FNM 2016 Program Committee cordially invites people to submit abstracts for The International Workshop on Functional and Nanostructured Materials to be held in Tbilisi, Georgia 6th -10th September 2016.

Exciton-polaritons in a strong terahertz field - doubly dressed bosons

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The research on light – matter interaction in the strong coupling regime, when quantum light emitter and photons can coherently exchange energy, before the coherence is lost, is one of the fundamental problems in cavity quantum electrodynamics (QED). This problem was widely adopted in an atom – cavity system, described within renowned Jaynes–Cummings model and even beyond this limit, in the ultra-strong coupling regime. But the ultra-strong coupling limit is difficult to explore as it requires the condition where the atom – cavity coupling rate reaches a significant fraction of the cavity transition frequency, which is difficult to realize experimentally.

In our work we demonstrate a new system, based on exciton-polaritons, quasiparticles born from the strong coupling of excitons in a semiconductor to the light field in the cavity. These quantum light emitters do not show a fermion-like statistics, but are truly designed bosons that can exhibit non-equilibrium Bose-Einstein phase transition. We study the phenomenon of double dressing: an exciton coupled to two photonic fields from distinct energy ranges: near-infrared (NIR) and THz, which bears no direct analogy in atomic physics. The coupling to NIR field is a cavity coupling described by vacuum Rabi oscillations. Coupling to THz field is a coupling to a strong coherent free field and the coupling strength is approaching the ultra-strong coupling regime. Such a double dressed bosonic quasiparticle is a new phenomenon, where the open dissipative system competes with strong coherence. This allows for the explorations of novel coherent phenomena in cavity-QED based on solid-state systems.

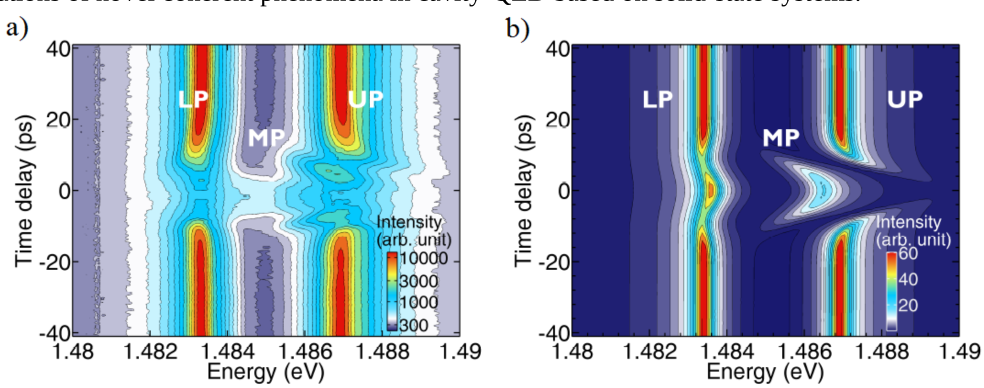

Figure 1. Transmission spectra (at normal incidence) of semiconductor microcavity revealing dressed polaritons and approaching to ultra-strong coupling regime. At weak perturbation (large time delays) the transmission spectra reveals unperturbed LP and UP states. As THz intensity increases (towards zero time delay), a red-shift of the LP and a blue-shift of the UP are observed and the additional MP line is visible. The THz induced opacity of the sample is revealed by the loss of the overall intensity of the transmitted signal due to the exciton ionisation effects. a) experimental results, b) theoretical model.

The THz photon couples *1s* and *2p* exciton states and contributes to the additional mixing of polariton modes. Upon intense THz field, resonant with *1s-2p* excitonic transitions, we observe the appearance of a third dressed polariton mode (middle polariton (MP) Fig. 1). The energy of the third mode strongly depends on the detuning of the THz photon from the *1s-2p* resonance and the detuning between the *1s* exciton and the cavity photon. The appearance of the third dressed mode is accompanied with the energy shift of the upper (UP) and lower (LP) initial states in opposite directions (red shift for LP and blue shift for UP). The shift is modified by the dynamical Franz-Keldysh effect. Upon extremely strong THz field we observe exciton ionization effects.

Our observations are confirmed by a detailed theoretical analysis treating quantum mechanically all three bosonic fields. Our theory demonstrates the unique nature of coupling in this system and reveals the structure of the quantum states. The doubly dressed quasiparticles retain the bosonic nature of their constituents, but their internal quantum structure strongly depends on the intensity of the applied terahertz field.

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