Quantum Science and Technology
Room 304 - Session QS-TuM

Quantum Sensing, Simulation, and Emerging Quantum Applications

Moderators: Suman Bhaumik, TEL Technology Center, America, LLC, **Walid Redjem**, University at Albany State University of New York, **Simon Seymour**, UIUC

8:15am **QS-TuM-2 Machine Learning from Steady-State Currents in Open Quantum Networks***, Yonatan Dubi,* Ben Gurion University of the Negev, Israel

Analog quantum computation offers a route to machine learning in which physical dynamics, not gate sequences, perform the computation. We show that open quantum transport networks can serve as complete machine-learning engines for both supervised and unsupervised tasks, using steady-state terminal currents as the sole readout: no qubits, no gate operations, no state tomography. A data vector is encoded as the excitation injected into a tight-binding network whose dynamics obey the GKSL master equation; the currents extracted at the output terminals then define a transport-induced representation of the input, and training amounts to optimizing the network hopping amplitudes. For supervised classification, the terminal carrying maximal current defines the class. This quantum classification network achieves precision and recall above 95% on wave-function overlap and localization tasks, and 86% average accuracy on experimental classification of aromatic aldehyde substrates by their deuteration reactivity, outperforming equivalent classical networks and resisting the overfitting that degrades them in the small-data regime. Classification survives dephasing rates up to about 100 times the mean hopping amplitude, within reach of current quantum-dot and photonic platforms. Removing the labels yields Qlustering, an unsupervised framework in which cluster assignments are inferred from correlations among output-current signatures. Benchmarks on synthetic clusters, localization separation, QM9 molecular subsets, and Iris show performance competitive with k-means, with a clear advantage where physically meaningful structure is encoded. We map the operating regime and outline implementation in programmable photonic and quantum-dot arrays.

8:30am **QS-TuM-3 Can NISQ-era Quantum Computing drive the design of new DFT Functionals?***, Simon Seymour, Andre Schleife,* University of Illinois, Urbana-Champaign

This work aims at comparing the epistemic uncertainty stemming from the lack of knowledge on the universal functional to the various uncertainty sources inherent to NISQ era quantum computing (QC). Three variational quantum subroutines with varying degrees of Quantum ErrorMitigations are implemented to estimate the total energies of quantum chemistry systems. Notably, one of the subroutines is novel and uses a Riemannian preconditioned Crank-Nicolson Markov Chain Monte-Carlo solver to infer the 2-Reduced Density Matrix (2RDM) of chemistry systems from sparse shadow tomography data. This construction was motivated to bypass both the limited quantum computational resources as well as to improve the scaling of previous 2RDM solvers based on Semi-Definite Programming. Finally, a dual Bayesian-Bootstrapping framework is established to identify the relevant sources of uncertainty within the QC workflow. This will help find strategies for improving QC performance and further the development of 2RDM tomography whose data we hope can eventually be used in the training stage of new Exchange-Correlation functionals.

8:45am **QS-TuM-4 Linearly Uncoupled Silicon Photonic Cavities for Quantum State Generation***, Prabha Prasad Nair,* University at Albany-SUNY

Quantum sensing leverages quantum mechanical resources to surpass classical limits of measurement precision. A key pathway is the use of squeezed states of light, which suppress quantum noise below the shot-noise limit and enable enhanced sensitivity in low-signal environments. In this work, we investigate the integration of squeezed light within silicon photonic circuits as a scalable platform for quantum-enhanced sensing. By embedding nonlinear optical processes into CMOS-compatible waveguides, we outline strategies for the on-chip generation and manipulation of squeezed states. To address the challenges associated with state-of-the-art squeezed-state generation, we propose a novel architecture consisting of two ring resonator cavities coupled through a Mach–Zehnder interferometer, enabling enhanced stability and control.

In addition to their applications in sensing, squeezed states play a crucial role in continuous-variable (CV) quantum information processing, underpinning protocols for universal quantum computation, quantum teleportation, quantum error correction, quantum secret sharing, and quantum key distribution. By combining compact nonlinear waveguides, interferometric architectures, and low-loss photonic integration, this work establishes a pathway toward fully integrated quantum sensors with sub-shot-noise performance, while simultaneously contributing to the broader development of scalable CV quantum technologies.

