凝縮系物理学ゼミナール

Condensed Matter Seminar

Date: 13:30-15:00, Wednesday, 16 November 2022

Title: Plasmonic Quantum Nonlinear Hall Effect: Toward Next Generation Plasmonic THz Photodetectors

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Abstract:

In the past decades, we have witness that quantum geometrical properties of Bloch electrons play a crucial role in various research areas of condensed matter physics. For example, valley Hall effect and intrinsic photogalvanic effect, which are essential in context of valleytronics and nonlinear optics, are described by such geometrical quantities as the so-called Berry curvature and the quantum metric tensor [1,2]. These phenomena are particularly remarkable in noncentrosymmetric materials with strong spin-orbit coupling, such as two-dimensional transition metal dichalcogenides (2D-TMDCs). In the context of plasmonics, on the other hand, we often exploit an electron hydrodynamic theory to describe collective electron dynamics and spatial modulations due to plasmonic nanostructures [3]. However, conventional hydrodynamic theory does not reflect the geometric nature of Bloch electrons, and thus, require an appropriate reformulation to give a complete understanding of plasmonics in noncentrosymmetric quantum materials.

In this work, we investigate an interplay between quantum geometrical effects and surface plasmons through surface plasmonic structures [4], based on an anomalous electron hydrodynamic theory proposed in Ref. [5]. First we demonstrate that the quantum nonlinear Hall effect can be dramatically enhanced over a very broad range of frequency by utilizing plasmonic resonances and near-field effects of grating gates. Under the resonant condition, the enhancement becomes several orders of magnitude larger than the case without the nanostructures, while the peaks of high-harmonic plasmons expand broadly and emerge under the off-resonant condition, leading to a remarkably broad spectrum. Furthermore, we clarify a universal relation between the photocurrent induced by the Berry curvature dipole and the optical absorption, which is essential for computational material design of long-wavelength photodetectors. Next we discuss a novel mechanism of geometrical photocurrent, which originates from an anomalous force induced by oscillating magnetic fields and is described by the dipole moment of orbital magnetic moments of Bloch electrons in the momentum space. Our theory is relevant to two-dimensional quantum materials such as layered WTe2 and twisted bilayer graphene, thereby providing a promising route toward a novel type of highly sensitive, broadband terahertz photodetector.

Reference:

[1] J. R. Schaibley et al., “Valleytronics in 2D materials”, Nat. Rev. Mater. 1, 16055 (2016).

[2] J. E. Sipe and A. I. Shkrebtii, “Second-order optical response in semiconductors”, Phys. Rev. B 61, 5337 (2000).

[3] Rozhansky et al., "Helicity-Driven Ratchet Effect Enhanced by Plasmons", PRL 114, 246601 (2015).

[4] Riki Toshio and Norio Kawakami, "Plasmonic quantum nonlinear Hall effect in noncentrosymmetric two-dimensional materials", Phys. Rev. B 106, L201301 (2022).

[5] Riki Toshio, Kazuaki Takasan, and Norio Kawakami, “Anomalous hydrodynamic transport in interacting noncentrosymmetric metals”, Phys. Rev. Research 2, 032021(R) (2020).