AVS Quantum Science Workshop
Room B110-112 - Session AQS-SuA

AVS Quantum Science Workshop: Materials & Surface Science of Quantum Sensing

Moderators: Philippe Bouyer, University of Amsterdam – Technical University Eindhoven, **Charles R. Eddy, Jr.**, Office of Naval Research Global - London

2:00pm **AQS-SuA-1 Single Ion Implantation for Quantum Devices and Materials using Focused Ion Beam Irradiation*, Edward Bielejec,*** Sandia National Laboratories **INVITED**

We will present an overview of Sandia's Ion Beam Laboratory (IBL) and its ongoing efforts to develop single ion implantation capability using a range of accelerators and detection techniques. The IBL operates seven focused ion beam (FIB) systems that range in ion energy from less than 1 keV to greater than 70 MeV, including a wide range of ion species from protons (H) to lead (Pb) over a range of spot sizes from nm to mm.This presentation will cover three topics:

(1) Novel liquid metal alloy ion source development (LMAIS) where we will concentrate on the development of LMAIS for our two mass filtered FIB systems, the A&D nanoImplanter (A&D FIB100NI) and the Raith Velion, both of which include 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 counting we demonstrate a seven-fold improvement on the expected ion implantation error over timed implantation.Using 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.

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2:40pm **AQS-SuA-3 On the Relevance of Avalanche Phenomenon in Wide Bandgap Technology*, Srabanti Chowdhury,*** Stanford University **INVITED**

Wide bandgap (WBG) materials like Silicon Carbide (SiC) and Gallium Nitride (GaN) have shown remarkable adaptability in fields ranging from optics to power electronics and radio technology. Their flexibility has led to a wide range of applications and a growing presence in the market. What makes them stand out is their exceptional ability to perform well in tough, high-temperature conditions. The progress in WBG materials has also sparked interest in a newer category of semiconductors known as ultrawide-bandgap (UWBG) materials, which have even wider bandgaps. Both WBG and UWBG materials are resilient to electric field issues due to their generous bandgap dimensions, offering advantages like improved efficiency, the ability to operate in high-temperature environments, smaller device sizes, simpler system designs, and energy savings. These technologies have the potential for broader positive impacts, including reducing carbon emissions. In terms of specific applications, GaN is currently a standout in lighting technology and has made significant contributions to radar and telecommunications. GaN has also found its way into power electronics. On the other hand, SiC excels in medium to high-power electronics and serves as an excellent foundation for GaN RF technology. As a result, SiC and GaN both complement and compete in different areas, shaping the landscape of applications and markets.

In our research focus on electronic device technology, we place particular emphasis on enhancing the efficiency of GaN through the phenomenon of avalanche multiplication. Avalanche, a fundamental occurrence in semiconductors, initiated by the impact ionization phenomenon, holds pivotal significance in various electronic devices, especially those designed for high-power and high-frequency applications. Our recent investigations have unveiled that beyond its traditional applications, avalanche can serve as a valuable tool for assessing material quality and refining device design. While achieving avalanche in GaN has become more common, attaining uniform avalanche behavior remains challenging. The relevance and intriguing observations associated with uniform avalanche will be discussed in our presentation. Concurrently, we are studying emerging technologies like AlGaN/AlN, Diamond, and β-Ga_2O_3, which have not yet demonstrated avalanche characteristics. The absence of avalanche phenomena prompts us to investigate the challenges faced by these materials. Our thorough examination covers different aspects of these materials, such as their properties, growth, and essential doping techniques. These factors are crucial in enabling avalanche capabilities in UWBG materials.

3:40pm **AQS-SuA-6 Interfacing Biomolecules with Coherent Quantum Sensors*, Peter Maurer,*** University of Chicago **INVITED**

Quantum metrology enables some of the world's most sensitive measurements. When applied to biophysical systems, diamond-based quantum sensors have the potential to probe processes that cannot be accessed by conventional technologies. Examples of such processes range from cancer research to neuroscience to developmental biology. However, interfacing coherent qubit sensors with fragile biological target systems has remained an outstanding challenge that has severely limited applications. In this talk, I will discuss a novel approach that combines single-molecule biophysics technology with quantum engineering to interface intact biomolecules on a diamond quantum sensor without impacting qubit coherence and bio-functionality. In a second part, I will discuss our recent work on engineering highly coherent quantum sensors based on diamond nanocrystal. Such nanosensors can readily be taken up by cells and integrated into intact organisms. However, coherence in these nanocrystal sensors is limited by surface noise, which severely reduces the sensor's sensitivity. In our work we developed a new approach to engineer spin coherence in core-shell nanostructures which leads to a 50-fold improvement in qubit sensitivity. Finally, potential future applications of quantum sensing to biophysics and diagnostics will be discussed.

4:20pm **AQS-SuA-8 Scale-Invariant Lasers Beyond the Schawlow-Townes Two-Mirror Strategy*, Boubacar Kanté,*** University of California at Berkeley **INVITED**

Lasers play a fundamental role in science and technology from quantum computing, to communications, sensing, and imaging. The scaling of lasers and in-particular of surface emitting lasers is a multi-decade long question that has been investigated since the invention of lasers in 1958. In the first part of the talk, I will argue that a surface emitting laser that remains single mode irrespective of its size, a scale-invariant laser, should of necessity also waste light at the edge. This is a fundamental departure from the Schawlow-Townes two-mirror strategy that preserves gain and minimizes loss by keeping light away from mirrors. The strategy was implemented in our recent discovery of the Berkeley Surface Emitting Laser (BerkSEL) [1]. In the second part of this talk, I will discuss our invention of functional topological lasers: integrable non-reciprocal coherent light sources as well as compact bound state in continuum sources [2-3].

References.

1- R. Contractor, W. Noh, W. Redjem, W. Qarony, E. Martin, S. Dhuey, A. Schwartzberg, and B. Kanté, "Scalable single-mode surface emitting laser via open-Dirac singularities," Nature 608, 692–698 (2022).

2- B. Bahari, A. Ndao, F. Vallini, A. El Amili, Y. Fainman, B. Kanté, "Nonreciprocal lasing in topological cavities of arbitrary geometries," Science 358, 636-640 (2017).

3- A. Kodigala, T. Lepetit, Q. Gu, B. Bahari, Y. Fainman, and B. Kanté, "Lasing Action from Photonic Bound States in Continuum," Nature 541, 196 – 199 (2017).

5:00pm **AQS-SuA-10 Panel Discussion*,***

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