Slot Mode Optomechanical System for Mass Sensing

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Optomechanical systems have demonstrated their significance in sensing applications. We study a slot mode optomechanical system where in a THz optical mode from a Photonic Crystal (PhC) cavity is coupled to a MHz mechanical mode of the cantilever to construct an effective mass sensitive device specifically operating at low-frequency region.

Improving ultimate mass sensitivity in resonant NEMS is achieved by the best combination of smallest mass resonator (m_{eff}), highest signal-to-noise-ratio (SNR) and largest mechanical quality factor Q represented by the figure of merit:

$$\frac{\delta f}{f} = \frac{m_{eff}}{QSNR} \tag{1}$$

The primary tension in this figure of merit comes from the fact that shrinking device size tends to lose both readout signal and drive efficiency and thus diminishes SNR. In previous work using a cantilever coupled to a racetrack optical resonator [1], it was shown that drive efficiency has a maximum for an optimum optical quality factor and that larger optomechanical coupling provides larger amplitude. It was further shown [2] that readout laser frequency could be tuned for cancellation of optomechanical nonlinearity potentially allowing relatively large driven amplitude. Shrinking the device to improve mass sensitivity would quickly diminish the optomechanical coupling value (G) which would endanger SNR in both the ability to resolve noise floor and the ability to drive a large peak amplitude. While adding optical power could partially mitigate SNR losses, this path is not available due to two-photon absorption nonlinearity limitations in the silicon system. The critical improvement required to solve this problem is one of increasing G in this system, even while maintaining or reducing coupled mass. This drives our present motivation for methods to increase G between a cavity and a low mass mechanical element. For a slot-mode system, the redistribution of energy into the slot should allow an increase to G per unit volume of coupling mechanical element, due to the increased sensitivity of the mode to the surface position boundary conditions. The use of a PhC better localizes the mode energy to the cantilever region also increasing G. Further, the mode energy in the slot may allow slightly higher optical powers due to reduced two photon absorption. Altogether, this motivates the choice of PhC with slot waveguide for best mass sensitivity.

In slot-mode optomechanical devices, the coupling of photonic and phononic beams is utilized to enhance the optomechanical coupling strength beyond what is achievable in single nanobeam crystals. We consider the integration of Silicon PhC with cantilevers on either side which essentially behave as a slot mode optomechanical system. A modified inline coupling technique in reflection mode is used to couple light into the cavity by manipulating losses at the mirrors [3]. To achieve this, the coupling end of the waveguide is provided with only 1 to 5 holes to access different coupling regimes. We utilized COMSOL to model our slot-mode optomechanical system, considering both photonic and phononic bandgap. The PhC- cantilever system was fabricated, and the chip underwent testing through a pump and probe system to evaluate the device's mass sensitivity. We were able to realize a mass sensitivity of 51zg despite the encountered temperature fluctuation noise. This aligns with the notion that our shorter cantilever demonstrated an improved G of 0.12 GHz/nm, as compared to the value achieved by our research group for a longer cantilever coupled to a racetrack resonator.

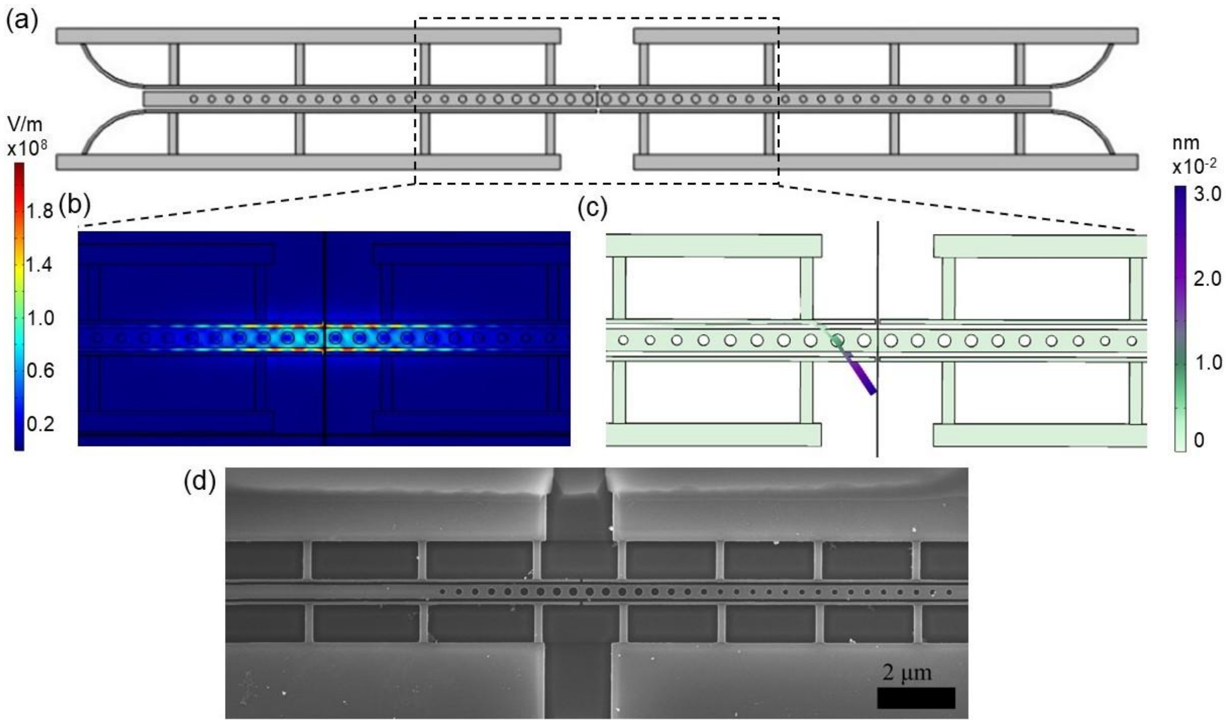

Fig. 4. (a) An illustration of Si Photonic Crystal-Cantilever Slot mode Optomechanical system. The FEM simulation of (b) First mode of optical resonance (c) Mechanical resonance of the cantilever (d) Scanning Electron Microscope Image (SEM) of the optomechanical device fabricated on SOI with one mirror on the coupling end

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References

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