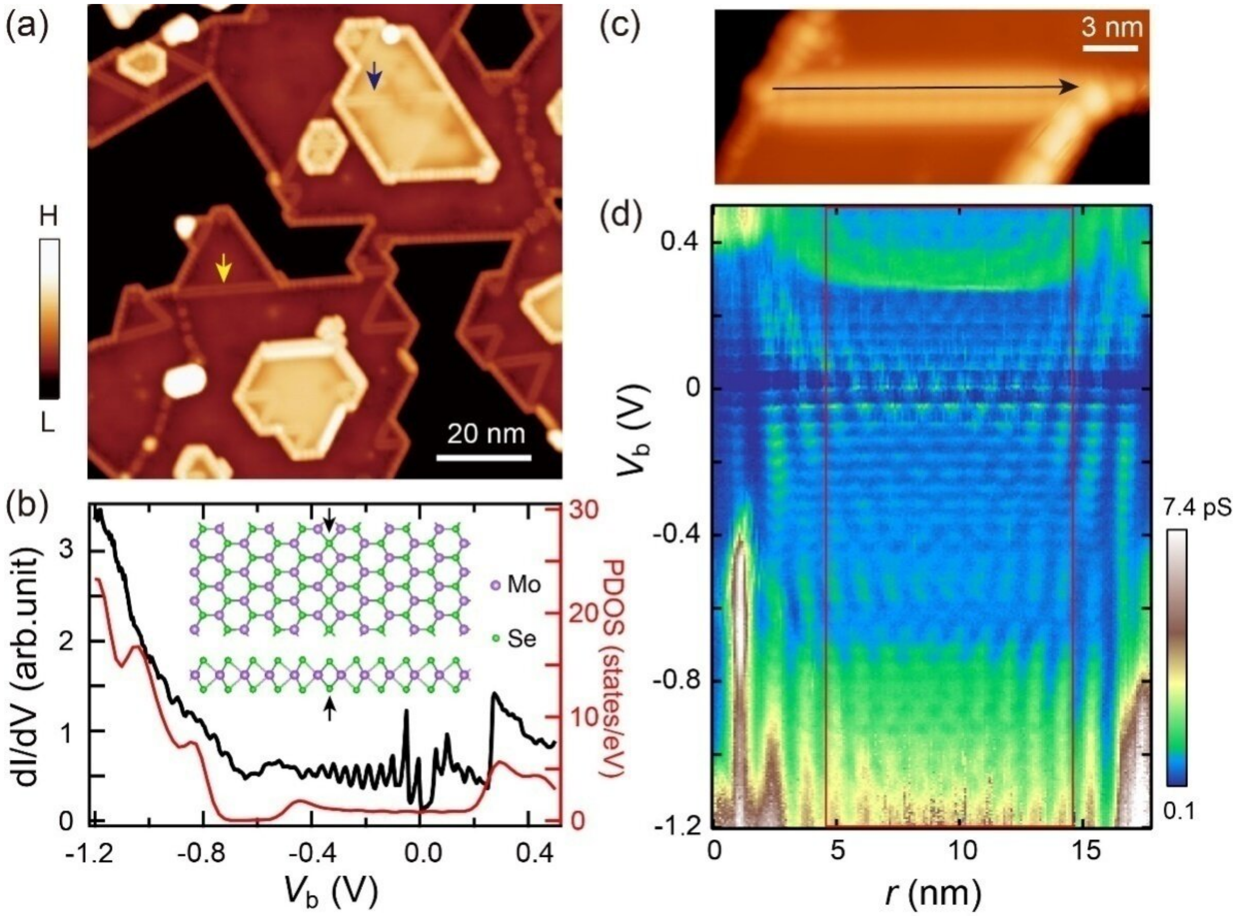
A Hubbard-type Coulomb blockade effect discovered in the mirror twin boundary of MoSe$_2$

October 28 2022



(a) STM image of MTB. Exemplified monolayer and bilayer MTBs are marked with yellow and black arrows, respectively. (b) DFT calculated DOS (red curve) and experimental spectrum (black curve) of an MTB. Inset: Top view and side view of the MTB crystal structure. The black arrows mark the MTB position.

