Experimental demonstration of waveguide-coupled round-cornered octagonal microresonators in silicon nitride

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Received September 9, 2004

We report laterally waveguide-coupled octagonal microresonators with designed round resonator corners in silicon nitride. We demonstrate nearly single-mode add–drop filter characteristics, when 50-μm-size round-cornered octagonal microresonators are used, with an optimum coupling efficiency exceeding 96%, a finesse of \( \sim 30 \), and a Q of \( \sim 6400 \). Our experiments also reveal two unforeseen phenomena in certain microresonator shapes: a pronounced drop in coupling efficiency and resonance notches in the drop spectrum. These device characteristics hint at the recently postulated multiple orbit interference in waveguide-coupled polygonal microresonators. © 2005 Optical Society of America

OCIS codes: 290.7390, 290.5750.

Laterally waveguide-coupled polygonal microresonators (μ resonators) shaped as squares,1–3 hexagons,4 and octagons5 have been attracting interest as alternative waveguide-coupled resonator designs for photonic signal-processing applications, namely, channel add–drop applications in wavelength-division multiplexing communications. These polygonal μ resonators, compared with conventional circular microdisk and microring resonators,5,7 have the advantage of a relatively long coupling length along flat resonator sidewalls for ease in lateral coupling with waveguides. Most recently, it has also been postulated that coherent N-bounce ray orbits coupling along various locations of an N-polygonal μ-resonator flat sidewall may interfere.4 Such multiple orbit interference may then result in interesting resonance characteristics that potentially mimic those of mutually coupled μ resonators.8

Previously,9 eight-bounce modes with good Q and good coupling efficiency were experimentally demonstrated in silicon nitride (SiN) laterally waveguide-coupled octagonal μ resonators. Nonetheless, the key issues that remain are twofold: phase matching between the octagonal μ resonator and the waveguide and possible diffractive loss at the μ resonator’s sharp corners.4,5 To address the corner-leakage issue we recently proposed octagonal μ resonators with designed round resonator corners.9 Our simulations suggested that the round-cornered designs could considerably reduce the cavity loss and much improve the add–drop filter characteristics.

Here we report our experimental results with these round-cornered μ resonator filters in SiN. By intentionally rounding the octagonal μ resonators’ corners we demonstrate significantly improved add–drop filter characteristics from those of sharp-cornered octagonal μ resonators. Our experiments also reveal in specific round-corner μ-resonator shapes an unexpected drop in coupling efficiency and, more interestingly, resonance notches in the drop spectrum.

Figure 1 is a schematic of the filter. A 45° arc with radius of curvature \( R \) is applied to each corner of a regular octagonal μ resonator. We define the μ resonator’s shape by the ratio of \( R \) to sidewall-to-sidewall distance \( L \). \( R/L = 0 \) means a regular octagon, and \( R/L = 0.5 \) means a circle. We also define the cavity sidewall length, \( a = (\sqrt{2} - 1)(L - 2R) \). The rounder the cavity corners, the shorter the cavity’s flat sidewalls. In our experiments we designed \( L = 50 \ \mu \text{m} \) and air-gap separation \( g = 0.35 \ \mu \text{m} \).

We employed standard silicon microfabrication processes as detailed in Ref. 5. The filter comprised a 1.1-μm-thick low-stress SiN film upon a 1.5-μm thick silica undercladding. The stack-layered structure was air clad. The plasma-etched ridge waveguides and μ resonators have a slab height of \( \sim 0.15 \ \mu \text{m} \). The device characterization employed a conventional laser wavelength-scanning technique with a resolution of \( \sim 0.02 \ \text{nm} \), as detailed in Ref. 5. The chip edges were manually cleaved and unpolished.

We tuned the \( R/L \) ratio (and the corresponding \( a \)) while we kept other design parameters fixed. Figures 2a–2f show top-view scanning-electron-microscope images of the fabricated filters of \( R/L = 0–0.5 \) (in steps of 0.1). Sidewall length \( a \) is reduced correspondingly. Here waveguide width \( w \) is 0.6 μm. Figures 2g–2l show the measured TM-polarized (E⊥ the chip) throughput (solid curve) and drop (dashed curves) spectra of these filters. The throughput and...
short eight-bounce round-trip lengths. We also measured a FSR of 7.35 nm, which displays only weak coupling (Fig. 2i). With \( R/L = 0.3 \) at various values of \( w \) from 0.5 to 0.9 \( \mu m \). The measured and simulated \( Q \) variations with \( w \) are consistent with each other. In both cases, \( Q \) is optimized at \( w = 0.8 \mu m \). We attribute this to the near \( k \)-vector match between the \( \mu \) resonator and the waveguide.

