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Influence of disorder on microcavity polariton linewidths

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Abstract

Polariton linewidths have been measured in a series of microcavities with different excitonic and cavity inhomogeneous broadening in the weak-disorder regime. We show experimentally that the behaviour of the polariton linewidths as a function of the detuning depends on the asymmetric line shape of an inhomogeneously broadened exciton line and particularly the disorder effect can be modulated and cancelled around resonance. When the disorder contribution is minimal, the behaviour of the cavity polariton linewidths tends to one of the homogeneous broadening system.

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The strong coupling regime between excitons and photons in semiconductor microcavities (MCs) has been studied intensively in the recent past [1,2]. In these systems, when all damping rates are small compared to the exciton–photon coupling, the exciton and photon dispersions are strongly modified and exhibit an anticrossing behaviour, resulting in mixed exciton–photon and polariton normal modes. The splitting between the two normal modes (Ω) is a measure of the strength of the exciton–photon interaction and depends on the number of quantum wells (QWs) N in the cavity and on the effective cavity thickness according to $\Omega\alpha\sqrt{N/L_{\mathrm{eff}}}$ [3].

More recently, the role of static disorder in the linewidth of cavity polaritons has been discussed experimentally and theoretically [4–7]. It has been found experimentally in resonance condition [4] that the linewidth of the lower polariton (LP) is smaller than expected by averaging of the bare exciton and cavity linewidths. Moreover, the LP linewidth is narrower than that of the upper polariton (UP). They explained this observation in terms of cavity-polariton picture. In fact, the polariton effective masses are much smaller than those of excitons, which make the cavity polaritons much less influenced by disorder than exciton without a microcavity. Therefore, the linewidth is reduced by averaging of the lighter particle over a larger disordered region; this topic has been addressed theoretically by several authors. In particular, Ell and co-workers [6] showed that these features were reproduced with a linear dispersion theory using a susceptibility of the bare QW. They concluded that the asymmetric line shape of an inhomogeneously broadened exciton absorption [8] is responsible for the cavity polaritons linewidth behaviour.

In this work, by using reflectivity spectroscopy, we report a detailed investigation of the polariton linewidths in a series of semiconductor MCs with different qualities where the exciton broadening is either larger or smaller than the width of the cavity mode, or comparable to it, in weak disorder regime. The samples, in the following labelled M1, M2 and M3, were grown by molecular beam epitaxy on GaAs (0 0 1) substrate. The microcavity referred as M1 consists of a λ GaAs spacer with 8 nm $In_{0.05}Ga_{0.95}As$ QW at the anti-node of the electric field in the cavity. This sample has 22/26 pairs AlAs/ AlGaAs Bragg reflector at the top/bottom. The sample M2 contains a $3\lambda/2$ cavity with two pairs of three 10 nm GaAs QW at each anti-node and

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13/23 pairs $AlAs/Ga_{0.8}Al_{0.2}As$ in top/bottom Bragg mirror. In order to study the influence of disorder on the linewidths, we investigate a particular (M3) structure which has QWs not only at anti-nodes of the field in the cavity layer but also at the first main anti-nodes in each mirror. This structure consists of $\lambda/2$ AlAs cavity surrounded by 16.5/20 pairs $AlAs/Ga_{0.8}Al_{0.2}As$ in top/bottom Bragg mirror. A set of four 7 nm GaAs QWs has been placed at the anti-node of the cavity. Eight similar sets are distributed at the first four field anti-nodes in both Bragg mirrors.

Since the cavity layer presents wedge-like shape, various detunings between the cavity mode and the exciton can be probed by moving the light spot on the sample. The gradient of the cavity resonance energy is about of 12 meV/mm for M1, 10 meV/mm for M2 and 19 meV/mm for M3. Reflectivity measurements have been performed at 10 K using a white light illumination from a 250 W tungsten wire lamp. The white light was focused on the sample with a spot size of 300 μm under 30° incidence inducing a variation of the cavity resonance over the spot size. White light is dispersed with 32 cm monochromator. The reflected signal was detected by a cooled GaAs photomultiplier.

Fig. 1 shows the energy of the polaritons versus the detuning, $\delta = E_C - E_{HH}$ for the microcavity M1 (a), M2 (b) and M3 (c). Scanning across the sample, the cavity-like peak moves towards the exciton HH-like peak due to the wedge of the spacer layer. An anti-crossing of the two modes characterizing the strong-coupling regime is observed for M1 and M3, with a splitting of 3.5 and 19 meV, respectively, whereas in M2, the coupling of the LH exciton results in the appearance of three polariton modes, the lower (LP), middle (MP) and upper (UP) polaritons with 7.7 meV C–HH splitting and 6.4 meV C–LH splitting. The smaller C–LH is due to the lower oscillator strength of LH exciton. Comparing these values, we can verify the increase of the splitting with the QW number [1] in the cavity layer (six QW in a $3\lambda/2$ cavity (M2) or by inserting QWs not only in the cavity layer but also in the Bragg mirror, as it is realized in M3 [9]. The large Rabi splitting may be of importance for device applications.