The sample bias is labeled as Vb.(c) Magnified STM image of a monolayer MTB. (d) Conductance plot along the black line in (c). The spectrum in (b) is averaged from (d) in rectangle. Photo credit: Xing Yang. Credit: Science China Press

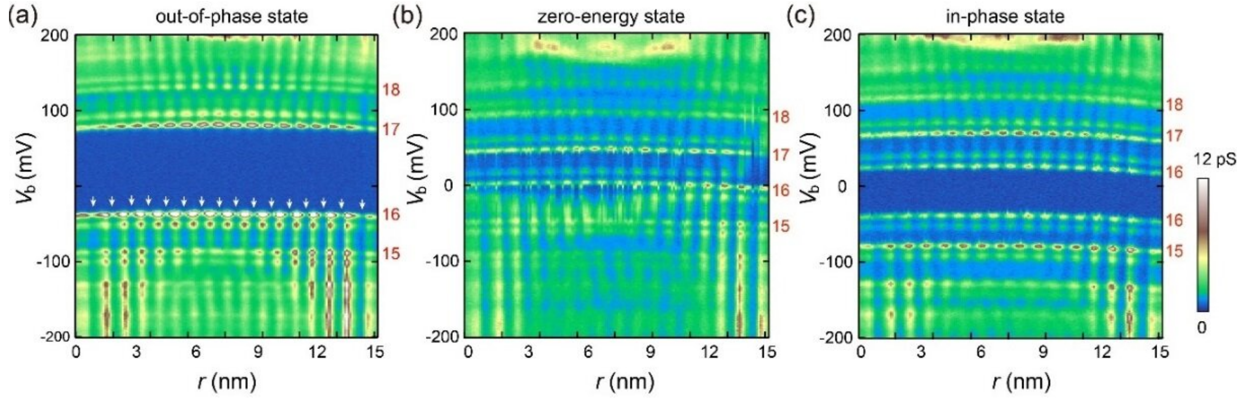
In a study of one-dimensional electron correlation states at the MTB of monolayer and bilayer $MoSe_2$, a research team found that two types of correlated insulating states driven by a dubbed Hubbard-type Coulomb blockade effect could be switched by tip pulses.

By means of molecular beam epitaxy, this team has grown single-layer and double-layer $MoSe_2$ films with one-dimensional MTB on graphene substrates. It is found by scanning tunneling microscopy that the one-dimensional MTB has metallic states. Due to its limited length, the one-dimensional states are subject to quantum confinement effect, resulting in quantized discrete energy levels.

They found two types of MTBs with different ground states, defined as in-phase and out-of-phase states respectively, according to the spatially modulated phase of the two discrete levels spanning the Fermi surface. More interestingly, by applying tip pulses, it is possible to reversibly switch the two states.

They showed that the Coulomb energies, determined by the wire length, drive the MTB into two types of ground states with distinct respective charge orders. The quantum well states at the Fermi surface are affected by the Coulomb effect.

When the Fermi surface is between two quantum-well states with different wave vectors, that is, the out-of-phase state, the energy level interval increases and becomes the sum of Coulomb energy and the interval of the quantum well states.



(a-c) 2D conductance plot of the same MTB shown in part (c) of the image above, displaying different ground states. The node numbers for each discrete level are marked in red, which are defined as the numbers of minima in the charge density modulations of corresponding levels, as exemplified with white arrows in (a). Photo credit: Xing Yang. Credit: Science China Press

