Strain engineering of valley-polarized hybrid excitons in a 2D semiconductor

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Encoding and manipulating digital information in quantum degrees of freedom is one of the major challenges of today's science and technology. The valley indices of excitons in transition metal dichalcogenides (TMDs) are well-suited to address this challenge. Here, we develop a nanomechanical technique to control the energy hierarchy of valleys in monolayer TMDs via their contrasting response to mechanical strain [1]. We demonstrate a new class of strain-tunable, valley-polarized hybrid excitons, comprising a pair of energy-resonant intra- and intervalley excitons [2]. These states combine the advantages of bright intravalley excitons, where the valley index directly couples to light polarization, and dark intervalley excitons, characterized by low depolarization rates. We demonstrate that the hybridized state of dark KK' intervalley and defect-localized excitons exhibits a degree of circular polarization of emitted photons that is three times higher than that of the constituent species. Moreover, a bright KK intravalley and a dark KQ exciton form a coherently coupled hybrid state under energetic resonance, with their valley depolarization dynamics slowed down a hundredfold [2]. These valley-polarized hybrid excitons with strain-tunable valley character emerge as prime candidates for valleytronic applications in future quantum and information technology.

References

[1] Kumar, Abhijeet M., Denis Yagodkin, Roberto Rosati, Douglas J. Bock, Christoph Schattauer, Sarah Tobisch, Joakim Hagel, Kirill I. Bolotin *et al.* "Strain fingerprinting of exciton valley character in 2D semiconductors." Nature Communications 15, no. 1 (2024): 7546.

[2] Kumar, Abhijeet M., Douglas J. Bock, Denis Yagodkin, Edith Wietek, Bianca Höfer, Max Sinner, Pablo H López, Kirill I. Bolotin *et al.* "Strain engineering of valley-polarized hybrid excitons in a 2D semiconductor." arXiv preprint arXiv:2502.11232 (2025).

Figures

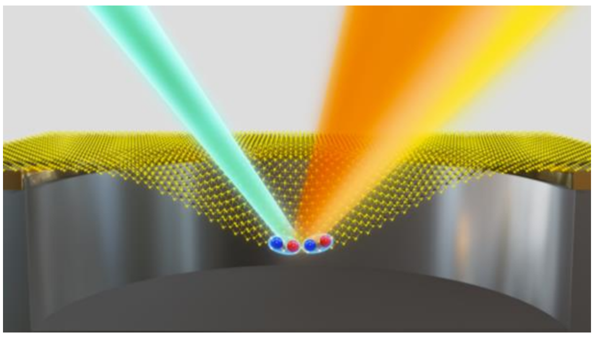

Figure 1: Schematic of a suspended monolayer TMD subjected to strain. Our electrostatic gating-based straining approach allows in-situ strain control at cryogenic temperatures. This enables fingerprinting of exciton valley character and an emerging class of valley-polarized hybrid excitons.