

A twist for nanolight

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Controlling the twist angles between three α -phase molybdenum trioxide single layers enables the programmable and reconfigurable canalization of phonon polaritons along multiple in-plane directions.

Twistronics, the study of how the rotation angles between layers of van der Waals materials can alter their electrical properties, has garnered great attention since the discovery of magic-angle graphene in 2018 (ref. 1). By engineering electronic quantum materials, twistronics has successfully unlocked phenomena such as superconductivity, correlated insulators and topological electronic states. Researchers are now exploring the potential of layer twisting as a new parameter in materials research, extending the applications from electronics to optics and photonics. In particular, tailoring the propagation of nanoscale electromagnetic waves is intriguing as it allows the manipulation of optical properties and energy at confined length scales. Now, writing in *Nature Materials*, Jiahua Duan and colleagues demonstrate that by twisting three layers of α -phase molybdenum trioxide (α -MoO₃), they could achieve broadband and reconfigurable canalization – diffractionless propagation – of infrared light at the nanoscale². The potential applications of this reconfigurable nanolight canalization in twisted α -MoO₃ trilayers are extensive, offering new possibilities for developing advanced nanophotonic devices with broadband and reconfigurable functionalities.

α -MoO₃ is a polar van der Waals semiconductor supporting phonon polaritons – hybrid photon–lattice vibration waves confined in materials. The biaxial nature of α -MoO₃ means its permittivity can have opposite signs in the basal plane ($\epsilon_x\epsilon_y < 0$). This extreme anisotropy leads to a unique concave wavefront for phonon polaritons in α -MoO₃ (Fig. 1a). When stacked together, the electromagnetic interaction among individual α -MoO₃ layers depends strongly on their twist angles. Therefore, the wavefront and propagation of phonon polaritons in stacked α -MoO₃ can be effectively configured by varying the twist angles. In previous works on twisted α -MoO₃ bilayers^{3–6}, researchers demonstrated the canalization of phonon polaritons at a specific angle – the photonic magic angle – where the energy distribution and propagation of nanolight waves are strictly confined along a straight line. Canalization is a precious phenomenon in wavefront manipulation with great potential in long-range interactions, energy management, nanophotonic communications and information processing.

The canalization in twisted α -MoO₃ bilayers is limited to specific magic angles and small ranges of canalization directions and frequencies, therefore limiting its further potential in practical nanophotonic devices. This is the challenge addressed by Duan and colleagues, reporting multiple magic angles, various directions, broadband and reconfigurable canalization of infrared nanolight in twisted α -MoO₃ trilayers. Twisted trilayers, first applied in the electronics sector where multiple twisted layers have led to new and robust superconductors^{7,8},

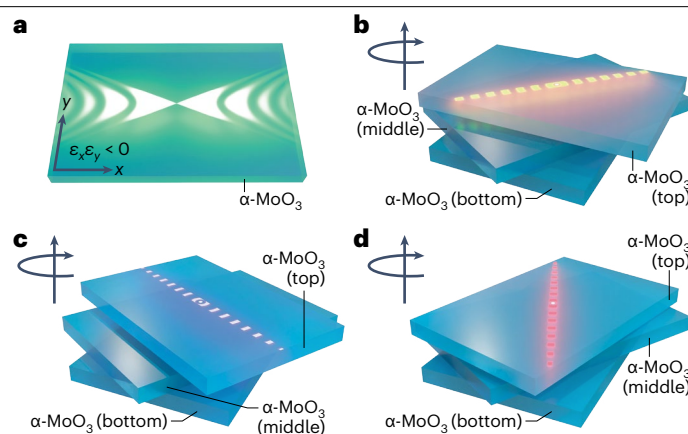


Fig. 1 | Multidirectional, broadband and reconfigurable nanolight canalization. **a**, The biaxial nature of α -MoO₃ results in permittivity with opposite signs in the basal plane ($\epsilon_x\epsilon_y < 0$) and a concave wavefront for phonon polaritons (green). This extreme anisotropy is crucial in engineering twisted bilayer and multilayer phonon-polariton wavefronts and dispersions. **b–d**, Twisted trilayer α -MoO₃ with various twist angles can support diffractionless propagation of nanoscale phonon polaritons in a range of directions and frequencies (orange, purple and red). Twisted trilayer α -MoO₃ can be reconfigured by reassembling the constituent layers. Panels **b–d** adapted with permission from ref. 2, Springer Nature Ltd.

have now been used to engineer nanophotonic properties. By fixing the angles of the first and second layers, canalization can be obtained along various directions and at a broad range of frequencies just by rotating the top layer (Fig. 1b–d). Using a scattering-type scanning near-field optical microscope, the authors directly visualize the propagation of phonon polaritons revealing their canalization. Such reconfigurable nanolight canalization in α -MoO₃ trilayers could be exploited for super-Coulombic long-range dipolar interactions⁹ and the directional coupling of quantum emitters.

Reconfigurable photonic structures with in situ tuning capabilities have gained increasing attention in recent years, and Duan and colleagues demonstrate here a milestone. However, their reconfigurability still requires reassembly of the twisted layers, whereas in situ dynamic control of the twist angles would be highly advantageous both from the perspective of fundamental science as well as practical applications. To this end, the in situ rotation technique proposed by Ribeiro-Palau and colleagues¹⁰ could provide a promising solution. This technique involves shaping the top α -MoO₃ flake in the three-layer structure into a rudder and using the tip of an atomic force microscope (AFM) to mechanically rotate the rudder. Duan and colleagues' nanoimaging platform is also based on an AFM. Thus, dynamic rotation of the top layer integrating such AFM-based twistable capability would be an interesting extension to the demonstrated reconfigurability. This integration could make it more efficient and convenient to investigate the nanophotonics properties of twist structures. As the field

of twistronics and twist-photonics progresses, novel techniques for in situ control of twist angles will be developed and employed to realize innovative applications.

We also highlight the fascinating realm of research involving the exploration of new and exotic nanolight wavefronts and dispersions through layer twisting. By carefully controlling the twist angle of each component and potentially incorporating spacers between the twisted multilayers, it becomes possible to customize the wavefront of polariton nanolight, shaping it into forms such as canalization, squircle and various other extraordinary shapes. These intricate wavefronts enable non-symmetric and directional propagation, surpassing the conventional capabilities to transfer energy and information flow using nanolight with a circular wavefront. The non-spreading nanolight devices, exhibiting propagation characteristics closer to their electronic counterparts, hold great potential as candidates for fast and integrated nano-optical circuits for computation and information processing. Moreover, in addition to manipulating the wavefront, twisted multilayers allow simultaneous engineering of nanolight energy–momentum dispersion and photonic density of states. This engineered high-momentum phonon-polariton nanolight activates previously evanescent channels for optical and thermal energy transfer. Consequently, these twisted multilayers can be utilized to build bright and highly efficient light sources as well as quantum emitters. Furthermore,

thermal energy in modern electronics may also be appropriately dissipated by harnessing engineered phonon-polariton nanolight.

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Competing interests

The authors declare no competing interests.