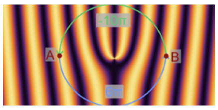

Controlling the Winding Number of Topological Defects through Materials Engineering

Certain topological defects manifest as singularities or «nodes» in a phase field and are characterized by a winding number. A edge dislocation, is a typical example of such a defect, observed across a range of condensed matter systems including liquid crystals, atomic lattices, and magnetic textures. These defects are currently experiencing renewed interest due to their potential applications. In particular, their presence in topological materials could serve as hosts for non-Abelian anyons—quasiparticles of great interest for fault-tolerant quantum computing. In an experimental study using scanning tunneling microscopy, researchers at INSP, in collaboration with colleagues from IPCMS and the University of Liège, demonstrate that in a moiré superlattice formed between two epitaxially grown materials, a dislocation in one of the atomic lattices induces a corresponding dislocation in the moiré pattern. The winding number of the resulting dislocation in the moiré pattern subtly depends on the structural parameters of the two constituent materials. Using a simple mathematical model, the researchers show that the winding number of such topological defects can be tuned through careful material engineering.

Moiré patterns are commonly observed in well-known van der Waals heterostructures, such as graphene on Ir, Pt, or Ru substrates, where the lattice constants of the monolayer and the substrate are very similar. When the crystallographic axes of the two materials are aligned, a first-order moiré forms, in which one unit cell of material A coincides with one of material B. In this configuration, a dislocation in the atomic lattice of material A directly maps onto the moiré lattice, preserving the winding number—for example, a dislocation with winding number of 1 in the atomic lattice leads to a moiré dislocation with winding number 1.

In this study, a monolayer of $CrCl_3$, a two-dimensional magnetic van der Waals material, was deposited by molecular beam epitaxy onto a Au(111) single crystal. Despite a significant lattice mismatch between the two materials, the $CrCl_3$ layer is not constrained by the gold substrate. This van der Waals epitaxial growth leads to the formation of a moiré superlattice. Notably, the lattice constant of $CrCl_3$ is approximately twice that of the gold substrate, resulting in a second-order moiré. In this configuration, a dislocation in the $CrCl_3$ atomic lattice is not merely scaled up in the moiré lattice—instead, its winding number is doubled.

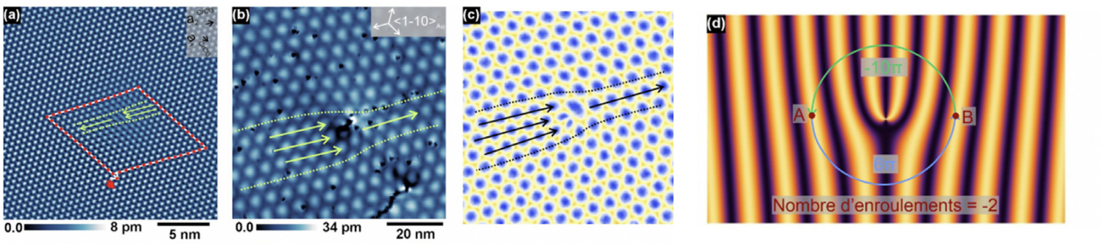

Figure 1

(a) Topography obtained by scanning tunneling microscopy showing that a dislocation with a winding number of 1 in the atomic lattice of $CrCl_3$ results in a dislocation with a winding number of –2 in the moiré lattice (b). (c) Numerical simulation of the moiré dislocation reproducing the experimental observations. (d) Analytical calculation of the winding number of the dislocation in the moiré pattern.

This study demonstrates that by simply tuning the lattice parameters of the materials in a van der Waals heterostructure, one can control the winding number of topological defects. Such engineered defects, especially in intrinsically topological materials, may act as hosts for non-Abelian anyons, offering a promising route toward the realization of fault-tolerant quantum computers.

Reference

"Higher Order Topological Defects in a Moiré Lattice"
Eugenio Gambari, Sebastian Meyer, Sacha Guesne, **Pascal David, François Debontridder,** Laurent Limot, Fabrice Scheurer, **Christophe Brun,** Bertrand Dupé, **Tristan Cren, Marie Hervé.**
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