Optical measurements of polariton strong coupling in semiconductor microcavities

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Introduction

Polaritons are energetic quasi-particles in semiconductors which can transition into coherent matter-waves called polariton Bose-Einstein condensates. These matter waves, when confined in annular geometries resemble extremely sensitive rotational detectors called Sagnac interferometers, a critical instrument in aerospace technology especially those requiring inertial navigation such as GPS satellites. It has been shown that very high rotational sensitivity is possible if coherent matter-waves are used even though the sizes are orders of magnitude smaller than the sizes typically used in optical gyroscopes. Hence, if a coherent matter-wave analog of Sagnac interferometers can be created in semiconductors, one could potentially have a fully-integrated, on-chip interferometric device that will offer the needed sensitivity, response time, robustness and miniaturization required for aerospace applications.

Here, we present our recent work with a new generation of GaAs semiconductor microcavities with very long polariton lifetimes which potentially allows for persistent coherent-matter waves.

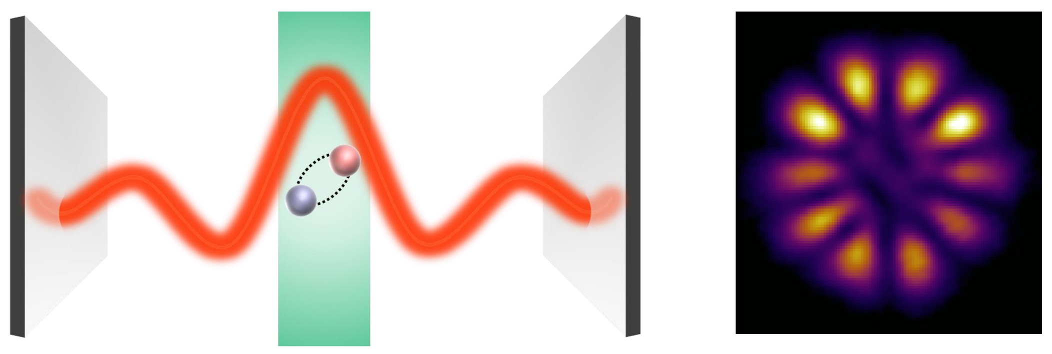

Figure 1. Left: Semiconductor microcavity polaritons These are particle excitations (excitons) in a semiconductor that couples with light inside an optical microcavity. Right: Counter-propagating polariton condensates on annular geometries (Cristofolini et. al., PNAS **111**, 8770 (2014))

Goals

(1) To characterize the long-lifetime microcavity structures

(2) To measure the strength of coupling between the upper and lower polaritons

(3) To try various spectroscopic techniques such as reflectivity, differential reflectivity, photoluminescence, and photoluminescence excitation to measure the polariton energy states