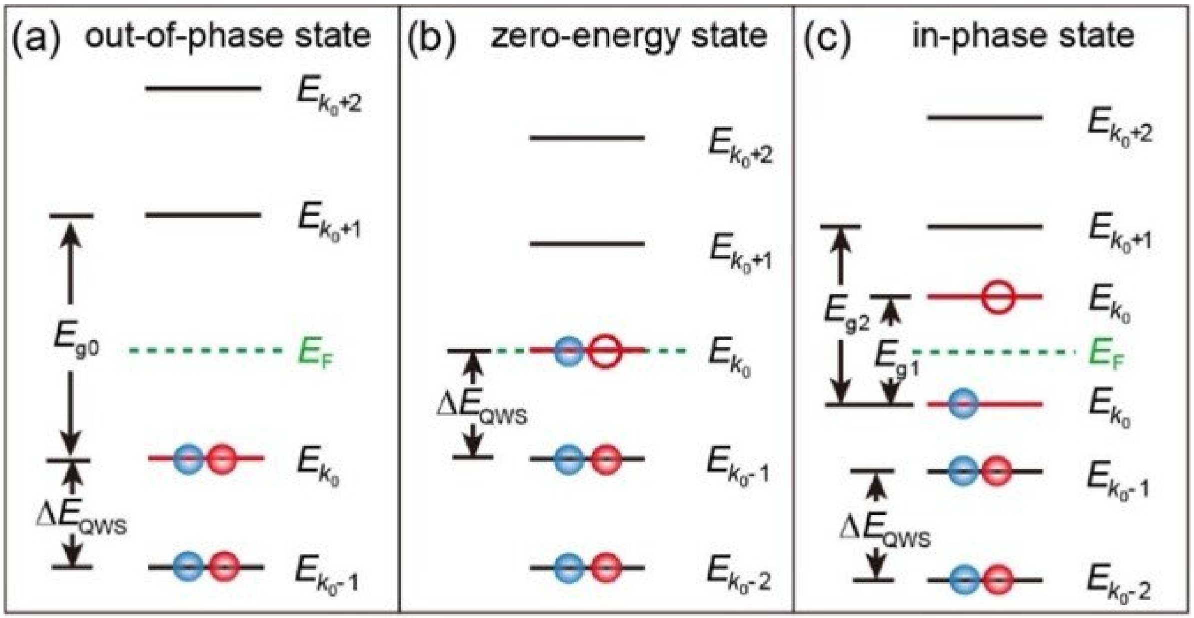
When a quantum well is exactly at the Fermi surface, that is, the in-phase state, the energy level is spin–split by Coulomb energy to form a single electron occupation, and the splitting size is the Coulomb energy.

The electron filling of MTB is tuned with the tip pulse, where the additional injected charges, as substantiated by first-principle calculations, are stabilized via a polaronic process, rendering it feasible to controllably adjust its number of electrons and its spin state.

The determined Coulomb energies are found to solely depend on the wire length, irrespective of the distance of the MTB to the graphene substrate, demonstrating the Coulomb interaction is short-range. This is different from the classical Coulomb blockade effect, where the

Coulomb energy depends on its capacitance to the environment and is thus long range.

Such short-range Coulomb energy has a similar expression to the classical Coulomb blockade effect, and is thus dubbed Hubbard-type Coulomb blockade effect.



(a-c) Schematics showing an energy level diagram at the mean-field level, namely, out-of-phase state (a), zero-energy state (b), and in-phase state (c), respectively. Each level is marked with its wave vector. The spin-up (spin-down) electrons are depicted with red (blue) balls. The solid (hollow) balls represent electrons residing occupied (unoccupied) levels. Photo credit: Xing Yang. Credit: Science China Press

This research team achieved control of electron correlation and spin states at the atomic scale, laying a foundation for understanding and tailoring correlated physics in complex systems.

The research was published in *National Science Review*.

More information: Xing Yang et al, Manipulating Hubbard-type Coulomb blockade effect of metallic wires embedded in an insulator, *National Science Review* (2022). DOI: 10.1093/nsr/nwac210

Provided by Science China Press

Citation: A Hubbard-type Coulomb blockade effect discovered in the mirror twin boundary of $MoSe_2$ (2022, October 28) retrieved 24 June 2024 from https://phys.org/news/2022-10-hubbard-type-coulomb-blockade-effect-mirror.html