24th International Conference on

THE PHYSICS OF SEMICONDUCTORS

Jerusalem, Israel

August 2 – 7, 1998

Editor

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World Scientific
Singapore • New Jersey • London • Hong Kong

DYNAMICS OF POLARITONS AND STIMULATED EMISSION IN GaAs MICROCAVITIES

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We have observed a very narrow and short-lived peak in the time-resolved photoluminescence spectra of quantum wells imbedded in a semiconductor microcavity. Due to its temporal behavior and to the threshold of pump power found, we attribute this peak to the stimulated emission from the photon-like polariton. Polarization measurements show that this process strongly modifies the spin dynamics of excitons.

Most of the work done with semiconductor microcavities has focused on their optical properties under low-power excitation[1,2]. Although there have been some experiments under high excitation, they have been done only under cw conditions[3]. Here we summarize the results of high-excitation time-resolved photoluminescence (PL) measurements that show the evolution of the stimulated emission, together with a striking behavior of the polarization of the radiation emitted by the coupled exciton-cavity system.

The microcavities we have studied have been grown by molecular beam epitaxy. They include dielectric mirrors separated by an $Al_{0.25}Ga_{0.75}As$ region in which 3 pairs of coupled GaAs quantum wells (QWs) are placed in the antinode positions of a $3\lambda/2$ planar microcavity. Each pair of coupled QWs consisted of 42 Å wells and 17 Å barriers. The cavities are wedge shaped and allow the tuning of the exciton–photon resonance across the wafer. The samples were cooled down to 5 K and non–resonantly excited with pulses from a Ti:Zf laser. PL spectra were time resolved (TR) with an up–conversion spectrometer of time resolution ~2 ps. For the polarization measurements, the exciting light was circularly polarized by means of a $\lambda/4$ plate, and the PL was analyzed into its σ^+ and σ^- components as a function of time delay after the excitation pulse.

We have identified the two branches of the cavity polariton by means of cw PL spectroscopy, which revealed the characteristic doublet of peaks of a coupled exciton-cavity system. The dominant character of each peak (excitonic for the one at low energy) was confirmed by the direction in which the coupling across the wafer increases and by temperature and magnetic-field dependence measurements[4].

Initial TR experiments were done under non-resonant excitation, keeping the pump power low enough to assure the coupling between excitons and photons inside the cavity. We have resolved the Rabi-splitting in PL ~300 ps after the exciting pulse. Changing the position of the laser over the sample we have found that this splitting varies from 4 to 7 meV. A study of the time evolution of both peaks confirms that there is no significant dependence of the characteristic rise and decay times on the strength of the coupling[5]. For our GaAs/AlGaAs cavities, these characteristic times are. τ_r^X ~100 ps, τ_d^X ~300 ps, τ_r^γ ~70 ps, τ_d^γ ~250 ps, where X(γ) and *r*(*d*) denote exciton- (cavity-) mode and rise (decay) time, respectively.

Under higher excitation the behavior of the TR PL spectra is quite different. A narrow peak (FWHM<1 meV) is observed at short times (Fig. 1) when the pump power is above ~500 kW/cm^2. This peak is very short lived (τ_r^γ ~30 ps, τ_d^γ ~20 ps) and is delayed ~30 ps with respect to the pump pulse. This finding, together with its threshold behavior (inset of Fig. 1), allows us to identify this band as stimulated emission from the photon-like branch of the cavity polariton. Under these excitation conditions, the excitons are blue shifted[6] relative to their position under lower pump power and they lie at higher energies than the cavity mode. Fig. 2 depicts the time evolution of both peaks; a clear anticrossing between exciton and cavity modes is observed once the stimulated emission is over (~200 ps). At longer delays (≥500 ps), the typical behavior of spontaneous emission is recovered, with the excitons lying at lower energies than the photons.

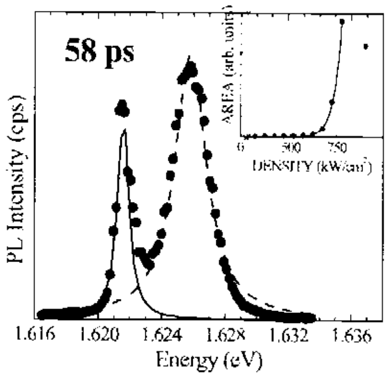

Fig. 1.- TR PL spectrum 58 ps after the excitation, recorded with ~500 kW/cm^2 and E_{exc}=1.706 eV at 5 K. The inset shows the pump power threshold of the low energy peak.

