High Q Photonic Crystal Cavities realised using Deep Ultraviolet Lithography

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Abstract: Deep Ultraviolet Lithography is essential for the mass production of silicon devices. To date, restrictions in the process have prevented the realization of high Q factor optical resonators. Here, we demonstrate Q-factor values of approx. 200,000 using an optimized design.

Photonic Crystal (PhC) resonators are the ultimate means of confining light in space and time (i.e. they give the highest Q to mode volume ratio), making them extremely attractive for the realisation of the high integration density, highly scalable and low power consumption optical links required to clear the current interconnection bottleneck in next generation computing. The high spatial confinement enables devices with footprints of less than 100μm^2 and mode areas of approximately 1μm^2, translating into optical modulators with some of the lowest capacitances reported [2]. High Q-factors enhance the light matter interaction and allow modulation with high extinction ratios to be achieved.They also require low voltages and provide new routes to silicon photo-detection [3]. Furthermore, the high optical finesse of PhC resonators provides very large free spectral range maximising the channels available for Wavelength Division Multiplexing [4].

Extremely precise fabrication processes are required for the realisation of high performance PhCs. Not only must the etched sidewalls be vertical and smooth (similar to Photonic Wire based devices), positioning accuracies at the nanometre level are also required [5]. To date, this combination has prevented the realisation of high Q-factor devices using Deep Ultraviolet Lithography, a key prerequisite for the mass manufacture of silicon based optical devices [6]. In this work, we use a recently developed PhC resonator design [7] that shows increased tolerance to fabrication imperfections and improved compatibility with DUV patterning to realise the highest silicon-based optical Q-factor yet realised using optical lithography.

The devices were fabricated in the advanced CMOS research environment of IMEC. The patterning was performed with an ASML stepper operating at 193nm and SOITEC Silicon On Insulator wafers with a 220nm device layer and 2μm buried oxide were used. After the PhC etch, the buried oxide layer was removed using hydrofluoric acid to increase the vertical refractive index contrast. As an aside, we note that high Q-cavities have also been realised with oxide cladding [8].

The design makes use of the Dispersion Adaption technique described in [7] which, while based on the gentle confinement approach, uses much larger modifications of the PhC lattice (holes are shifted up to ~70nm, see figure 1a). We believe this to be the origin of the greater stability with respect to limitations of the fabrication process. Additionally, the far field pattern of PhC resonator was optimised using a superimposed secondary grating, implemented through variations in the diameter of alternate holes.

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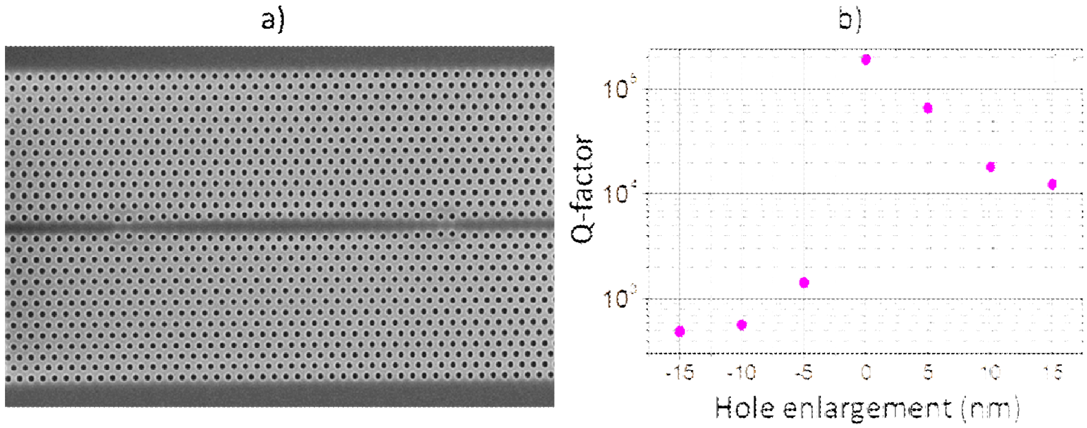

Figure 1: a) Scanning electron microscopy image of a Dispersion Adapted Photonic Crystal. b) Resonant scattering measurement as a function of the enlargement of the holes forming the secondary grating.

The improved farfield dramatically improves the coupling efficiency to the PhC resonator [9] easing characterisation and making them more useful for many applications (such as nonlinear optics). The resonance linewidth was measured using the resonant scattering technique whereby light is incident polarised at 45° to the resonator axis, hence input and output light can be made orthogonal and are only coupled through the resonator, resulting in a very low background [10]. Figure 1b shows the resulting Q-factor as a function of the secondary grating. A maximum Q-factor of ~200,000 was observed. The farfield optimisation naturally reduces the Q-factor with increasing magnitudes of hole enlargement [9].

Conclusion

We have realised high Q silicon photonic crystal resonators using DUV lithography. To our knowledge, these are the highest Q factors realised to date with such pattern definition, which represents an exciting development for the mass production of ultra-compact nanophotonic devices.

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References

1. M. Notomi, Reports on Progress in Physics **73**, 096501 (2010)
2. K. Debnath, L. O'Faolain, F. Y. Gardes, A. G. Steffan, G. T. Reed and T. F. Krauss Optics Express **20**, 27420-27428 (2012)
3. K. Debnath, F. Y. Gardes, A. P. Knights, G. T. Reed, T. F. Krauss and L. O'Faolain, Applied Physics Letters **102**, 171106 (2013)
4. Y. Takahashi, T. Asano, D. Yamashita and S. Noda, Optics Express **22**, 4692-4698 (2014).
5. H. Sekoguchi, Y. Takahashi, T. Asano and S. Noda Optics Express 22, 916-924 (2014)
6. Wim Bogaerts, Roel Baets, Pieter Dumon, Vincent Wiaux, Stephan Beckx, Dirk Taillaert, Bert Luyssaert, Joris Van Campenhout, Peter Bienstman, and Dries Van Thourhout Journal of Lightwave Technology 23, 401 (2005).
7. K. Welna, S. Portalupi, M. Galli, L. O'Faolain and T. Krauss, Quantum Electronics, IEEE Journal of 48, 1177-1183 (2012)
8. K. Debnath, K. Welna, M. Ferrera, K. Deasy, D. G. Lidzey and L. O'Faolain, Optics Letters 38, 154-156 (2013)
9. S. L. Portalupi, M. Galli, C. Reardon, T. F. Krauss, L. O'Faolain, L. C. Andreani and D. Gerace, Optics Express 15, 16064-16073 (2010).
10. M. Galli, S. Portalupi, M. Belotti, L. Andreani, L. O'Faolain & T. Krauss, Applied Physics Letters 94, 071101 (2009)