing on thermodynamics and structural stability and supporting the ongoing development of high-performance white-light LED technologies. (Reported by Bi-Hsuan Lin)

This report features the work of E-Wen Huang and his collaborators published in Appl. Phys. Lett. ***124****, 094105 (2024).*

TPS 21A X-ray Nanodiffraction
TPS 23A X-ray Nanoprobe

- XRF, XEOL, XAS
- Materials Science, Structure, Emission Properties, Applications of High-Entropy Materials

Reference

1. Y.-H. Wu, T.-N. Lam, S.-W. Ke, W.-J. Lee, C.-Y. Lee, B.-Y. Chen, G.-C. Yin, W.-Z. Hsieh, C.-Y. Chiang, M.-T. Tang, B.-H. Lin, E-W. Huang, Appl. Phys. Lett. **124**, 094105 (2024).

Exploring Quantum Materials by Using Synchrotron X-rays

Superconducting qubits composed of aluminum (Al) and aluminum oxide (Al_2O_3) play a pivotal role in advancing quantum information science.

The United Nations proclaimed 2025 as the International Year of Quantum Science and Technology (IYQ). Quantum technology will have a significant impact on human life. Synchrotron facility plays a vital role in the development of science and technology. This article will introduce how synchrotron X-rays can be used for quantum technology. Minghwei Hong (National Taiwan University) and his collaborators investigates the structural and superconducting properties of nanometer-thick aluminum (Al) films grown on sapphire substrates using molecular beam epitaxy (MBE), with an emphasis on the use of an *in situ* deposited aluminum oxide (Al_2O_3) capping layer to maintain the pristine condition of the ultrathin films.

This paper aims to describe the key challenges in developing materials for superconducting quantum circuits, where high crystallinity and minimized dielectric losses are essential for enhancing the coherence times. By carefully controlling the growth parameters and implementing the Al_2O_3 capping layer, they achieved high-quality Al films with remarkable crystallinity, abrupt interfaces with adjacent layers, and superconducting properties, which demonstrate potential for applications in quantum information technologies.

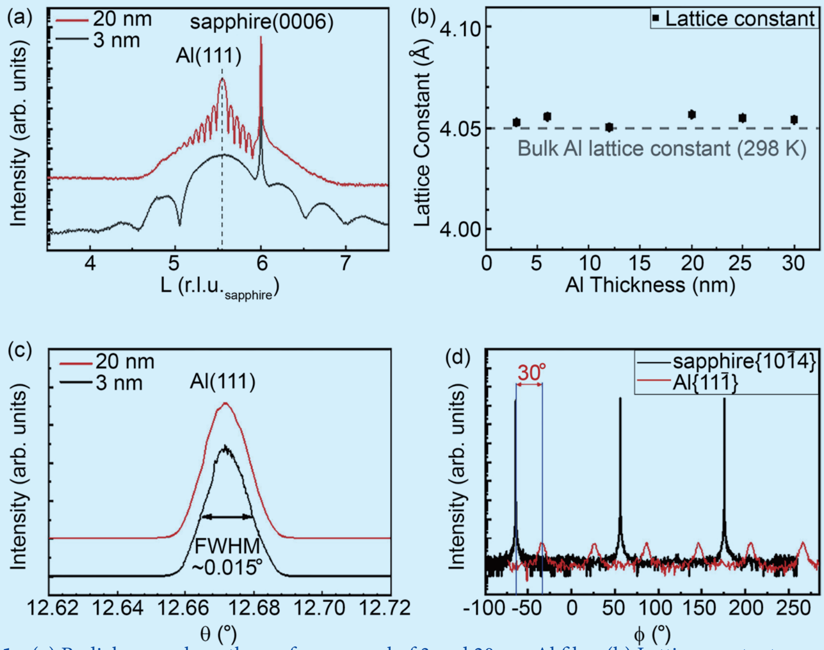

Fig. 1: (a) Radial scans along the surface normal of 3 and 20 nm Al film. (b) Lattice constants derived from inter-planar spacing along surface normal as a function of film thickness. (c) θ-rocking curves of 3 and 20 nm-thick Al films. (d) Azimuthal ϕ-scans across off-normal Al{11$\bar{1}$ and sapphire{10$\bar{1}$4 reflections. [Reproduced from Ref. 1]

Figure 1 demonstrates the high structural quality, crystallographic orientation, and stability of lattice properties in the nanometer-scale Al films. The radial scans along the surface normal, θ-rocking curves, and azimuthal ϕ scans exhibit the structure, crystallographic quality, and the epitaxial alignment of the nanometer-thick Al films. X-ray diffraction (XRD) using synchrotron X-ray (**TLS 17B1** and **TLS 13A1**) can provide the capability for measuring the nanometer-thick Al films.