Our theoretical modeling and circuit-level simulations demonstrate the potential for significant noise reduction and improved detection sensitivity across applications such as biosensing, navigation, and precision metrology. This work lays the foundation for the experimental realization of integrated squeezed-light sources, advancing the development of compact, high-performance quantum sensors for real-world applications.

9:00am **QS-TuM-5 High Precision Fiber-Integrated Micro-Optics for Quantum Photonic Interfaces***, Raman Kumar, Sebastian Will,* Brookhaven National Laboratory

Scalable quantum photonic technologies require efficient light matter interfaces that are compact, alignment stable, and compatible with optical fiber infrastructure. Here, we report the nanofabrication of high precision micro-optical elements directly on the end facets of single mode fibers. Our approach is based on focused ion beam nano-machining, enabling a new class of fiber integrated quantum photonic components. We fabricate and characterize multiple classes of fiber-integrated optics, including micro-concave and micro-convex spherical elements, spiral phase plates, and axicons, using focused-ion beam (FIB) to define three-dimensional optical profiles directly on the fiber core [1].

Precise alignment to the guided optical mode is achieved by selectively etching the fiber facet, which reveals the doped core as an alignment marker before FIB machining. Atomic force microscopy shows that the spherical surfaces achieve subwavelength form accuracy. Surface roughness analysis further shows no measurable degradation after optimized FIB processing, with roughness remaining in the sub nanometer range establishing quantum grade optical performance.

Optical characterization with visible laser illumination confirms the intended functionality of the fabricated elements. Axial imaging demonstrates fiber-integrated focusing from spherical micro-optics with radii of curvature in the range of hundreds of microns, while Mach-Zehnder interferometry verifies the azimuthal and radial phase structures generated by spiral and axicon fibers, respectively. The resulting far field patterns and interferometric signatures confirm deterministic phase control.

These results establish FIB-fabricated fiber micro-optics as a compact, alignment free, and quantum-grade platform for quantum photonic interfaces, with applications in fiber coupled atom cavity QED, and structured light generation for high dimensional quantum information processing.

References:

[1] Kumar, R., & Will, S., “High precision micro-optical elements on fiber facets via focused-ion beam machining.” *arXiv:2604.18426* (2026).

9:15am **QS-TuM-6 Selective Area Growth of Highly Lattice-Mismatched PbSe Nanostructures on GaAs by Molecular Beam Epitaxy***, Ashlee Garcia,* Stanford University*; Hosni Kaissi,* University of Minnesota*; Jarod Meyer, Kira Martin,* Stanford University*; Maksim Gomanko,* University of Pittsburgh*; Laura Stern, Pooja Reddy, SeongJin Park,* Stanford University*; Wilson Yanez-Parreno,* University of Minnesota*; Sergey Frolov,* University of Pittsburgh*; Vlad Pribiag,* University of Minnesota*; Kunal Mukherjee,* Stanford University

Selective area growth (SAG) of PbSe by molecular beam epitaxy offers exciting opportunities for integrated photonics and quantum technologies. PbSe and its alloys with other IV-VIs have advantageous properties, such as a narrow bandgaps, high spin-orbit coupling, low Auger recombination rates, and a desirable defect tolerance,[1-9] that combined with selective area growth, have the potential to surpass current defect-sensitive state-of-the-art platforms for large-scale integration of site-selective quantum dots,[3] hybrid nanowire networks,[4] and low-cost mid-infrared (opto)electronics.[1,5] By using an amorphous mask to define its crystal growth, geometric control and deterministic placement of epitaxially smooth nanostructures on dissimilar substrates can be achieved without etching, mitigating degradation of quantum efficiency and disorder, to fully leverage its intrinsic properties.[4,10-12] In this work, we demonstrate PbSe SAG for the first time, characterize its promising growth morphology

and optical quality of PbSe islands and nanowires, and leverage these selectively grown structures for transport-based devices.

