Valley-polarized Hyperbolic-Exciton–Polaritons in Multilayer 2D Semiconductors at Visible Frequencies

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Abstract

We show that resonant exitonic-based hyperbolicity can be induced in transition-metal-dichalcogenides (TMDs), leading to the existence of hyperbolic-exciton-polaritons (HEPs). Furthermore, we show that owing to the valley properties of TMDs, the HEPs are coupled to the valley degree-of-freedom, leading to a hyperbolic spin-valley hall effect. We analyze the HEPs' confinement and loss properties, finding large momentum modes with losses that increase slower than the confinement. Such highly confined and valley-polarized HEPs provide new opportunities and means of controlling strong light-matter interaction at the atomic scale.

Hyperbolic materials exhibit opposite signs of the real part of the in-plane ($\varepsilon_{\perp}$) and out-of-plane ($\varepsilon_{\parallel}$) components of the permittivity tensor: $Re\{\varepsilon_{\perp}\} \cdot Re\{\varepsilon_{\parallel}\} < 0$. Such materials support hyperbolic modes of arbitrarily large wavevectors, making them highly important for photonics and optoelectronics. Recently, transient HEPs in thick (~450nm) layers of TMDs that stem from the Rydberg series transitions of TMD excitons in the MIR spectrum, have been observed via ultrafast photoexcitation of electron-hole pairs[1]. Here, we show for the first time that TMDs can obtain a hyperbolic material response at VIS-NIR frequencies, at the frequency of the main exciton resonance, and at steady-state conditions (fig1(a)). This hyperbolicity stems from the combination of an in-plane negative permittivity, induced via the use high-quality van der Waals heterostructures at cryogenic temperatures[2], and an out-of-plane positive permittivity. The dispersion relation of the resulting visible frequency HEPs supported by multilayer TMDs is presented in fig1(b), showing very large momenta. Furthermore, the inherent spin-valley selection rules for excitons in TMDs lead to HEPs that are coupled to the TMD's valley degree-of-freedom. This can be seen via the directional coupling of HEPs in response to left/right circular polarization (CP), introducing a spin-valley Hall effect for HEPs (fig1(c)).

References

[1] Sternbach, A. J. et al. Science 371, 617–620 (2021).
[2] Epstein, I. et al. 2D Materials 7, 035031 (2020).

Figures

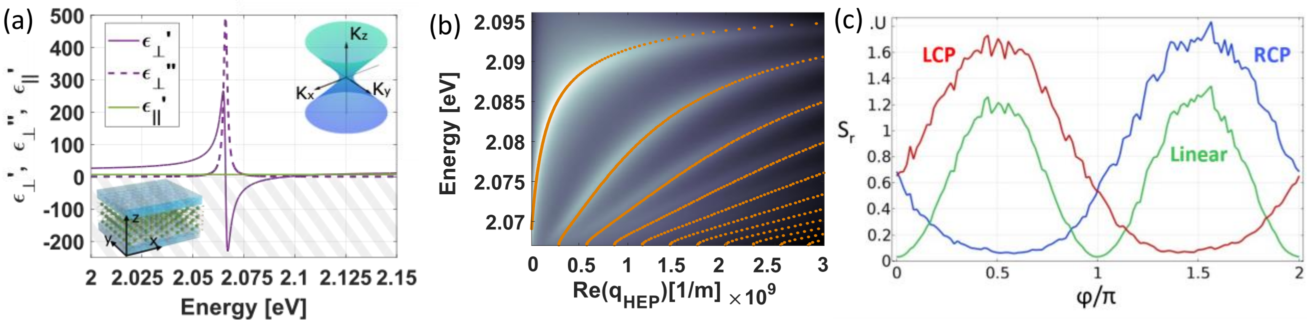

Figure 1: (a) Resonant exciton-induced hyperbolicity in multilayer TMDs. (b) Resulting HEPs dispersion relation in multilayer TMDs, carrying large momenta. (c) Radial component of the Poynting vector, S_r for the case of right/left CP and linear dipole, showing a symmetrical excitation for linear polarization, and an asymmetric one for CPs, demonstrating a spin-valley Hall effect for HEPs.