Incoherent and coherent manipulations of valley excitons via a photonic Rashba effect

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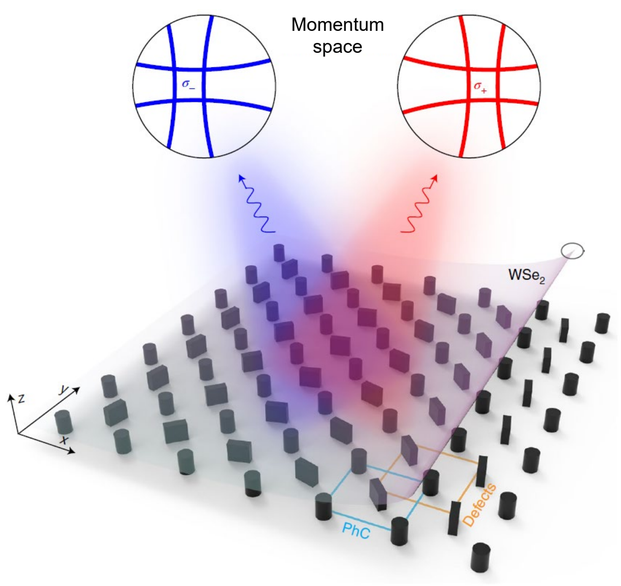
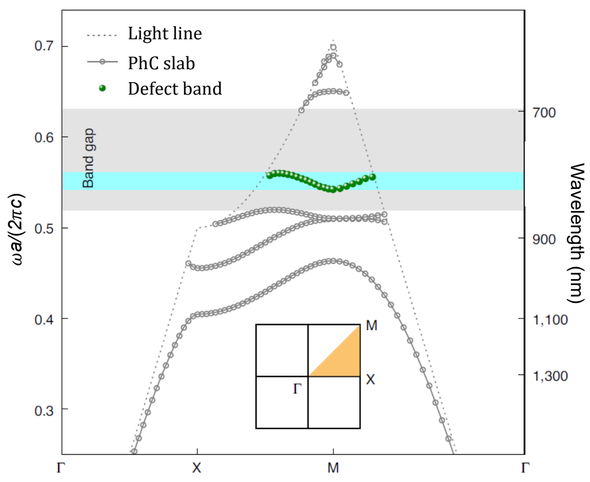
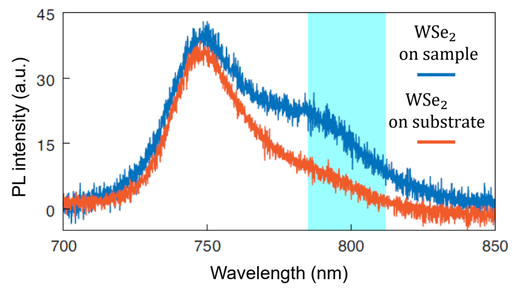
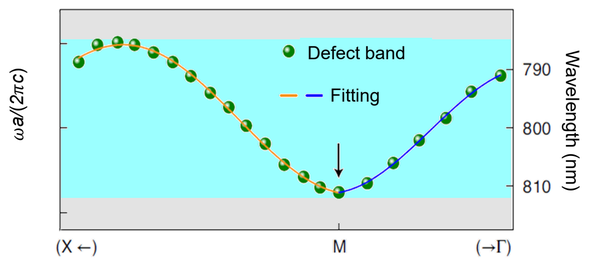
The photonic Rashba effect describes a momentum-space spin-split dispersion $\omega(k \pm \sigma \mathbf{K}_{sl})$ from an inversion-asymmetric pseudospin lattice, with $\sigma \mathbf{K}_{sl}$ being the spin-dependent reciprocal lattice vector due to optical spin-orbit interactions. Here, we show the room-temperature manipulations of valley excitons both in an incoherent (by exploiting the valley polarization) and a coherent manner (by exploiting the valley coherence) via a photonic Rashba effect. These results establish a multifunctional valley-photon interface for valley information transportation. Firstly, we demonstrate a photonic Rashba effect from valley excitons by incorporating a WSe_2 monolayer into a photonic crystal slab with geometric phase defects [1]. The effect arises from a coherent geometric phase pickup assisted by the Berry phase defect mode, whereby valley excitons effectively interact with the defects for site-controlled excitation, photoluminescence enhancement, and momentum-space valley separation. Secondly, we report on a spin-optical monolayer laser by incorporating a WS_2 monolayer into a heterostructure microcavity supporting high-Q spin-valley resonances [2]. Inspired by the creation of valley pseudospins in monolayers, the spin-valley modes are generated from a photonic Rashba-type spin splitting of a bound state in the continuum, which gives rise to opposite spin-polarized $\pm$K valleys under inversion symmetry breaking. The Rashba monolayer laser shows intrinsic spin polarizations, high spatial and temporal coherence, and inherent topological protection features, enabling valley coherence in the WS_2 monolayer upon arbitrary pump polarizations at room temperature.