Figure 4(a) shows the measured coupling efficiency at various \( R/L \) ratios (or \( a \)) for \( w = 0.6 \mu m \) (solid curve) and \( w = 0.5 \mu m \) (dashed curve). Contrary to our expectation based on previous research with polygonal \( \mu \) resonators, the coupling efficiency does not have a simple linear dependence on sidewall length \( a \). For both \( w = 0.5, 0.6 \mu m \), the coupling efficiency drops to \( \sim 30\% \) at \( R/L = 0.2 \) (\( a = 12.43 \mu m \)). We also observed a relatively low coupling efficiency for the sharp-cornered octagonal \( \mu \) resonator with long flat sidewalls but a relatively high coupling efficiency for the round-cornered octagonal \( \mu \) resonators with reduced sidewall lengths. For \( w = 0.6 \mu m \) the coupling efficiency has maxima near \( a = 16.57 \mu m \) and \( a = 4.14 \mu m \). However, it is conceivable that part of this variation in coupling efficiency may be due to the different phase-matching conditions between the waveguide and the various shaped \( \mu \) resonators.

To further probe these unexpected coupling efficiency variations, we examined the integrated scattering intensity at resonances from top-view optical microscope images at various \( R/L \) ratios for \( w = 0.6 \mu m \) (solid curve) and \( w = 0.5 \mu m \) (dashed curve).
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(dashed curve) sharp resonance notches that mimic
(curve), as shown in the inset of Fig. 4(a). We reasoned that the integrated top-view scattering intensity provides a glimpse into the cavity’s internal field. Interestingly, we obtained a pronounced peak at \( R/L = 0.2 \) for both values of \( w \). The trend appears to be a mirror image of that of the coupling efficiency. Thus it is tempting to argue that light has after all been input coupled at \( R/L = 0.2 \) (\( a = 12.43 \mu m \)) and has built up an enhanced cavity internal field. The observation that the spectra [Fig. 2(i)] reveal only weak modulation may then hint at out-of-phase interference at the throughput and at the drop port among multiple orbits that are coherently input and output coupled along various locations of the flat \( \mu \)-resonator sidewalls.

We observed another unexpected resonance phenomenon that may also hint at the postulated multiple orbit interference: Fig. 4(b) shows the measured spectra with \( R/L = 0.25 \) (\( a = 10.35 \mu m \)) and \( w = 0.5 \mu m \). We observed in the drop spectrum (dashed curve) sharp resonance notches that mimic the resonance line shapes expected in interacting \( \mu \) resonators. The resonance notches may be attributed to destructive interference among coherent multiple orbits that are output coupled to the drop port. These previously unforeseen phenomena should call for further detailed experiments and theoretical modeling.

In conclusion, we have experimentally demonstrated laterally waveguide-coupled round-cornered octagonal \( \mu \) resonators in silicon nitride. Our measurement of a 50-\( \mu m \)-sized \( \mu \)-resonator filter revealed nearly single-mode characteristics with an optimum coupling efficiency exceeding 96%, a finesse of \( \sim 30 \), and a \( Q \) of \( \sim 6400 \). It is conceivable that both the resonator shape and the sidewall length are key design parameters for round-cornered polygonal-type \( \mu \) resonators. We also observed a pronounced drop in the coupling efficiency and resonance notches in the drop spectrum with specific round-cornered \( \mu \)-resonator shapes and sidewall lengths. These resonance-coupling phenomena may constitute indirect evidence of the recently postulated multiple orbit interference in polygonal \( \mu \) resonators.

The research was substantially supported by grants from the Research Grants Council and the University Grants Council of the Hong Kong Special Administrative Region, China (projects HKUST6166/02E and HIA01/02.EG05). C. Li’s studentship was partially supported by grant I2MS01/02.EG07 from the Institute of Integrated Microsystems of the Hong Kong University of Science and Technology. A. W. Poon’s e-mail address is eeawpoon@ust.hk.

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