STEVENS INSTITUTE OF TECHNOLOGY 1870

Ph.D. DISSERTATION DEFENSE

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Degree:	Doctor of Philosophy
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Title:	Emergent Magnetic and Photothermal Properties of Low-Dimensional Materials Toward Advanced Spintronic and Bio-diagnostic Devices
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ABSTRACT

Engineering and controlling electron charge, spin, and light interactions at the nanoscale is a central challenge for next-generation spintronics and bioelectronics. Low-dimensional materials offer a unique platform for accessing and manipulating these interactions due to their reduced dimensionality, enhanced surface sensitivity, and tunable electronic structures. Among these systems, two complementary material classes have emerged as particularly promising: two-dimensional (2D) materials for engineering spin and electronic functionalities, and plasmonic nanostructures for manipulating light-matter interactions and localized energy transfer. Heavy transition-metal doping in selected 2D transition metal dichalcogenides (TMDs) monolayers provides a pathway to long-range magnetic ordering, and plasmonic nanostructures offer a distinct route for controlling light-matter interactions at the nanoscale, where localized surface plasmon resonances enable rapid photothermal conversion under optical excitation.

In this context, this dissertation is articulated in two main research objectives. First, substitutional doping is explored to engineer the magnetic and interfacial properties of TMDs. Substitutionally doped Fe-doped WSe_2 (Fe:WSe_2) monolayers were synthesized via chemical vapor deposition. Structural characterization, including scanning transmission electron microscopy, X-ray photoelectron spectroscopy, and Raman spectroscopy, confirms successful dopant incorporation within the crystal lattice. The magnetic properties of Fe:WSe_2 were studied using a vibrating-sample magnetometer, revealing ferromagnetic ordering induced by substitutional Fe incorporation. Additionally, the interfacial spin interactions in Fe:WSe_2/Pt heterostructures were explored, exhibiting unconventional magnetic transport behavior characterized by antisymmetric humps in the Hall resistivity. These features are attributed to proximity-induced non-collinear spin textures, highlighting the potential of Fe:WSe_2 as a platform for two-dimensional topological spintronic devices.

Additionally, this work expands the applications of MoS2 and plasmonic gold nanoparticles (AuNPs) to bio-diagnostic systems. Under light exposure, MoS2. enables rapid thermal cycling and enhances PCR amplification efficiency, as evidenced by lower cycle threshold values compared to non-illuminated conditions; however, performance is limited by strong biomolecule adsorption and fluorescence quenching.

To address these challenges, this research further developed a plasmonic AuNP-based digital photonic PCR platform that combines a nanoplasmonic hydrogel micropillar array with ultrasound-assisted sample preparation to detect plasma-derived exosomal miRNA biomarkers associated with type 1 diabetes (T1D). The platform achieves ultrafast PCR amplification within 3.5 minutes, with high heating rates (~30°C s^{-1}) in a 10,000-PEG-PEGDA hydrogel micropillar array, and reaches a detection limit of 10 copies per microliter. Successful detection of patient-derived exosomal miRNAs highlights the potential of this approach for rapid and highly sensitive early-stage T1D diagnostics.