Valley Qubits and Qutrits in TMD Heterostructures

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Monolayer semiconducting transition-metal dichalcogenides (TMDs) form a unique platform for developing gated spin- or valleytronic devices due to efficient gate tunability. This is because of sizable band gap and highly controllable dielectric environment, as well as strong spin–orbit coupling present in these materials [1]. Valley isospin can serve as quantum information host in optically controlled devices or gate-defined quantum dots (QDs) [2]. Experiments on gated QDs [3], or defect-defined in-gap QDs [4] in TMD are in progress, however, there is still no experiment showing coherent manipulation of valley, or spin-valley degrees by electrical means.

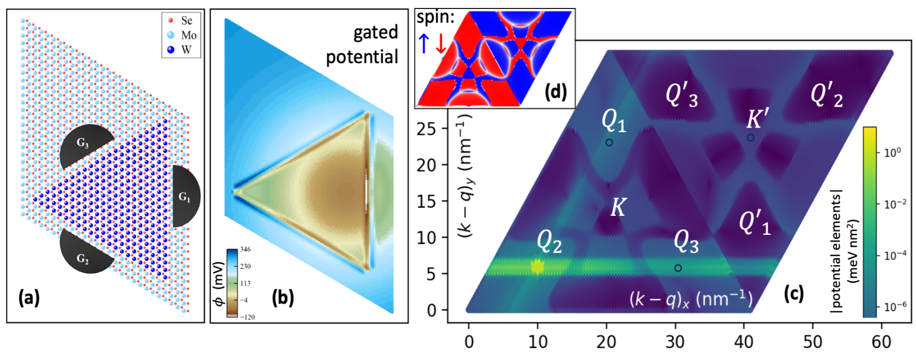

Fig. 1. (a) A lateral QD, built as a $MoSe_2/WSe_2$ triangular flake surrounded by $MoSe_2$ bilayer, and 3 top gates G_i localizing electron at the triangle middle (b), and controlling its interactions with the edges. (c) Coupling elements between selected valleys, here $\langle Q_2|Q_3\rangle$. (d) Spin texture at CB: Q_i valleys span spin-down (red) subspace.

TMD heterostructures open intriguing new possibilities for developing devices to host solid-state qubits [5]. As an example, in $MoSe_2/WSe_2$ vertical heterostructure the conduction band is composed of 6 non-equivalent Q valleys for both spins, giving 3 possible valleys in each spin subspace ($Q_{1,2,3}$ and $Q'_{1,2,3}$ – see Fig. 1c). In this presentation, I will explore new possibility of defining qubits not only on K-valley degree of freedom active in TMD monolayers, but also using three Q_i-valleys, forming a *qutrit*. It is defined in a triangular hard-wall QD composed of 3 lateral heterojunctions along the zigzag orientations (see Fig. 1a) supplemented by 3 top gates G_i (Fig. 1b) creating the lateral Gaussian potential localizing the electron in the centre of the triangular QD and controlling its interaction with the junctions. Controllable resonances with the 3 different edges allow for selective choice of $\langle Q_i|Q_j\rangle$-valley couplings (Fig. 1c), thus making operations within Q_i-valleys subspace needed to fulfil any single-qutrit operations. Triangular islands can be formed in epitaxial growth [6] or in a form of scalable triangular defects [7].

On the other hand, epitaxial growth of lateral TMD dots in a controllable manner with a high-quality junction along a fixed crystallographic axis (zigzag) may be very difficult at present. Therefore, we will also discuss the possibility of performing operations on valley qubits by coupling them to states localized on defects [8], recently observed and analyzed in TMD monolayers [4].

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