Manufacturing Integrated Quantum Technologies with Direct-bonded Diamond Membranes

Xinghan. Guo[1], Avery Linder[1], Mouzhe Xie[1], Anchita Addhya[1], Zixi Li[1], Ian N. Hammock[1], Clayton T. DeVault[1,2], Yuzi Liu[3], Uri Zvi[1], Amy Butcher[1], David D. Awschalom[1,2,4], Nazar Delegan[1,2], Peter C. Maurer[1], F. Joseph Heremans[1,2], Alexander A. High[1*]

[1] *Pritzker School of Molecular Engineering, University of Chicago, Chicago, IL 60637, USA*

[2] *Center for Molecular Engineering and Materials Science Division, Argonne National Laboratory, Lemont, IL 60439, USA*

[3] *Center for Nanoscale Materials, Argonne National Laboratory, Lemont, IL 60439, USA*

[4] *Department of Physics, University of Chicago, Chicago, IL 60637, USA*

*[*ahigh@uchicago.edu](mailto:ahigh@uchicago.edu)*

Color centers in diamond have been used for many landmark experimental demonstrations for quantum sensing and networking. The continued evolution of diamond-based quantum technologies dictates the need for heterogeneous material integration and overall scalability. Currently, heteroepitaxy of single crystal diamond remains limited, greatly restricting technological integration efforts. Whereas thin-film wafer bonding, standard in CMOS technologies, has not yet been extended to diamond. Here, we demonstrate direct bonding of single-crystal diamond membranes to a wide variety of materials including fused silica, sapphire, thermal oxide, and lithium niobate. Our bonding process combines dry surface functionalization, annealing, and a customized membrane transfer process, allowing for minimal contamination while providing pathways for high yield and scalability. We show bonded membranes with overall thickness ranging from 15 nm to 500 nm, having nanometer-scale thickness variability over 200 um by 200 um areas. Transmission electron microscope (TEM) imaging reveals sub-nm interfacial regions on crystalline substrates. Additionally, the versatility and usability of this materials platform is demonstrated in quantum photonic and biosensing technologies. In order to improve defect addressability and spin-photon coupling efficiency, nanophotonic cavities with quality factor Q beyond 10,000 were demonstrated with the diamond membranes. Whereas quantum bio-sensing was achieved by functionalizing the membranes for biomolecule conjugation and cell growth in a total internal reflection fluorescence (TIRF) microscopy scheme. The processes demonstrated herein provides a full toolkit to synthesize heterogeneous diamond-based hybrid systems for next-generation quantum technologies.

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