Pulley-type Ring Resonator and Optimization

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Abstract: In this work, we propose a guideline to design the high Q-factor ring resonators. To keep the optical energy in the ring, the radiation loss of the ring should be reduced. The difference of the propagation constant between the bus waveguide and the ring should be enlarged to prevent from the light in ring to be coupled back to the bus waveguide. The phase difference of the light between the bus waveguide and ring should be adjusted to obtain the destructive interference at the output port (critical coupling). From these points mentioned above, we compare the 6 types of ring resonators. We conclude that the high Q-factor pulley-type ring resonator can be more easily designed. The experimental Q-factor of the pulley-type ring resonators with ring radius of only 4.43μm can be obtained up to 1.73×10^5.

1 INTRODUCTION

The microring resonator is an important and versatile integrated optics component. For example, several devices such as filter (Little et al., 1997), gyroscope (Matsko et al., 2004) and optical switch (Almeida and Lipson, 2005) can be constructed by the microring resonator. In the past decade, several types of microring resonator are developed such as the single microring with single bus waveguide (Terrel et al., 2009) or double bus waveguides (Nawrocka et al., 2006), the racetrack type (Menon et al., 2004) and the multiple microrings type (Poon et al., 2004). However, to decrease the device dimension, the reduction of the ring size is required. The disadvantage of above microring structures is the huge bending or radiation loss from the microring resulting in the lower Q-factor. In order to obtain the high Q-factor, the size of the above microring structures must be increased to reduce the bending loss or radiation loss. The microdisk and microring with the pulley-type coupling configuration, pulley coupler, have been reported for the applications of integrated optical isolators and sensor devices in Ref. (Hu et al., 2008) and (Hosseini et al., 2010) respectively. The Q-factor of the ring resonators with pulley-coupler has been reported to be 10,000 to 210,000, respectively. However, the performance of the pulley-type ring resonators has not been compared to that of the other types of ring resonators.

In this work, we propose a guideline to design the high Q-factor ring resonators. We compare the 6 types of ring resonators. We conclude that the high Q-factor pulley-type ring resonator can be more easily designed.

2 SIMULATION

To design the high Q-factor ring resonators, the optical energy should be kept in the ring. First, the radiation loss of the ring should be reduced. Secondly, the difference of the propagation constant between the bus waveguide and the ring should be enlarged to prevent from the light in ring to be coupled back to the bus waveguide.

Thirdly, the phase difference of the light between the bus waveguide and ring should be adjusted to obtain the destructive interference at the output port (critical coupling). Fine tune of the dimensions of the ring should be performed.

Table 1 shows the dimension parameters that can be varied for finely tuning the ring resonators to obtain the high Q-factor. We can observe that only the bus waveguide width change one property of the ring resonators, β. Therefore, in this work we finely tune the performance of the ring resonators by changing the bus waveguide width.

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Table 1: Dimension parameter of ring resonators and the influences on the properties of ring resonators.

Dimension Parameters	Influences
Ring radius	L, β, λ
Gap	β, κ, λ
Ring waveguide width	L, β, λ
Bus waveguide width	β
Refractive index	λ, β

L: the length of cavity, β: the propagation constant λ: the resonant wavelength, κ: the coupling coefficient.

In this study, we adopt the 2-D finite-difference time- domain method (2-D FDTD) to investigate the energy decay in the ring resonators. The microring resonator of the 6 types to be studied are schematically shown in Fig. 1(a)-(e).

The refractive index of bus waveguides and the ring is 3.48. The background refractive index is unity. The inner radius, R0, and the outer radius, R1, of the ring are 4.33 μm and 4.53 μm, respectively. The inner radius, R2, and outer radius, R3, of the curved bus waveguide is 4.68 μm and 4.88 μm. The ring waveguide width, d1, and the bus waveguide width, d3, are both 0.2 μm. The gap, d2, between the ring and the bus waveguide is 0.15 μm. The light at the wavelength of 1550nm in the TM polarization is launched into the waveguide.

