Trapezoidal Shape Subwavelength Grating Waveguide Based High Quality Factor Micro-ring Resonator

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Abstract: We report the design and experimental demonstration of high quality factor, trapezoidal shape subwavelength grating waveguide micro-ring resonators (SWGMRs). A 5 μm radius SWGMR with a quality factor as high as 11,500 has been demonstrated for the first time.
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In recent decades, photonic devices on silicon-on-insulator (SOI) platform have been attracting intensive interest due to the advantageous compact dimensions and high-volume manufacturability [1,2]. Particularly, micro-ring resonators on SOI platform have been widely exploited as a basic building block for a vast range of applications [3]. However, conventional strip waveguide based micro-ring resonators suffer from the intrinsic dilemma in achieving high light confinement and strong light-matter interaction simultaneously. Subwavelength grating (SWG) waveguides, comprised of periodically interleaved high and low refractive index materials with a pitch less than one wavelength, have been demonstrated as a promising alternative [4,5]. The ratio of silicon and cladding materials can be engineered microscopically to achieve desired macroscopic properties. The control of these properties could potentially lead to significant performance improvements compared to conventional micro-ring resonator based photonic devices, such as filters [6] and sensors [7]. However, SWG waveguide based micro-ring resonators (SWGMRs) that have been demonstrated so far can only provide a moderate quality factor (~5600) with a pretty large radius (e.g. 15 μm), which greatly jeopardize the wide spread research efforts in this area. In this paper, we propose to use trapezoidal silicon pillars to reduce the loss of SWG bends and therefore improve the quality factor of SWGMRs [8].

The schematic of an SWGMR with trapezoidal silicon pillars (T-SWGMR) is shown in Fig. 1(a), where *r* and *g* denote the radius of the SWGMR and the gap size between the center of the bus waveguide and the center of the curved waveguide, respectively. The 5 μm and 10 μm T-SWGMRs are designed based on optimizing the trapezoidal silicon pillars [8] via 3D FDTD (FullWAVE^{TM}, Synopsys Inc.) to minimize the mode delocalization induced by the bending curvature. A control group of SWGMRs with conventional rectangular silicon pillars (R-SWGMR) is also designed. Fig. 2(b) shows a typical top view of the optical field (quasi-TE polarization, Re[Hz] component) of a T-SWGMR on resonance (*r*=5 μm and *g*=800 nm).

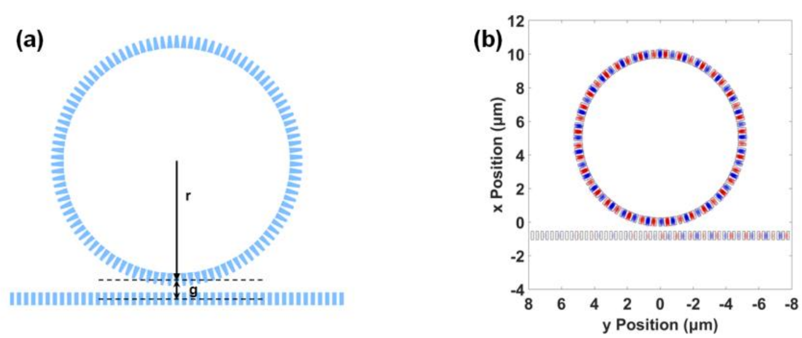

Fig.1 (a) Schematic of a T-SWGMR. (b) Typical top-view of the optical field of a T-SWGMR on resonance.

Four types of SWGMRs (5 μm radius T-SWGMR, 5 μm radius R-SWGMR, 10 μm radius T-SWGMR and 10 μm radius R-SWGMR) have been fabricated for experimental demonstration. The devices are fabricated on an SOI wafer (manufactured by Soitec.) with a 250 nm thick top silicon layer and a 3 μm thick buried oxide layer. All structures are patterned in a single E-beam lithography (JEOL 6000 FSE) step. The patterns are then transferred into the silicon layer through reactive-ion-etching (PlasmaTherm 790). SU-8 2005 (MicroChem Corp.) is spin-coated at

3000 rpm to form a 5 μm thick top cladding. An overnight baking in an 80 ℃ oven is applied to reflow the SU-8 for a thorough infiltration. Fig. 2(a) and 2(b) are SEM images of 5 μm radius R-SWGMR and T-SWGMR, respectively. Fig. 2(c) shows the coupling region of a 5 μm radius T-SWGMR.

