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Magnetoplasmon Fano resonance in Bose-Fermi mixtures

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We investigate theoretically the magnetoplasmon (cyclotron) resonance in a hybrid system consisting of spatially separated two-dimensional layers of electron and dipolar exciton gases coupled via Coulomb forces. We study the dynamics of this system under the action of a weak alternating external electromagnetic field in the presence of a uniform magnetic field, perpendicular to the layers. We reveal that the electromagnetic power absorption exhibits a double-resonance spectrum. We show that the first resonance is associated with the conventional well-studied magnetoplasmon excitations of the electron gas and it has a standard Lorentzian shape, whereas the second resonance is a peculiarity attributed to the Bose-condensed exciton gas. Further, we explicitly demonstrate that the spectrum of the system exhibits an asymmetric Fano-type profile, where the excitonic peak is extremely narrow in comparison with the magnetoplasmon one. We show that the shape of the resonance and the position of the peaks depend on the magnitude of the applied magnetic field, exciton-condensate density, and exciton-impurity scattering time. In particular, the Fano profile turns into a Lorentzian shape with decreasing exciton-impurity scattering time and the position of the plasmon-associated resonance is mainly sensitive and determined by the magnetic field strength, whereas the exciton-condensate peak position is determined by the exciton-condensate density. It opens the experimental possibility to determine the latter quantity in cyclotron resonance experiments.

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Introduction. Hybrid Bose-Fermi systems represent a test bed for studying many-body phenomena and are a promising platform for future applications [1]. In cold atomic gases, recent research has been concentrated on studies devoted to the Feshbach resonance phenomena [2–5] and aimed at tuning the strength of the two-particle interaction between atoms, leading to new types of phase transitions [6,7]. In the solid state, Bose-Fermi mixtures are usually studied employing exciton or exciton-polariton gases [8] which represent Bose-Einstein condensates [9,10] (BECs) interacting with either electrons and holes coexisting in the same layers or neighboring two-dimensional layers containing electronic gases (2DEG). In particular, it has been demonstrated that the interaction between a 2DEG and the indirect excitons can lead to the formation of a so-called excitonic supersolid phase [11,12].

One of the possible physical realizations of Bose-Fermi systems is a semiconductor heterostructure, where the bosonic subsystem is represented by excitons localized in a quantum well (QW) or double quantum well (DQW), and fermions are a 2DEG in a parallel QW. In the lateral (let it be xy) plane, both the excitons and electrons can propagate freely. Their motion, self-interaction, and exciton-electron interactions result in the possibility for each sort of particles to propagate along different paths which, in order, can interfere between each other. In the case of constructive interference, it is reasonable to assume that we can achieve enhancement phenomena and the emergence of resonant effects. Instead, destructive interference might result in the suppression of particle transport [13,14]. In this Rapid Communication we are aiming at checking this assumption. In particular, we are interested in the Fano resonance phenomenon which is known to be a general type of resonance and it can be observed in the case of path interferences [15]. The Fano resonance is conventionally characterized by a peculiar asymmetric profile of the spectral line. In particular, it usually consists of two peaks and one dip. One of the peaks lies in close proximity to the dip, manifesting the coexistence of resonant transmission and reflection in the system.

Theory of magnetoplasmon resonance. We consider a system which represents two parallel layers of electrons and excitons (see Fig. 1). Electrons occupy the QW and form a 2DEG. The excitons are considered to be rigid dipoles, having their dipole moment oriented perpendicular to the plane of the layers containing the DQW and moving freely as a whole within. We assume that the exciton's internal degrees of freedom are not excited by the external applied electromagnetic (EM) field or temperature, thus we consider a zero-temperature case when the quantum effects manifest themselves most clearly. The uniform magnetic field is directed along the growth axis of the structure, thus it is oriented perpendicular to the electronic and excitonic layers. We will also assume that the magnetic field is weak and thus it cannot affect the exciton center-of-mass motion. In contrast, it can substantially affect the motion of electrons.

Such an external EM field, $\mathbf{E}(\mathbf{r},t) = (E_0,0,0)e^{i\mathbf{kr}-i\omega t}$, with the electric field component lying in the plane of the QW, produces deviations of the electronic density from its equilibrium value, $\delta n(\mathbf{r},t) = n(\mathbf{r},t) - n_0$, where $\mathbf{r}$ is a vector coordinate in the QW plane, and $\mathbf{k}$ is the in-plane wave vector. In typical

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