Next-generation integrated quantum technologies with thin-film, single-crystal diamond

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Diamond is the leading solid-state platform for quantum networking and room-temperature deployable quantum sensing technologies. The continued evolution of quantum technologies in diamond requires heterogenous material platforms for sophisticated functionalities, device integration and packaging, and improved qubit performance. At UChicago and Argonne National Laboratory, we are creating pristine single-crystal diamond thin-films that host coherent color center qubits and utilizing direct-bonding processes to integrate them with a wide range of materials including fused silica, sapphire, thermal oxide, lithium niobate, tantalum, silicon and YIG (figure 1).[1] High-resolution imaging of a diamond membrane/sapphire interface showcases crystalline reconstruction, signifying bonding between the diamond and host substrate, and hosted color centers maintain excellent coherence throughout processing (figure 2).

In this talk, I will present our diamond thin-film synthesis and integration methods, and present in-depth characterization of the thin-films following integration, and update on recent results from the Advanced Photon Source at Argonne. I will highlight performance of the thin-films in quantum device architectures for networking and sensing, including record-setting qubit and photonic performance. I will demonstrate how material heterostructures composed of thin-film diamond bonded to thin-film lithium niobate unlock new functionalities for quantum networking nodes. For instance, we show that by utilizing the piezoelectric effect in lithium niobate, we can dynamically control strain within the diamond layer and tune critical qubit properties. I will also demonstrate how integration of thin-film diamond with glass substrates can be utilized to generate significant tensile strain in diamond, unlocking axial-free qubits within the diamond.

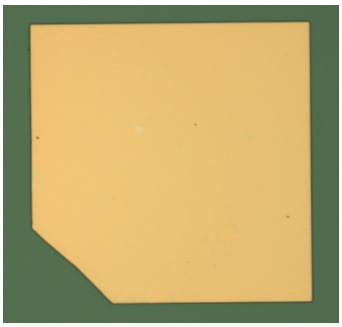

Figure 1: Microscope image of thin-film diamond bonded to oxide

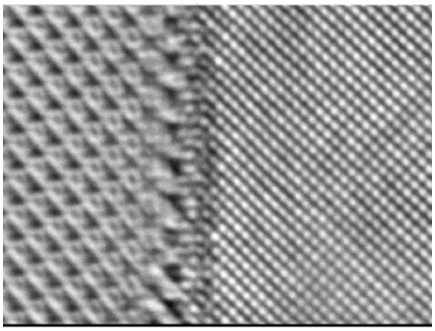

Figure 2: TEM of diamond (right) bonded to sapphire (left)

[1] X. Guo et al. Nature Communications 15, Article number: 8788 (2024)

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