Selective PbSe growth was performed over patterned SiO_2 films on (001) GaAs, and smooth growth morphology (~0.5 nm root-mean-square roughness) was achieved in 100×100nm^2 square openings in the mask at 365°C. The islands were observed to be highly ordered with well-faceted low-energy {001} sidewalls and >99% single-orientation, which was confirmed by scanning transmission electron microscopy. Electron channeling contrast imaging measurements showed evidence of defect-free islands and coalescence boundaries despite the large 8% lattice mismatch. These SAG arrays showed room-temperature photoluminescence in the mid-IR, indicating that the optical functionality of PbSe was retained. Finally, gate-tunable Josephson junctions based on SAG nanowires grown under the optimized conditions were demonstrated, establishing phase-coherent electrical transport across the 130 nm junction and observing modulation of the critical current under in- and out-of-plane magnetic fields.

[1] J. Meyer et al. APL Mater. (2021) [2] G. Springholz. Molecular Beam Epitaxy (2nd Ed.), Ch. 11, Elsevier, 2018. [3]P. Kumar, Ch. 8, Woodhead Publishing, 2022. [4] J. Jung et al., Adv. Funct. Mater. 2022. [5] J. E. Meyer et al. Adv. Opt. Mater. 2024. [6] P. C. Findlay et al. Phys. Rev. B, 1998. [7] R. Klann et al. J. of Appl. Phys., 1995. [8] J. R. Meyer et al. IEEE J. Quantum Electron., 2021. [9] X. Zhang et aal. Phys. Rev. Lett., 2020. [10] S. Birudavolu et al. Appl. Phys. Lett., 2004. [11]T Schumann et al. Nanotechnology, 2011. [12] P. Aseev et al. Nano Lett., 2019.

9:30am **QS-TuM-7 Rejuvenating Photonic Quantum Sensing by Replacing Traditional Beamsplitters with Higher-Dimensional Gauge-Invariant Multiports**, ***Alexander Sergienko,*** Boston University **INVITED**

Photonics quantum sensors are among the central areas of quantum technologies. The optical Michelson or Mach-Zehnder interferometers are core elements of many photonics sensors. Introducing entangled and noise-squeezed quantum states in such interferometers boosts their sensitivity and resolution beyond classical limits. The original resolution of all conventional Michelson or Mach-Zehnder interferometers is limited by the maximum attainable slope of the intensity interference pattern as a function of the phase shift. The (cos^2) shape of all existing interferograms is determined by the physical properties of the optical beamsplitter - a traditional device that introduces an optical superposition and governs the operation of many known optical devices.

We introduced a novel concept of higher-dimensional gauge-invariant multiports. The directionally unbiased four-port Grover coin can be considered a higher-dimensional generalization of beam splitters, in which inputs to the four available ports have equal probability of exiting any of the four ports, including back reflection. *This offers direct access to a greater number of degrees of freedom* [1] (Fig.1).

We demonstrated that traditional interferometers acquire novel features and offer a dramatically ***enhanced resolution in phase measurement when directionally unbiased Grover multi-ports replace traditional beam splitters*** (Fig. 2). We demonstrated experimentally that the Grover-based counterpart of the conventional Michelson interferometer can substantially improve the phase measurement resolution due to a new feature of increasing the intensity-phase slope by 10X÷20X times instead of a traditional (cos^2) profile limited to 1 (Fig. 3). This converts any Michelson or Mach-Zehnder interferometer into a super-resolution sensor [2,3].

This novel approach dramatically elevates the baseline for optical interferometric measurements, even before quantum states of light are involved, thereby rejuvenating the field of high-resolution sensing. The introduction of quantum light (such as entangled or squeezed states) into new Grover-Mach-Zehnder or Grover-Michelson interferometers will increase the photonic measurement resolution even further.

[1] C. R. Schwarze, A. D. Manni, David S. Simon, A. Ndao, and A. V. Sergienko ''Next-Generation Interferometry with Gauge-Invariant Linear Optical Scatterers, '' Metrology, **v. 5**, 5040065 (2025).

[2] C. R. Schwarze, D. S. Simon, and A. V. Sergienko, Phys. Rev. A 106, 052615 (2023).

[3] C. R. Schwarze, D. S. Simon, A. D. Manni, A. Ndao, and A. V. Sergienko, ''Experimental demonstration of a Grover-Michelson interferometer'', Optics Express, v.32, p. 34116-34127 (2024).

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