Ph.D. Course in Materials Science and Nanotechnology

University of Milano-Bicocca, Department of Materials Science, via Cozzi 55, 20125 Milano

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Seminar room - Department of Materials Science U5

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Enhanced light-matter interaction in an atomically thin semiconductor coupled with all-dielectric nano-antennas

By confining strong electromagnetic fields at their surfaces, resonant nano-structures with sub-wavelength dimensions can enhance the light-matter interaction of closely coupled luminescent emitters. While these phenomena have been extensively studied for surface plasmons in noble metals, recently high-refractive-index dielectrics have gained attention as they host optical Mie resonances, offering a low-loss platform to overcome plasmonic quenching mechanisms. Between atomically thin materials beyond graphene, the family of 2D semiconductors transition metal dichalcogenides (TMDs) offers appealing optical properties, such as tightly bound excitons and a transition to direct bandgap in single layers, with favorable integration with nano-photonic structures. Most of the efforts so far have been given to plasmonic structures, while coupling with dielectric nano-antennas is mostly unexplored.

In this work , we transferred single and double layer TMD WSe_2 onto an array of gallium phosphide (GaP) dimer nano-antennas, leading to a strong enhancement of WSe_2 photoluminescence (PL) intensity, over 10^4 compared when on planar GaP. We show that this is a result of an increased absorption and enhanced spontaneous emission rate, provided by the strongly confined optical mode of the nano-antennas, as well as an emission redirection. Further manifestation of the strong photonic confinement is observed in the enhanced Raman scattering signal, exceeding 10^3, and polarization dependent PL.

Furthermore, the resonant nano-structures displace the thin semiconducting layers in the out-of-plane direction, allowing the strain-tuning of the local WSe_2 band structure. We model the strain topography and show a co-location of largest tensile strain and that of the maximum photonic enhancement. This concurrence let us probe the strain-induced WSe_2 band structure renormalization from distinct spectral signatures. In monolayers we observe a tuning of the excitonic resonance above 50 meV. For bilayers, an indirect bandgap semiconductor, high level of strain results in the transition to direct bandgap. At cryogenic temperatures we confirm that the strain-induced potential acts as a trap for photo-generated excitons, together with the positioning of strain-induced single-photon emitters at the nano-antenna location.

Our results highlight dielectric nano-structures as a platform to improve light-matter interaction in 2D semiconductors and in novel 2D quantum emitters.