Imaging Ultrafast Electron Dynamics and Controlling Topological Phases with Lightwave-Driven Microscopy at the Atomic Scale

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Lightwave-driven scanning tunneling microscopy offers a powerful new window into quantum phenomena at the atomic scale [1–8]. By combining single-cycle terahertz pulses with scanning tunneling microscopy (THz-STM), we achieve simultaneous picometer and picosecond spatio-temporal resolution, enabling terahertz time-domain spectroscopy and microscopy with unprecedented precision [7–9]. We have used this technique to explore terahertz-driven tunneling dynamics across a wide range of materials, including noble metals [4,7], conventional semiconductors [3,7,9], graphene nanoribbons [5], and a topological Weyl semimetal [8]. THz-STM also enables visualization of how local surface potentials influence the ultrafast evolution of photoexcited charge carriers near atomic defects [9]. Further yet, the tightly confined and strongly enhanced THz fields can be used to drive local phase transitions such as in WTe_2, where a terahertz-induced interlayer shear displacement triggers a reversible topological switch of the topmost surface layer near the tip apex [8]. By combining picometer resolution with sub-cycle temporal precision, THz-STM opens the door to an entirely new regime of quantum measurement, transforming how we observe, understand, and control matter at its most fundamental scale.

References

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