Imaging the atomic-scale effects of controlled disorder on an ordered electronic state in 2D quantum materials

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Use of controlled disorder in 2D quantum materials to design electronic states at the atomic scale is a major goal in quantum materials research [1]. 2D quantum materials often show remarkable properties arising as a result of a complex interplay of charge, lattice, spin, and orbital degrees of freedom. This interplay gives rise numerous electronic phases including superconductivity, anti-ferromagnetism, charge-density waves (CDW), spin-density waves, Mott-insulating among others [2-4]. Systematic introduction of external perturbations such as controlled disorder through doping or irradiation is one approach that has been used to probe this interplay [5-7]. However, the influence of induced disorder coupled with the intricate interaction between electronic and lattice degrees of freedom can trigger complex structural evolution and distribution of various electronic phases at the atomic scale [1, 4]. It's therefore necessary to understand how disorder-induced changes in the atomic lattice and the electronic ordered states are correlated at the atomic scale. We have investigated the correlation between the atomic-scale responses of the charge density wave electronic state and the underlying atomic lattice in 1T-$TiSe_2$ and O-TaS_3 exposed to controlled electron irradiation. Atomic-scale transmission electron microscopy imaging supported by electron energy loss spectroscopy shows that the CDW electronic phase responds with an elastic-like strain response to irradiation induced defects and deformations in the atomic lattice. This is characterized by a proliferation of phase defects including CDW dislocations, discommensurations, and domain walls. Our results show the importance of disorder-induced defects in modulating, stabilizing or destroying electronic phases at the atomic scale in 2D quantum materials.

References

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