Topological Transitions and Tunable Polariton Canalization in Twisted Hyperbolic Surfaces

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Twisted stacks of two-dimensional (2D) van der Waals heterostructures have been at the basis of a new playground for nanoelectronics within the emerging field of *twistronics* - manipulating the electron wavefunction via rotation. Various applications have emerged from this paradigm, including superconductivity in twisted graphene bilayers, moiré excitons in semiconductor twisted bilayers (tBLs), and interlayer magnetism in 2D magnetic tBLs. Inspired by these advances, we have recently applied twistronic concepts to photons and polaritons, opening exciting opportunities for nano-optics.

2D materials can support polaritons, quasi-particles emerging from strong interactions of matter with photons, enabling unprecedented control of light at the nanoscale, with applications in classical, quantum and nonlinear optics. Their dispersion can be engineered to yield highly unusual optical responses by leveraging surface anisotropy in carefully designed metasurfaces, such as deeply subwavelength nanoribbon arrays of graphene or of hexagonal boron nitride. These structures form hyperbolic metasurfaces supporting extreme density of states and sub-diffractive canalization of propagating polaritons[1,2]. In our recent works, we have laid the foundations for twistronics of photons by stacking and twisting hyperbolic polaritonic surfaces[3,4].

Rotating a metasurface made of densely packed graphene nanoribbons with respect to a second closely spaced one (panel **a**) enables extreme dispersion engineering of plasmon polaritons[3], which undergo a topological transition of their band dispersion, from hyperbolic to elliptical dispersion contours, as a function of the rotation angle. This transition can be described by a change in topological invariant, corresponding to the number of anti-crossing points (N_{ACP}) of the dispersion lines of the individual surfaces (panel **b**). At the rotation angle for which N_{ACP} changes, the dispersion diagram changes from closed to open contours, and at this transition highly collimated and diffractionless polariton propagation is observed. Panel **b** shows the broad range of frequencies and angles over which this phenomenon can be observed and tuned over.

We experimentally verified these phenomena in twisted α-MoO_3 bilayers (panel **c** and **d**), van der Waals nanomaterials that naturally support in-plane hyperbolic phonon polariton propagation at mid-infrared frequencies[5]. Using real-space nanoimaging techniques we mapped hyperbolic-to-elliptical topological transitions vs. the twist angle and observed broadband tunable polariton canalization[4]. These results pave the way for extreme photonic dispersion engineering and low-loss diffraction-free nanoscale photon transport based on twistronic concepts, with applications in light manipulation at ultimately small dimensions and advanced classical and quantum nano-photonics.

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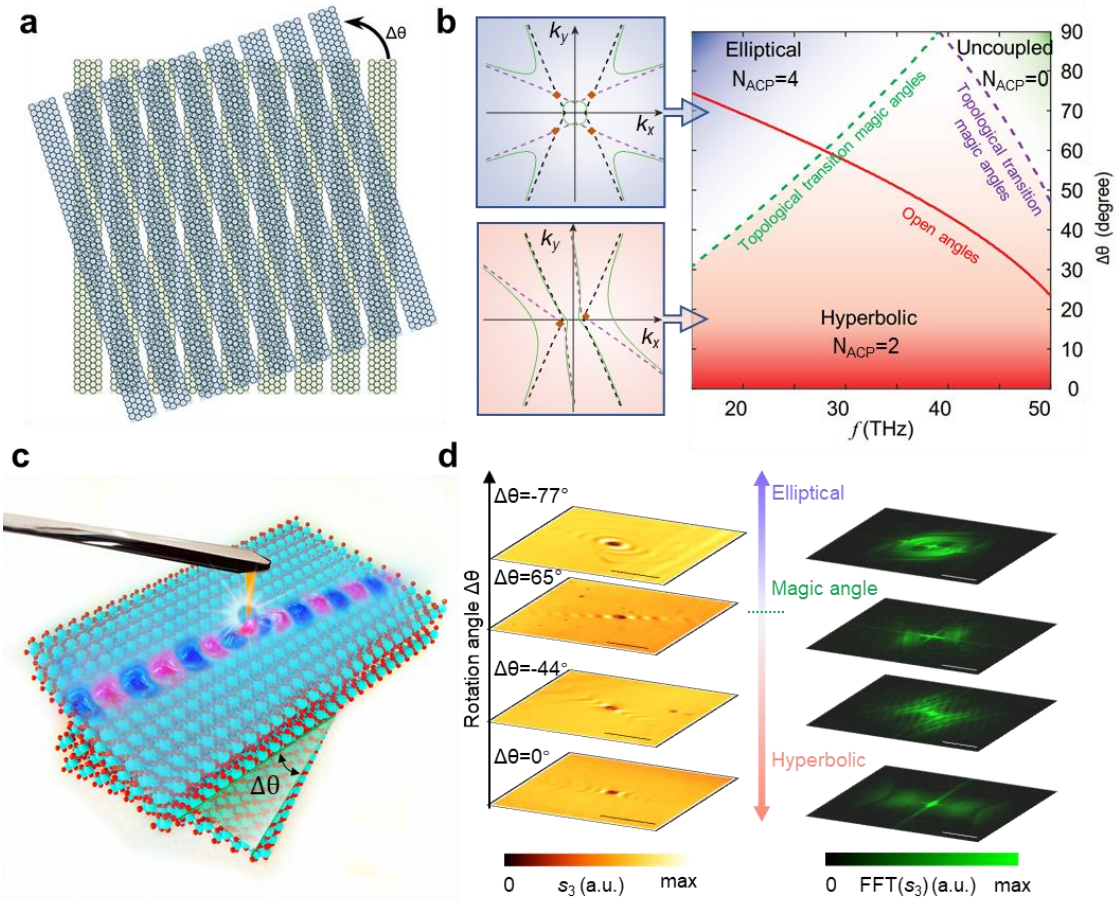

a Schematics of hyperbolic twisted bilayers made of densely packed graphene nanoribbons. **b** Topological transition and tunable dispersion features. Hyperbolic propagation is found when N_{ACP}=2, elliptical when N_{ACP}=4 [3]. **c** α-MoO_3 twisted bilayer. **d** Near-field distribution (scalebar: 2μm, left) and retrieved dispersion (scalebar: 20k_0, right), demonstrating a topological transition as the twist angle changes [4].