

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

4:00pm **QS2-TuA-8 Sandia's Approach to Scalable Single Defect Center Creation using Focused Ion Beam Implantation, Edward Bielejac**, Sandia National Laboratories

INVITED

We will present an overview of Sandia's Ion Beam Laboratory (IBL) and its ongoing efforts to develop focused ion implantation capability using a range of accelerators to create scalable defect centers in wide bandgap materials. This presentation will cover three main topics:

(1) Novel liquid metal alloy ion source development (LMAIS) where we will concentrate on the development of LMAIS for our two mass filtered Focused Ion Beam (FIB) systems, the A&D nanoinplanter (A&D FIB100NI) and the Raith Velion, both of which combine high spatial resolution with CAD based patterning to enable the formation of arbitrary patterned implantation in a wide range of substrates.

(2) In-situ counting and in-situ photoluminescence (PL) to enable single defect center creation in wide bandgap materials such as diamond and silicon carbide. Using in-situ counting we demonstrate a seven-fold improvement on the expected ion implantation error over timed implantation. Using in-situ PL we enable real-time error correction on the formation of low yield optically active defect centers. The combination of counting and PL is a promising pathway towards deterministic formation of these defect centers.

(3) The development of ultra-low energy (<1 keV) focused ion implantation capability based on a biased sample holder configuration. This enables ultra-low energy implantation while maintaining an expected implantation resolution of between 100-300 nm.

It is the combination of these three topics that fundamentally enables the IBL approach to scalable single defect creation using FIB implantation.

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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 ($\sim 6 \times 10^{-18}$ cm²). 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

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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 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. Nitrogen Vacancy (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 Tin Vacancy (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 Focused 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.

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 ultimate 1000X 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 than 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

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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.

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