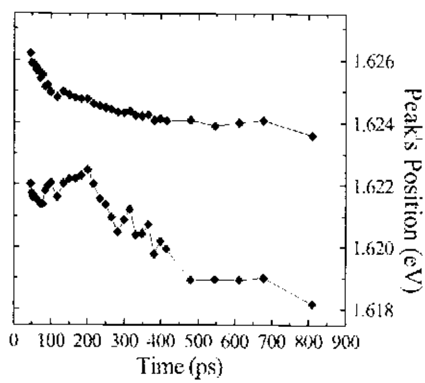

Fig 2.- Evolution of the energy positions of the peaks observed in TR PL for ~500 kW/cm^2 . These positions are obtained by a two lorentzian fit.

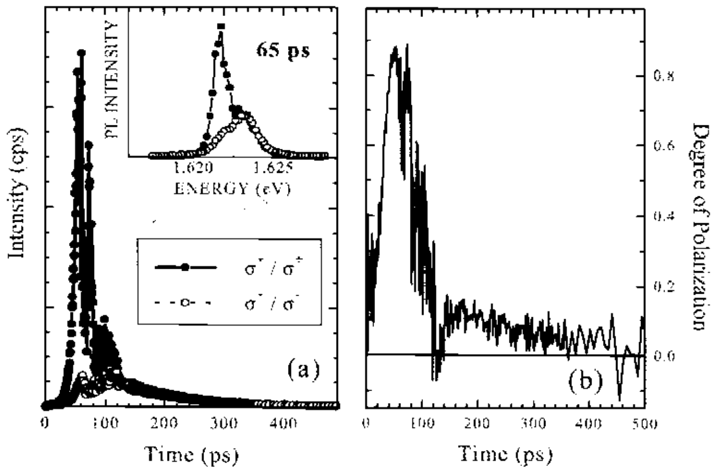

Fig. 3.- (a) Time evolution of the stimulated emission for both polarizations. The inset shows the PL spectra 65 ps after the excitation pulse. (b) Polarization spectrum. All the spectra are recorded at 5 K with an excitation power density of ~ 500 kW/cm^2 at 1.707 eV.

Additionally, polarization-resolved measurements were performed. In this set of experiments the "spin", i.e., the third component of the total angular momentum, is studied. Excitons are photocreated with +1 spin using σ^+ polarized light and they can flip their spin both to −1 via exchange interaction or to ± 2 (optically inactive states) if only one of the single constituents of the exciton, electron or hole, flips the spin[7]. When the system is excited with σ^+ polarized pulses it takes about 30 ps for the stimulated emission to start, and then it lasts ~100 ps, as shown in Fig. 3(a). A similar behavior is seen for both polarizations, however the intensity of the σ^- emission is considerably lower than that of the σ^+ (inset of Fig. 3(a)). The degree of polarization of the PL is defined as

$$\wp = \frac{I(\sigma^+) - I(\sigma^-)}{I(\sigma^+) + I(\sigma^-)} \tag{1}$$

and is plotted in Figure 3(b) for the stimulated emission. It shows a striking behavior: in contrast to excitons in QWs, for which $\wp$ reaches a maximum almost instantly after the pulsed excitation[8], the highest value of $\wp$~90% is attained at a time delay of ~50 ps. This time coincides with that at which the intensity of the stimulated emission is maximum. This observation means that a gradual alignment of exciton's spins happens during the stimulated emission, followed by a depolarization process which lasts ~50 ps, much longer than the ~20 ps decay time of the stimulated emission. This surprising result requires a systematic study before it can be fully understood. Also unexplained are the strong oscillations in the σ^{+} emission between ~60 ps and ~150 ps (Fig. 3(a)), which may be related to Rabi oscillations inside de cavity.

In conclusion, we have observed stimulated emission from the photon-like polariton in a semiconductor microcavity ~60 ps after pulse-excitation, with a pump power threshold of about 500 kW/cm^2. We have also found a strong modification in the time dynamics of the PL, i.e., the appearance of a very sharp peak and an anomalous time evolution profile. Polarization-resolved measurements reveal that stimulated emission occurs basically with +1 excitons, which have realigned their spin during the process.

We acknowledge J. Fernández-Rossier for helpful discussions. This work has been partially supported by "Fundación Ramón Areces", Spanish DGICYT under contract PB96-0085, the Spanish-Northamerica Joint Commission and the US Army Research Office.

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