Photonic crystal cavities for quantum optics

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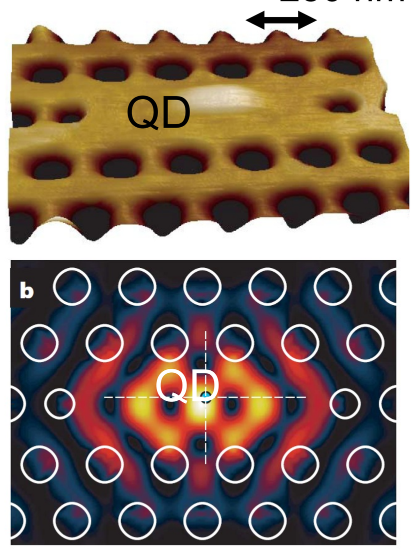
Abstract: Photonic crystal (PhC) cavities have been the subject of intense studies in the field of cavity quantum electrodynamics (QED) and optical spintronics [1,2] due to the high quality factor Q and small mode volume achievable. The recent demonstrations of the strong coupling regime with a PhC cavity and a single quantum dot (QD) [3-4] are encouraging results for solid state systems. However, future implementation will require scalable devices with highly robust design against fabrication imperfections. Here we investigate the sensitivity of the high Q of a PhC cavity to deviations in the cavity geometry and demonstrate a strongly coupled QD to a PhC waveguide cavity which can easily form large scale arrays of coupled resonators.

Motivation



Spatial position matching QD to High Q PhC cavity Mode by deterministic coupling

K. Hennessy et al. Nature 445, 896 (2007)

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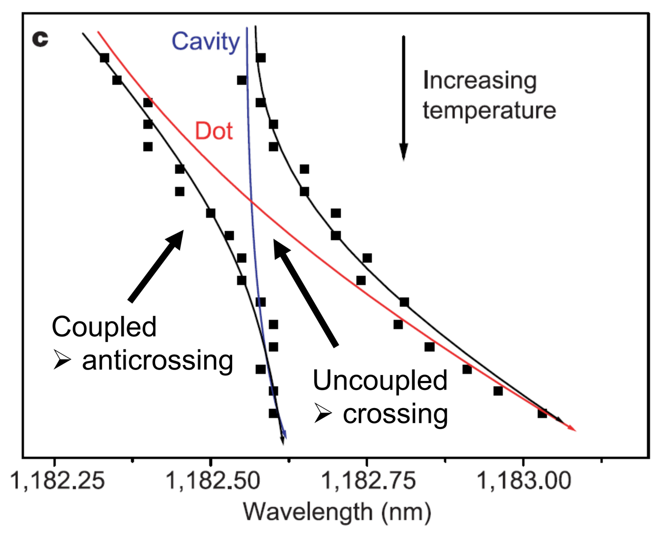
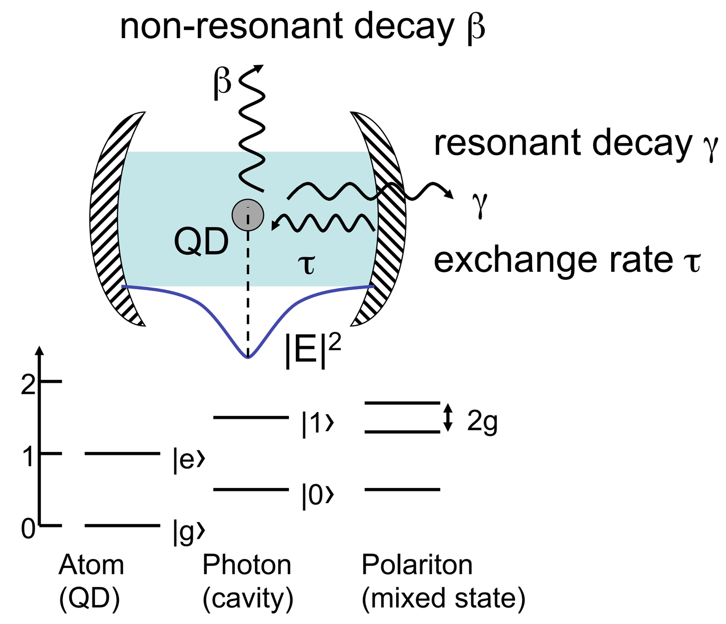


