Fabrication and Characterization of a cm-scale, 400 nm-thick Torsional Pendulum

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One of the pivotal measurement instruments of weak fundamental forces is the torsion pendulum[1]. Recently, in the physics community, there has been interest in observing gravity's alleged quantum nature and calls for experiments where gravitationally attracting macroscopic mechanical oscillators are simultaneously prepared in quantum states of their motion[1]. In support of this endeavor, we fabricated a centimeter-scale high-quality torsion pendulum for use in a novel "mirrored optical lever" whose quantum-noise-limited sensitivity of 10^{-12} rad/$\sqrt{\mathrm{Hz}}$ is 13 dB below the zero-point motion of the pendulum[1].

We began the fabrication with a double-sided, 400 nm thick Si_3N_4-on-Si wafer (WaferPro). We used the process shown in Fig 1 to fabricate the bridge, where a photo of the finished result shown in Fig. 1. We used mask lithography to pattern the bridge design on the top, then etched that pattern into the SiN with a reactive ion etch (RIE). We aligned an open window pattern on the backside and used lithography and RIE steps to etch away the SiN window. After cleaning off any remaining photoresist from the previous steps, we etched the supporting Si from the bridge in a heated potassium hydroxide (KOH) bath.

After fabricating the bridge, we found that its fundamental torsional mode resonated at $\Omega_0 = 2\pi \cdot 35.95$ kHz with quality fac tor $Q = 1.4 \cdot 10^7$ inferred by ringdown measurements[1] (in vacuum, at $6 \cdot 10^{-7}$mbar). The measured Q was consistent with the expected dilution factor[1] $D_Q \approx 2300$.

As one of the next steps in this series of experiments, we fabricated another bridge design that was five times larger than the first. This will be used to validate the same Q as the 1 cm bridge, but at a lower frequency. The fabrication process and photo of the final bridge are shown in Fig. 2. The extended length of the bridge caused some complications in its fabrication. Specifically, the bridge consistently broke in the KOH step. We overcame this obstacle by reducing the size of the backside window on the sample.

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[1] Shin, Dong-Chel & Hayward, Tina & Fife, Dylan & Menon, Rajesh & Sudhir, Vivishek. (*Unpublished data*). Laser cooling a centimeter-scale torsion pendulum. 10.48550/arXiv.2409.02275.

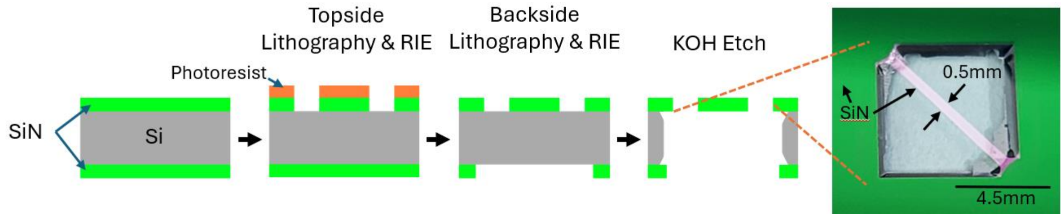

Fig. 1: Essential process flow of 0.9 cm bridge.

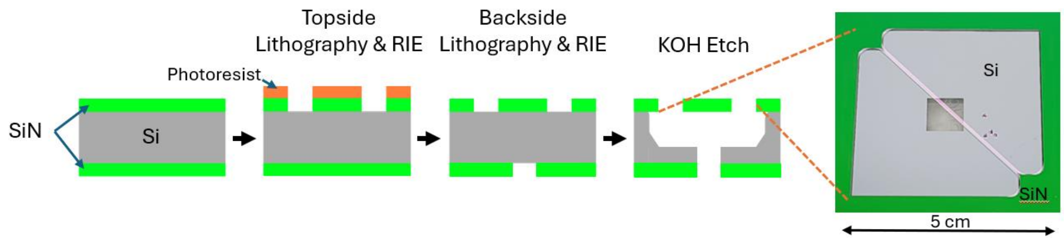

Fig. 2: Essential process flow of 5 cm bridge.