Methods

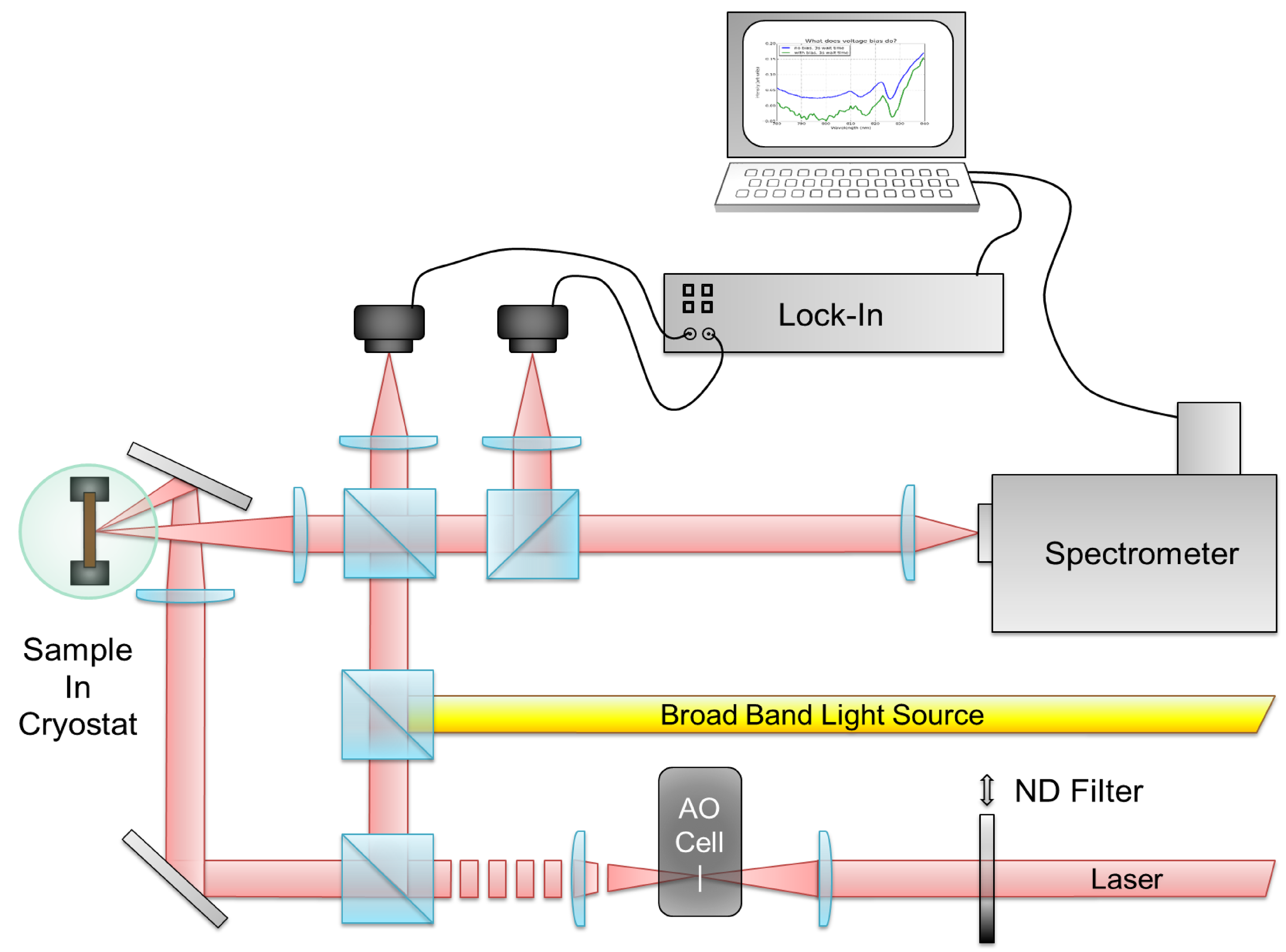

Figure 2. Set-up with functionality varying based on method

To characterize the energy signatures of the polaritons which have become extremely difficult to detect, as is the cost of using high-quality microcavities, we used three different methods in our experiments: Reflection spectroscopy, differential reflectivity, and photoluminescence excitation (PLE) spectroscopy.

(1) **Reflection spectroscopy:** In this method, white light spanning from 750 to 900 nanometers is incident upon the sample and is then reflected into a imaging spectrometer from which the intensity of the reflection would be measured as a function of wavelength.

(2) **Differential reflectivity:** Similar to reflection spectroscopy, this method differs in two specific ways: One, monochromatic laser light is used rather than a continuum of wavelengths as the incident light; two, the incident light is split by a beamsplitter before it reaches the sample, half of this light being reflected off the sample into a detector, the other half running through to another detector as a clean signal source. The difference between these two beams is calculated, and the process is repeated across the length of the sample. We would then repeat this over a range of wavelengths of the laser in which we predicted the upper polariton resonance to be.

(3) **PLE spectroscopy:** In this method, we scanned a continuously tunable laser over the range in which the upper polariton resonance was predicted to be. Then, rather than directly observing the upper polariton, we recorded the intensity of the lower polariton. The energy of the upper polariton corresponds directly to the wavelength at which the photoluminescence intensity of the lower polariton is at its maximum. The intensity of the lower polariton was then recorded via an intensified CCD camera.

