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PHOTOLUMINESCENCE INTENSITY IN A SEMICONDUCTOR MICROCAVITY

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Measurements of the photoluminescence intensity are presented in a semiconductor microcavity showing the strong coupling regime in the 10–80 K range. In spite of the photoluminescence enhancement in the resonance direction, the results are consistent with an overall excitation decay process essentially insensitive to the microcavity effect. Evidence is also given for a non-thermalization of the excitation in the cavity-polariton dispersion relation at least in this temperature range and large detuning conditions. Copyright © 1996 Elsevier Science Ltd

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Semiconductor microcavities tend to play an increasing role in the design of photodiodes and surface emitting vertical semiconductor lasers. By embedding quantum wells (QWs) between two high reflectivity Bragg mirrors, the shape of the radiation pattern can be modified, giving rise to more efficient devices [1, 2]. However, another step can be made when the mirror reflectivities are so high that the interaction between light and a discrete electronic level is modified, going from the usual weak coupling regime, where the coupling between light and matter can be considered as a perturbation for the electronic system, towards the strong coupling regime, where mixed photon-exciton states, usually called cavity-polariton states, must be considered. The first experimental evidence in QW planar semiconductor microcavities was given by Weisbuch *et al.* [3] from reflectivity and transmission experiments. The observation of the so-called Rabi splitting is a consequence of the in-plane invariance of the QW and planar microcavity system: a photon with a given in-plane wave vector is in interaction with the $1S$ exciton state which presents the same center of mass in-plane wave vector. The theoretical understanding of the experimental observations can be achieved either from quantum theories [4, 5], or from semiclassical ones [6] by adding a phenomenological frequency-dependent QW dielectric permittivity.

The problem of the QW microcavity photoluminescence in the strong coupling regime is more complicated. If excitons are created in a non-resonant way (as it is the case in potential applications) these excitons must first relax towards the bottom of their energy band before recombination. A first problem arises: is this relaxation modified by the cavity-polariton effect [7]? Anyhow, there does exist relaxed excitons or more exactly, cavity-polariton excitations, with many in-plane wave vectors (in a range which depends on temperature). Then, the second problem is the following. There is a strong modification of the light-matter interaction in a well-defined direction, where the electron and photon states are at resonance. But is it sufficient to modify the overall spontaneous emission of the excited system in all the 4π solid angle [8]? These problems are the subject of increasing investigations. Angle-resolved photoluminescence experiments have been performed, showing the cavity-polariton dispersion curves [9]. Time-resolved experiments attempt to show the modification of the photoluminescence decay time near the resonance [10, 11].

We wish to describe here additional experiments which consist in studying the temperature and angle dependence of the photoluminescence intensity in a semiconductor microcavity. The photoluminescence intensity has only been studied at a given temperature and near resonance [12, 13]. The results presented here show in particular that, at least not too close to resonance and at low temperature, the photoluminescence cavity-polariton states cannot be considered as thermalized.

The sample contains three 75 Å-thick $In_{0.13}Ga_{0.87}As$ quantum wells, separated by 100 Å-thick GaAs barriers, located near the center of a λ GaAs microcavity. 19.5 (15) pairs of $\lambda/4$-thick GaAs/AlAs layers were grown on top on the GaAs substrate before and after the GaAs cavity. Because of the interruption of the rotation of the sample during part of the growth, the energies of the normal incidence cavity mode E_{cav} and of the 1S excitonic mode E_{exc} vary along the surface of the structure, which allows to modify the detuning energy $\delta = E_{cav} - E_{exc}$ by changing the position of the incident light spot on the sample. The energy of the 1S exciton is 1348 meV when $\delta = 0$ at 10 K, which corresponds to a wavelength equal to 9200 Å. Illumination was provided by an Argon pumped Ti–Sa laser. Resonant reflectivity measurements have shown that the cavity-mode has a full width of 1 meV, while the exciton line width and the Rabi splitting Ω are equal to 5 and 4 meV, respectively (see the inset of Fig. 1) [14]. In non-resonant photoluminescence experiments, the exciting laser was tuned to a 8400 Å-wavelength leakage mode of the Bragg-mirror sample. The radius of the focused spot on the sample was about 60 μm. By checking the reflectivity spectra, care was taken to be in the low excitation regime, where no many-body effects could alter the discrete nature of the 1S excitonic state. Note that the excitation is provided only in the QWs, and not in the GaAs barrier. The temperature was varied from 10 to 90 K. Some angle-dependent measurements were performed at 2 K. Light was analysed through a double monochromator by an InGaAs photomultiplier and standard lock-in techniques.

