Van der Waals materials for nanophotonic applications

Panaiot G. Zotev[1], Yue Wang[2], Daniel Andres-Penares[3], Toby Severs Millard[1], Luca Sortino[4], Nic Mullin[1], Donato Conteduca[2], Xuerong Hu[1], Charalambos Louca[1], Mauro Brotons-Gisbert[3], Sam Randerson[1], Armando Genco[1], Jamie Hobbs[1], Brian Gerardot[3], Thomas F. Krauss[2], A.I. Tartakovskii[1]

[1]*Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK*
[2]*Department of Physics, University of York, York, YO10 5DD, UK*
[3]*School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, EH144AS, UK*
[4]*Nanoinstitute Munich, Faculty of Physics, Ludwig-Maximilians-Universität, München, 80539, Munich, Germany*

Nanophotonic structures enable a range of applications including optical waveguiding, Purcell enhancement of emission, low-threshold lasing and higher harmonic generation enhancement. Many research fields and technologies have benefited from nano-scale resonators and waveguides previously fabricated from noble metals [1] or high refractive index dielectrics such as silicon [2] and III-V materials [3]. While these offer a large range of opportunities for both research and technology, van der Waals materials may expand the possibilities of nanophotonics in the visible and near-infrared portion of the spectrum due to high, super-Mossian refractive indices (n≈4) [4], a large range of transparency windows, and numerous advantages due to their weak van der Waals attractive forces. In order to inspire and facilitate nanophotonic structures fabricated from these layered materials, we extract the dielectric constants of a diverse set including transition metal dichalcogenides (TMDs), III-VI semiconductors, and magnetic layered materials. Employing well established techniques, we fabricate nanoresonators with a range of geometries from these materials and observe Mie resonances as well as strong coupling between the excitonic features of TMDs and anapole modes with Rabi splittings up to 140 meV. After the transfer of a monolayer of WSe_2 onto WS_2 nanoantennas, we observe room temperature Purcell enhancement of emission [5] and low temperature formation of single photon emitters with enhanced quantum efficiencies within a system fabricated entirely from layered materials. Due to the weak van der Waals interactions of the nanoresonators and the substrate, we were able to employ an atomic force microscopy (AFM) cantilever in the repositioning of double-pillar nanoantennas to achieve ultra-small gaps (≈10 nm) [5]. This post-fabrication technique enables applications such as stable, low-power optical trapping of quantum emitters with Purcell enhancement factors above 150.

[1] Y. Luo et al, *Nature Nanotechnology* **13**, 1137-1142 (2018).
[2] Y. Li et al, *Nature Nanotechnology* **12**, 987-992 (2017).
[3] L. Sortino et al, *Nature Communications* **12**, 6063 (2021).
[4] R. Verre et al, *Nature Nanotechnology* **14**, 679-683 (2019).
[5] P. Zotev et al, *ACS Nano* **16**, 6493-6505 (2022).