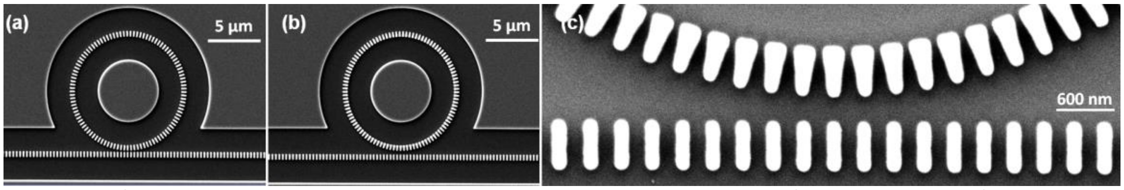

Fig.2 SEM images of (a) 5 μm radius R-SWGMR and (b) 5 μm radius T-SWGMR. (c) High magnification SEM image of the coupling region of a 5 μm radius T-SWGMR

The devices are tested in a customized grating coupler alignment system shown in Fig. 3(a). Two xyz stages are used to align the fibers to on-chip grating couplers and a camera mounted on another xyz stage is tilted at 45° angle to visually assist the alignment. Light from a broadband amplified spontaneous emission (ASE) source (1510 nm–1630 nm) is guided to the grating coupler through a polarization maintaining fiber mounted on a tilting stage. After passing through the devices, light signal is collected by the output fiber and fed into an optical spectrum analyzer (OSA) to capture the optical spectra. Fig. 3(b) and 3(c) show the transmission spectra of the four types of SWGMRs. The 5 μm radius T-SWGMR can provide a resonance peak with a quality factor as high as 11,500, which is 4.6 times as high as the highest quality factor (~2,800) that a 5 μm radius R-SWGMR can achieve. For 10 μm radius SWGMRs, the T-SWGMR can achieve a quality factor as high as 45,000, which is 3 times as high as the R-SWGMR (quality factor~15,000).

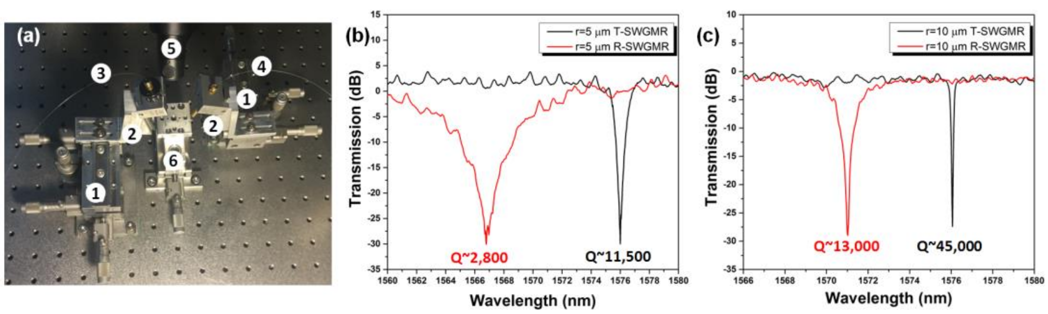

Fig. 3. (a)Manually grating coupler alignment system. (1)xyz stage (2)fiber mounts on tilting stage (3)input polarization maintaining fiber (4)output single mode fiber(5) 45° tilted camera (6)adjustable sample stage. Transmission spectra of selected resonance peak of (b) 5 μm radius SWGMRs and (c) 10 μm radius SWGMRs. T-SWGMR and R-SWGMR are both included.

In conclusion, we for the first time demonstrated the smallest SWGMR (5 μm radius) with a quality factor as high as 11,500. This study offers a promising platform for light-matter interaction research.

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