Polariton-induced superconductivity in transition metal dichalcogenides

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Exciton polaritons (polaritons for short) are hybrid particles of excitons (bound electron-hole pairs) and microcavity photons, which can exhibit Bose-Einstein condensation and other coherent phenomena. One striking proposal would use the polariton condensate to mediate an effective interaction between electrons, which can in turn be used to produce a novel kind of light-induced superconductivity [1]. However, most geometries proposed thus far are multi-layer, which reduces the electron-polariton interaction strength [2].

Here, we present a theoretical study aimed at addressing this conundrum. We propose instead a single monolayer design (Fig. 1a), made of a 2D tungsten-based transition metal dichalcogenide (TMDs). These monolayer TMDs host excitons with high binding energies [3], and thus host strong light-matter coupling [4]. With this strong coupling, it is experimentally feasible to tune the lower polariton energy close to the trion energy [5] and exploit that Feshbach resonance, further increasing the electron-polariton interaction strength. Tungsten-based TMDs also have a strong spin-orbit coupling, which causes an inversion (Fig. 1b) of their spin-split conduction bands [6]. This enables us to host dopant electrons and polaritons in a single layer without strongly affecting polariton formation. Our results highlight that polariton-induced superconductivity is possible in such systems with sufficiently large detunings, complementing recent discoveries of superconductivity in their bilayer analogs through other mechanisms [7].

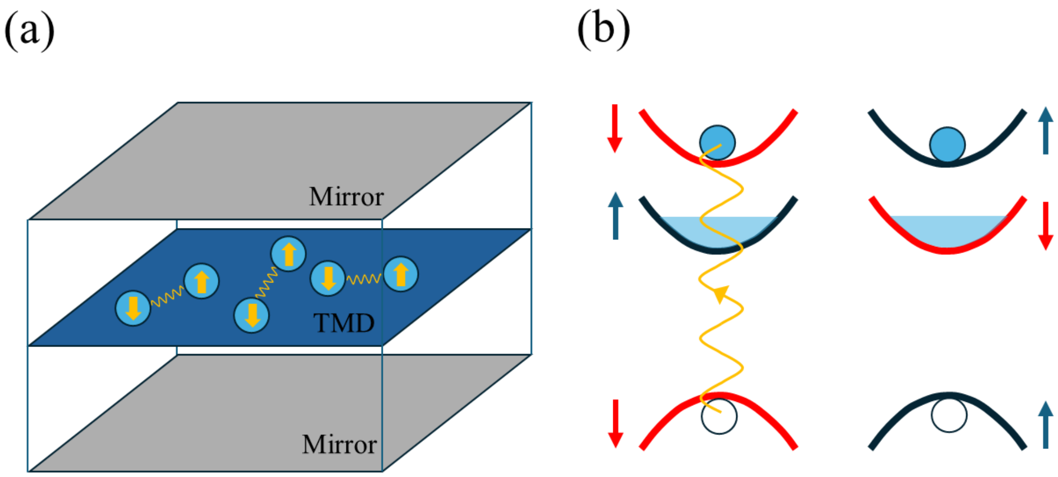

Figure 1: (a) Schematic of our proposed monolayer design. Interactions between doped electrons of opposite spins (blue circles) in the tungsten-based TMD are mediated by polaritons (yellow wiggle). (b) Bandstructure of the tungsten-based TMD. The excitons coupled to light can be formed in either spin valley (blue and red colouring) from a hole in the valence band (empty circle) and an electron in the top conduction band (filled blue circle), while the bottom conduction bands are filled with doped electrons (blue sea) which can form Cooper pairs.

References

[1] F. P. Laussy, A. V. Kavokin, and I. A. Shelykh, "Exciton-Polariton Mediated Superconductivity", Physical Review Letters **104**, 106402 (2010).
[2] F. P. Laussy, T. Taylor, I. A. Shelykh, and A. V. Kavokin, "Superconductivity with excitons and polaritons: review and extension", Journal of Nanophotonics, **6**(1), 064502 (2012).
[3] K. He et al., "Tightly Bound Excitons in Monolayer WSe_2", Physical Review Letters **113**, 026803 (2014).
[4] M. Król, et al., "Exciton-polaritons in multilayer WSe_2 in a planar microcavity", 2D Materials **7**(1), 015006 (2020).
[5] T. P. Lyons et al., "The valley Zeeman effect in inter-and intra-valley trions in monolayer WSe_2", Nature Communications **10**, 2330 (2019).
[6] Z. Wang, L. Zhao, K. F. Mak, J. Shan, "Probing the spin-polarized electronic band structure in monolayer transition metal dichalcogenides by optical spectroscopy", Nano Letters **17**(2), 740 (2017).
[7] Y. Xia, Z. Han, K. Watanabe, T. Taniguchi, J. Shan, K.F. Mak, "Superconductivity in twisted bilayer WSe_2", Nature **637**, 833 (2025).

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