# Evolution of a Centimeter-Scale Torsional Oscillator: Fabrication and Characterization at 100 nm Thickness

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A torsion pendulum is a key instrument for probing weak fundamental forces. Recently, interest has grown in testing gravity's possible quantum nature, motivating proposals to place gravitationally interacting macroscopic mechanical oscillators into simultaneous quantum states of motion. Building toward that long-term goal, our previous work demonstrated a 9 mm long, 400 nm-thick SiN torsional oscillator integrated into a laser-cooling setup[1]. With this setup, we demonstrated that optical damping could suppress its natural motion, which will prove essential for the precision measurements envisioned in future experiments[1]. To further improve the laser cooling capabilities, we must increase the sensitivity of the torsional oscillator's angular motion measurements. Our current experiment pushes towards the necessary sensitivity by using an optical cavity to increase the measurement efficiency of the torsional oscillator.

To support this new measurement setup, we have developed a new torsional oscillator consisting of a 12 mm long, double clamped, $Si_3N_4$ ribbon. Our calculations indicated the optimal measurement strengths would occur with $Si_3N_4$ thicknesses of about 400 nm and 100 nm, respectively, and we will test both designs.

The oscillator fabrication process, shown in Fig. 1, began with a lithography step to pattern the oscillator on one side of a $Si_3N_4$ coated Si wafer, then a reactive ion etching (RIE) to transfer that pattern to the $Si_3N_4$. The same process is used to create the open window on the backside of the wafer. We then use potassium hydroxide (KOH) to etch away the exposed Si, releasing the torsional oscillator. In the case of the 400nm oscillator (Fig. 2), we were able to simply rinse the oscillator in water, then isopropanol (IPA), then let it dry in air. However, the 100 nm $Si_3N_4$, (Fig. 3), has proved to be more delicate than the 400 nm oscillator, and requires careful handling during and after the KOH etch. Because the 100 nm membrane is highly susceptible to damage during the liquid-to-vapor transition, we will incorporate critical point drying to preserve its structural integrity.

Once completed, the torsional oscillators will be integrated into the optical cavity experimental setup to evaluate their angular motion readout performances.

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[1] Shin, Dong-Chel, Tina M. Hayward, Dylan Fife, Rajesh Menon, and Vivishek Sudhir. 2025. "Active Laser Cooling of a Centimeter-Scale Torsional Oscillator." *Optica* 12(4): 473. doi:10.1364/OPTICA.548098.

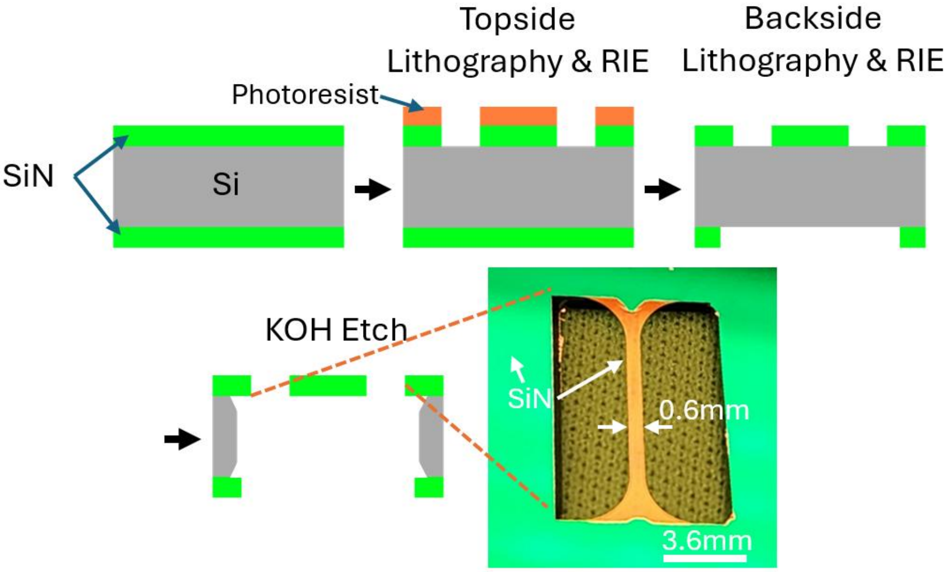

Fig. 1: Process flow for both 400nm and 100nm ribbons.

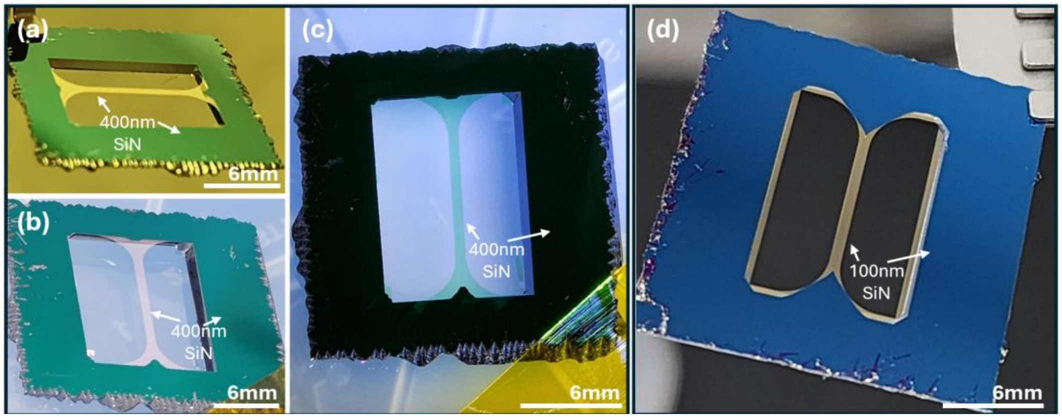

Fig. 2: Photos of fabricated ribbons, where the SiN is (a-c) 400nm and (d) 100nm thick. Note: the SiN in the clamp areas in (d) are not fully free of Si; this is something we will be correcting going forward.