Spectral matching by temperature tuning

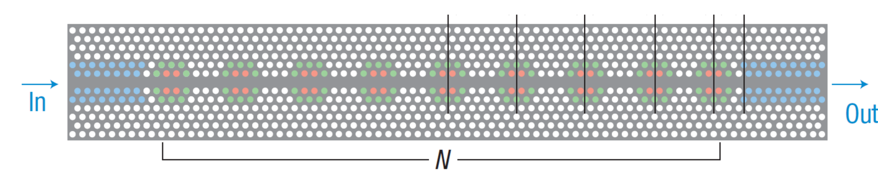
T. Yoshie et al. Nature 432, 200 (2004)



Strongly coupled system when τ » (γ,β)
- ➢ reversible exchange of energy
- ➢ Rabi splitting 2g
- ➢ anticrossing

Characteristics of photonic crystal cavities:
- very high Q achievable (10^6 demonstrated)
- fundamental limit to photon confinement achievable
- ➢ very small mode volume V ~ $(\lambda/n)^3$
- ➢ very high Q/V
- ➢ ideal for quantum optics experiments

Challenges:
- robust cavity design against fabrication imperfections
- ➢ FDTD simulation for design optimisation
- scalability and photonic integration
- ➢ incorporation of cavity with small footprint in photonic crystal waveguide:



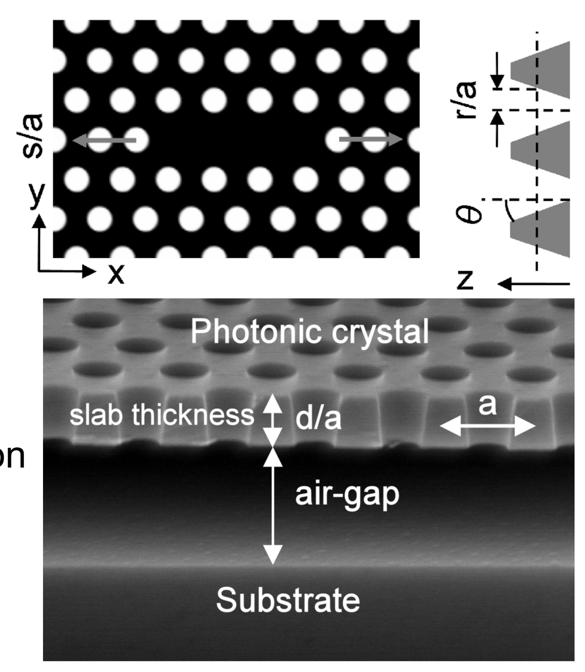
PhC coupled cavities formed by local width modulation of a PhC waveguide

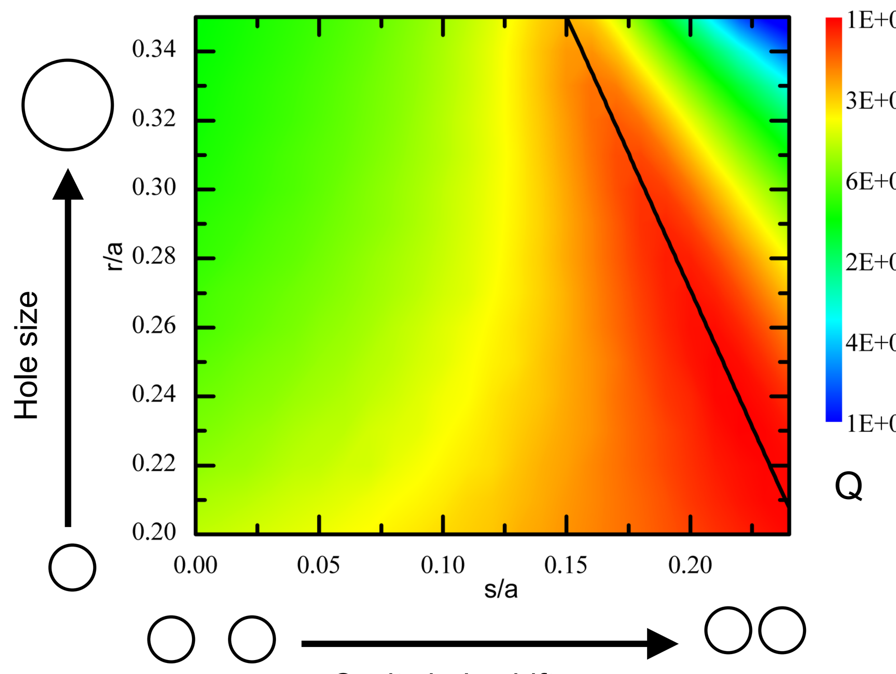
M. Notomi et al. Nature photonics 2, 741 (2008)

