Quantum Science and Technology
Room 304 - Session QS-TuM

Quantum Sensing, Simulation, and Emerging Quantum Applications

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

8:00am **QS-TuM-1 Opportunities for Quantum Sensing and Computing for Energy and Infrastructure Security Applications***, **Hari P. Paudel**, Yuhua Duan,* National Energy Technology Laboratory **INVITED**

Quantum information science (QIS) harnesses quantum mechanics to solve problems that are beyond the reach of traditional methods and devices. The rapid advances of quantum sensing and computing are creating promising pathways to improve energy production, distribution, and consumption, and minimizing security challenges. However, applying emerging technologies in quantum information science to real-world systems remains challenging. The National Energy Technology (NETL) is actively leveraging both experimental and computational tools to strengthen the nation's energy and security competitiveness.

This presentation will highlight recent advances in quantum sensing for energy and infrastructure security applications. Examples of mineral detection and exploration will be discussed, and possibilities for the deployment of quantum tools will be examined. The presentation will also showcase opportunities for materials chemistry and complex optimization problems in areas such as energy storage, fluid dynamics, and grid operations. This presentation will review quantum simulations of ground state and vibrational properties of small molecules, benchmarking current algorithms against qubit counts, basis sizes, and memory demands. The presentation will conclude by identifying high-value application pathways for addressing major challenges in the energy sector.

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.

<u>References:</u>

[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 The Role of QED-C in Growing the Quantum Industry***, **Sebastian Engelmann**,* QEDC, United States Minor Outlying Islands (the)

The Quantum Industry has gathered lots of interest and is on track to surpass 3B market size by 2028. While many advances in the scientific community are highlighted, commercial success is still not a given.

In the US, an Industry led consortium called QED-C has formed, which collects input from industry, academia and Government agencies. I will introducte QED-C, its mission and services to its members. In particular I will showcase the emerging Technologies TAC (technical advisory committee) and our recent activites.

In this talk I would like to highlight the items that are important for community, specifically what QED-C is doing in regards to testbeds, standards and foundry pathways.

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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