Photonic crystal nanocavities: Efficient light-matter interaction at the nanoscale

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Controlling light on the nanoscale is an equally exciting and challenging goal, and it allows us to strongly enhance light-matter interactions. Photonic crystals offer such control without inherent losses; they allow us to slow light down, confine it to wavelength-scale spaces and considerably enhance nonlinear interactions. These abilities are enabled by the careful engineering of the photonic crystal's properties and their nanofabrication. Here, we discuss three examples of enhanced light-matter interaction, namely a) farfield-optimised cavities for harmonic wavelength generation, b) substantial control of defect-based light emission via the Purcell factor and c) the strong confinement of light in air for sensing, all enabled by the photonic crystal toolkit.

I. Cavities. High-Q photonic crystal nanocavities have become very popular in recent years, as they offer a unique way for enhancing light-matter interaction due to their ability of combining very high Q-factors with very small volumes [1] thus allowing us to achieve strong enhancement of optical nonlinearities such as harmonic generation. In particular, we have observed both second and third-harmonic generation using only mW-level diode pump sources [2]. A major issue with the design of such high-Q cavities is their off-plane radiation pattern, which makes vertical in- and out-coupling difficult. We have investigated the possibility of modifying the far-field radiation pattern in order to achieve simultaneously high quality factor and high coupling efficiency to an external laser beam in a vertical-coupling configuration [3].

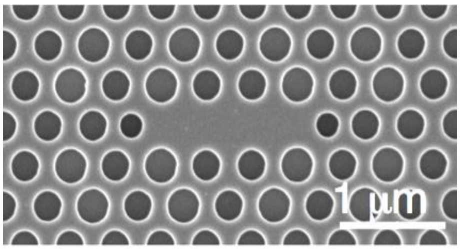

Figure 1. *Photonic crystal cavity with farfield engineering. The alternating smaller and larger holes act as a superimposed second order grating that much improves the farfield radiation pattern without overly compromising the Q-factor; in the best case, for example, the Q-factor drops from 120k to 80k while the extraction efficiency increases by an order of magnitude.*

II. Light emission. While studying the nonlinear behaviour of these cavities, we also noted significant levels of light emission in the 1.4 µm - 1.6 µm band, even at room temperature. The emission is understood to arise from the H_2 – based defects, the H_2 being introduced by the implantation process that occurs during SOI manufacturing. We observe sharp and intense photoluminescence peaks that correspond to the resonant modes of the photonic crystal nanocavities, with an up to 300-fold enhancement of the emission from the nanocavity compared to the background, corresponding to a Purcell factor of around 12 [4]. The weak temperature dependence is one of the most striking features, i.e. there is a less than 2-fold reduction between 10 K and room temperature, which makes this approach suitable for the realization of efficient room-temperature light sources at telecom wavelengths as well as providing a quick and easy tool for the broadband optical characterization of SOI-based nanostructures.

III. Slotted cavities. While the above techniques have provided the means for engineering the cavity mode inside the material, they can also be adopted for confining light in air, thus affording opportunities for very strong light-matter interaction in a range of dielectric materials. To this end, we have modified the well-known slotted waveguide configuration [5] and embedded it into the photonic crystal environment. This geometry affords us significant control over the waveguide mode, even outside the dielectric material. As a result, we have been able to achieve confinement in air and reached Q-factors as high as 50,000, which has obvious implications for environmental sensing [6].

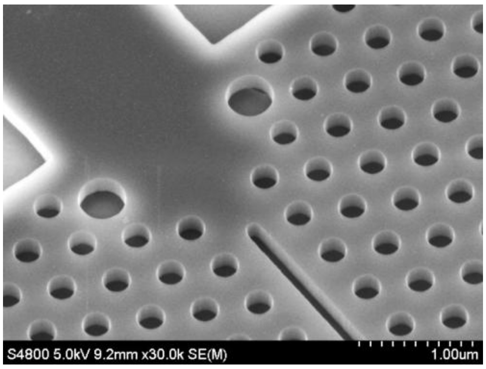

Figure 2. *Interface between slotted photonic crystal and conventional waveguide; careful engineering of this interface affords an injection efficiency of better than 1dB. [7].*

In conclusion, it is clear that photonic crystals offer a host of opportunities in confining light at the nanoscale, especially for applications in nonlinear optics, light emission control and environmental sensing.

IV. References

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