Influence of hole size, hole shift, slab thickness and hole tapering on a high Q cavity (FDTD results)

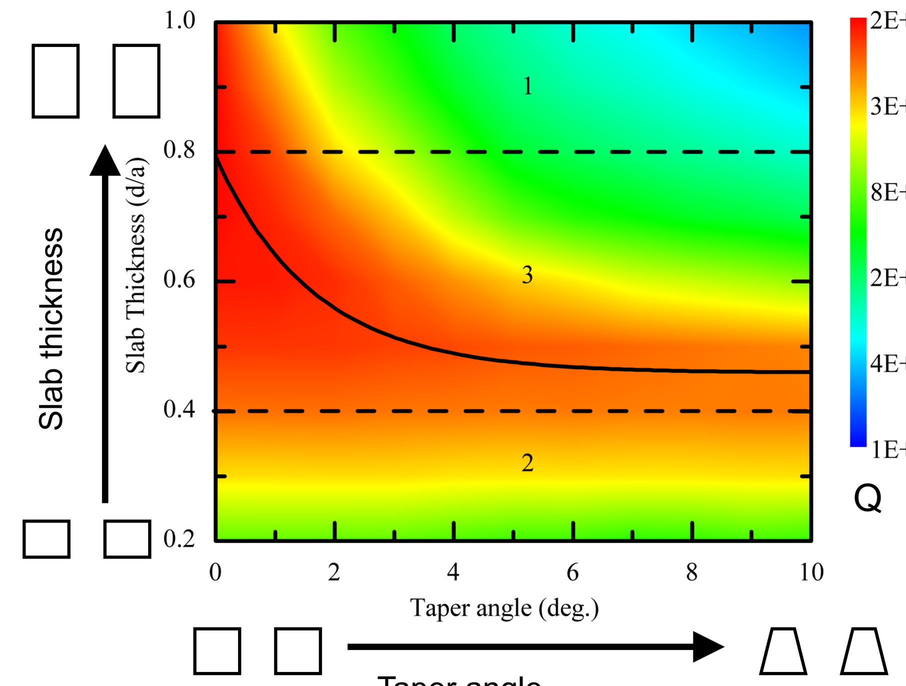
Schematic

SEM Cross-section





Large out-of-plane losses due to radiative scattering



Large in-plane losses due to polarisation mode mixing

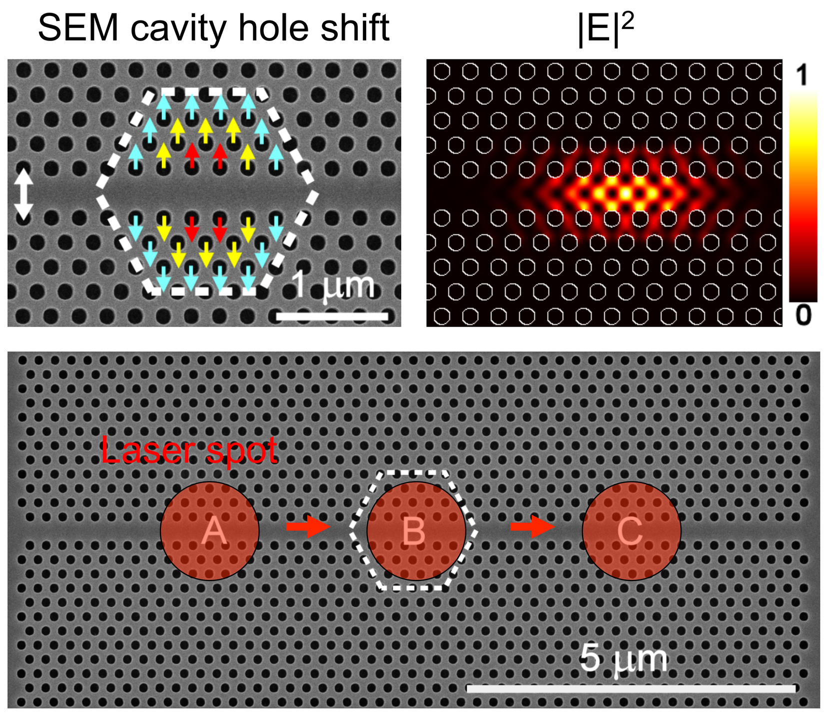
Limit out-of-plane losses by in-plane design:
- ➢decrease hole size
