Quantum Science and Technology Mini-Symposium
Room 208 W - Session QS2-TuA

Scalable Fabrication for Quantum Technology

Moderators: Ekta Bhatia, NY CREATES, **Bernardo Langa, Jr.**, University of Maryland

4:15pm **QS2-TuA-9 Scalable, Precise, and Reliable Positioning of Colour Centres for Quantum Computing and Simulation**, ***Mark Mills***, *Gianfranco Aresta, Kristian Stockbridge, Kate McHardy, Paul Blenkinsopp,* Ionoptika Ltd., UK

Quantum computing has the potential to revolutionize many aspects of modern technology and colour centres in diamond are a well suited system to be used as quantum simulators, quantum sensors and quantum networking interfaces. NitrogenVacancy (NV) centres are the most extensively studied due to their ground-state spin's long coherence times at room temperature. Next to NV centres, also group-IV colour centres in diamond offer a promising platform for quantum networks and started gathering interest as an alternatives, with the TinVacancy (SnV) centres standing out among group-IV defects due to their optimal spin-orbit coupling.

The technological challenges related to the fabrication of quantum devices based on these systems are related to the reliable and precise positioning of N and Sn atoms into the diamond matrix and the subsequent post implantation process such as thermal annealing and the scalability of the whole process.

In 2024 Ionoptika Ltd started a joint development project, partially funded by Innovate UK, in partnership with Surrey University, Fraunhofer Institute for Applied Solid State Physics IAF and XeedQ GmbH, bringing together a Focussed Ion Beam (FIB) System company, experienced FIB users and materials research Institutes with a quantum computing company. The aim of this project is to define a process for Scalable, Precise, And Reliable positioning of colour centres (NV and SnV) for Quantum computing and simulation.

We will be reporting on the engineering of a novel ion-beam column based on the well-established Ionoptika's Q-One platform for ion implantation. This single novel column will allow for use of both Liquid Metal Alloy Ion Source and Plasma Source. It will be equipped with an automated source adjustment system and ion beam autotuning. Parallel studies are being carried out with existing Q-One systems at Surrey University in collaboration with the other partners, Fraunhofer IAF and XeedQ, within this project, and we will report on these. We will also report on colour centres formation results obtained by other research institutes by using the Q-One ion implanter.

4:30pm **QS2-TuA-10 Scalable Single-Erbium Ion Qubits in Silicon Carbide for Integrated Photonics in the Telecom Band**, ***Spyros Galis***, *Alexander Kaloyeros,* University at Albany-SUNY

Advancing quantum photonics and communications requires scalable optical quantum devices compatible with chip-scale device integration and higher temperature operation (≥77 K) for integration into photonic integrated circuits (PICs). Highly integrable silicon carbide (SiC) has emerged as a promising PIC platform, offering ideal material and optical properties for classical and quantum photonics. In parallel, scalable material platforms doped with erbium (Er^{3+}), which has an optical transition in the telecom range at ~1532 nm, can enable a plethora of exciting photonic and quantum technologies operating in the telecom C-band. Toward this, telecom single-photon emitters (SPEs) and qubits based on single ions in semiconductors are essential for quantum PICs (qPICs), yet scaling them beyond the lab remains challenging due to material constraints, stringent fabrication and temperature requirements, and random emitter placement, complicating PIC integration.

Our approach utilizes a novel, scalable nanofabrication scheme to address these challenges, enabling the creation of SiC nanowires (NWs) and hollow nanopillars (HNPs). This approach facilitates the following key-enabling innovations: 1) the precise (<5 nm) placement of Er^{3+} ions in these nanostructures via advanced nanofabrication and implantation engineering and 2) an enhanced effective excitation cross-section (~6×10^{-18} cm^2). By leveraging these innovations, we have successfully isolated and characterized single and few-erbium ions in SiC NWs and HNPs at temperatures of ≥77 K—otherwise unattainable in bulk materials. Furthermore, through nanofabrication engineering and the minimization of implantation-induced defects, we have demonstrated single-photon Er^{3+} emission with a narrow optical linewidth of 90 MHz and single-Er^{3+}-ion qubit control, performed by Rabi oscillations in the optical domain and at temperatures of ≥77 K, in HNP SiC structures. Pertinent results will be presented, which, to our knowledge, represent the first experimental demonstrations of solid-state SPEs and single-ion qubits based on isolated Er^{3+}, highlighting our platform's viability for higher-temperature operation. We also concisely discuss opportunities for realizing Er-based SiC quantum integrated devices with improved performance and functionality, aiming to achieve practical qPIC devices for quantum and nanophotonic applications at telecom wavelengths.

