Slow reflection and two-photon generation of microcavity exciton-polaritons: supplementary material

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1. SAMPLE DETAILS

This sample is the same as used in Refs [1, 2]. A $3\lambda/2$ microcavity contains three sets of four GaAs quantum wells located at the antinodes of the cavity mode. The QWs are nominally 70 Å pure GaAs embedded in pure AlAs barriers nominally 30 Å thick. The optical mode is confined between distributed Bragg reflectors made of AlAs/Al_{0.2}Ga_{0.8}As with 32 pairs on the top surface and 40 pairs on the bottom surface. Molecular beam epitaxial growth of the sample leads to an inherent wedge to the cavity thickness, resulting in a gradient of the cavity as well as exciton energies. At 5 K, the polariton exhibits a Rabi coupling of 6 meV, which corresponds to an upper polariton-lower polariton splitting of 12 meV; the cavity mode gradient is 13 meV/mm and the exciton gradient is 1.5 meV/mm.

2. METHODS

The sample was held in a cold-finger cryostat at 5 K for all experiments.

Emission was collected using a N.A.=0.42 microscope objective. A preliminary imaging lens permitted spatial filtering of the real space image data, and a subsequent iris in the Fourier image plane permitted filtering of the emission angle. Secondary lenses could be exchanged to image either the real-space or angle-resolved emission. Luminescence was imaged through a spectrometer onto either a standard CCD or onto a Hamamatsu streak camera.

3. ONE-PHOTON INJECTION

In the resonant injection experiment, polaritons were resonantly injected at $\lambda = 778$ nm with a picosecond laser far on the photonic side of the sample. The injected polaritons were created at a detuning of approximately -2 meV corresponding to the high k value of $k_{\parallel} = 5.5 \times 10^4$ cm⁻¹. This state was created by an external pump angle of roughly 42°. The $k_{\parallel} = 0$ detuning at this position is -30 meV.

The sample and pump laser were arranged such that the polaritons were moving anti-parallel to the cavity gradient, which was aligned with the time slit. The angle of incidence was larger than the collection angle of the optics, so the reflected beam was not collected. Additionally, the pump spot was spatially outside the field of view such that scattered light was not collected. At a distance of approximately 2 mm from the injection point, emission entered the collection range of the optics. At the turn-around point, the 778 nm polaritons are more photonic with a detuning of -7 meV which corresponds to a photon fraction of 75%.

Figure S1 demonstrates the polariton dispersion relation at three points along its trajectory in the data of Fig. 3(a). Dispersions in Fig. S1(a), (b) and (c) correspond respectively to $x = 0, 1.75$ and 2.25 mm from the injection point. Thus, frame (a) indicates the polariton dispersion at the point of injection, frame (b) corresponds to the point at which the polaritons enter the imaging field of view, and frame (c) shows the dispersion just at the turn around point. Black dashed lines indicate the bare photon dispersion at each point, while the black dashed-dotted lines indicate the bare exciton dispersion. Frame (d) overlays the

Fig. S1. Calculated polariton dispersion relations for three spatial points relevant to the data presented in Fig. 3(a). Frames (a-c) show the dispersions at the injection point, where the polaritons enter the field of view, and the turn around point respectively. Black dashed and dashed-dotted lines show the bare photon and exciton dispersions respectively. The polariton dispersions are overlaid in (d) and the injection conditions are shown by a red circle. The collection angle of the optics is shown by the black brackets. The red arrow indicates the trajectory of the polaritons in momentum space as they are accelerated by the cavity wedge.

three polariton dispersions for easier comparison. The injection momentum condition is shown by the red circle at $\approx 5 \mu\text{m}^{-1}$. The cavity gradient in the $-x$ -direction leads to an acceleration to negative momentum, as indicated by the red arrow. The polaritons propagate at constant energy. The black brackets indicate the numerical aperture of our collection optics, so we can only observe polaritons with wavevector $\|k\| < 3 \times 10^4 \text{ cm}^{-1}$.

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4. TWO-PHOTON INJECTION

For the two-photon injection experiment, a 200-fs pulse generated by a Coherent OPA system was tuned to one-half the energy of the desired polariton transition. For the 40° injection case, the laser was tuned to excite at $\lambda = 778 \text{ nm}$. For the 0° injection case, the laser was tuned to excite at $\lambda = 780 \text{ nm}$.

5. DISTANCE CALIBRATION

The x -distance from the injection point for the 40° injection cases was estimated as follows: the x -distance in Figs. 2, 3(a), and 4(a) was determined from the fit of the polariton x vs t trajectory presented in Fig. 3(a). Extrapolation of this fit back to time $t = 0$ (as determined by locating scattered laser light) determines the initial position of excitation. This initial excitation position is consistent with the sample parameters and injection conditions. This method assumes that the acceleration of the polaritons is strictly constant from creation to turn around. Variation in the acceleration due to a non-constant energy gradient in addition to the changing mass of the polariton implies uncertainty on the overall offset of this axis, but the spatial magnification was measured directly.

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