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Ph.D. DISSERTATION DEFENSE

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Title: Quantum Photonic Devices from Strained-Engineered and Plasmonic Nanocavity Coupled 2D Semiconductors

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ABSTRACT

Deterministic quantum emitters (QEs) underpin secure quantum communication, scalable photonic computing, and ultrasensitive metrology. Atomically thin transition-metal dichalcogenides (TMDCs) are attractive hosts because their excitonic properties can be tuned by strain and nanophotonic confinement. Among them, WSe_2 offers two complementary exciton classes. A monolayer supports direct intralayer excitons with bright, in-plane dipoles and valley contrast, while a 2H-stacked bilayer hosts momentum-indirect interlayer excitons whose large out-of-plane dipole moment enables strong Stark tuning and long lifetimes but renders them unfortunately optically dark.

My doctoral work combines engineered strain with plasmonic gap-mode nanocavities to transform both exciton classes into bright, polarization-defined QEs. For the bilayer platform, gold nanocube stressors whose dimensions are optimized to match the gap-plasmon resonance are used to localize interlayer excitons in bilayer WSe_2. The stressor-induced wrinkle tilts the emission dipole, and the tilt angle is subsequently quantified by angle-resolved photoluminescence (PL). Magneto-PL isolates a g-factor of 9.5, confirming the Q–K transition of the interlayer species. Coupling the emitters to gap-plasmon cavities raises their brightness by an order of magnitude and shortens radiative lifetimes 24-fold, yielding single-photon rates up to 1.45 MHz at the desired free-space optical communication wavelength of 810 nm.

For monolayer WSe_2, I show that triangular gap-plasmon cavity based on an acute-angle (20°) isosceles nanotriangle concentrates the optical field at each vertex. The resulting strain folds reproducibly create three QEs per site. As a result, the spontaneous-emission rate is enhanced up to 68-fold, delivering 126 MHz photons into the first lens. Within a 2.5 µm-pitch array, 41 QEs share a polarization axis within ±5°, demonstrating uniform dipole alignment within the array.

Together, these results establish a strain-and-plasmonics toolkit that yields site-selective, wavelength-tunable, and polarization-uniform single-photon sources in 2D semiconductors, paving a scalable route toward dense on-chip quantum-light engines and hybrid photonic–plasmonic circuits.