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Acoustoexcitonic effects in the 2D dipolar exciton gas

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Abstract. The theory of acoustoexcitonic effects is developed in the 2D dipolar exciton gas. Surface acoustic wave absorption and acoustoexitonic drag effect are considered for temperatures both above and below the Bose condensation temperature of the exciton gas. The influence of the disorder on the acoustoexcitonic effects is also discussed.

Method of acoustic spectroscopy is widely used to study two-dimensional electron gas [1]. Recently, this method has been adopted for experimental study of exciton and exciton-polariton 2D gases in wide single or double quantum well (DQW) nanostructures [2]. The excitons created in such systems being the Bose-type particles exhibit the number of intriguing physical phenomena. Indirect excitons — a bound state of the electron and hole localized in spatially separated QWs — possess essential longer life-time in comparison with usual excitons. Long life-time of indirect excitons at sufficiently low temperatures allows one to accumulate a large amount of excitons in the lowest quantum state, i.e. the BEC phenomenon [3,4].

From the experimental point of view, detection of the exciton gas phase transition into Bose-condensed state is mainly based on the optical experiments. Bose-condensate is a coherent state of the exciton system that results in the coherent emission of the light. This is viewed as drastic narrowing of the exciton luminescence line below the critical temperature T_c of exciton condensation. Additionally to the optical spectroscopy methods, acoustic methods can also be used for analyzing the BEC physics of indirect exciton systems.

We consider 2D dipolar exciton gas in the double quantum well structure placed upon elastic substrate. We study theoretically the interaction of this exciton gas with the surface acoustic wave (SAW) of Rayleigh type travelling along the surface of the substrate. We analyze the SAW attenuation coefficient and the drag exciton current due to the SAW. We focus on the frequency and exciton concentration dependences of the SAW attenuation coefficient and exciton drag current both below and above the critical Bose condensation temperature of the exciton gas. It is shown that, at zero temperature, condensate and noncondensate excitons give different contribution to the SAW absorption and exciton drag current. The condensate excitons produce the resonance contribution to the acoustoexcitonic effects: the SAW absorption and exciton drag current have a very narrow resonance dependence on the SAW frequency. Such a dependence is due to the excitation of the excitons from the condensate to the noncondensate states by the SAW. This is a wave-transformation microscopic exciton-SAW interaction mechanism. The noncondensate particles also contribute to the SAW absorption and drag effects. We found that, at zero temperatures, noncondensate particle contribution is described by the Belyaev mechanism: the excitation of two Bogoliubov quasiparticles by the SAW phonon. The Belyaev mechanism produces unusual behavior of SAW absorption coefficient and drag current on exciton concentration: if the exciton concentration exceeds some critical value, the SAW absorption and drag current vanish.

The described picture is dramatically changed at high temperatures. In this case there is no condensation and the main microscopic mechanism of the SAW absorption and drag exciton current is the Landau-type processes like in the electron plasma. We develop an appropriate theory and find that the SAW absorption coefficient and exciton drag current have monotonic dependences on SAW frequency and exciton concentration in contrast to the condensate state. We assume that this difference in the behavior of the acoustoexcitonic effects in normal and bose-condensed exciton gas phases can be used as an experimental method of the exciton gas bose-condensed phase detection.

One of the main aspects of the exciton condensate theory is the exciton-impurity interaction or exciton interaction with static quantum well width fluctuations. The disorder may be an important factor that can influence the physical phenomena described above. To the best of our knowledge, exciton-impurity interaction in the exciton Bose-Einstein condensate was first considered for the 3D system in the framework of the Bogoliubov approach in [5]. Recently, the problem of the disordered Bose condensate has attracted the researchers attention with respect to the development of the atomic Bose condensates theory [6]. We examine the acoustoexcitonic phenomena described above in the disordered exciton gas. It is shown that the frequency dependencies of the SAW attenuation coefficient and the exciton drag current are changed in the presence of disorder. We also found the damping of the Bogoliubov excitation caused by impurity scattering. The calculations show that the damping is stronger for the 2D system, as compared to the 3D Bose condensate.

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