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Superradiant meta-atoms strongly coupled to intersubband transitions

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Short Abstract In this contribution, we will investigate the effects arising, when coupling a metamaterial surface supporting a superradiant energy loss to intersubband transitions in the terahertz regime.

1. Introduction

Starting with the early investigations of harmonically driven two level systems, the research field of light matter interaction has gained more and more attention in the last decades. Progress in time lead to increasing interaction strengths reaching first the strong- and nowadays even the ultrastrong coupling regime in which it is possible to observe completely new quantum phenomena[1]. The enormous dipole moment of intersubband transitions yield the ideal framework for ultrastrong coupling experiments in the terahertz regime with coupling strengths on the order of the bare transition energy[2]. Here, we want to focus on the cavities used in these types of experiments, which are mostly based on single- or double metal metamaterial structures. We investigate, if the general assumption of non-interacting elements is justified, especially under the condition of subwavelength arrangement, i.e. when the radiative metamaterial response can be substantially influenced by their arrangement[3].

2. Experiment

We present a comprehensive study based on time-domain-spectroscopy. The samples we investigate are based on planar metamaterial resonators interacting with intersubband transitions in quantum well semiconductor heterostructures[4]. This system has the advantage, that it is possible to use an increased number of interacting electrons, which then directly affects the measured vacuum Rabi frequency[5]. The general assumption in these kinds of experiments is that there is no cavity interaction, i.e. each cavity is independently coupling to N_{el} electrons. As a consequence, the vacuum Rabi frequency will not be influenced by the number of resonators.

A metamaterial surface consists of many elements in order to increase the amplitude response of the measured (in our case) transmission signal. We have shown that the density of meta-atoms can have substantial influence on the radiative losses of these elements [3]. In that way, we are able to control their radiative response due to their subwavelength arrangement.

In this study we want to focus on the two abovementioned effects often neglected in (ultra)strong coupling experiments. First, we introduce the general possibility to include cavity losses in the metamaterial – intersubband transition system, which manifest themselves as additional loss terms in the Hamiltonian describing the system. A lossy cavity is then expected to shift the system to the weakly coupled Purcell regime [6]. Second, we investigate the effects arising when using a metamaterial surface supporting a superradiant energy loss.

Measurements at room temperature enable us to characterize the cavity losses, as shown in Fig.1 (red points: measured data, lines: Lorentzian fits). By taking the transmission spectra at liquid Helium temperature (blue), we are then able to draw conclusions about the polariton properties of the ultrastrongly coupled system. In this way, it is possible to compare the system's response for the usual, non-interacting cavity approach with the one featuring an increased radiative cavity loss due to their interaction.

Surprisingly, our results show, that it is still possible to observe the formation of polaritons without being able to reach the expected Purcell regime. With the derived modified Hamiltonian, we are then able to calculate the vacuum Rabi frequency for a superradiantly decaying metamaterial surface coupled to intersubband transitions in the THz regime.

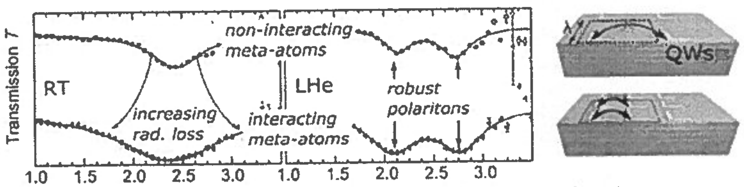

Figure 1: The meta-atom transmission spectra measured at room temperature (RT) show an increasing linewidth for meta-atoms interacting in the λ-unit cell, whereas the polaritons measured at liquid helium temperature (LHe) remain robust.

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