PD Research Report for the 2016 year

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Research Theme Theoretical studies on electronic properties of atomically-thin materials

Research Period April, 2016 ~ March, 2017

Research Results

In this year, we have published three papers include one on Physics Review Letters. We also have one more paper submitted to Phys. Rev. B which is under the review process. Here is the list of papers published from April, 2016 to March, 2017:

1. F. Liu and K. Wakabayashi, "Novel topological phase with a zero Berry curvature", Phys. Rev. Lett. 118, 076803 (2017).

2. F. Liu and K. Wakabayashi, "Numerical study of carbon nanotubes under circularly polarized irradiation", Appl. Phys. Express 9 085101 (2016), selected as spot light

3. H.-Y. Deng, F. Liu and K. Wakabayashi, "Optical excitation of surface plasma waves without grating structures", EPL 114 35002 (2016)

4. F. Liu and K. Wakabayashi, "Quadratic Dirac fermions in two-dimensional photonic crystal", under review of Phys. Rev. B

In this report, we focus on the results of the first three papers in the above list.

Result I:

Usually, topological materials are associated with non-vanishing Berry curvatures, as Berry curvature is a geometric analogue of magnetic field in the momentum space. However, inspired by the situation of Aharonov-Bohm effect, where electrons are affected by the vector potential in spite of zero magnetic field, we have discovered a novel nontrivial topological phase in 2D systems in the absence of Berry curvature. 2 This novel topological phase is characterized by the Berry connection, which is the geometric counterpart of vector potential in the momentum space, and its integration over BZ yields the 2D Zak phase accompanying fractional wave polarization in each direction. These fractional wave polarization manifests themselves as doubly degenerate edge states with opposite parities.

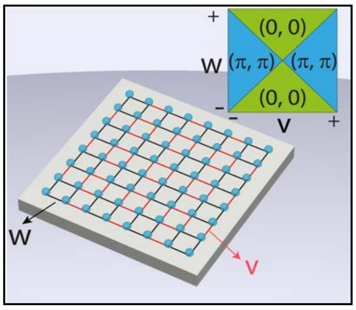

Fig. 1: schematic of 2D lattice model, which shows nontrivial topological phase in the absence of Berry curvature when |W|<|V|.

This novel topological phase resides in a 2D square lattice model with Peierl's distortions on the basis of Su-Schrieffer-Heeger model, where the hoppings are classified as intracellular and intercellular ones, receptively (Fig. 1). When the intracellular hopping is smaller than the intercellular one, the system enters topological nontrivial phase characterized by Zak phase (π, π) [as displayed by the inset of Fig.1]. The discovery of this novel topological phase offers a new view point for designing topological materials.

Result II:

By rolling graphene into a cylinder, one obtains the so-called carbon nanotube (CTN), which shares similar electric and mechanical properties as graphene. Electrons in CNTs also hold the valley indices and it is suitable to use CNTs as a platform for investigating the extraction of valley information. To obtain the valley information explicitly, one needs to break the symmetry between two valley indices K and K'. By shining the CNTs with circularly-polarized light we have realized that the eigen wavefunctions of the CNT possess different valley indices on the top and bottom of the CNT (see the schematic of Fig.2). More interesting, one can also choose which valley index like K and K' to present on the top or bottom of the CNT by applying light with left or right polarization, which is useful for a light polarization sensor.

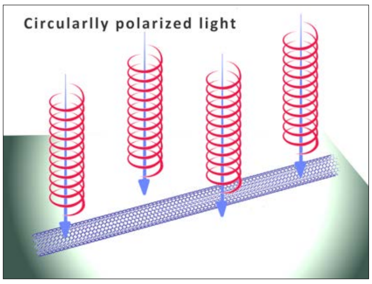

Fig.2: carbon nanotube under circularly-polarized light, which possesses opposite valley indices on the top and bottom of the carbon nanotube.

Why the polarizations of light can pick up the valley indices of wavefunctions? This is because that the polarized light breaks the both the time reversal and spatial inversion symmetries of the CNT, which leads to the valley contrasting—K and K' points in the first Brillouin zone are not symmetric anymore. The amplitude of applying light is about 1015W/m^2 and its frequency is around 3eV, which are within the current reachability of technology.

Result III:

Surface plasma waves (SPWs) are usually discussed in the context of a metal in contact with a dielectric. However, they can also exist between two metals. In this work we study these bimetallic waves. We find that their dispersion curve always cuts the light line, which allows direct optical coupling without surface grating structures. We propose practical schemes to excite them and the excitation efficiency is estimated. We also show that these waves can be much less lossy than conventional SPWs and their losses can be systematically controlled, a highly desirable attribute in applications. Figure 3 shows the simulation result of transmission of plasmon between two metals, which displays high efficiency. The inset of Fig.3 displays the plasmon wave between two metal.

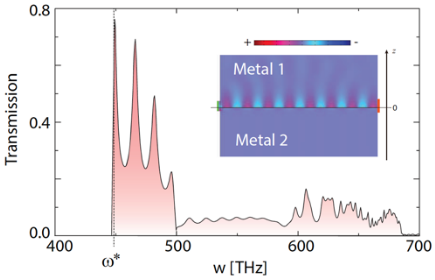

Fig.3: Simulation shows that the plasmon between two metals can be excited with high efficiency. The inset displays the plasmon between two metals.