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Superfluidity of Polaritons in Semiconductor Microcavities

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A Defects in semiconductor microcavities

High crystalline quality semiconductor microcavities are grown using molecular beam epitaxy. With this technique the semiconductor material is deposited on a substrate by the addition of single atomically thick monolayers. The structure of a semiconductor microcavity requires the growth of several nanometres thick layers of alternating materials, GaAs and AlGaAs. The specific thickness of each layer of the Bragg mirrors and that of the cavity spacer, determines the energy of the photonic mode in the microcavity. During the growth process, the single monolayer deposition may not be completed in a specific area before the first layer of the following material starts to be deposited. In this way, islands with a one monolayer step difference are formed, resulting in the appearance of localised regions where the cavity mode has a slightly different energy than that around it, thus giving rise to a *photonic* defect.

Another possible origin of the defects observed in the microcavity arises from crystalline dislocation in the structure of the Bragg mirrors. The materials that compose the alternating layers of the mirrors (GaAs and AlGaAs) have a very similar, but not identical, lattice constant, which enables the high quality growth in these heterostructures. However, when a high number of alternating layers is grown, the small lattice constant difference may result in an accumulated stress across the heterostructure, which relaxes in the form of localized crystalline dislocations, giving rise to defects in the photonic mode of the cavity. Again, the energy of the photonic mode in the region of the defect is different to the energy around it[29].

Even though the fluctuation monolayer mechanism may also give rise to the appearance of defects associated to the exciton energy of the quantum wells[30], those formed in the Bragg mirrors are much more likely to appear due to the high number of layers in the mirrors.

Supplementary references

29. Savona, V. Effect of interface disorder on quantum well excitons and microcavity polaritons. *J. Phys: Condens. Matter* **19**, 295208 (2007).
30. Savona, V. & Langbein, W. Realistic heterointerface model for excitonic states in growth-interrupted GaAs quantum wells. *Phys. Rev. B* **74**, 075311-18 (2006).

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SV1 Supplementary Video 1

File name: "NPHYS-2008-12-01730 SV1 Fig 2 superfluid regime.mov"
Type: Quick Time ".mov"
Size: 1.019 KB

This video shows the detailed *experimental* power dependence of the near (left) and far (right) field emission in the conditions of Fig. 2 ($k_{p\|}$ = -0.337 μm^{-1}; superfluid regime). At low power, polariton-polariton interactions are negligible and the polariton fluid scatters on a defect giving rise to characteristic parabolic wavefronts in real space and a resonant Rayleigh scattering ring in the far field. As the excitation density is increased, polariton-polariton interactions result in a blueshift and reshaping of the spectrum of excitations of the fluid, eventually driving the system into the superfluid regime characterized by an undisturbed flow around the defect and a collapse of the far field scattering ring. The overall horizontal size of the real space field of view is 130 μm.

SV2 Supplementary Video 2

File name: "NPHYS-2008-12-01730 SV2 Fig 3 cerenkov regime.mov"
Type: Quick Time ".mov"
Size: 1.931 KB

This video shows the detailed *experimental* power dependence of the near (left) and far (right) field emission in the conditions of Fig. 3 ($k_{p\|}$ = -0.521 μm^{-1}; Čerenkov regime). Again, at low power, polariton-polariton interactions are negligible and the polariton fluid scatters on a defect giving rise to parabolic wavefronts in real space and a resonant Rayleigh scattering ring in the far field. As the excitation density is increased, the reshaping of the spectrum of excitations due to polariton-polariton interactions gives rise to a Čerenkov pattern characterized in the real space images by linear density wavefronts starting from the position of the defect. The overall horizontal size of the real space field of view is 176 μm.

SV3 Supplementary Video 3

File name: "NPHYS-2008-12-01730 SV3 Fig 2 SIMULATION superfluid regime.mov"
Type: Quick Time ".mov"
Size: 900 KB

This video shows the detailed *simulated* power dependence of the near (left) and far (right) field emission in the conditions of Fig. 2 ($k_{p\|}$ = -0.337 μm^{-1}; superfluid regime), corresponding to the experimental data shown in Supplementary Video 1. Analogously, the collapse of the Rayleigh scattering ring is observed when the polariton gas enters in the superfluid regime.

SV4 Supplementary Video 4

File name: "NPHYS-2008-12-01730 SV4 Fig 3 SIMULATION cerenkov regime.mov"
Type: Quick Time ".mov"
Size: 1.026 KB

This video shows the detailed *simulated* power dependence of the near (left) and far (right) field emission in the conditions of Fig. 3 ($k_{p\|}$ = -0.521 μm^{-1}; Čerenkov regime), corresponding to the experimental data shown in Supplementary Video 2. Analogously, when the excitation density is increased, the reshaping of the spectrum of excitations due to polariton-polariton interactions gives rise to a Čerenkov pattern characterized in the real space images by linear density wavefronts starting from the position of the defect.