Polaritonic emission from an electrically injected semiconductor device

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Abstract—**We report on the first observation of polaritonic emission from an electrically pumped semiconductor device, operating up-to room temperature. The system is a quantum cascade electroluminescent structure, embedded in a planar microcavity.**

Index Terms— **Infrared measurements, Light-emitting diodes, Optoelectronic devices**

The light-matter strong coupling regime has been experimentally and theoretically studied in a large variety of systems. The eigenstates of the full Hamiltonian, which are called cavity polaritons, exhibit a characteristic spectral anticrossing behaviour as a function of the energy detuning between the bare cavity photon mode and the material excitation.

Intersubband (ISB) polaritons have been observed for the first time in reflectance measurements by D. Dini et al. [1]. Recently, a considerable effort has been devoted to the conception and realisation of devices operating in the strong coupling regime. E. Dupont et al. have reported the observation of the vacuum Rabi splitting in a quantum well infrared photodetector [2], and electrically injected polariton emission has been realised in a cavity organic LED [3].

Here we report the observation of polaritonic emission from a semiconductor ISB electroluminescent (EL) device. Our system is composed by a GaAs/$Al_{0.45}Ga_{0.55}As$ quantum cascade EL structure, emitting at 7.6µm, embedded in a planar microcavity [4]. The light confinement takes place between an $Al_{0.95}Ga_{0.05}As$ layer and a metal contact, which also assures the electrical injection. The sample facet is polished at 70°, in order to allow the exploration of an angular range useful to map the anticrossing curve.

The device has been first characterized by photovoltaic measurements at 78K. To investigate the coupling between the cavity mode and the intersubband transition, the energy of the photonic mode was tuned, by varying the angle of incidence.

The inset of fig.1 shows a photovoltage spectrum, measured at 75° (internal angle) (red line) with TM polarized incident light. The spectrum can be deconvoluted in three curves: a Lorentzian function, corresponding to the lower polariton (LP), a Gaussian function corresponding to the upper polariton (UP) and a third curve, centered at the energy of the bare intersubband transition. The third peak has the same energy position and shape in all the spectra collected at different angles. This curve is obtained in photovoltage measurements with TE polarized incident light. Moreover, the TE spectrum corresponds in shape and energy position to what can be measured below the critical angle for total internal reflection. The presence of this peak in our spectra can be due to scattering processes, occurring at the mesa sidewalls, which randomize the momentum and the polarization of the incident light [5].

The energies of the measured photovoltage polaritonic peaks at different internal angles are reported in fig.1 (dots). A clear anticrossing behavior is observed, with a vacuum field Rabi splitting of 16 meV. The energy position of the polaritonic states is in good agreement with our calculations (open triangles), realized within the transfer matrix formalism.

We also performed EL measurements at 78K, for an applied voltage of 5V. Fig. 2 shows the EL spectra obtained at different angles. Far from the resonance, typically for angles close to the critical angle for total internal reflection, we observe a single peak, corresponding to the bare intersubband transition. By increasing the angle, we also observe the lower polariton branch (shown by squares in fig. 1), with the same angle dispersion as in photocurrent measurements. This observation is a strong evidence of polariton emission under electrical injection. The lower polariton branch is still observable in the electroluminescence spectra at room temperature, while the upper polariton branch is not visible at 78K, nor at 300K.

We believe that our results represent the first integration of the strong coupling regime into an electrically pumped semiconductor injection device. As a perspective, judicious

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band structure quantum engineering could allow us to design structures to explore the fascinating ultra-strong coupling regime, where the vacuum Rabi splitting is comparable to the material excitation energy [6].

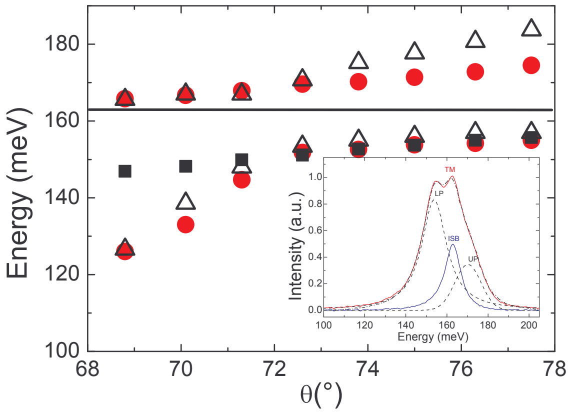

Fig. 1 Energy position of the photovoltage peaks as a function of the angle (dots) at 78K compared with the results of transfer matrix simulations (triangles). The horizontal line indicates the energy of the intersubband transition. Squares indicate the angular dispersion of the electroluminescence peaks. In the inset, a photovoltage spectrum at 75° (solid line) is shown. It is fitted (dashed-dotted line) by a three peaks curve. The peaks correspond to the lower and upper polaritons (dashed lines) and to the ISB transition (solid blue line).

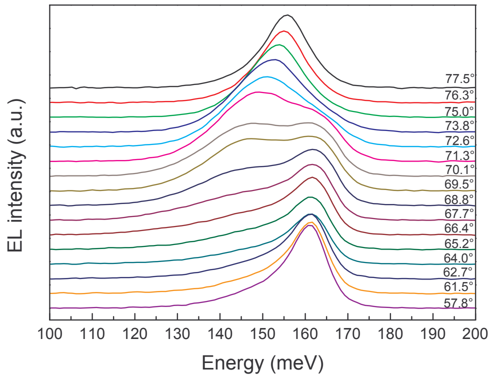

Fig. 2 Electroluminescence angle resolved spectra, at 78K, for an applied voltage of 5V. The lower polariton is visible, as well as the emission of the uncoupled intersubband transition at lower angles.

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