Gate-tunable nanoscale negative refraction of polaritons demonstrated in van der Waals heterostructure

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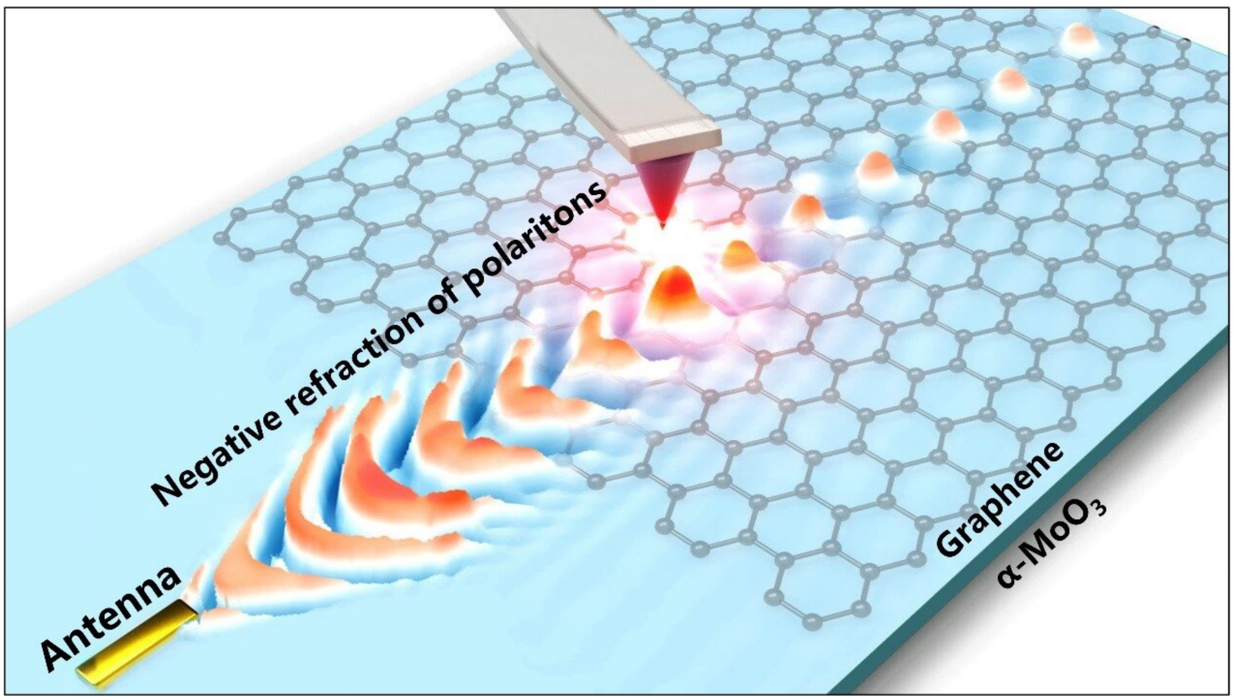

Basic principle of the "polariton transistor". The van der Waals heterostructure is constructed by decorating graphene on the molybdenum trioxide, and the antenna stimulates the polariton to transmit through the interface to form negative refraction. Credit: Dai Qing et al.

A new study led by Dai Qing's team from the National Center for

Nanoscience and Technology (NCNST) of the Chinese Academy of Sciences (CAS) and Javier Abajo from the Institute of Photonic Sciences (ICFO) in Spain has shown a gate-tunable nanoscale negative refraction of polaritons in the mid-infrared range through a van der Waals heterostructure of graphene and molybdenum trioxide.

The atomically thick heterostructures weaken scattering losses at the interface while enabling an actively tunable transition of normal to negative refraction through electrical gating.

The work was published in *Science*.

The photonic-electronic fusion at the nanoscale is an important development direction for future high-performance information devices. The integration of optoelectronic devices is determined by the optoelectronic interconnection method, which affects its speed and power consumption and is the key to improving device performance.

However, photons do not carry charges and the transmission of light is limited by the optical diffraction limit, making it difficult to manipulate and control photons at the nanoscale compared to electrons, which can easily be regulated through electrical means.

In 1951, Chinese solid-state physicist Academician Huang Kun predicted the polariton quasi-particle formed by the interaction between photons and matter through his famous "Huang equation." After years of investigation and constant in-depth discovery, polaritons have been proven to be able to easily break through the optical diffraction limit and compress the wavelength of light to the nanoscale, and the field distribution of polaritons is closely related to the dielectric environment.

The team from NCNST suggested the use of polaritons as a medium for optoelectronic interconnections to capitalize on their high compression and easy modulation of light. It was anticipated that polaritons would not only enable effective optoelectronic interconnections but also offer new information processing capabilities that would significantly improve the performance of optoelectronic fusion devices.

In recent work, Dai's team and their collaborators discovered the "axial dispersion" effect of polarized excitons in low-symmetry crystals, solved the long-range transport problem of plasmonics in graphene, and proposed a new mechanism for the regulation of polaritons by heterojunctions.

Based on this, the researchers designed and fabricated a nanoscale graphene/molybdenum trioxide van der Waals heterostructure.

They explained that the van der Waals heterostructure fully exploits the nanophotonic properties of various materials, where the atomic layer thickness provides the basis for highly compressed optical modes, the lattice structure properties support isotropic (circular) and anisotropic (hyperbolic) transport modes, the van der Waals stacking satisfies the near-field matching of mode hybridization, and the linear energy band structure provides a platform for mode hybridization.

In addition, the researchers realized dynamically tunable positive-negative refractive transitions in the deep subdiffraction limit and overcame performance bottlenecks in terms of waveband, loss, compression, and modulation of conventional structural optical solutions such as the use of metamaterials and photonic crystals.

"This dynamically tunable positive and negative refraction conversion phenomenon can be understood as a 'polariton transistor' function that uses one kind of polariton to regulate the switching of another polariton, which allows the construction of optical logic units such as those with and without gates and is anticipated to be applied in many fields, such as photoelectric fusion," said Dai, one of the paper's corresponding authors.

More information: Hai Hu et al, Gate-tunable negative refraction of mid-infrared polaritons, *Science* (2023). DOI: 10.1126/science.adf1251. www.science.org/doi/10.1126/science.adf1251

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