# Mid-infrared Silicon Microphotonic Cavities with High Resonance of Q~$10^5$

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## ABSTRACT

One dimensional photonic crystal 1D-PhC silicon waveguide resonators with quality factor, Q~$10^5$, are demonstrated at mid-infrared wavelengths between 2 um to 5 um. Silicon has several advantages for mid-infrared applications including its broad mid-infrared transmission spectrum which extends out to 9 um, CMOS compatible fabrication processing, and ease of electronic-photonic integration. The proposed resonators are composed of photonic crystal cavities with optimized (i) lattice parameter a, (ii) cavity width w and (iii) hole radius r. Finite difference time domain (FDTD) simulations are used to adjust these three parameters, *a*, *w*, and *r*, to select a resonant frequency of interest within the mid-infrared spectral range. Due to the high quality factor Q, these PhC silicon waveguide resonators have much higher sensitivity as chemical sensors and have the potential to replace bulky instruments such as an FTIR.

***Keywords***: mid-Infrared, silicon microphotonics, photonic crystals

## 1 INTRODUCTION

Micro-photonic cavities with resonant frequencies in the mid-infrared have attracted a great deal of attention recently because of the rapid development of on-chip chemical sensors. Integrated light sources, sensing elements, and waveguide-coupled detectors, the required components in a lab-on-a-chip system, can benefit from such waveguide resonators. For example, many organic/inorganic compounds have strong mid-infrared absorption [1]. Hence, by measuring the transmission/reflection spectra of mid-infrared optical waveguides we are able to identify chemical hazards and their concentration without using bulky instruments such as FTIR. Previously we have shown that a high Q resonator in the near-infrared enhances the sensitivity even as it minimizes the footprint [2]. In this study, we show, theoretically, that a high quality factor Q ( $4x10^5$) can be obtained using a 1D-PhC shown schematically in Figure 1. We have also experimentally demonstrated these resonant cavity structures in silicon, thereby making monolithic integration a feasible option.

## 2 DESIGN AND FABRICATION OF A MID-INFRARED ONE DIMENSIONAL PHC WAVEGUIDE IN SILICON

Figure 1 shows a schematic of our mid-infrared microresonator in which the mirrors of the resonator are obtained by placing 1D-PhC on either side of a cavity. The PhC is composed of dielectric layers of silicon and air with a layer thickness of 350 nm. The silicon microresonator has a length of 1 μm. In this study, we have tested the grating with four, seven, and ten dielectric stacks in order to understand the relationship between the reflectivity of the cavity mirrors and the qualify factor Q.

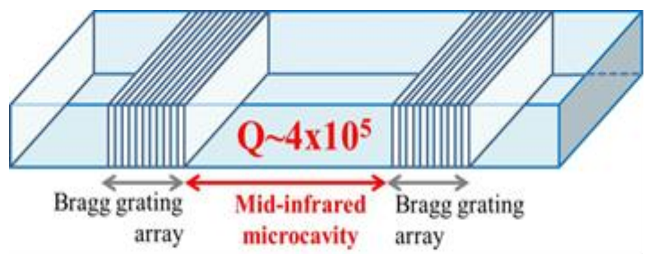



Fig. 1. Schematic of a mid-infrared microresonator with mirrors formed by 1D-PhC on either side of a cavity. The PhC is composed of alternating layers of silicon and air.

Figure 2 shows the fabricated mid-infrared microresonator. The grating is patterned on a SOI wafer by dual beam focused ion beam milling [3].

