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Normal-Mode Linewidths in a Semiconductor Microcavity with Various Cavity Qualities

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We measure the normal-mode linewidths in a semiconductor microcavity with various exciton–photon interaction strengths. Variation of the normal mode coupling and thus of the exciton–photon interaction is obtained reducing the cavity quality by stepwise removing of top mirror pairs. Excellent agreement of the measured linewidths with results of a linear dispersion theory is obtained.

High-quality semiconductor microcavities allow to access regimes of strong exciton–photon interaction which leads to two coupled normal modes in the reflectivity spectra when exciton and cavity energies are close to resonance [1]. But the optical properties of such microcavities are also governed by disorder phenomena which influence the normal-mode linewidths. Recently, the hierarchy of the exciton–photon and the exciton–disorder interaction was controversely discussed [2, 3]. The two competing models for the normal-mode linewidths are a polariton picture where exciton–photon interaction dominates [2] and a linear dispersion theory [3] where exciton–disorder interaction dominates and polaritonic effects are not included. In the first case, a polariton is formed and then interacts with disorder, in the second case, the inhomogeneously broadened exciton interacts with the cavity mode.

Our approach to clarify this controversy is to vary the strength of the exciton–photon interaction in *one* sample by stepwise reduction of the cavity quality removing mirror pairs of the microcavity top reflector. The relative importance of exciton–photon and exciton–disorder interactions is then changed because the photon lifetime τ_p (the exciton–photon interaction time) is varied from values comparable to the exciton lifetime τ_x (the exciton–disorder interaction time) to values much shorter than τ_x. Our sample structure is a 2λ sin-type cavity with 4×3 strain-compensated (GaIn)As/Ga(PAs) quantum wells placed in the antinodes of the electric field in the cavity. The bottom Bragg mirror consists of 15 and the top mirror consists of 12.5 pairs of AlAs/GaAs $\lambda/4$ layers [4]. We can remove a variable number of top-mirror pairs (TMPs) by selective etching at different sample positions in order to reduce the cavity quality. A staircase-like structure is used for the experiment as shown schematically in Fig. 1. The calculated top-mirror reflectivity changes from 98.98% for 12.5 TMPs to 66.69% for 2.5 TMPs.

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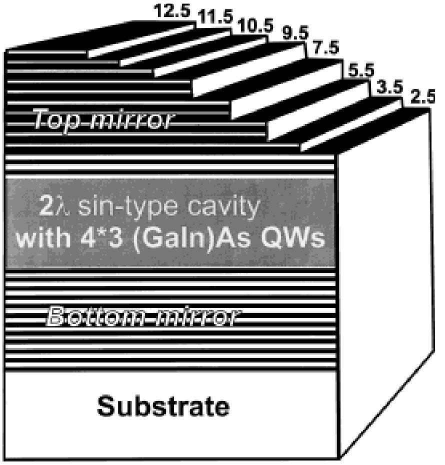

Fig. 1. Scheme of the sample structure

A large normal-mode splitting of 10.42 meV is obtained for 12.5 TMPs as a result of the large number of quantum wells in our sample. The splitting is reduced to 6.71 meV for 2.5 TMPs. The variation of the splitting with the number of TMPs demonstrates that the partial removal of the top mirror not only varies the damping of the photon mode (cavity-mode linewidth) but also changes the exciton–photon interaction considerably.

The measured normal-mode linewidths close to resonance of exciton and cavity mode are shown in Fig. 2 for variable number of top mirror pairs. Numerical values for the linewidths are obtained by a double Lorentzian fit to the measured reflectivity spectra. The linewidth of the high energy (upper) branch increases monotonously from 3 meV for 12.5 TMPs to 15 meV for 2.5 TMPs while the linewidth of the lower branch increases from 1 meV for 12.5 TMPs to 4 meV for 2.5 TMPs.

We compare the measured data with linewidths calculated with a linear dispersion theory. The susceptibility of the active region, which enters the linear dispersion theory, is obtained from absorption measurements. The top and bottom mirrors of the microcavity sample are removed completely by etching and the absorption spectrum of the remaining quantum wells is measured at different temperatures. The refractive index spectra and the optical susceptibility are obtained with a Kramers-Kronig transformation. The susceptibility is used for a calculation of the microcavity reflectivity using the transfer-matrix technique.

The calculated linewidths are also shown in Fig. 2. An excellent agreement with the experiment is obtained. Also, the dependence of linewidths on detuning between exci-

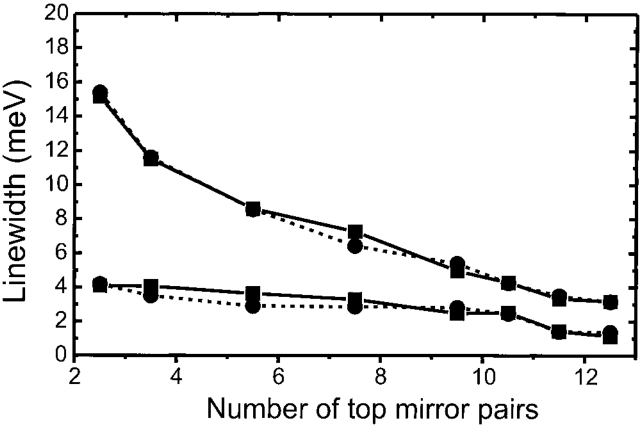

Fig. 2. Experimental and theoretical normal-mode linewidths at resonance as a function of the number of TMPs. The squares describe the experimental data, the circles show the theoretical data. The solid and the dotted lines are guides to the eye for the experimental and for the theoretical data, respectively

ton and cavity resonances at all numbers of mirror pairs is very well reproduced. Detuning of the exciton resonance relative to the cavity mode is achieved by variation of the temperature.²)

We want to point out that, in contrast to previous experiments, we vary the strength of the normal-mode coupling on the same sample by almost a factor of two. Nevertheless, we still do not find features which cannot be described by the linear dispersion theory. We thus conclude that exciton–disorder interaction dominates over polaritonic effects even when photon lifetime and exciton lifetime are equal.

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²) The temperature-dependent contribution to the strongly inhomogeneously broadened exciton linewidth (6 meV) is negligible up to 150 K so that the tuning into resonance by increasing the temperature up to 75 K has no influence on our results.