High-Q silica microdisk optical resonators with large wedge angles on a silicon chip

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We experimentally demonstrate high optical quality factor silica microdisk resonators on a silicon chip with large wedge angles by reactive ion etching. For 2-μm-thick microresonators, we have achieved wedge angles of 59°, 63°, 70°, and 79° with optical quality factors of 2.4 × 10^7, 8.1 × 10^6, 5.9 × 10^6, and 7.4 × 10^6, respectively, from ~80 μm-diameter microresonators in the 1550 nm wavelength band. Also, for 1-μm-thick microresonators, we have obtained an optical quality factor of 7.3 × 10^6 with a wedge angle of 74°.

1. INTRODUCTION

Whispering gallery mode (WGM) optical microresonators, owing to their high quality factors and small mode volumes, have been widely used in cavity quantum electrodynamics, optical communication, nonlinear optics, chemical/biological sensing, and cavity optomechanics [1,2]. Recently, coupled optical microresonators have attracted more and more attention for their potential applications in coupled-resonator optical waveguides [3,4], analogues to electromagnetically induced transparency [5–7], quantum information processing [8,9], phonon lasers [10], parity-time-symmetric optics [11,12], etc.

So far, chip-based high-Q optical microresonators have been realized using various kinds of materials such as silicon [13,14], silicon nitride [15], silica [16–19], III–V semiconductor [20,21], polymer [22,23], and diamond [24]. Among them, silica microresonators, in the forms of toroid [16], sphere [17], and disk [18,19], exhibit ultrahigh optical quality factors on chip due to their ultralow material absorption and extremely smooth surfaces. For the silica microtoroid [16] and microsphere [17] cavities, their quality factors are obtained by reducing the surface roughness down to atomic scale with the help of CO₂ laser reflow. However, this process significantly shrinks the diameters of the microcavities, which limits their applications in device integration and makes it challenging to fabricate two or more microcavities close to each other on the same silicon chip. Recently, a wedge-shaped silica disk resonator (7.5 mm diameter) with a wedge angle smaller than 30° has achieved the record optical quality factor of 8.75 × 10^8 on chip [19]. However, to boost the optical quality factor of this structure, the silica disk is over etched using buffered HF, which makes the size of the disk smaller than the original pattern on the photomask [18,19]. Also, the small-angle wedge structure pushes the optical WGMs away from the disk perimeter [18,19], which further limits certain device applications in coupled microresonators.

Here, we fabricate a class of high optical quality factor silica microdisk resonators with large wedge angles using the reactive ion etching process. In previous works, dry-etched silica microdisk resonators including single-layer [25,26] and double-layer [27,28] structures have been demonstrated with quality factors of ~5 × 10^5 for coupled microresonators [25,26] and with a quality factor of 1.75 × 10^6 for gradient-force-actuated cavity optomechanics [27,28]. Moreover, these microdisk resonators were fabricated using metal or e-beam resist as a mask for reactive ion etching, which limited the Q-factor or the thickness of the microresonators. In this work, we demonstrate dry-etched silica microdisk resonators on a silicon chip with large wedge angles due to the anisotropic nature of dry etching using photoresist as an etch mask. We have obtained silica microdisk resonators with thickness as large as 2 μm and a record Q-factor of 2.4 × 10^7 for dry-etched silica microdisk cavities on chip at the wavelength of ~1550 nm.

2. DEVICE FABRICATION AND MEASURED RESULTS

As shown in Fig. 1, the fabrication process for the silica microdisk resonators mainly contains four steps. First, a NSR-1755i7B stepper is used to pattern the photoresist (AZ 6130) on a thermally grown silicon oxide film with a thickness of 1 or 2 μm. After exposure, a post-exposure bake is performed to reduce the sidewall roughness of the photoresist pattern. Then, the reactive ion etching with SF₆/CHF₃/He chemistry is employed to transfer the pattern of the photoresist onto the silicon oxide layer. The residual photoresist after the reactive ion etching is removed using the photoresist remover (AZ remover 700) followed by H₂SO₄/H₂O₂ solution. Finally, the silica microdisk is undercut by the
XeF$_2$ dry etching to form a silicon pillar. Figures 2(a)–2(e) show the typical scanning electron microscope (SEM) images of the fabricated silica microdisk resonators with a thickness of 2 μm. By changing the radio frequency power during the fabrication process, we have obtained silica microdisk resonators with different wedge angles of 59°, 63°, 70°, and 79°, respectively [Figs. 2(b)–2(e)], which are much larger than those of the previously demonstrated silica microresonators fabricated using the buffered HF wet etching process [18,19]. The diameters of the silica microdisks are around 80 μm, which is very close to the size of the patterned photoresist mask.

In order to characterize the fabricated silica microdisk resonator, a tapered optical fiber is used to excite the WGMs of the microresonator via the evanescent wave [29]. A tunable external cavity semiconductor laser (New Focus, model TLB-6328) with a linewidth of less than 300 kHz is coupled into the fiber taper to measure the transmission spectrum of the microresonator by scanning the wavelength of the laser. During the experiment, the measured resonant linewidths of the cavity modes are calibrated by a fiber Mach–Zehnder interferometer, and the silica microdisk resonator is kept in a nitrogen-purged enclosure to prevent unwanted water and particle contaminations.

Figure 3(a) shows the measured transmission spectrum of a fundamental TE-like mode from the 59°-wedge-angle silica microdisk resonator with a thickness of 2 μm and a diameter

![Image](image_url)
obtained the optical silica microdisk resonators with a wedge angle of 74° and to a finesse of \( \sim \) for the microresonator, we have also fabricated 1-

In conclusion, dry-etched silica microdisk resonators with different large wedge angles have been demonstrated on a silicon chip. A Q-factor as high as \( 2.4 \times 10^5 \) is observed from an 80-μm-diameter microdisk resonator with a thickness of 2 μm and a wedge angle of 59°. This kind of high-Q silica microdisk resonator with a large wedge angle will enable monolithic integration of the microdisk resonators coupled to a waveguide and will be useful in coupled-resonator optical waveguides, nonlinear optics, and cavity optomechanics.

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