Harnessing light-matter interaction in intersubband microcavities

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***Abstract*— The strong-coupling of intersubband transitions with the confined mode of a semiconductor microcavity, resulting in the formation of intersubband polaritons, has recently been observed. The system is particularly interesting because manipulation of light-matter interaction can be realized through the control of the polariton ground state. Electron depletion by gating, charge transfer between tunnel-coupled wells, and quantum interference of the electronic wavefunctions will be discussed as operating mechanisms.**

***Index Terms*— semiconductor microcavity, resonators, polaritons, intersubband transitions**

Intersubband transitions are the underpinning element behind novel optoelectronic devices like ultrafast optical modulators, QWIPs, and QCLs. Recently, the strong-coupling of intersubband excitations with the confined electromagnetic field of a semiconductor microcavity, leading to formation of *'intersubband cavity polaritons',* was experimentally demonstrated [1]. They exhibit a characteristic anticrossing in energy with a separation termed "vacuum-field Rabi splitting", in analogy to the atomic physics phenomenon. Intersubband microcavities represent a particularly appealing system because their versatility allows for new features and regimes to be explored. It is possible to control externally the light-matter interaction in such systems by tuning the system ground state, a characteristic difficult to implement in excitonic microcavities. In the intersubband resonators presented here, light is confined by the total-internal reflection at the active region-cladding interface on one side and by the metallic reflection on the other.

The vacuum-field Rabi splitting is proportional to the square root of the number of electrons in the quantum wells, N. Thus, changing the charge density in the wells has the same effect as tuning the strength of the electromagnetic coupling. Recently we have demonstrated in GaAs/AlGaAs heterostructures, how the mode coupling, and thereby the polariton dispersion, can be easily controlled through the variation of carrier density. This was achieved by using a biased gate to deplete the quantum wells down to the limit where the Rabi splitting is suppressed and the polariton picture destroyed [2].

In the tuning of Rabi splitting by electrical gating, the device capacitance unavoidably limits the speed of modulation. In order to overcome this issue, charge transfer can be implemented via electron tunneling between energetically aligned conduction band ground states of an asymmetric coupled quantum well structure. A demonstration of the principle has been performed manipulating the carrier density in the polariton well through electric field assisted charge transfer (Fig.1.) [3]. Tunnel oscillation of electron wavepackets between energetically aligned conduction band ground states of such a device could be utilized for ultrafast all-optical control of polariton coupling. This would be of considerable interest in the *'ultra-strong coupling regime'* of light matter interaction, where the Rabi splitting is a significant fraction of the intersubband transition energy [4,5].

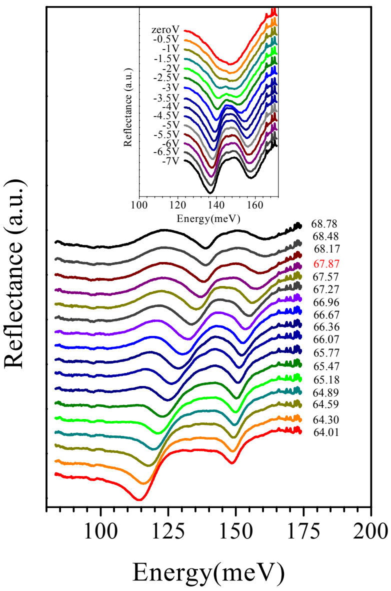

Fig. 1. TM reflectance data of the resonator with tunnel-coupled asymmetric quantum well active region at an electric field of ~100 kV/cm. The inset contains the reflectance spectra at anti-crossing (67.87°) for different electric fields.

Both the above schemes rely on the external control of the electron number in transition ground subband. Utilizing the tailorability of transition parameters through structural design offered by the intersubband system, we also study the possibility of tuning polariton coupling by quantum-interference of the wavefunctions. The control of Rabi

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splitting is realized in active regions having localized energy states in the continuum created by means of electron Bragg mirrors as barriers, by altering the oscillator strength of the absorption by means of electric field. Another device concept for quantum-interference manipulation is by changing the intersubband absorption linewidth through Fano interference. In such a device, the first excited state of the quantum well which is resonant to the cavity is coupled to a continuum of energy levels, resulting in very broad intersubband absorption. The absorption can progressively evolve into a narrow bound-to-bound transition by the application of electric field, giving rise to strong-coupling with the cavity.

In conclusion, our observations confirm the potential of intersubband microcavities in the control of light-matter interaction, with many interesting implementations in the study of fundamental physics as well as in new device concepts.

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