Layered materials for plasmonics and metamaterials

Morten Niklas Gjerding [1,4]
René Petersen[2,5], Mohnish Pandey[1], Thomas Garm Pedersen[2,5], Niels-Asger Mortensen[3,4], Kristian Thygesen[1,4]
[1]Department of Physics, Technical University of Denmark (DTU), DK-2800 Kgs. Lyngby, Denmark
[2]Department of Physics and Nanotechnology, Aalborg University, DK-9220 Aalborg East
[3]Department of Photonics Engineering, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark
[4]Center for Nanostructured Graphene (CNG), DK-2800 Kgs. Lyngby, Denmark
[5]Center for Nanostructured Graphene (CNG), DK-9220 Aalborg East, Denmark
mogje@fysik.dtu.dk

In this work we show, using first-principles calculations, that ohmic losses are reduced in certain layered metals, such as the transition metal dichalcogenide 2H-TaS_2, due to an extraordinarily small density of states for scattering in the near-IR originating from their special electronic band structure (Fig. 1), which possibly provides a solution to the detrimental Ohmic losses that haunt applications of plasmonics[1]. Based on this observation we propose a new class of band structure engineered van der Waals layered metals composed of hexagonal transition metal chalcogenide-halide layers with greatly suppressed intrinsic losses and show that the suppression of optical losses lead to improved performance for thin film waveguiding and transformation optics.

Furthermore, we show that the broad class of layered transition metal dichalcogenides (TMDs) are naturally hyperbolic[2,3]. The diverse electronic properties of the TMDs result in a large variation of the hyperbolic frequency regimes ranging from the near-IR to the UV. Compared to artificially structured metamaterials, the absence of internal structure reduces scattering losses and greatly increases the number of hyperbolic modes leading to extremely large and broadband Purcell factors (Fig. 2). Additionally, we demonstrate how the hyperbolic properties can be further controlled by combining different two-dimensional crystals into van der Waals heterostructures.

References

[1] Khurgin, J. B., Nature Nanotechnology 10 (2015), p. 2–6.
[2] Poddubny, A., Iorsh, I., Belov, P. & Kivshar, Y., Nature Photonics 7 (2013), p. 948-957.
[3] Narimanov, E. E. & Kildishev, A. V. Nature Photonics 9 (2015), p. 214–216.

Figures

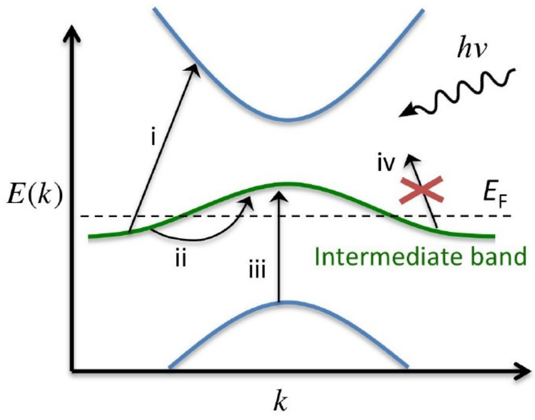

Figure 1: Cartoon band structure of 2H-TaS_2 that exhibits an intermediate metallic band that reduces the density of states for scattering.

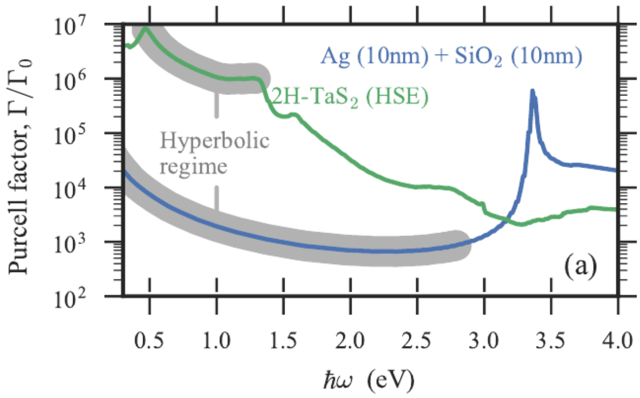

Figure 2: Purcell factor of 2H-TaS_2 compared to an Ag-SiO_2 hyperbolic metamaterials.