Van-der-Waals nano-photonics

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Van-der-Waals materials have been the focus of many research efforts since the discovery of graphene [1]. Further observations of a direct bandgap [2] and single photon emission [3] from monolayers of transition metal dichalcogenides (TMDs) have bolstered the importance of materials which consist of covalently bonded layers stacked into bulk crystals due to van-der-Waals interactions. In the past, the role of these layered materials has been limited to few-layer active media often integrated with nano-photonic structures fabricated from other more traditional materials, such as silicon [4] or gallium phosphide [5], for the enhancement of light emission properties. More recent works have involved the etching of nano-photonic architectures directly into layered materials such as hBN [6] and TMDs [7]. These are promising for the fabrication of such structures due to large refractive indices [7], low absorption within a large portion of the visible spectrum and the advantages which result from their van-der-Waals attractive nature to a wide variety of substrates. In our work, we utilize well established techniques to fabricate nano-photonic resonators with a range of geometries (see Fig. 1(a)) from a diverse set of van-der-Waals materials which exhibit Mie resonances as shown in Figs. 1(b)-(e). Signatures of strong coupling between excitonic features of TMDs and anapole modes were also observed as most clearly shown in Figs. 1(c)-(e). We demonstrate Purcell enhancement of emission from a TMD monolayer due to a nano-resonator mode induced in another material of the same family. Our subsequent observation of the formation of bright single photon emitters in a WSe_2 monolayer transferred onto WS_2 nano-antennas may lead to Purcell enhancement of quantum emission in a structure fabricated entirely from layered materials. Due to the weak van-der-Waals interaction with the SiO_2 substrate, we were able to employ an atomic force microscopy (AFM) cantilever in the repositioning of double-pillar (dimer) nano-antennas to achieve ultra-small gaps ($\approx$ 10 nm as shown in the left inset of Fig. 1(f)). This may enable applications such as stable optical trapping of quantum emitters and Purcell enhancement factors above 150 as shown by the simulations in Fig. 1(f).

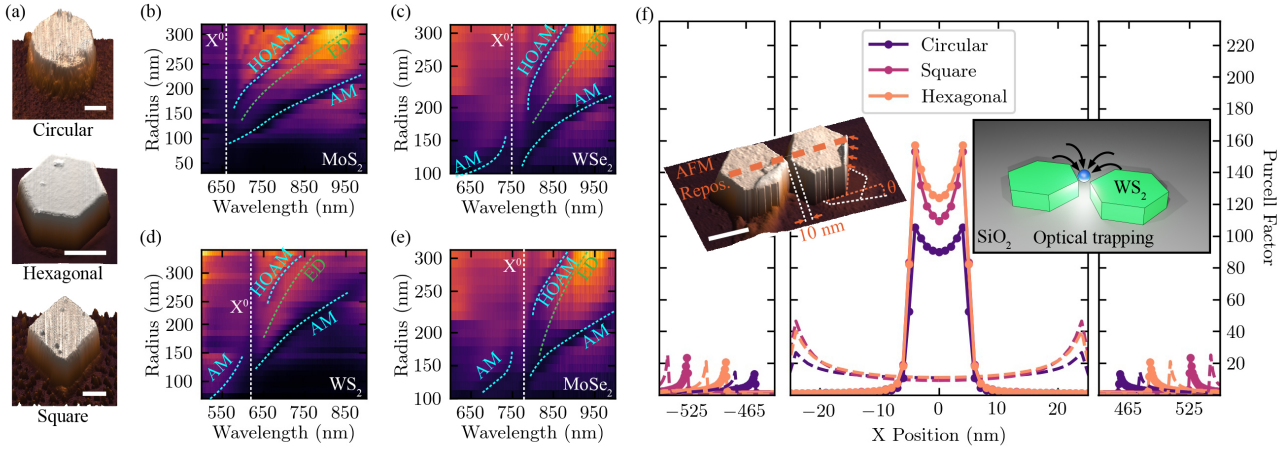

Figure 1: **Van-der-Waals nano-antenna experiments and simulations.** **(a)** AFM scans of fabricated geometries of layered material nano-antennas. **(b)-(e)** Dark field spectra of fabricated nano-antennas in different TMD materials exhibiting an electric dipole (ED) resonance, anapole (AM) and higher order anapole (HOAM) modes which anti-cross with the neutral exciton resonance (X^0). **(f)** Purcell enhancement of emission for an AFM repositioned hexagonal WS_2 dimer with a gap of 10 nm (solid lines) and an as fabricated 50 nm gap (dashed lines) at positions shown by the thick dashed line in the left inset. Left inset: AFM repositioning method to achieve a 10 nm dimer gap. Right inset: Schematic of optical trapping simulation of colloidal quantum dots. Scale bars = 200 nm.

References

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