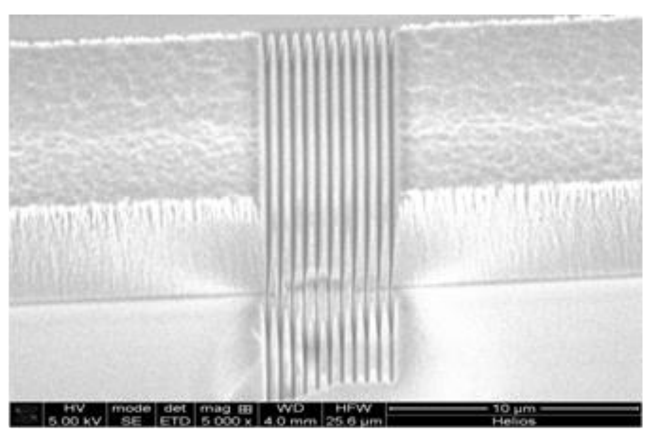
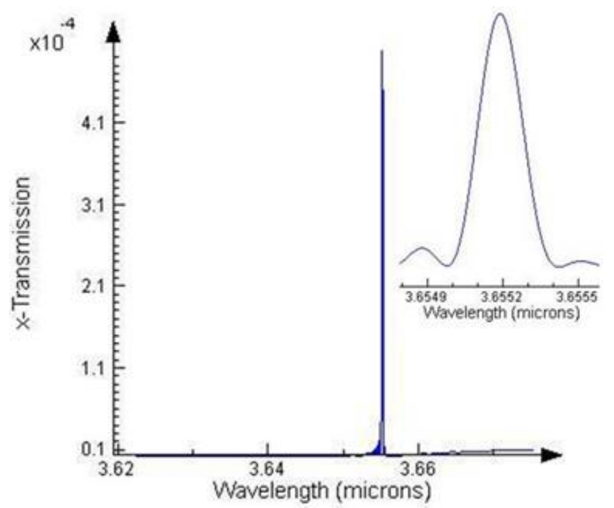


Fig. 2. Experimentally fabricated mid-infrared 1D-PhC on SOI wafer fabricated by dual beam focused ion beam milling. Ten dielectric stacks are generated. The grating has periodicity of 700 nm and the height of the grating is 5 µm.

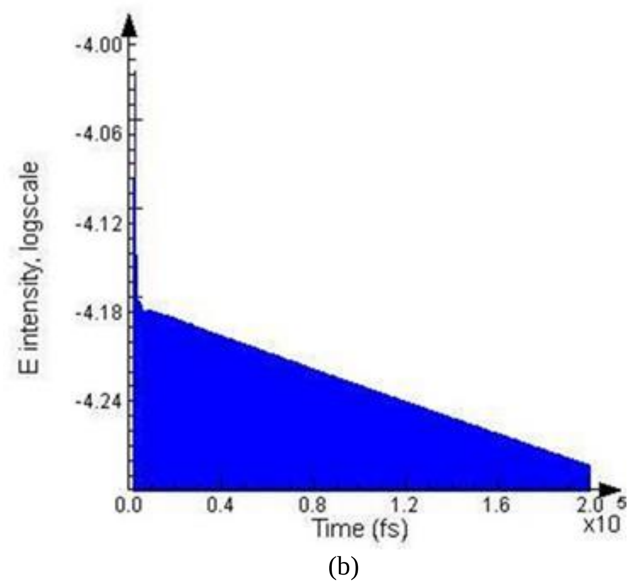
The ion beam current was 1.5 nA and patterning time was 300 s for each PhC structure. Ten dielectric stacks are fabricated. The PhC has a periodicity of 700 nm and the height of the grating is 5 µm. Highly smooth vertical edges are observed in the tilted SEM image which shows that roughness is minimized through use of ion beam milling. In addition, the milled columns are regularly distributed without any misalignment or distortion.

## DISCUSSION TRANSMISSION SPECTRUM AND THE Q FACTOR OF MID-INFRARED MICRORESONATOR

Figure 3 (a) shows the calculated transmission spectrum of a mid-infrared waveguide microresonator.




(a)




(b)

Fig. 3. (a) The calculated transmission spectrum of the mid-infrared waveguide microresonator. A resonant peak is found at λ= 3.655 um. (b) The transient response of the electromagnetic field inside the resonators shows a Q-factor of 4.2x105 is achieved at λ= 3.655 um by amplitude decay method.

A sharp resonant peak is observed at a wavelength λ= 3.655 um, where the photonic stop band is from 2.6 um to 4.6 um. A zoom-in spectrum shows that the resonance has a full width at half maximum (FWHM) of 0.2 nm. For greater calculation accuracy, we derive the quality factor Q from the transient response of the electromagnetic fields inside the resonator. Figure 3 (b) shows the decaying signals of the resonant wavelength. By fitting the decaying curve with amplitude decay method we find that a Q factor of $4.2 \times 10^5$ is achieved at λ= 3.655 um.

## REFERENCES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