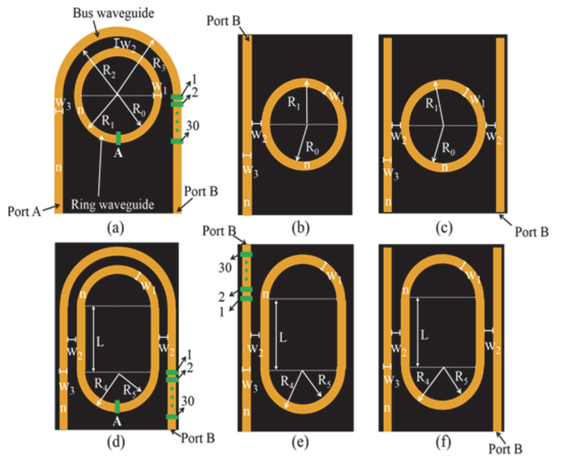

Figure 1: (a) Schematic drawing of the pulley-type microring resonator. (b)-(e) Schematic drawing of the various ring resonators.

Fig. 2(a) shows the bending loss per propagation distance of the single ring waveguide and the two concentric ring waveguides. The single ring waveguide with the central radius, Rc, defined as (R0+R1)/2 is schematically shown in Fig. 2(b). Fig. 2(c) illustrates the two concentric ring waveguides. The gap between two waveguides is 0.15 μm. The inner and outer waveguide widths are 0.2 μm and 0.23 μm, respectively. We launch an impulsed light in the ring and to obtain the bending loss per propagation distance of ring waveguide.

We can observe that the bending loss of the two concentric ring waveguides is lower than that of the single ring waveguide. This is due to the fact that the outer waveguide of the concentric ring waveguides can collect the light of the radiation loss of the inner waveguide. Since the light in the outer waveguide can be coupled back to the inner waveguide, the bending loss of the ring can be reduced.

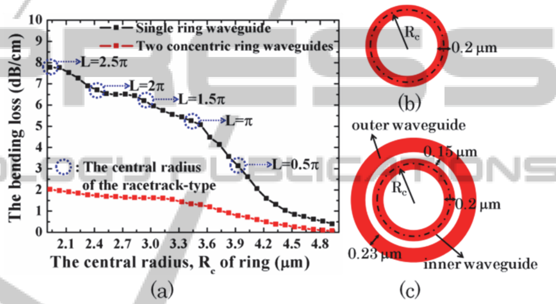

Figure 2: (a) Bending loss per propagation distance of single ring waveguide and two concentric ring waveguides for different Rc. (b) and (c) Schematic drawing of single ring waveguide and two concentric ring waveguides, respectively.

Table 2: Q-factors and Db for the 6 ring resonator structures illustrated in Figure 1.

Structure	Q-factor	Δβ
Fig. 1(a)	7×10^{5}	3.4372
	1.4×10^{3}	1.2103
Fig. 1(b)	1.24×10^{5}	10.2
	1.98×10^{4}	5.367
Fig. 1(c)	7.16×10^{4}	10.2
	9.06×10^{3}	5.367
Fig. 1(d)	3.6×10^{4}	4.465
		0
	5.8×10^{3}	1.355
		0.2418
Fig. 1(e)	2.83×10^{5}	9.6078
	5.86×10^{3}	0
Fig. 1(f)	1.79×10^{5}	9.7684
	3.6×10^{3}	0

3 FABRICATION AND CHARACTERISATION

We fabricate the pulley-type microring resonators by using the e-beam lithography. The SOI with the top silicon layer of 250 nm thick and the buried oxide layer of 3 μm thick is used. The sample is prebaked on the hotplate with 90 ºC during 1 minute. The E-beam writer, RAITH150-TWO, with the acceleration voltage 20 kV and the aperture size of 30 μm is employed to define the pattern of the pulley-type ring resonators. The ring waveguide width, the gap width, the bus waveguide width and the radius of ring are chosen to be 0.2, 0.15, 0.23 and 4.43 μm, respectively. The grating coupler is employed to couple the light into and out of the ring resonators with the optical fibers. The period of grating is 620 nm. The duty cycle of grating couplers is gradually varied from 13 % to 50 % with the step of 1.6 %. The taper segments with the length of 150 μm are used to connect the bus waveguide and the grating coupler. The developer (MF-319: TMAH=99%: 1%) is used to remove the unexposed photoresist during 20 seconds. After developing, the sample is rinsed by deionized water (DI water) during 20 seconds to remove the residual developer. Finally, the sample is dried by the N2 gas. Before etching, the sample is hard baked on the hotplate with 100 ºC during 10 minutes to firm the photoresist. The pattern of the pulley-type ring resonators and the grating couplers are transferred to the SOI wafer by the reactive-ion etching (RIE) with the power of 160 W, the working pressure of 80 mTorr, CF_4 (48 SCCM) (SCCM stands for cubic centimeter per minute at standard conditions for temperature and pressure) and CHF_3 (12 SCCM). The etching depth of device is around 150 nm. After the dry etching, the acetone (ACE) is used to remove the residual photoresist. The scanning electron micrograph (SEM) image of the pulley-type ring resonator, the grating coupler and the schematic structure of device are shown in Fig. 3.

