PHOTONICS INSIGHTS

Light walking in low-symmetry 2D materials

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Two-dimensional (2D) materials, due to their exotic electromagnetic responses and strong interaction with light, have been intensively studied over the past decades since the discovery of graphene in 2004[1]. Except for graphene, natural van der Waals (vdW) materials[2] also serve as indispensable members in the library of 2D materials, where adjacent atomic planes are bonded by weak vdW force so that monolayers can be readily obtained through methods such as mechanical exfoliation. Nowadays, numerous 2D materials have been widely implemented in applications such as unconventional superconductivity, ultra-sensitive biosensing, and high-order harmonic generation. Most recently, a special group (low-symmetry) of 2D materials, where the arrangement of the intralayer atoms varies along different directions, has attracted great attention because of the extreme in-plane anisotropy and the support of low-loss and highly confined hyperbolic polaritons[3]. This additional degree of freedom provides brand-new insight into the manipulation of light at the nanoscale, promising more unique phenomena and applications within these low-symmetry 2D materials.

As recently published in *Photonics Insights*, Huang *et al.*[4] present a thorough review of low-symmetry 2D materials, including their fundamental optical properties as well as the hyperbolic polaritons sustained. First, the authors discuss the interband absorption, photoluminescence, and excitons in different materials such as black phosphorous (BP), group IV monochalcogenides MX (M = Ge, Sn and X = S, Se), rhenium dichalcogenides ReX_2, and other anisotropic 2D materials. Then, they introduce the non-linear optical properties and band structure engineering of low-symmetry 2D materials, where high-order harmonic generation and the moiré effect in twisted bilayer systems are briefly discussed.

When light "walks" through the materials, the induced oscillations of electrons, phonons, and excitons could be hybridized with electromagnetic radiations to form quasiparticles called polaritons. However, the traditional realization of polaritons usually requires an interface between dielectric and noble metals (e.g., Ag, Au), which suffers from large absorption loss and limited operation bandwidth[5]. Ever since the experimental observation of propagating graphene plasmon polaritons[6], efforts have been devoted to studies of low-loss and long-lifetime polaritons in various 2D materials with a spectrum ranging from visible to far-infrared frequencies. In this review, Huang *et al.* focus on the research progress of in-plane hyperbolic polaritons in low-symmetry 2D materials, starting from the fundamental theory to their probing methods, bridging the gap between theoretical analysis and experimental verifications. Subsequently, they highlight three types of hyperbolic polaritons (i.e., phonon, plasmon, and exciton polaritons), followed by four manipulation approaches, among which, in our opinion, integrating graphene with low-symmetry 2D materials (or in general, hybridization of 2D materials) will continue to thrive and become the future tendency for research of polaritons[7]. Excitingly, the latest experiment[8] has just indicated the plausibility of gate-tunable plasmon–phonon polaritons in the graphene/α-MoO_3 heterostructure. This review also incorporates various applications concerning polaritons to complete the discussion, including polarization engineering[9] (e.g., on-chip wave plates), planar nanophotonics[10] (e.g., nano-focusing, negative refraction), enhancement of spontaneous emission and biosensing, and thermal radiation.

Low-symmetry 2D materials have manifested unprecedented optical properties and applications during the past few years, and are about to gain further advancement in the future with their enormous potential. One of the possibilities may lie in exploiting new materials. For example, very recently, shear hyperbolic polaritons have been reported in bulk crystals such as β-gallium oxide (bGO)[11] and cadmium tungstate ($CdWO_4$)[12]. We may also anticipate this exotic phenomenon to be observed within its 2D counterpart. All in all, this review is comprehensive, working as a detailed guidance for beginners; it is very timely as well, furthering expertise to acquire cutting-edge developments of this fast-growing field.

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