Design and Fabrication of Silicon Nitride Membrane Resonators with Hybrid Photonic/Phononic Crystals

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Silicon nitride (SiN) membrane resonators have enabled significant advancements in cavity optomechanics due to their low mechanical dissipation and low optical absorption. In recent years, nano-patterning of tensioned SiN membranes with phononic crystal (PnC) and photonic crystal (PhC) engineering has been extensively studied to achieve high mechanical quality factor, Q, and optical reflectivity. Tsaturyan et al. [1] demonstrated a mechanical Qf product (quality factor × resonance frequency, f) exceeding 10^{14} Hz at room temperature with PnC engineered SiN membranes, while Zhou et al.[2] achieved a reflectivity over 99.98% with silicon nitride flat membranes using PhC designs.

Here, we report on the design and fabrication of a hybrid structure that integrates a two-dimensional PhC into the center of a stoichiometric SiN PnC membrane, achieving a device with both high mechanical Q and high optical reflectivity. The PhC designs follow the procedure described in our previous work[3]. A set of PnCs with varying number of unit cells and defect geometries was developed using finite element simulations (Figure 1), and the effects of geometry and the unit cell count on the mechanical response were investigated experimentally.

Fabricating these hybrid membranes presented challenges, such as cracking of the PhC (Figure 2) during membrane release with traditional KOH wet etch methods. To address this, we developed a novel fabrication process to reliably produce suspended hybrid SiN membranes with high yield (Figure 3). Our approach combines electron beam lithography (low speed, high resolution) and direct laser write lithography (high speed, low resolution). After PhC patterning, an oxide hard mask was added for protection. Membranes were released using deep reactive ion etching to thin the silicon wafer to ~50 μm, followed by KOH etching (30% concentration at 60°C). The compressed oxide film successfully prevented cracks during the release process. This work demonstrates a robust approach to fabricating hybrid PhC/PnC SiN membranes, paving the way for hybrid cavity optomechanical devices with improved performance metrics.

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[1] Y. Tsaturyan, A. Barg, E. S. Polzik, and A. Schliesser, Nat. Nanotechnol. 12, 776–783 (2017)
[2] F. Zhou, Y. Bao, J. J. Gorman, and J. Lawall, Laser Photonics Rev. 17, 2300008 (2023)
[3] F. Zhou, Y. Bao, J. J. Gorman, and J. Lawall, APL Photonics, 9, 076120 (2024).

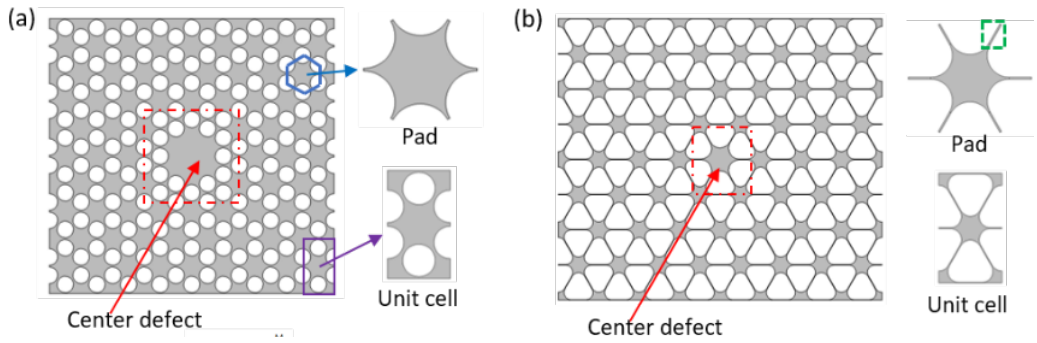

Figure 1. (a) PnC design (Type A) with a honeycomb lattice of air holes. (b) PnC design (Type B) incorporates an extended tether to the Type A pad, enhancing the tuneability of the resonator's mechanical mode response.

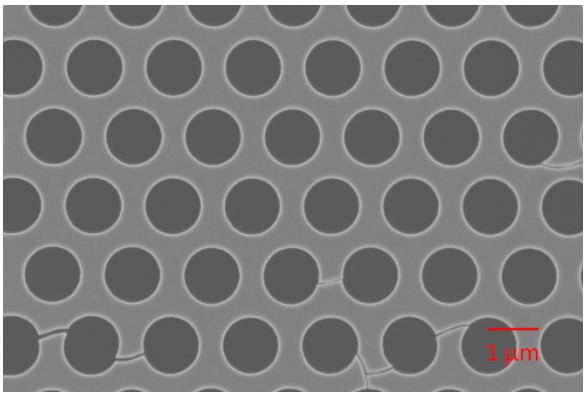

Figure 2. SEM Image of suspended PhC with cracking from traditional KOH releasing.

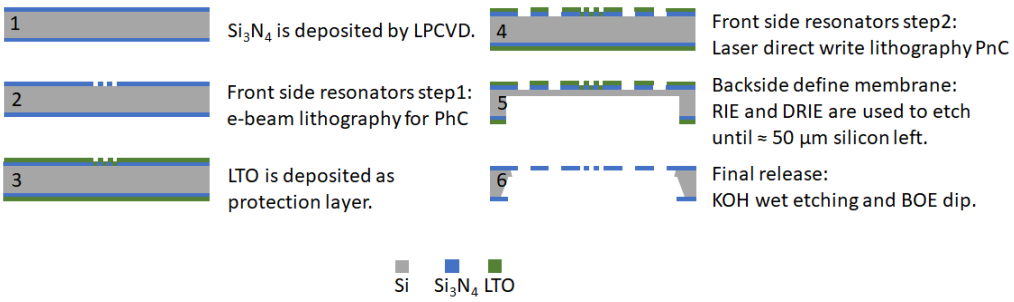

Figure 3. Fabrication process for stoichiometric *SiN membrane resonators with hybrid PnC and PhC.*