- ➢increase hole shift

Limit in-plane losses by out-of-plane design:
- ➢optimum slab thickness

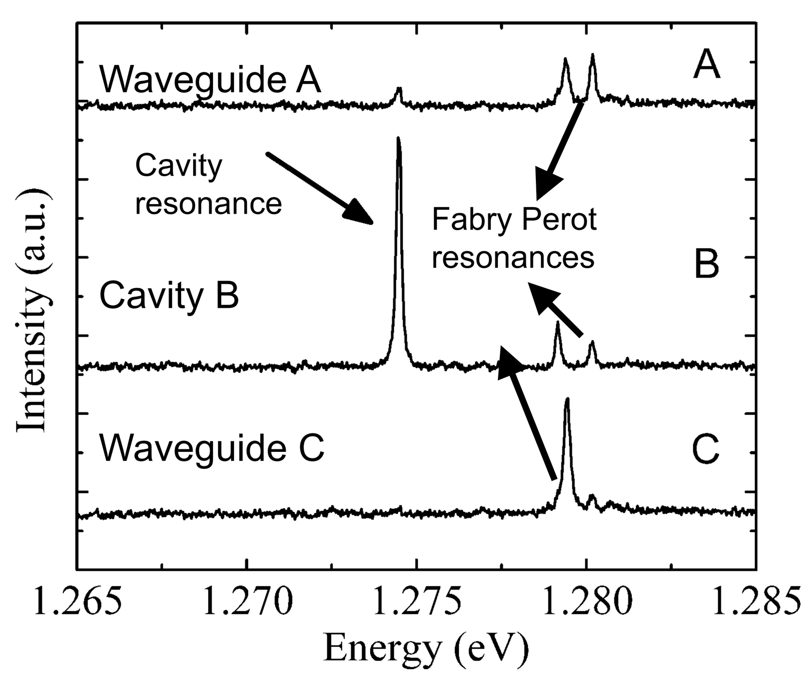
➢Weaken the spatial mode confinement in-plane and out-of-plane to reduce sensitivity to imperfections

F.S.F. Brossard et al. submitted to Optics Letters

Resonant mode of a PhC waveguide cavity formed by local width modulation (experimental results)

