Superfluidity and Bose-Einstein Condensation in Two-dimensional Nanomaterials

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We study the superfluidity and Bose-Einstein condensation (BEC) of spatially indirect excitons in double layers of two-dimensional (2D) nanomaterials and exciton polaritons, formed by excitons, in a graphene monolayer, embedded in a semiconductor microcavity.

A study of the formation of a spatially indirect exciton as a pair of an electron and a hole in two layers of either gapped graphene [1,2], or transition metal dichalcogenide (TMDC) [3,4], or phosphorene [5], which are separated by a dielectric is presented. We propose to observe BEC and superfluidity for a quasi-two-dimensional gas of such dipole excitons in these double layers. The energy spectrum of the collective excitations and the sound spectrum are functions of the energy gaps, the exciton density and the interlayer separation. The superfluid density and temperature of the Kosterlitz-Thouless phase transition are decreasing functions of the energy gaps as well as the interlayer separation, and therefore, could be controlled by these parameters.

The superfluidity of 2D spatially indirect excitons, at low densities in TMDC double layers form a two-component weakly interacting gas of A and B excitons. The energy spectrum, binding energy, wave functions for A and B dipolar excitons, and the sound velocity for a two-component dilute weakly interacting Bose gas of excitons were obtained analytically, considering screening effects by employing the Keldysh potential [6] for the interaction between the charge carriers. It was demonstrated that the mean field critical temperature T_c for a two-component dilute weakly interacting Bose gas of excitons in a TMDC double layer is an increasing function of the factor Q, determined by the effective reduced mass of A and B excitons.

The spatially indirect excitons in a phosphorene double layer are characterized by anisotropic energy spectrum. We predicted that a weakly interacting gas of dipolar excitons in a double layer of black phosphorous exhibits superfluidity due to the dipole-dipole repulsion between the spatially indirect excitons. We have shown that the critical velocity of superfluidity, the spectrum of collective excitations, concentrations of the superfluid and normal component, and mean field critical temperature for superfluidity are anisotropic and demonstrate the dependence on the direction of motion of dipolar excitons.

The BEC of excitonic polaritons in a gapped graphene layer, embedded in a semiconductor microcavity, without magnetic field [7] and in high magnetic field [8] is predicted. A gas of excitonic polaritons in high magnetic field was considered in a planar harmonic potential trap. The superfluid density and temperature of the Kosterlitz-Thouless phase transition for polaritons without magnetic field and the BEC critical temperature for polaritons in high magnetic field as a function of magnetic field were obtained.

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