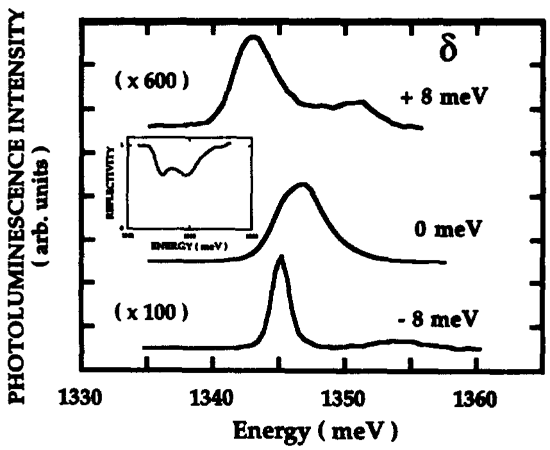

Fig. 1. Photoluminescence spectra at 10 K of the microcavity sample at three sample points which correspond to three detuning energies $\delta = E_{cav} - E_{exc}$. The reflectivity spectrum at resonance is shown in the inset.

Figure 1 shows three cw photoluminescence spectra obtained at 10 K under normal observation at sample points where the detuning energy is $\delta = -8$, 0 and +8 meV. Except near resonance, where the two lines are not resolved, it is possible to plot the PL integrated intensity of the excitonic-like and cavity-like modes as a function of δ (Fig. 2). The two peaks are well resolved (and therefore the measurements are relevant) at $|\delta| > 4$ meV, i.e. $|\delta/\Omega| > 1$. The $\delta = 0$ point is taken to be half of the total unresolved PL integrated intensity at resonance. Below resonance, where the cavity mode is the fundamental mode, the cavity mode is about three times more efficient than the exciton mode, independently of δ, provided that $|\delta| > 4$ meV. Above resonance, the efficiencies of the two modes are comparable. With increasing temperature, the exciton mode efficiency decreases by a factor of about three. The temperature variation of the ratio of the cavity mode PL integrated intensity over the exciton mode PL integrated intensity is plotted in Fig. 3(a) for $\delta = +15$ and +8 meV and in Fig. 3(b) for $\delta = -8$ and −15 meV. Care was taken to maintain the detuning energy constant in temperature dependent

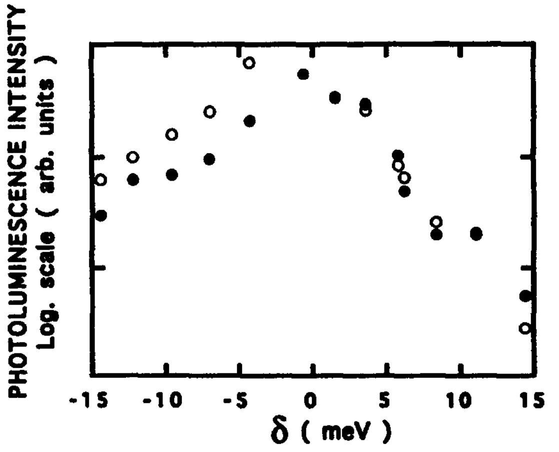

Fig. 2. Photoluminescence integrated intensity of the exciton mode (solid circles) and of the cavity mode (open circles) as a function of the detuning energy for different points of the sample. The temperature is 10 K. At resonance, the photoluminescence intensity is taken to be half of the total intensity of the non-resolved PL line.