Photonic Rashba effect from valley excitons (incoherent)

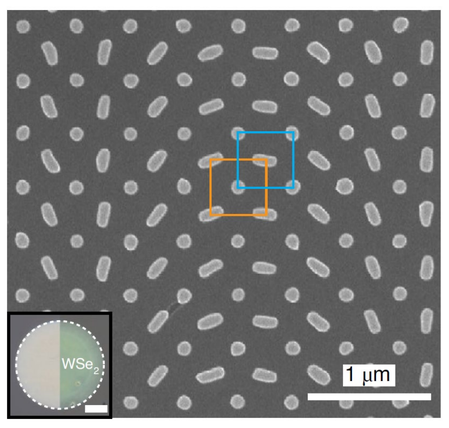


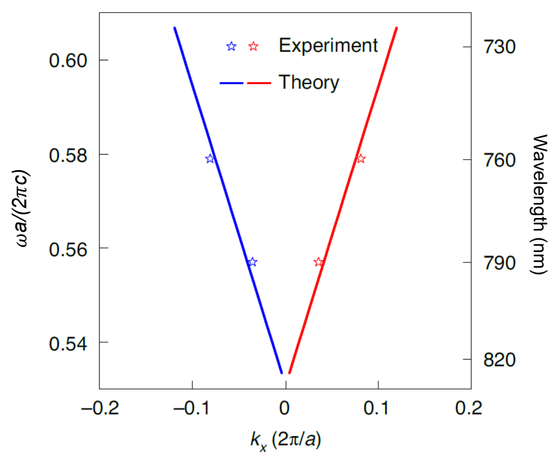


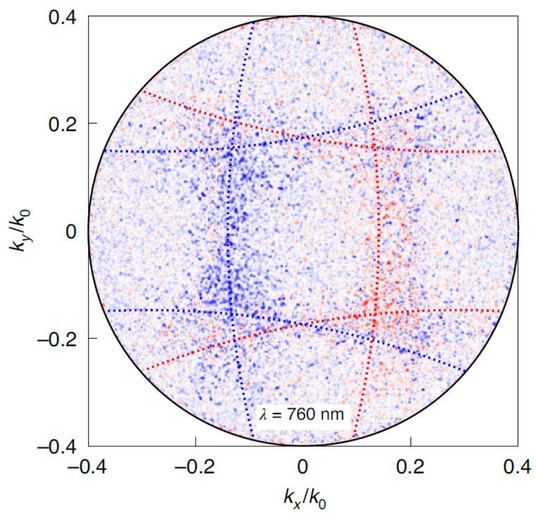


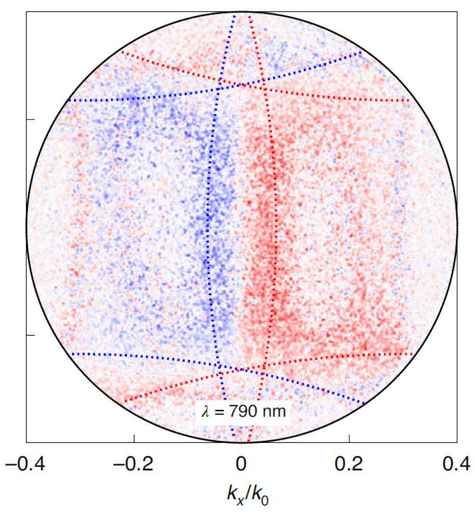


Room-temp. momentum-space valley separation

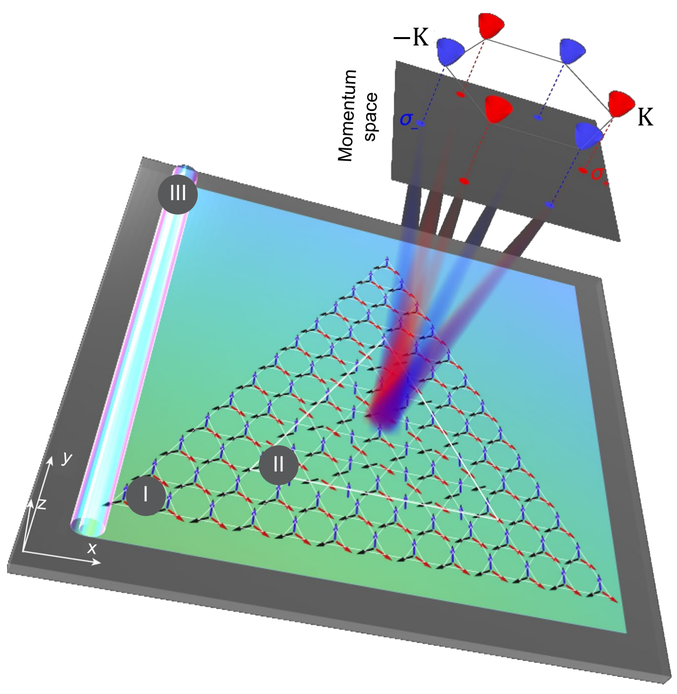


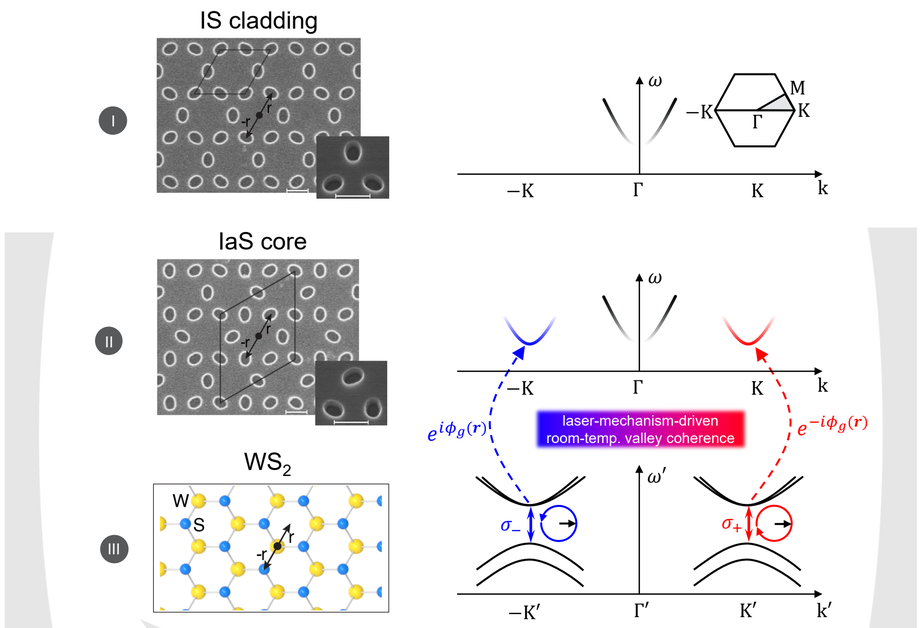






Spin-valley Rashba monolayer laser (coherent)

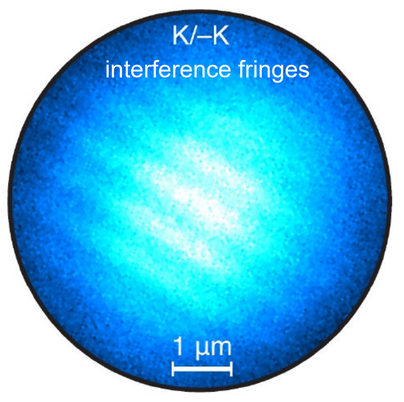




$$|\Psi_{sl}\rangle = e^{i\phi_g(r)}|\Psi_{-K}\rangle + e^{-i\phi_g(r)}|\Psi_K\rangle$$

Coherent superposition of spin-valley modes

Room-temp. valley coherence



Emission spectrum

Spin-polarized emission

Lasing transition

Spatiotemporal coherence

[1] Rong, K. *et al.* Photonic Rashba effect from quantum emitters mediated by a Berry-phase defective photonic crystal. *Nat. Nanotechnol.* **15**, 927–933 (2020).

[2] Rong, K. *et al.* Spin-valley Rashba monolayer laser. (Under review.)

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