Hyperbolic surface exciton-polaritons at superlattices of 2D materials

M. R. Andrade[1], P. L. M. S. Silva[2], *D. R. da Costa*[1], *and André J. Chaves*[2]

[1]*Departamento de Física, Universidade Federal do Ceará, Campus do Pici, Fortaleza, Ceará, Brazil*

[2]*Departamento de Física, Instituto Tecnológico de Aeronáutica, DCTA, São José dos Campos, Brasil*

michel.andrade@fisica.ufc.br

Abstract

Recently, it has been raised a renewed interest in polaritonic excitations, due to enhanced light-matter interactions in novel two-dimensional (2D) materials[1]. Among the several advantages of 2D materials-based polaritonics, as compared with the widely studied in the past, metal-dielectric-based ones, we can mention that it allows overcoming the problem of absorption losses and limited range of operating frequencies of the optoelectronic devices. These materials can also offer tunability in situ, as the electronic and optical properties depend on the environment of the material. Different excitations can be originated by the coupling with light, such as plasmons-polaritons, phonon-polaritons, and excitons-polaritons. Excitons in 2D materials show high binding energies and long nonradiative lifetime as compared with conventional semiconductors, as well as its excitonic properties are strongly dependent on the surrounding dielectric environment. [2]

Excitons in transition metal dichalcogenides (TMD) have a strong coupling with light. For frequencies close but lower than the exciton resonance, the real part of the dielectric function can have opposite signs for the axial and tangential directions. This is similar to what happens due to phonons in hexagonal Boron Nitride (hBN). These materials are classified as a hyperbolic media.

To preserve the strong light coupling of monolayer TMD and enhance the polaritonic properties observed for a single monolayer, we consider a superlattice of encapsulated TMDs and show the existence of hyperbolic modes. Using the transfer matrix method, we obtain the loss function for different stacks compositions, number of stacks, and different TMDs, showing the presence of surface exciton-phonon polaritons. We numerically calculated the poles of the loss function for complex wavenumber that enabled us to extract the electromagnetic field profile for hyperbolic surface exciton-polaritons. The methodology that we developed here can be extended to study the optical properties of arbitrary stacked van der Waals materials.

References

[1] Low T., Chaves A., Caldwell J. D., Kumar A., Fang N. X., Avouris P., Heinz T. F., Guinea F., Martin-Moreno L., Koppens F. *Polaritons in layered two-dimensional materials*. Nature materials. 2017 Feb;16(2):182-94.

[2] Chaves A, Azadani J. G., Alsalman H., da Costa D. R., Frisenda R., Chaves A. J., Song S. H., Kim Y. D., He D., Zhou J., Castellanos-Gomez A. *Bandgap engineering of two-dimensional semiconductor materials*. npj 2D Materials and Applications. 2020 Aug 24;4(1):1-21.