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Oscillations of the four-wave mixing signal of semiconductor heterostructures: quantum beats and Rabi oscillations.

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Quantum beats of exciton states in semiconductor heterostructures and vacuum Rabi oscillations in microcavities are the experimental manifestation of coherence of optical excitations in these systems. Study of coherent phenomena is important from both the fundamental and practical points of view because the optical coherence may be used for realization of quantum computing. One of the most effective methods of the coherence detection is the two-pulse pump-probe method when the first (pump) pulse creates a coherent state of the system and the second (probe) one delayed in time detects evolution of the state. This method is typically used in one of the two possible geometries of experiment. The first one is the pump-probe geometry when the signal is detected in the direction of the transmitted or reflected probe beam. The second one is the four-wave mixing geometry when the signal is detected in the direction of the pump beam diffracted at the grating created in the structure by joint action of the mump and probe beams. It is important that the four-wave mixing signal persists while the optical coherence is conserved. At the same time, for the quantum beat signal, the mutual coherence of excited states is only required. So, a comparative study of these two signals allows one to identify the nature of coherence in the structure. In this work, we demonstrate that such comparative study can be performed in one geometry of experiment.

We have used ordinary pump-probe geometry. An integral intensity of the transmitted or reflected probe beam is detected as a function of the delay between the pump and probe pulses. A femtosecond Ti:sapphire laser with the pulse repetition rate of 80 MHz is used. Quantum beats of the quantum confined excitons states are studied in sample A with a 95-nm InGaAs/GaAs quantum well with the 3% of indium content. Rabi oscillations are observed in sample B with a microcavity containing four 10-nm InGaAs/GaAs quantum wells with 6% of indium sandwiched between two Bragg reflectors. The laser spots on the samples are of about 50 mkm. The sample temperature is of 4 K.

The experiments have shown clearly observable oscillations of the pump-probe signal for both the samples as for positive as for negative delay of the probe pulses relative to the pump ones. Analysis shows [1] that the oscillating signal detected at the negative delays is due to the four-wave mixing effect detected at the non-standard direction. The beat frequencies observed for sample A correspond to the energy distances between quantum-confined exciton states and, therefore, are attributed to the quantum beats of these states. For sample B, the observed beat frequency corresponds to the splitting of the upper and lower polariton states and is attributed to the vacuum Rabi oscillations. Comparison of the oscillation signal decays for the positive and negative delays gives rise to valuable information about the decoherence processes in the structures under study.

[1] Trifonov, A. V., Gerlovin, I. Y., Ignatiev, I. V., Yugova, I. A., Cherbunin, R. V., Efimov, Y. P., ... & Kavokin, A. V. (2015). Multiple-frequency quantum beats of quantum confined exciton states. *Physical Review B*, *92*(20), 201301.

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