One-dimensional metals in twin grain boundaries of $MoSe_2$

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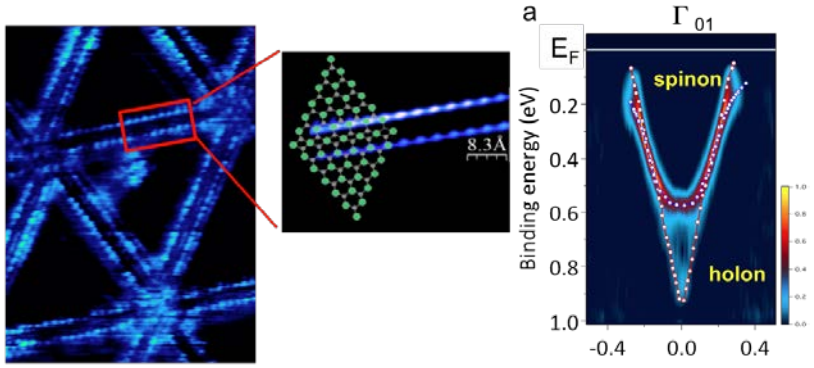
Electrons confined in one-dimension (1D) behave fundamentally different from the Fermi-liquid in higher dimensions. Material line defects are one dimensional but the search and proof of 1D electron behavior in such defects has been so far unsuccessful. In this presentation we show that a line defect in the 2D semiconductor MoSe2 is metallic and hosts 1D electrons. Scanning tunneling microscopy of monolayer MoSe2 films grown by MBE on other van der Waals materials reveal a high density of these line defects (figure). Furthermore, low temperatures STM shows the formation of a charge density wave (Peierl's transition) as is expected for any 1D-metal. Importantly, the high density of these crystallographically aligned defects enables the characterization of the electronic properties by angle resolved photoemission spectroscopy (ARPES) and thus, for the first time, a direct k-space resolved measurement of the electronic structure of a material's line defect. The measured Fermi-wave vector agrees with the measured periodicity of the charge density wave in STM. Further important verification of 1D behavior of these metallic states comes from the Tomonaga Luttinger liquid behavior of the density of states at the Fermi-level.



STM image with atomic corrugation on a twin-grain boundary network in $MoSe_2$. The ARPES data reveal metallic states in the band gap of $MoSe_2$, whose spectral line is split into a spinon and holon band.

The most 'exotic' property of 1D quantum liquids is, however, the separation of spin- and charge-excitations. Our ARPES measurements (figure) clearly exhibit the splitting of the spectral line into 'spinon' and 'holon' excitations. To understand these distinctive k-dispersion lines one has to go beyond the traditional Tomonaga Luttinger formalism for 1D electrons. Using a 1D Hubbard model with finite-range interactions enables to exactly reproduce our experimental data, demonstrating the observation of spin-charge separation in these line defects. Our results also imply that isolated quantum wires can be formed in twin boundaries of 2D transition metal dichalcogenides, which should enable quantum transport on these individual quantum line defects in the future.

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