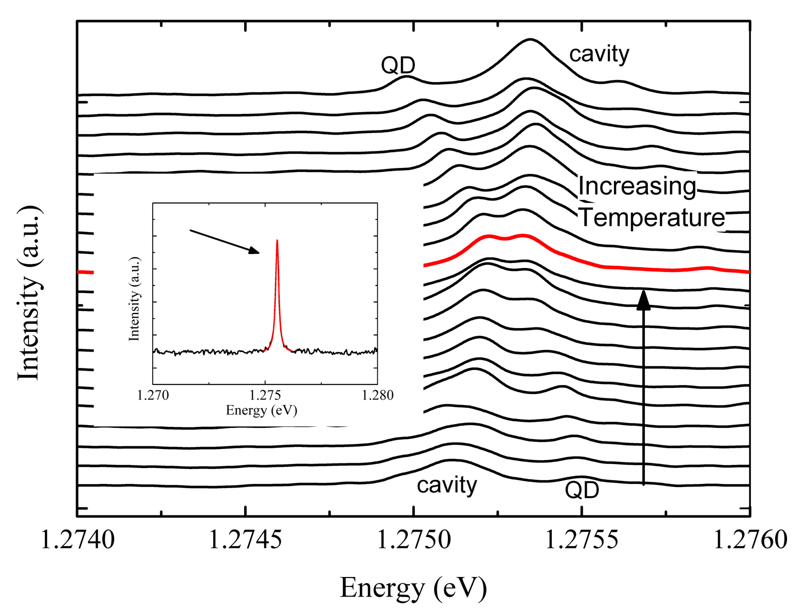


SEM PhC waveguide and cavity

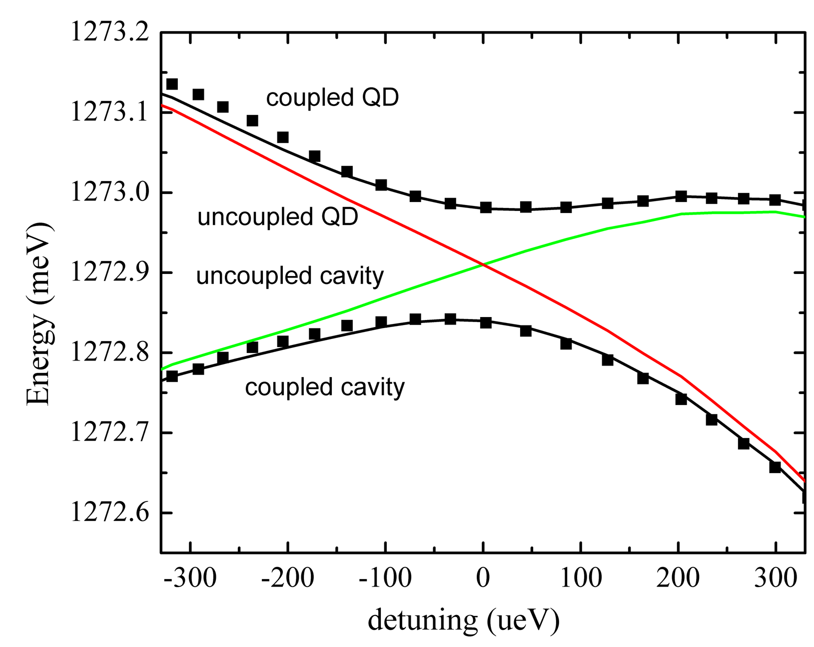


Characteristics of the PhC waveguide cavity:
- small hole shift by a few nm creates a high Q cavity mode confined by the photonic bandgap of the PhC waveguide
- ➢ cavity mode clearly identified by photoluminescence mapping of the out-of-plane scattered signal
- sharp Fabry Perot resonances spectrally close to cavity mode due to reflections from the cavity-waveguide interface and waveguide ends (section A and C)
- ➢ Possibility of probing the state of QD located inside the cavity through the Fabry Perot resonances

Demonstration of the strongly coupled system (experimental results)



PL spectra of the strongly coupled system near zero detuning (red)



Energy of the polaritons for various detunings

➢First strongly coupled system formed by a single QD and a PhC waveguide cavity demonstrated

➢Measured Rabi splitting of 140 µeV

F.S.F Brossard et al. arXiv:1003.5185 (submitted)

References: [1] H-G. Park *et al.* Science, 305 1444 (2004), [2] A. Imamoglu *et al.* Phys. Rev. Lett., 20 4204 (1999), [3] T. Yoshie *et al.* Nature, 432 200 (2004), [4] K. Hennessy *et al.* Nature, 445 896 (2007).