4:45pm **QS2-TuA-11 Investigating Processing Spaces of Epitaxially Grown Nitride Materials with Quantum and Conventional Supervised Learning**, ***Andrew Messecar***, Western Michigan University*; Kevin Vallejo,* Idaho National Laboratory*; Steven Durbin,* University of Hawai'i at Mānoa*; Brelon May,* Idaho National Laboratory*; Robert Makin,* Western Michigan University

The experimental design of material synthesis occurs within highly complex processing spaces defined by multiple design parameters. Traditional identification of optimal values for each design term often involves an iterative, costly, Edisonian trial–and–error strategy for experiment design. Therefore, there is great interest in leveraging machine learning–based approaches to enhance and expedite the strategic design of materials and their synthesis pathways. Here, information describing plasma–assisted molecular beam epitaxy (PAMBE) growth trials of transition metal and group–III nitrides have been organized into distinct, composition–specific data sets. For each synthesis record, the complete recipe of experiment design parameters (substrate temperature, element source conditions, growth duration, etc.) are associated with binary numerical labels representing sample crystallinity and surface morphology as determined via *in–situ* reflection high–energy electron diffraction (RHEED) patterns. A Bragg–Williams measure of lattice ordering (S^2) is also investigated as an additional, continuous figure of merit pertaining to atomic–scale disorder. Quantum and classical machine learning algorithms – including linear models, neural systems, tree–based algorithms, and quantum support vector machines – are fit to the data to investigate which growth parameters have the most statistically significant influence over each material property of interest. When predicting the occurrence of monocrystalline PAMBE–grown GaN sample surfaces, supervised learning techniques incorporating quantum computation display notable generalization advantage when compared to classical machine learning approaches. The class–conditional probabilities of obtaining single crystalline, atomically–flat thin film crystals – as well as the degree of lattice ordering measured by S^2 – are forecasted across broad ranges of possible PAMBE operating parameter combinations. These predictions are compared to experimental best practices as well as the results described in published literature detailing the PAMBE synthesis of these materials. The improved generalization performance displayed by the quantum–aware models when predicting GaN crystallinity implies a potential advantage gained via quantum computational studies of synthesis–property relationships in other material systems.

*This work was supported in part by the United States Department of Energy (award number DE–SC0025835) as well as the National Science Foundation (grant number DMR–2003581).

5:00pm **QS2-TuA-12 Integration of Atomic Precision Solid State Quantum Hardware with energy efficient circuit, architecture and algorithm co-design for Energy Efficiency Scaling**, ***Tina Kaarsberg***, Department of Energy*; Sadasivan Shankar,* SLAC National Accelerator Laboratory*; Scott Lockledge,* Tiptek

It is auspicious that this abstract is being submitted on April 14—World Quantum Day--a date that includes the first three digits of Planck's constant, which is a fundamental constant in quantum physics. The United States Department of Energy (DOE) Advanced Materials and Manufacturing Technology Office (AMMTO) multi-organization initiative to reduce computational energy use with energy efficiency scaling for two decades (EES2) will likely rely in part on advances in quantum computing—including quantum hardware to reach its ultimate1000X energy efficiency goal. Under this initiative, DOE/AMMTO has funded analysis identifying new breakthrough approaches to energy efficient computing. For example, in Summer 2023, a SLAC analysis showed that using quantum algorithms for quantum mechanical calculations could use as little as one thousandth the energy of the same calculation on a classical computer. AMMTO also supports quantum hardware, for example in 2024, it announced two SBIR

grants for qubit manufacturing development of 3D atomically precise (AP) qubits made using hydrogen depassivation lithography. Such AP qubits have inherently lower error rates that more macro-sized qubits. This paper will highlight co-design integration of such AP solid-state quantum hardware with quantum software. The co-design will include innovations in circuit, architecture and algorithm for a wide range quantum calculations that could enable DOE to reach its 1000X energy efficiency goal

5:15pm **QS2-TuA-13 Measurement of Dielectric Loss in Piezoelectric Materials for Hybrid Quantum Systems***, **Ivan Lainez**,* University of Maryland College Park*; Richard Mattish,* Clemson University*; Bernardo Langa, Jr.,* University of Maryland College Park*; Maggie Marte, Deepak Sapkota,* Clemson University*; Christopher Rouleau, Jong Keum,* Oak Ridge National Laboratory*; Ashish Alexander,* Laboratory for Physical Sciences*; Kasra Sardashti,* University of Maryland College Park

An approach has been emerging to create hybrid quantum devices by combining quantum devices realized in distinct physical systems and therefore combining their advantages. In particular, piezo-acoustic cavities are of particular interest as they are capable of direct coupling of systems operating in the microwave regime to systems operating at the acoustic regime via acoustic modes through piezoelectric modulation. However, creating a piezo-acoustic cavity requires on-chip integration of physically disparate piezoelectric and superconducting materials while maintaining a coherent behavior at microwave frequencies and milliKelvin (mK) temperatures. The extent of dielectric loss in the piezoelectric elements within the cavities has not been well studied. Here, we study the dielectric loss in epitaxial heterostructures of barium titanate (BTO), Strontium titanate(STO), and Lanthanum nickel oxide (LNO)-on-silicon as promising platforms for piezo-acoustic cavities. We use a 6-resonator superconducting coplanar waveguide design as a pilot device to measure microwave losses at mK temperatures. By changing the thickness of various layers within the BTO/Si, STO/Si, and LNO/Si heterostructures, including the buffer layers (e.g., YSZ, CeO2), we determine the loss contributions for each oxide layer. Microwave transmission for each chip is measured at 30 mK-2 K with powers ranging from -60 to -120 dBm. The transmission spectra are then analyzed to extract the actual resonant frequency, quality factors (internal vs. external), and effective dielectric constant for each chip.

Author Index

Bold page numbers indicate presenter