Journal of Semiconductors
(2019) 40, June 2019 | JOS

OPTICAL MANIPULATIONS OF 2D TMDC

2D metamaterials coherently steer nonlinear valley photons of 2D semiconductor

Nat. Photonics, 2019, doi: 10.1038/s41566-019-0399-1

Monolayer transition-metal dichacolgenides (TMDCs) present a direct optical bandgap at the Brillouin zones, so-called valleys. Those energetically degenerate valleys (K and K') present different valley pseudospins, emitting the valley photons with opposite spin angular momentums due to nonlinear optical selection rules. Furthermore, although atomically thin, two-dimensional (2D) TMDCs have giant nonlinearity, which can be enhanced by the valley-excitons. However, there are still big challenges for optical approaches to coherently access and manipulate the valley degree of freedoms of 2D TMDCs, especially in nonlinear region.

Now, an international team led by Prof. Cheng-Wei QIU from National University of Singapore has proposed and demonstrated that they can use the optical 2D metamaterials, namely metasurface, to boost, selectively pump and steer the nonlinear chiral photons from different valleys of monolayer tungsten disulfide (WS_2). The optical metasurface can apply the spin-dependent geometric phases to the fundamental-frequency light, which could further pump the 2D materials. Thanks to the coherent light-matter interaction of second-harmonic generation (SHG) and the spin-valley-exciton-locked SHG in 2D TMDCs, the geometric phase can be further inherited by nonlinear photons, showing a valley-dependent geometric phases and thus spatially steering chiral valley photons with nearly perfect figure or merits. Meanwhile, SHG of 2D WS_2 can be also enhanced by localized plasmon resonance in metasurface. This work points out the possibility to synthesize the optical metamaterials and metasurfaces with 2D materials for double-win applications and could stimulate the widespread interest in nonlinear metamaterials, 2D optoelectronics, quantum optics and others.

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doi: 10.1088/1674-4926/40/6/060201

PHOTO-CATALYTIC PROPERTY OF 2D MATERIALS

Unique interfacial thermodynamics of few-layer 2D MoS_2 for (photo)electrochemical catalysis

Energy Environ. Sci., 2019, doi: 10.1039/c9ee00513g

The exploitation of heterogeneous semiconductor (photo)electrocatalysis is a significant avenue to study renewable energy for adapting a commodity chemical supply to satisfy the growing global energy demands. The fundamental thermodynamics that guided the understanding of electron transfer processes and predictive power of materials design for bulk-semiconductor heterogeneous (photo)electrocatalysis are generally understood within the framework pioneered by Gerischer and Marcus. However, new materials, such as van der Waals bound 2D transition metal dichalcogenides (TMDCs), display electronic characteristics unlike those found in bulk semiconductors. Therefore, it is necessary to adapt the fundamental electrochemical principles that guide catalyst design for utilization these materials to construct heterogeneous catalysts.

Recently, Carroll group studied the interfacial energetics of 2H-phase MoS_2 by probing the changes to its electronic structure as a function of applied potential using in situ spectroelectrochemical measurements. The results showed that electron injection into the conduction band was coupled with a low energy shift of the exciton resonance, both properties are closely related to the number of MoS_2 layers in the vertical dimensions. In addition, the broadening Raman signals indicated that the applied electric field/electronic doping imparted a structural change. In contrast to conventional semiconductors, the conduction band electron injection was dependent on the change in the excitonic energy and not just the applied potential. This observation indicated that the relevant semiconductor liquid interfacial energetics changed with varied electric fields, a property not observed in typical semiconductors. It also demonstrated that the spectroscopic signatures of band gap reduction and carrier injection occur under electrocatalytic hydrogen evolution conditions. The results reported by the group highlighted the possibility of using 2D TMDCs more effectively to improve energy conversion efficiencies over traditional semiconductors, and provided a new and potentially interesting avenue to explore for heterogeneous (photo)electrocatalysis.

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doi: 10.1088/1674-4926/40/6/060202

WEYL SEMIMETAL DEVICE

Topological photodetection

Nat. Mater., **18**(**5**), 476–481 (2019)

Nonlinear optoelectronic responses play a crucial role not only in optical devices but also in probing the fundamental properties of quantum materials. The recently discovered Weyl semimetals, belonging to the class of topological metallic phases, provide an ideal platform to explore the physical effects that relate to topology in gapless materials. The defining feature of a Weyl semimetal is the divergence of Berry curvature at the Weyl nodes, leading to topological semi-metallic phases. The divergence behaves like magnetic monopoles of the momentum space and the sign of the monopole determines the chirality. Recently, an international team of researchers led by Dong Sun, Ji Feng and Jian-Hao Chen from Peking University have made progress on high-performance photodetection based on topological properties of Weyl semimetal

Journal of Semiconductors
(2019) 40, June 2019

$TaIrTe_4$. They reveal that a photocurrent measurement can capture the fundamental topological feature of a Type-II Weyl cones. Furthermore, through the third-order nonlinear effect, they demonstrate that the chirality of charge carriers in this Weyl semimetal can be jointly controlled by the helicity of excitation light and an in-plane electric field, which offers new means to manipulate electron chirality. This work greatly boosts the responsivity of semimetal based photodetector at mid-infrared wavelength, and establishes the fact that photodetection is the direction that is closest to real applications for topological materials.

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doi: 10.1088/1674-4926/40/6/060203