Optics in 2025

Photonic Origami of Silica on a Silicon Chip

RESEARCHERS

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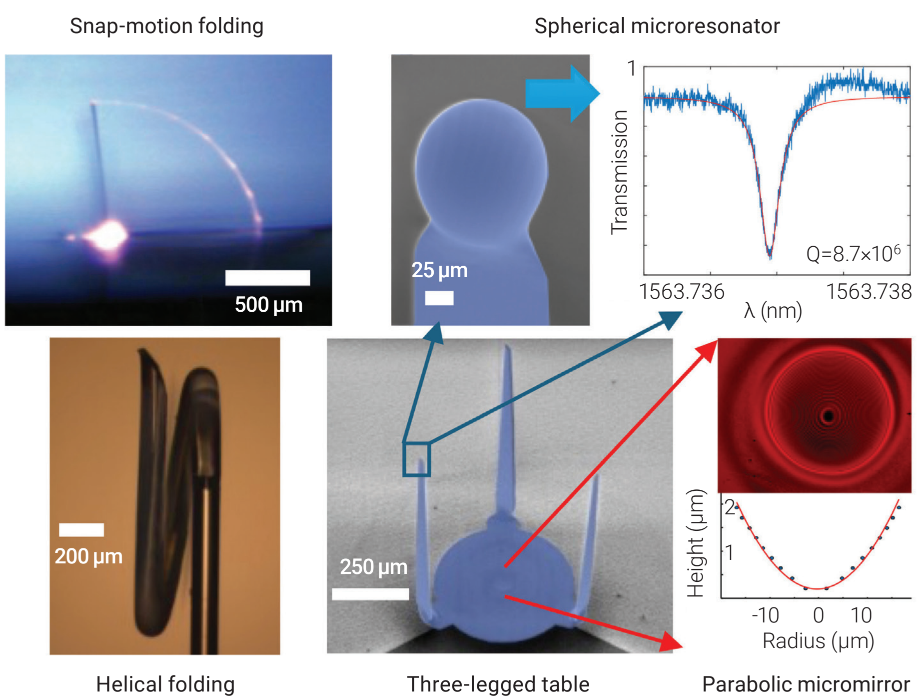
Silica is beneficial for fabricating nanometer-smooth resonators, giving them ultrahigh quality, as well as supporting record finesse for concave micro-mirrors.[1] But previously, folding such planar photonics[1,2] into 3D architectures was out of reach. In our recent work,[3] we borrowed hygroscopic principles used in plants, including in seed-release mechanisms, to fold photolithographed silica by harnessing surface tension.

To prepare the glass for folding, we thermally grow a very smooth and thin (down to 0.5 μm) amorphous silica layer on top of a silicon chip with cleanroom-grade silicon and oxygen, then release the silica from the silicon with dry xenon difluoride silicon etching. Using a CO_2 laser, we selectively liquefy one side of a 5-μm-thick silica bar, which allows it to be folded in a controllable, touchless and additive-free manner. The laser heats the contact point to 3000 K, starting to liquify it. In contrast, the side of the silica opposite the laser contact point reaches a temperature of 1500 K, which is slightly above the transition temperature of glass, turning it into a soft solid. Surface tension at the hotter liquified side, together with the soft solid on the other side, then causes the silica bar to bend. We demonstrated a bending event where a laser pulse initiated a snap-motion fold to 90° within less than a millisecond. Our 3D structures contain microresonators with a quality factor, Q, exceeding 8×10^6 as well as 30-μm-diameter parabolic mirrors, which are made by reflowing or evaporating the silica accordingly.

While most 3D-printing techniques rely on additive fabrication in discrete steps, leading to challenges in uniformity, purity, smoothness and voxel size (which are related to their inherent nonlinear photocuring mechanisms); we combine subtractive 2D lithography with tunable bending by harnessing surface tension to fabricate 3D structures that are ultrasmooth. We demonstrated bending from 0° to unlimited helices with 0.1-microradians resolution. One example of a fabricated device is a three-legged table containing a parabolic mirror. Fully releasing this table might permit optical levitating cavity mirrors[4] for testing gravity models. Another example relates to our fabricated 3-mm-long, 500-nm-thick bars that reach the ultimate size-to-weight limit and might therefore serve in lightsails.[5] OPN



Left: Snap-motion folding of a horizontal silica bar by 90° within less than a millisecond. The molten silica at the knee emits light that is guided through the bar and scattered from its tip, creating an arc-shaped flare (top). Helical folding by moving the bar under the focused folding laser (bottom). Right: A three-legged table where we reflow legs to become a spherical microresonator with Q exceeding 8×10^7, or evaporatively evacuate material to generate a parabolic micromirror with a 0.41 numerical aperture, as correspondingly measured from their spectral linewidth and interferogram.