Ultra-high-Q toroid microcavities on a chip

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Abstract: We demonstrate microfabrication of ultra-high-Q microcavities on a chip, exhibiting a novel toroid-shaped geometry. The cavities possess Q-factors in excess of 100 million which constitutes an improvement close to 4 orders-of-magnitude in Q compared to previous work [1].

OCIS codes: (230.5750) Resonators (220.4000) Microstructure fabrication

There is considerable interest in obtaining high-Q factors in microcavities. At a fundamental level these devices can be used to study nonlinear optical processes [2] and cavity QED [3] and from an applied standpoint they enable low-threshold lasers [4] and nonlinear oscillators [5]. So far however, reaching the ultra-high-Q regime has only been possible using rather exotic microcavities such as liquid microdroplets or microspheres. These cavities, which are formed by surface tension, possess record high quality factors in excess of 100 million. However, control over their fabrication and the ability to combine them with other functions is challenging. In contrast, planar microcavities offer wafer-scale control and fabrication parallelism. They are also potentially integrable with other functions on a chip. To date, however, the highest reported Q value for a chip-based resonator is 17,000 [1].

Here we demonstrate a process to make planar microcavities-on-a-chip possessing ultra-high-Q in excess of 100 million (a four order-of-magnitude improvement over prior chip-based microcavities). The fabrication process is illustrated in figure 1. First, a combination of wet-etching and isotropic XeF_2-etching is used to create equally undercut circular silica disks on a silicon support pillar. The quality factor of these structures was measured to be in excess of 10^5, believed to be limited by the visible roughness of the surface at the perimeter of the disk.

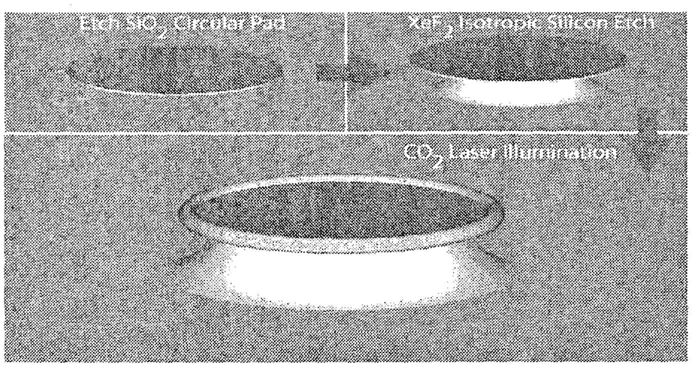

Fig. 1. Schematic of the process used to create ultra-high-Q toroid-shaped microcavities on a chip.

To create cavities with extremely low surface roughness we introduce a novel, processing step. The disks are surface-normal irradiated with a CO_2 laser, at power levels which melt the silica. The underlying silicon support structure remains un-melted and shows no deformation in this process. Surface tension causes the molten silica disk to collapse from it's perimeter, forming a toroid-shaped microcavity. The final dimensions of the toroid can be controlled by both the duration and intensity of the CO_2 laser irradiation. An SEM micrograph of an unlasered disk (inset of figure 2) and a laser-processed disk is shown in figure 2.

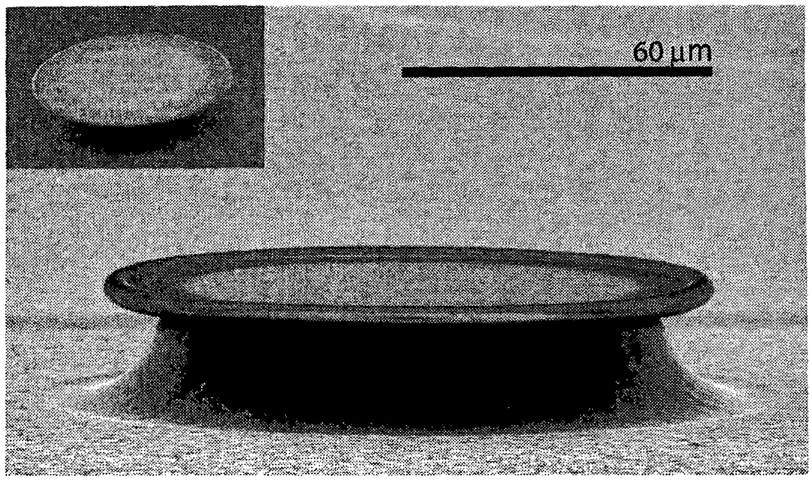

Fig. 2. SEM micrograph of o toroid-shaped silica microcavity. The quality factor of this toroid was measured to be 1.00×10^8. The inset shows the silica disk prior to melting.

The quality factor and mode spectrum of the toroid microcavity were measured in the telecommunication band (1550 nm). Tapered optical fibers, typically having a waist of a few microns in diameter, were used to excite toroid-cavity resonances. The quality factor was directly inferred from cavity ringdown. Figure 3 shows the cavity decay field after a resonance of the toroid has been excited at criticality (vanishing waveguide transmission) and the input field is gated off. The signal is a decaying exponential as is expected for a single excited mode.

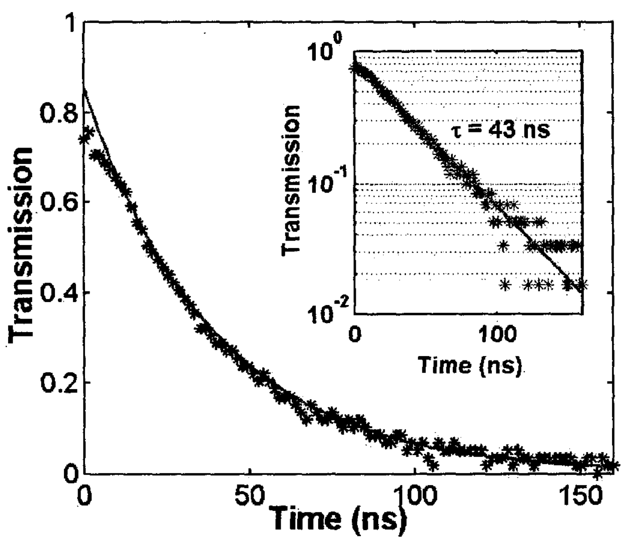

Fig. 3. Ringdown measurement of a 90-micron-diameter disk at the critical-coupling point. The measured lifetime of $\tau crit=43$ ns corresponds to an intrinsic quality factor of $Q= 1.25 \times 10^8$.

After correcting for the counter-propagating wave excitation (which is described by an dimensionless intermode coupling parameter ¡ [6]) and taper-waveguide-loading, the inferred intrinsic quality factor was determined to be in excess of 100 million:

$$Q_0 \equiv \omega\tau_0 = \omega\tau_{crit}(1+\sqrt{1+\Gamma^2}) \approx 1.25 \cdot 10^8$$

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