To characterize the pulley-type ring resonator, the broadand amplified spontaneous emission (ASE) light source and the optical spectrum analyzer are employed.

The output power spectrum of the pulley-type microring resonator is shown in Fig. 4. The vertical axis is presented in dBm scale. The deepest notch is located at 1575.65 nm as the bus waveguide width is 0.23 μm. The Q-factor of 1.73×10^5 is obtained by employing the Lorentz curve fitting. The shift of the resonance wavelength between the design and the experimental result is around 9.69 nm due to the fabrication error. This work shows that by changing the bus waveguide width to achieve the critical coupling, the maximal energy of the traveling light at the resonance wavelength of 1575.65 nm stored in the ring resonator can be optimized. The measured Q-factor of 1.73×10^5 is lower than the theoretical Q-factor of 7×10^5. This is due to the fact that the roughness of the waveguide surface can scatter the traveling light out of the pulley-type ring resonator.

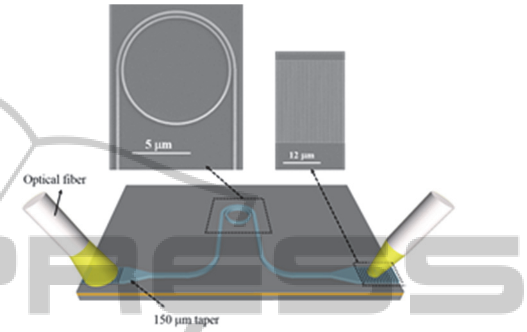

Figure 3: Schematic drawing of the characterisation setup including the SEM micrograph of the pulley-type ring resonator and the grating couplers.

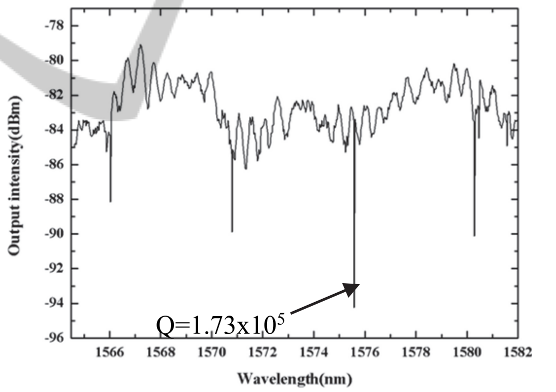

Figure 4: Measured spectrum of the pulley-type ring resonator.

4 DISCUSSION AND CONCLUSION

In Ref. (Hu et al., 2008); (Hosseini et al., 2010), the microdisk with the radius of 20μm is fabricated on the As_2S_3 platform. The Q-factors are 2.1×10^5 and 1.5×10^5 for the TM and TE modes, respectively. (Hu et al., 2008) The Si_3N_4 microdisk with the radius of 20μm is fabricated on the SiO_2 platform. The Q-factor characterized by the launched source in the TE mode is 6×10^5.(Hosseini et al., 2010) In our work, the radius is only 4.43μm. However, we can obtain the Q-factor with the same order of magnitude. Our result shows that the pulley-type ring resonator can be ameliorated by enlarging Δβ and shows the possibility to obtain the ring resonators with higher Q factor if the ring radius is enlarged or the sidewall roughness of the waveguides is improved.

