Integration Transition Metal Dichalcogenide Heterostructures in Plasmonic Cavities

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Certificate of Original Authorship

I, Thinh Tran, certify that the work in this thesis titled, 'Integration Transition Metal Dichalcogenide Heterostructures in Plasmonic Cavities' has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

The emergence of interlayer excitons from atomically layered transition metal dichalcogenides (TMDs) heterostructures has drawn a tremendous attention due to their unique and exotic optoelectronic properties. Coupling the TMD van der Waals heterostructures into optical cavities provides distinctive electromagnetic environments which plays an important role in controlling multiple optical processes such as optical nonlinear generation or photoluminescence (PL) enhancement. However, there is a gap in current research on the integration of interlayer excitons in TMDs heterostructures and optical cavities, especially plasmonic cavities. To address this shortage, this project is devoted to investigating the light and matter interaction between the interlayer excitons and plasmonic nanocavities based on a nanogap plasmonic structure consisting of a silver nanocube on a flat metallic mirror. Spectroscopic studies reveal an order of magnitude enhancement of the interlayer exciton at room temperature and a 5-time enhancement in fluorescence at cryogenic temperature. Also, finite-difference time-domain (FDTD) simulations of the plasmonic cavity system was carried out to elucidate the mechanism of the enhancement, despite of low spontaneous radiative decay rate enhancement. As a result, enhancement of the emission is based on increasing excitation efficiency and Purcell effect from the cavity. Our results show a novel method to control the excitonic processes in TMDs heterostructures to build high performance nanophotonic and optoelectronic devices.

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List of publications

Article(s) with results included in this thesis

1. **Tran, T. N.**, Kim, S., White, S. J. U., Nguyen, M. A. P., Xiao, L., Strauf, S., Yang, T., Aharonovich, I., & Xu, Z.-Q. Enhanced emission from interlayer excitons coupled to plasmonic cavities. *Small* **17**, 2103994 (2021).

Article(s) not included in this thesis

3. Li, C., Fröch, J. E., Nonahal, M., **Tran, T. N.**, Toth, M., Kim S., & Aharonovich, I. Integration of hBN quantum emitters in monolithically fabricated waveguides. *ACS Photonics* **8**, 2966–2972 (2021).

2. Kim, S., Lim, Y.-C., Kim, R. M., Fröch, J. E., **Tran, T. N.**, Nam, K. T., & Aharonovich, I. A single chiral nanoparticle induced valley polarization enhancement. *Small* **16**, 2003005 (2020).

1. Chen, Y., **Tran, T. N.**, Duong, N. M. H., Li, C., Toth, M., Bradac, C., Aharonovich, I., Solntsev, A. & Tran, T. T. Optical thermometry with quantum emitters in hexagonal boron nitride. *ACS Appl. Mater. Interfaces* **12**, 25464–25470 (2020).

List of figures

Abbreviations

TMD	transition metal dichalcogenide
2D	two dimensional
BEC	Bose–Einstein condensation
PL	photoluminescence
PCC	photonic crystal cavity
vdW	van der Waals
CB	conduction band
VB	valance band
IR	infrared range
LDOS	local density of states
CVD	chemical vapor deposition
PDMS	polydimethylsiloxane
hBN	hexagonal boron nitride
AFM	atomic force microscopy
PVA	poly(vinyl alcohol)
TCSPC	time-correlated single photon counting
IRF	instruments response function
FWHM	full width at half maximum
TRPL	time-resolved photoluminescence
FDTD	finite-difference time-domain
SEM	scanning electron microscope

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