# Novel insight on the charge density wave ground state by scanning tunneling microscopy

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Charge density wave (CDW) phases permeate the phase diagram of many correlated electron systems. Despite decades of research, CDWs are still lacking a detailed understanding. There is renewed interest in CDWs motivated by the possible competition of this quantum phase with superconductivity, in particular in high temperature superconductors. Moreover, robust evidence for nesting at the Fermi level, the preferred mechanism, is firmly established only in very few CDW systems, while the nature and amplitude of the associated gap in the band structure remain largely unsettled. We will discuss recent scanning tunneling microscopy and spectroscopy experiments providing novel insight on the CDW phase observed in transition metal dichalcogenides (TMDs). After a brief review of some open issues in selected CDW systems, we discuss unique investigation opportunities offered by the recent developments preparing exfoliated TMDs of variable thicknesses, from bulk to monolayer. We find a striking non-monotonic thickness dependence of the CDW phase transition temperature ($T_{CDW}$) in $VSe_2$ [1]. $T_{CDW}$, determined directly from the charge modulation amplitude imaged by STM, is found to diminish with thickness above 20nm. Meanwhile, below 10nm thickness, $T_{CDW}$ is increasing to exceed the bulk values by nearly 40% in the thinnest specimen. Although a detailed theoretical understanding is yet to be developed, this behavior reflects a 3D to 2D dimensional crossover followed by quantum confinement in the thinnest samples. Next, we introduce a powerful real space fitting procedure, allowing us to map the full complex CDW order parameter with a spatial resolution of the order of half a CDW period. Thus obtained images of the local amplitude, phase and wavelength provide unprecedented insight into the CDW ground state. We find in particular that the CDW in TMDs consists of three individual components. Phase contrast images reveal domain walls, discommensurations and topological defects such as vortices and vortex anti-vortex pairs in each of the three components. Finally, we show how the atomic resolution capabilities of scanning probe imaging [3] gives insight into the three dimensional real space structure of the CDW reconstruction.

**References**

[1] Á. Pásztor et al. 2D Materials 4, 041005 (2017).

[2] Á. Pásztor et al. arXiv:1806.08676 (2018).

[3] M. Spera et al. arXiv:1710.04096 (2017).