In our previous work, we propose a fast method to calculate the coupling length of the concentrically curved waveguides using the conformal mapping. (Cai et al., 2012) Fig. 5 shows the schematic refractive index profile of the concentrically curved waveguides before and after conformal mapping. We can observe that the effective index of the outer waveguide is higher that of the inner waveguide. This implies that the propagation constant of the two curved waveguides is not inherently identical. In the case of the directional couplers with straight waveguides, the 100% energy coupling is not possible. However, in the case of the ring resonators, the critical coupling can be achieved due to the fact that the circumference of the ring the integer multiple of the resonant wavelength, even if the propagation constant of the concentrically curved waveguides is not identical. Therefore, the fine tuning of the outer concentrically curved waveguide width can achieve the critical coupling. Since the effective refractive index of the outer curved waveguide is higher than that of the inner waveguide, the radiation loss of the ring can be reduced due to the good optical confinement of the higher refractive index profile of the outer curved waveguide.

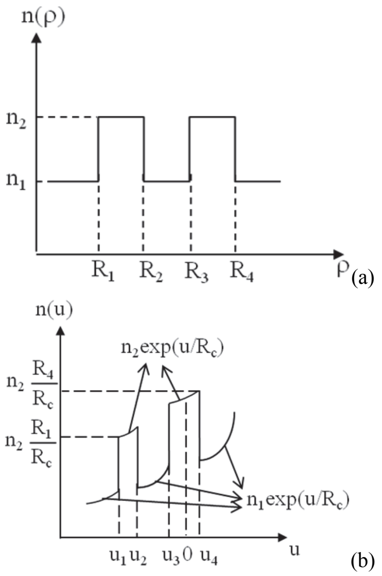

Figure 5: (a) Refractive index profile of two concentrically curved waveguides (b) Refractive index profile after conformal mapping.

In summary, the rigorous FDTD method has been employed to analyse the 6 types of ring resonators. Since the bending loss per propagation distance of the two concentrically curved waveguides is lower than that of the single curved waveguide, the pulley-type ring resonator can provide lower optical loss.

In this work, we fabricate the pulley-type ring resonator based on the SOI platform. The Q-factor of the pulley-type ring resonator is measured to be 1.73×10^5 as the bus waveguide width of 0.23 μm and the ring radius of 4.43 μm. The Q-factor might be ameliorated by smoothing the sidewall of waveguide. The high Q-factor of the pulley-type ring resonator with tiny radius is helpful for the miniaturization of the integrated optical devices.

REFERENCE

B. E. Little, S. T. Chu, H. A. Haus, J. Foresi, and J.-P. Laine, J. Lightwave Technol. 15, 998 (1997).

A. B. Matsko, A. A. Savchenkov, V. S. Ilchenko, and L. Maleki, Opt. Comm. 233, 107 (2004).

V. R. Almeida and M. Lipson, Opt. Lett. 30, 2733 (2005).

M. Terrel, Michel J. F. Digonnet, and S. Fan, "Performance comparison of slow-light coupled-resonator optical gyroscopes," Laser & Photon. Rev. 3,452 (2009).

M. S. Nawrocka, T. Liu, X. Wang, and R. R. Panepucci, "Tunable silicon microring resonator with wide free spectral rang," Appl. Phys. Lett. 89, 071110 (2006).

V. M. Menon, W. Tong, and S. R. Forrest, "Control of Quality Factor and Critical Coupling in Microring Resonators Through Integration of a Semiconductor Optical Amplifier," IEEE Photon. Technol. Lett. 16, 1343 (2004).

Joyce K. S. Poon, J. Scheuer, Y. Xu, and A. Yariv, "Designing coupled-resonator optical waveguide delay lines," J. Opt. Soc. Am. B 21, 1665 (2004).

J. Hu, N. Carlie, N. Feng, L. Petit, A. Agarwal, K. Richardson and L. Kimerling, "Planar waveguide-coupled, high-index-contrast, high-Q resonator in chalcogenide glass for sensing," Opt. Lett., 33, 2500 (2008)

E. S. Hosseini, S. Yegnanarayanan, A. H. Atabaki, M. Soltani and A. Adibi, "Systematic design and fabrication of high-Q single-mode pulley-coupled planar silicon nitride microdisk resonators at visible wavelength," Opt. Express, 18, 2127 (2010).

D. P. Cai, C. C. Chen, C. C. Lee, and T. D. Wang, "Study of Coupling Length of Concentrically Curved Waveguides," IEEE Photon. J. 4, 80 (2012).