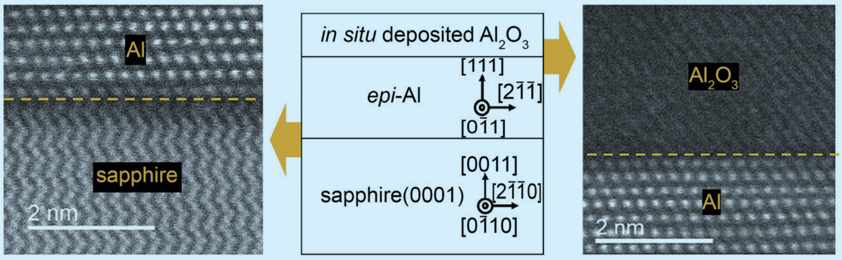

Fig. 2: High-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) images of cross-sectional views of the MBE-grown *epi*-Al/sapphire heterostructure (left) and the *in situ* deposited Al_2O_3/*epi*-Al heterostructure (right). A schematic representation of the heterostructure (center) shows the orientations of the *epi*-Al film and the sapphire substrate. [Reproduced from Ref. 1]

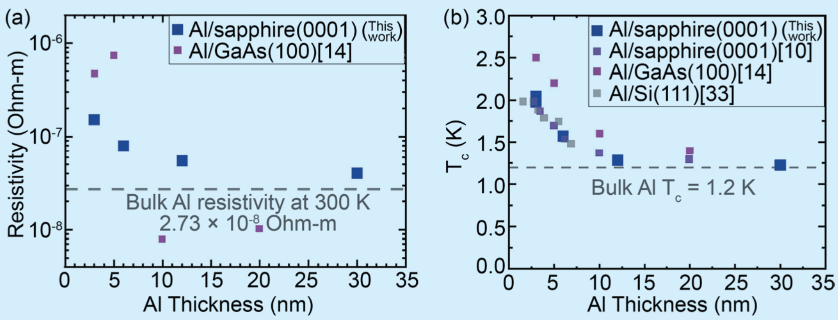

Fig. 3: (a) Resistivity vs. Al film thickness and (b) superconducting critical temperature vs thickness of Al films. [Reproduced from Ref. 1]

Figure 2 exhibits the excellent crystal growth capability of MBE and visually confirms the success of the *in situ* Al_2O_3 capping layer technique in maintaining the pristine, well-ordered structure of ultrathin Al films. These results are prerequisites for the development of reliable, low-dielectric-loss superconducting devices in quantum computing, demonstrating that the perfected growth process can produce the high-quality, stable interfaces required for effective superconducting quantum circuits.

To understand the potential of these ultrathin Al films in superconducting quantum circuits, we illustrate in **Fig. 3** the electrical properties of the nanometer-scale Al films, particularly their resistivity and superconducting critical temperature (T_c), as a function of film thickness. This study successfully demonstrated superconductivity in these nanometer-thick Al films, with T_c varying with the film thickness. T_c ranged from 1.2 K for thicker films up to approximately 2 K for the thinnest films. This variation in T_c with thickness is likely due to quantum confinement effects or modifications in phonon modes, which alter the superconducting properties as the dimensions of the film decrease. These results suggest that these ultrathin Al films could be valuable for applications requiring superconducting materials at scaled dimensions as they maintain superconductivity even at nanometer-scale thicknesses.

In summary, this study provided valuable insights into the growth and superconducting properties of ultrathin epitaxial Al films for quantum computing applications. By employing precise MBE growth techniques and implementation of an *in situ* Al_2O_3 capping layer, Hong and his collaborators successfully demonstrated the potential of these ultrathin films to meet the serious demands of superconducting qubits, such as high crystallinity, abrupt interfaces, and stable superconducting properties at low temperatures. This paper highlights a new direction for fabricating Josephson junctions and microwave resonators, the key components in superconducting qubits for quantum computing. (Reported by Bi-Hsuan Lin)

This report features the work of Minghwei Hong and his collaborators published in J. Appl. Phys. ***136****, 074401 (2024).*

TLS 13A1 X-ray Scattering
TLS 17B1 X-ray Scattering

- XRD, XRR
- Materials Science, Surface, Interface, Superconducting Quantum Circuits

Reference

1. Y. H. G. Lin, C. K. Cheng, L. B. Young, L. S. Chiang, W. S. Chen, K. H. Lai, S. P. Chiu, C. T. Wu, C. T. Liang, J. J. Lin, C. H. Hsu, Y. H. Lin, J. Kwo, M. Hong, J. Appl. Phys. **136**, 074401 (2024).