GRAPHENE AND TOPOLOGICAL INSULATOR AS A METAMATERIAL FOR THE ELEMENTS OF PLASMONICS, NANOPHOTONICS AND PHOTONIC CRYSTALS

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We discuss various applications of graphene and topological insulator as a metamaterial for the elements of plasmonics, nanophotonics and photonic crystals.

Plasmon polaritons in a monolayer and bilayer doped graphene embedded in optical microcavity were studied. The dispersion law for lower and upper cavity plasmon polaritons was obtained. Peculiarities of Rabi splitting for the system were analyzed; particularly, role of Dirac-like spinor (envelope) wave functions in graphene and corresponding angle factors were considered. Typical Rabi frequencies and frequencies of polaritons near polariton gap were estimated. The condition of existence of the lower pair of polaritons in the bilayer graphene system (corresponding to the antiphase plasmon mode) was obtained. The plasmon polaritons in considered system can be used for high-speed information transfer in the THz region.

The influence of the optical contrast between the two media, located on opposite sides of graphene on the behavior of electromagnetic waves with TE and TM polarization was studied. It was found that TE-polarized waves becomes leaky due to the increase of the optical contrast. In considered case TE-mode frequency lies only in the window determined by the contrast. Analytical expressions describing the frequency range and extent of leakage depending on the contrast were deduced. The different characteristics of leaky modes: the wave vector, phase and group velocities, the characteristic length of leakage were studied in detail. The sensitivity of TE-modes to changes in contrast was estimated. Near the frequency where the imaginary part of the conductivity of graphene vanishes, the very high sensitivity and very low detection limit are observed. The considered effect can be used for design of highly sensitive optical sensors based on graphene. It is expected that they can outperform modern plasmon resonance sensors by several orders.

The influence of metamaterial substrate on the TE-polarized electromagnetic waves in graphene was studied. It was found that TE-modes in graphene may exist not only in ordinary range but also for those frequencies where magnetic permeability of the metamaterial is negative. That can be used for detecting small concentrations of molecules absorbed on the graphene and excitation of TE-modes in graphene in terahertz range or lower. The advantage of TE-polarized electromagnetic waves in graphene in comparison with TM-polarized (plasmons, plasmon-polaritons) is that they propagates along the graphene layer with the velocity close to the velocity of light and have a weak damping.

The collective excitations in a helical electron liquid on a surface of three-dimensional topological insulator were studied . Electron in helical liquid obeys Dirac-like equation for massless particless and direction of its spin is strictly determined by its momentum. Due to this spin-momentum locking, collective excitations in the system

manifest themselves as coupled charge- and spin-density waves. The quantum field-theoretical description of spin-plasmons in helical liquid was developed and their properties and internal structure were studied. Value of spin polarization arising in the system with excited spin-plasmons was calculated. Also the scattering of spin-plasmons on magnetic and nonmagnetic impurities and external potentials was considered. It was shown that the scattering occurs mainly into two side lobes. Analogies with Dirac electron gas in graphene were discussed. According to the macroscopic Maxwell equations approach the dispersion laws of plasmon polaritons on the surface of topological insulator were obtained. The case of one-side and two-side excitation was considered. The condition of existence of the antiphase plasmon polaritons in the topological insulator film was obtained.

The topological insulator Bi_2Se_3 based one-dimensional photonic crystal was studied. Due to the high bulk refractive index of Bi_2Se_3 it can be considered as high contrast photonic crystal. It was found that the spectrum of transmission of the system has very narrow frequency and angle peaks. The number of peaks on the angle scale depends on the number of photonic crystal layers. This photonic crystals can be used for the creation of collimated light and the design of unidirectional absorbers. Also there application for the design of optical sensors was considered.

A novel type of one-dimensional photonic crystal formed by a periodic array of graphene layers was proposed. The photonic band structure and transmittance of such photonic crystal were calculated. The graphene-based photonic crystals can be used effectively as the frequency filters and waveguides for the far infrared region of electromagnetic spectrum. Due to substantial suppression of absorption of low-frequency radiation in doped graphene the damping and skin effect in the photonic crystal are also suppressed. The advantages of the graphene-based photonic crystal were discussed.

The problems discussed in the talk are partly represented in [1-21].

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