SPP10
Launching and Manipulation of Higher-Order In-Plane Hyperbolic Phonon Polaritons in Low-Dimensional Heterostructures

Guanyu Lu[1], Zhiliang Pan[1], Christopher R. Gubbin[2], Ryan A. Kowalski[3], Simone De Liberato[2], Deyu Li[1], Joshua D. Caldwell[1]

1. Department of Mechanical Engineering, Vanderbilt University, Nashville, Tennessee 37212, United States
2. School of Physics and Astronomy, University of Southampton, Southampton SO17 1BJ, United Kingdom
3. Interdisciplinary Materials Science, Vanderbilt University, Nashville, Tennessee 37212, United States

guanyu.lu@vanderbilt.edu

We demonstrate the efficient launching and precise manipulation of highly confined, directionally dependent in-plane hyperbolic light propagation in a low-dimensional heterostructure composed of two polar materials with overlapping Reststrahlen bands. These results provide the experimental evidence of preferential and direct launching of higher-order in-plane hyperbolic phonon polaritons (HPhPs) modes that feature much stronger wavelength compression than the fundamental mode. This coincides with one of the principal goals of nanophotonics, i.e., the ability to concentrate light to length scales much shorter than the free-space wavelength.

HPhPs are stimulated by coupling infrared (IR) photons with the polar lattice of highly anisotropic crystal structures, offering highly confined, low-loss, and ray-like light propagation within the volume of the medium. HPhPs in natural materials were first reported in the uniaxial medium such as hBN, with characteristic out-of-plane hyperbolicity results in polaritons propagating radially in plane. Very recently, in-plane hyperbolicity was reported within biaxial crystals, such as α-MoO_3, where the polariton propagation is restricted to only a single allowed in-plane direction dictated by the hyperbolic isofrequency contours (IFCs). For HPhPs, while a hyperbolic dispersion implies multiple propagating modes with a distribution of wavevectors can be supported at the same frequency, so far it has been challenging to experimentally launch and probe these higher-order, higher momenta modes, especially for in-plane HPhPs reported so far.

In this work [1], we provide experimental evidence of higher-order in-plane HPhPs within low-dimensional heterostructures comprised of a 3C-SiC nanowire (NW) on α-MoO_3 flake. In the spectral region where α-MoO_3 exhibits in-plane hyperbolicity, a 3C-SiC NW supports strong near-field resonances within its own Reststrahlen band, thereby bridging the wavevector mismatch for stimulating the aforementioned higher-order, high momenta HPhPs modes. The higher-order in-plane hyperbolic modes are directly imaged in the near-field experiments with these results being in excellent agreement with our electromagnetic simulations. We further study the launching mechanism and determine the requirements for efficiently launching such higher-order modes: a low-loss, highly reflective and strongly resonant scatterer with a size smaller or comparable to the polariton wavelength. Furthermore, the energy-momenta HPhP dispersion can be precisely controlled via controlling the misorientation angle between the 3C-SiC NW long axis and α-MoO_3 principal crystal axes, which is unambiguously revealed by our near-field experiments and theoretical calculations. This also provides an opportunity for on-demand tuning of the in-plane HPhPs without the restrictions and additional losses induced via nanofabrication. Therefore, we present a novel low-dimensional material platform to explore extreme anisotropic light-matter interactions with ultrahigh photon confinement at the nanoscale, with immense potential in IR sensing, routing, nano-imaging, and on-chip photonics.

References

[1] Lu, G., Pan, Z., Gubbin, C. R., Kowalski, R. A., De Liberato, S., Li, D., Caldwell, J. D., 2023. *Adv Mater*, accepted.