In the inset, the reflectivity spectrum is shown for three MCs at zero detuning. An asymmetric behaviour of the upper and LP linewidths is remarked in M2 and M3 but a symmetric one is measured in M1. In order to investigate the role of the disorder in polariton linewidths, we have measured the detuning dependence of the LP and UP linewidths [full-width at half-maximum (FWHM)] as shown in Fig. 2 for the different samples which differ in their inhomogeneity structures. The closed squares and the open circles are, respectively, the UP and LP linewidths as indicated. We remark that at the detuning $\delta < 0$, the lower branch which is cavity like is inhomogeneously broadened; its linewidths (γ_c) are about 1.2, 2.5 and 3 meV, respectively, measured in M1, M2 and M3. Due to the wedge geometry and the variation of the cavity energy with the in-plane vector [10], the inhomogeneous cavity linewidth

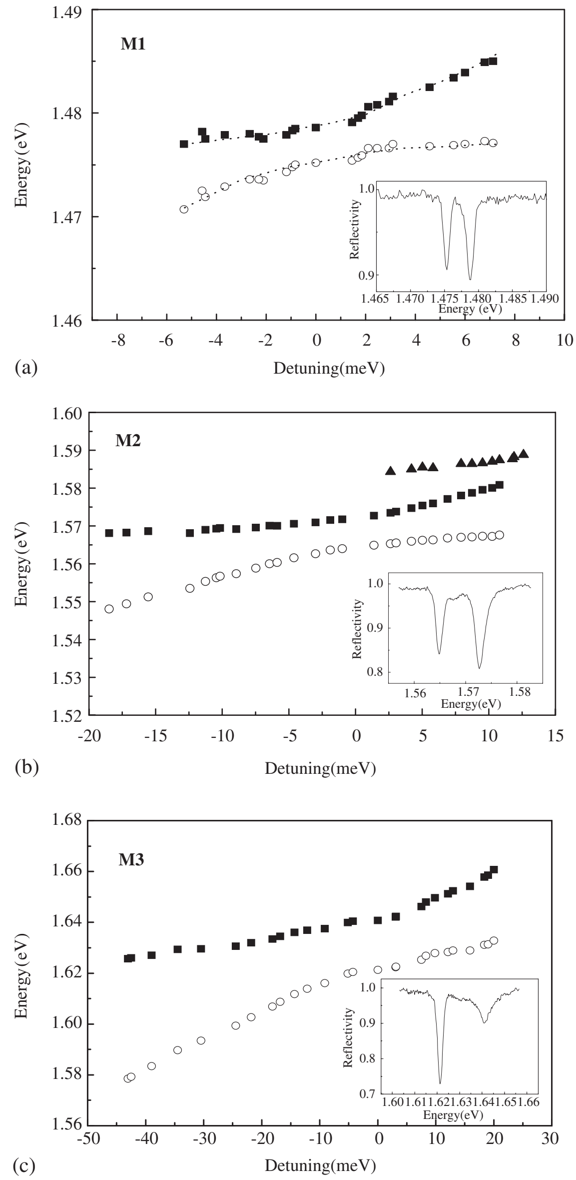

Fig. 1. Polariton energies versus detuning measured in microcavity M1 (a), M2 (b) and M3 (c) at 10 K. The inserts show the reflectivity spectrum at zero detuning.

depends on the spot size and on the gradient of the cavity resonance energy. On the other hand, the cavity finesse decreases by reducing the number of top-mirror pairs [11]. Therefore, the narrower cavity linewidth measured in M1 arise from the higher mirror reflectivity in this sample. Despite the higher number of the top-mirror pairs in M3 than in M2, we measure a large cavity linewidth. This broadening can be attributed to the presence of the QW in the Bragg mirrors which broke the periodicity of the mirror layers partially and causes a disorder in the mirrors.

At the same detuning region, the UP is predominately exciton-like its measured linewidths (γ_{ex}) are about 1.7, 1.9 and 5 meV, respectively, in M1, M2 and M3 which contain a various number of QWs. The difference in exciton quality comes from the limits in current growth technology, in fact,