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# Two-dimensional routing of valley polaritons in monolayer $WS_2$ by plasmonic nanostructures through optical spin-orbit coupling

Excitons in monolayer transition metal dichalcogenides (TMDs) at the two energy-degenerate K and K' valleys possess additional valley degree of freedom, which can be addressed optically using circularly polarized light [1-3]. Incorporating monolayer TMDs into an optical microcavity further enables the formation of valley polaritons when the excitons and cavity photons are strongly coupled [4]-[6]. A valley polariton represents a half-light and half-matter quasiparticle, whose spin (associated with the valley index) and momentum (associated with the propagation direction) can be coupled through the spin-orbit interactions (SOI) of light [7], in analogy with spin-Hall effect in electronic systems. Structured optical fields with subwavelength scales spatial inhomogeneity, such as in plasmonic and nanophotonic structures, can enable a strong SOI of light, providing an unprecedented platform to address the valley degree of freedoms for valleytronic applications.

In this work, we demonstrate a two-dimensional routing of valley polariton emissions from monolayer TMDs coupled to a one-dimensional plasmonic nanostructures. Helicity-dependent directional coupling of surface-plasmon-polaritons (SPPs) with the valley excitons in monolayer TMDs has been achieved. We use a periodic array of metallic nanogrooves fabricated by focused ion beam as the plasmonic structures to create spatially inhomogeneous optical fields. In such fields, the spin and orbital properties are coupled to each other. Nanogroove arrays were etched on single crystalline silver and capped with a 4-nm of $Al_2O_3$ to protect the metal surface. $WS_2$ monolayers were then transferred on top of the nanogrooves. Figure 1a shows the scanning electron microscope image of a fabricated nanogroove array. We apply Fourier space spectroscopic techniques to measure the energy-momentum dispersions of the $WS_2$-nanogroove hybrid system. Guided SPP modes propagating along the grating direction (x) and the groove direction (y) show very distinct dispersions, as shown in Figure 1b and 1c. Figure 1d shows the K-space PL image (without selecting polarization) of the $WS_2$-nanogroove hybrid system, where the excitonic emission of $WS_2$ monolayer predominantly couples to the guided SPP modes of the structure. Polarization-resolved PL measurements shows that the left and right circularly-polarized PL images become asymmetric, as depicted in Fig. 2a and 2b. The distribution of the degree of circular polarization (DOP) in k space shown in Fig. 2d thus demonstrate a two-dimensional routing of valley polariton propagations. Figure 2e shows the polarization-resolved PL imaging in real space, where a valley-dependent directional propagation of valley polaritons can be observed. Our results show that the launched valley excitons with different valley indices can be directed toward different directions, providing a unique way to read out the valley information carried by the valley polaritons for valleytronic applications.

## References

[1] Cao, T. *et al. Nat. Commun.* **3** (2012) 887.

[2] Mak, K. F., He, K., Shan, J. & Heinz, T. F. *Nat. Nanotechnol.* **7** (2012) 494–498.
[3] Zeng, H., Dai, J., Yao, W., Xiao, D. & Cui, X. *Nat. Nanotechnol.* **7** (2012) 490–493.
[4] Chen, Y.-J., Cain, J. D., Stanev, T. K., Dravid, V. P. & Stern, N. P. *Nat. Photonics* **11** (2017) 431–435.
[5] Sun, Z. *et al. Nat. Photonics* **11** (2017) 491–496.
[6] Dufferwiel, S. *et al. Nat. Photonics* **11** (2017) 497–501.
[7] Bliokh, K. Y., Rodríguez-Fortuño, F. J., Nori, F. & Zayats, A.V. *Nat. Photonics* **9** (2015) 796–808.

## Figures

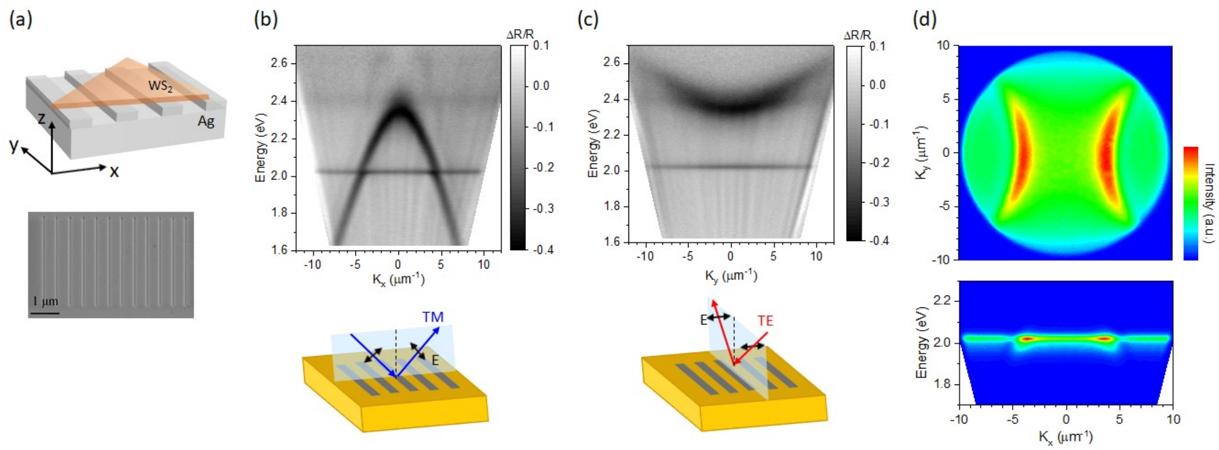


**Figure 1:** (**a**) Schematic of the hybrid $WS_2$-nanogroove system. And the SEM image of a fabricated nanogroove array. (**b**) and (**c**) depict the energy-momentum dispersions of the hybrid system measured in directions perpendicular (x-direction) and along the grooves. The corresponding measurement schematics are illustrated below. (**d**) K-space PL images and PL spectra along the x-direction.

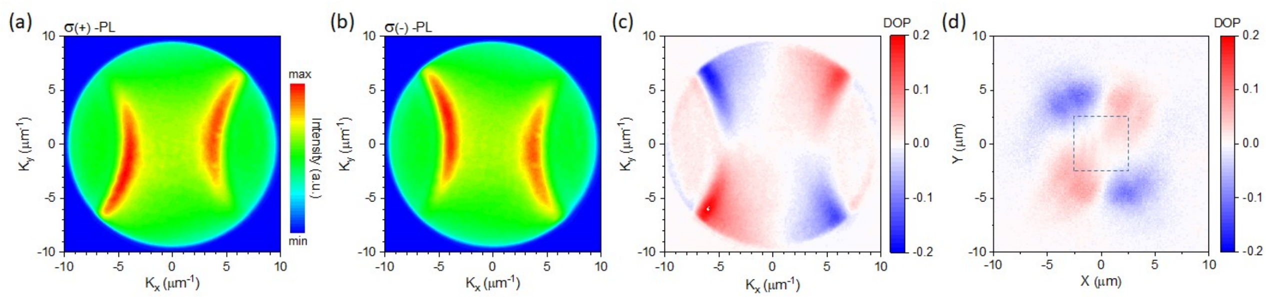


**Figure 2:** Separation of valley PL emission of monolayer $WS_2$ coupled to a plamonic nanogroove array. σ(+) (**a**) and σ(-) (**b**) K-space PL images. (**c**) K-space image of the PL circular polarization contrast from the hybrid $WS_2$-nanogrooves. (**d**) Real space PL polarization contrast of the same hybrid $WS_2$-nanogrooves. The dashed square indicate the region of the nanogroove array.