Results

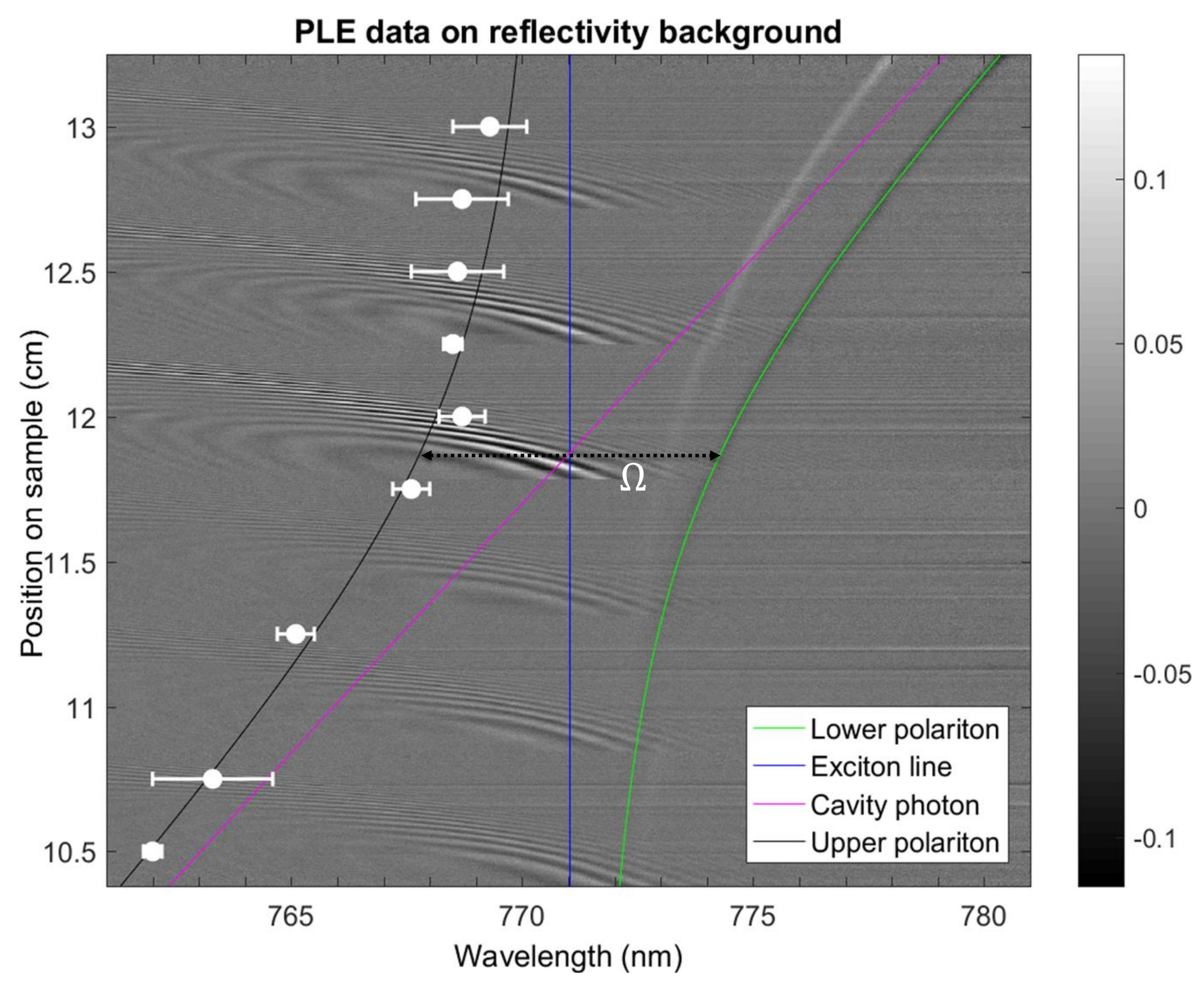

Figure 3. Polariton wavelength at various positions on a semiconductor microcavity sample. The reflectivity from our reflection spectroscopy data is used as the background for the data points and the theoretical calculations. The green line is the fitted lower polariton wavelength based on the lower polariton's reflectivity dip seen as the dark trend on the background of the green line. The blue, magenta, and black lines are the predicted exciton, photon, and upper polariton wavelengths respectively calculated using a coupled-oscillator model. The white points with error bars are the upper polariton wavelengths at various positions on the sample.

(1) We found that reflection spectroscopy is not a sensitive enough method to determine the upper polariton energies, but it is sufficient enough for getting good, continuous lower polariton data.

(2) Differential reflectivity—though more sensitive than reflection spectroscopy—did not result in clear reflectivity at all points on the sample.

(3) PLE spectroscopy proved to be the most successful method by which we observed the upper polariton signatures.

Conclusions

We successfully characterized the energy signatures of the polaritons including the upper polariton which has not been detected since the arrival long-lifetime polaritons in high-quality microcavities. Using photoluminescence excitation spectroscopy, we measured the strength of coupling of the photons and excitons in the semiconductors. Our results clearly show the anti-crossing of the lower and upper polariton with a Rabi splitting of 14 meV. This shows that the polaritons are in the strong coupling regime.

Acknowledgements

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