STEVENS INSTITUTE OF TECHNOLOGY 1870

Ph.D. DISSERTATION DEFENSE

Candidate:	Seyed Sepehr Mohajerani
Degree:	Doctor of Philosophy
School/Department:	Charles V. Schaefer, Jr. School of Engineering and Science / Physics
Date:	Friday, April 25th, 2025
Time/Location:	1:30 p.m. / Burchard 714
Title:	Fabrication and Acoustic Manipulation of Quantum Emitters in 2D Semiconductors
Chairperson:	Dr. Stefan Strauf, Department of Physics, School of Engineering & Sciences
Committee Members:	Dr. Yuping Huang, Department of Physics, School of Engineering & Sciences, Stevens Institute of Technology Dr. Xiaofeng Qian, Department of Physics, School of Engineering & Sciences, Stevens Institute of Technology Dr. Stephanie S. Lee, Department of Chemistry, School of Art & Science, New York University

ABSTRACT

Quantum technologies rely on robust single photon sources, whose emission can be precisely controlled for use in secure quantum communication, sensing and scalable on-chip photonic circuitry. Achieving such control typically requires quantum emitters (QEs) that feature narrow spectral linewidth and high brightness. Equally important is the ability of dynamic high-speed manipulation of these QEs to tune their emission energies on demand for photonic circuit integration to enable on-chip technologies. While 2D semiconductors such as hexagonal boron nitride (hBN) and transition metal dichalcogenides (TMDs) have proven fertile ground for discovering new quantum light sources, scalable fabrication of QEs with desired properties for quantum information technology and integrating them with advanced tuning strategies remains a critical challenge as being addressed in my work.

I first report on the scalable fabrication of oxygen-related color centers in hBN through a high-temperature oxygen annealing technique. In contrast to well-known hBN carbon-related defects, these oxygen-based QEs show strikingly narrow and stable emission linewidth at room temperature extending into the near-infrared (700–820 nm), without a phonon sideband, and strong linear polarization which makes them a suitable candidate for free space optical communication application. The robust single photon rate of 1 MHz put them among the brightest hBN QEs reported, yet they require no additional passivation layer. The ultra narrow line width of 87 μeV recorded in low-temperature spectroscopy measurements revealed their potential to achieve a near-transform-limited emission via advanced techniques such as electrostatic gating or cavity coupling. Furthermore, I demonstrate acoustic manipulation of deterministic QEs in monolayer WSe_2 by integrating them with surface acoustic wave (SAW) transducers on the lithium niobate platform. Traveling mechanical waves dynamically modulate the optical transitions of site-controlled QEs engineered via gold nanocube stressors. These stressors overcome the stochastic positioning of defect-based QEs by introducing localized strain, thereby activating QEs at predefined locations. SAW excitation enables the emitter energy

shift of up to 0.58 meV on nanosecond timescales, enabling high-speed quantum-light modulation. Our device scheme enabled quasi-resonance excitation of the gold nanocube via sub-gigahertz SAW which resulted in a cooperative manipulation mechanism where both SAW displacement and eigen mode deformation of the nanocube contribute to the energy shift of QE. The cooperative mechanism resulted in a non-linear manipulation response. This work highlights the potential for scalable and fast control of single-photon emissions, as a crucial feature for practical quantum networks and integrated photonic circuits.