

Sound generation by the two-dimensional gas of indirect dipolar excitons

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Abstract. Acoustic waves generation by a gas of two-dimensional indirect dipolar excitons has been studied. It has been shown that excitons emit an acoustic wave which is, generally, a superposition of longitudinal and transverse waves. The frequency dependences of both waves amplitudes have been calculated at temperatures above and below the exciton gas condensation temperature. The generated acoustic wave is almost completely transverse at high electromagnetic perturbation frequencies.

Introduction

The condensation of dipolar exciton in a wide quantum well or in a double quantum well attracts great attention. The exciton gas is well described within the model of weakly nonideal Bose gas, provided the gas density is rather low, and exhibits some interesting features [1,2].

We examine the acoustic waves generation by the two-dimensional excitonic gas (2DEG) perturbed by the electromagnetic wave. Depending on temperature the exciton gas can be in either the condensed or noncondensed state. Thereby, the main problem is the influence of the exciton gas phase state on the frequency dependence of the acoustic wave amplitude. This problem is not only of general physical interest, but also of applied interest as a method for the experimental probing 2DEG state.

1. Problem

The system under study is shown in the figure. The incident monochromatic electromagnetic wave perturbs the exciton gas. To provide a momentum transfer to the exciton gas, the electromagnetic wave is modulated by a metallic grating structure placed above the two-dimensional exciton gas. The disturbed 2DEG, in turn, interacts with the crystal lattice by deformation potential and emits acoustic waves. We consider the excitons interaction with one harmonic of diffracted electromagnetic wave.

Within the linear response theory, the concentration fluctuation of 2DEG caused by the external potential is given by:

$$\delta N(\mathbf{k}, \omega) = S(\mathbf{k}, \omega) W(\mathbf{k}, \omega), \quad (1)$$

where $S(k, \omega)$ is the linear response function of the exciton gas and $W(k, \omega)$ is the Fourier transform of the perturbation. Within this approximation, the amplitude of emitted acoustic waves is proportional to the response function, which is defined by the 2DEG state. Therefore, the frequency dependence of the generated sound amplitudes is determined by the behavior of the response function $S(k, \omega)$ above and below the exciton gas condensation temperature.

2. High temperature

At a temperature above the critical one, the exciton condensate is absent and the dispersion law of exciton center of mass is

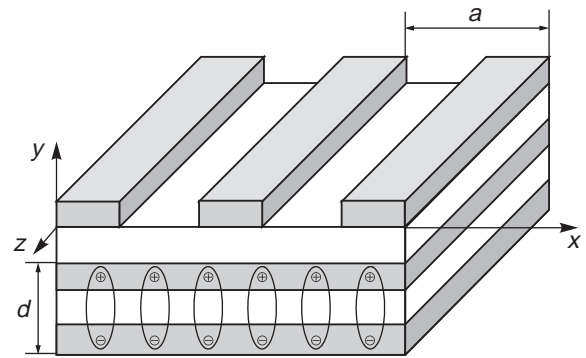


Fig. 1. Exciton gas in the double quantum well.

quadratic in momentum. Our calculations show that, at high frequency $\omega \gg 2\pi \max[c, v_t]/a$ (where c is sound velocity, v_t is thermal velocity of excitons and a is grating period) the x -projection of transverse acoustic wave component A_x^t is dominant and is proportional to $1/\omega^3$. In the other case — $2\pi v_t/a \gg \omega \gg 2\pi c/a$ we have $A_x^t \sim 1/\omega$.

3. Zero temperature

At zero temperature, 2DEG consists of two fractions — condensed excitons in the ground state and noncondensed ones with the nonzero momentum. In this case, the response function is found by the Bogoliubov model of a weakly nonideal gas and includes two contributions stemming from condensed and noncondensed excitons. The calculations show that, at high frequency, noncondensed excitons give the main contribution to the acoustic wave emission and $A_x^t \sim 1/\omega^2$. In the opposite case of low frequencies, the amplitude is proportional to $1/\omega$ again, but with a different constant, as compared to the case of high temperatures.

4. Second acoustic harmonic generation

We also consider the effect of second acoustic harmonic generation by 2DEG. Being a non-linear effect, it is determined by a second-order response of excitons density to external electromagnetic perturbation. The second order response function is calculated at the temperatures above and below the exciton condensation temperature. Using the equations of motion of the elastic medium we derive the dependence of acoustic wave amplitude with the doubled frequency on 2DEG density and electromagnetic wave frequency. The second harmonic ampli-