Improving the dimensional tolerance of microrings with adiabatically widened bends

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Abstract: Silicon microrings with widened waveguides have higher dimensional tolerances than conventional designs with single-mode wire waveguides. We show microrings where the resonance wavelength shifts from waveguide width variations are reduced by a factor of 2.5.
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1. Introduction

Silicon-on-insulator (SOI) has emerged as a promising platform for integrated optics because of its compatibility with standard CMOS processes and for its large core-cladding refractive index contrast, which allows light to be confined to submicron dimensions and enables compact photonic circuits. However, the high index contrast also causes the optical properties of devices to become sensitive to nanometer-scale dimensional variations [1]. In a 248 nm or 193 nm photolithography fabrication process, dimensional variations can be tens of nanometers, which can result in a low yield if the high index contrast is to be fully exploited.

This problem is especially apparent in microring devices (e.g., modulators and filters), in which the transmission is sensitive to the losses, phase-shift, and coupling-coefficient(s) of the ring. For a single microring formed using single-mode SOI wire waveguides that are 500 nm wide and 220 nm tall (typical waveguide cross-sections), the resonance wavelength shifts by ~0.6 nm per 1 nm change in the waveguide width. Thus, given the dimensional variations in typical foundry processes, microring devices require tuning over one full free spectral range (FSR) to align a resonance to a desired wavelength. The tuning increases the power consumption of the device [2].

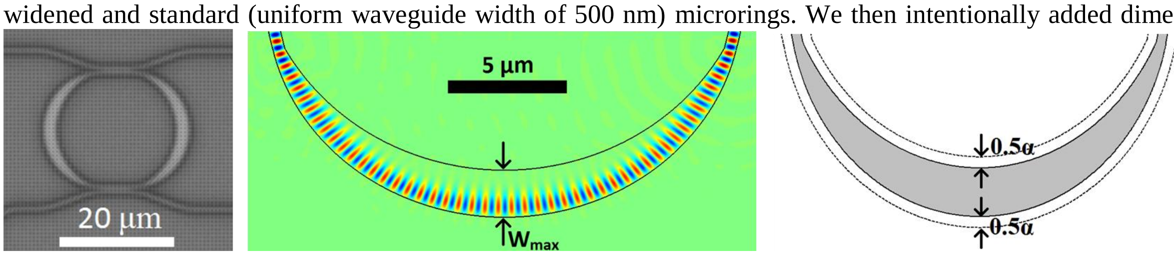
2. Device Design

To improve the dimensional tolerance, we propose to use wide, multi-mode waveguides in microrings. To excite only the fundamental mode, a strip waveguide mode is adiabatically transformed to the lowest order whispering gallery mode (WGM) of the wide section in the waveguide bend. The effective index of a WGM only depends on waveguide width through the bend radius, and can be 1 to 2 orders of magnitude less sensitive to width variations than a wire waveguide mode. Adiabatically widened microrings have been used for electrical contacts [3] but have not been investigated for dimensional tolerance.

Our design of a microring add-drop filter with widening bends is shown by the microscope image in Fig. 1(a). The width of the bend connecting the two couplers varies smoothly from 500 nm at the coupler to a maximum of W_{max}. The 3D FDTD simulation in Fig. 1(b) shows the optical mode is transformed from that of the wire waveguide at the coupler to the fundamental WGM and back. The widening bend is designed to be short while avoiding insertion losses and the excitation of higher order modes. For the experiments here, we use a circular outer wall with a 10 μm bend radius and a parabolically widening width with $W_{max} = 2.2$ μm. Our FDTD simulations show the insertion loss of the widening bend is < 0.02 dB at a wavelength of 1550 nm.

3. Fabricated Devices

To controllably test the feasibility of the widened bend approach, we designed a set of matching adiabatically widened and standard (uniform waveguide width of 500 nm) microrings. We then intentionally added dimensional



(a) (b) (c)

Fig. 1: (a) Optical microscope image of a fabricated widening microring in SOI with an oxide cladding. (b) 3D FDTD simulation of propagation through a widened bend of radius 10 μm and W_{max} of 2.2 μm (H_z component), showing the conversion to a WGM mode at the apex. (c) Schematic depicting the effect of a dimensional offset α. This offset is applied to every part of the device.

offsets, α, to the waveguide width in both types of micorings without altering the centerlines, as depicted in Fig. 1(c). α ranged from -20 nm to + 20 nm. The devices were fabricated on a single chip at the University of Washington Microfabrication Facility in SOI (220 nm thick Si, 3 µm thick BOX) using their standard electron-beam lithography process [4]. The silicon was fully etched and the fabricated devices were clad with a PECVD oxide. In a photolithographic process, a uniform change in the waveguide width would result from changes in the exposure conditions, resist, or placement of the chip relative to the focus [5].

4. Results

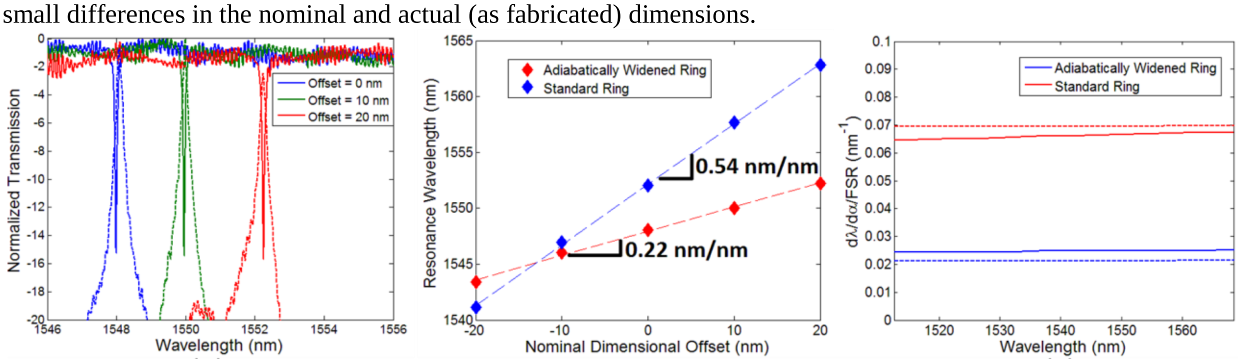
The properties of a set of microrings with an outer radius of 10 µm are summarized in Table 1. The resonance closest to a wavelength of 1550 nm is analyzed. The widened rings had a larger FSR than the standard ring because the WGMs are less dispersive than wire waveguide modes, leading to a reduced group index. The quality (Q) factors of the devices were similar. Despite the loss introduced by the transition to a WGM mode, the widened ring can have high Q-factors because a WGM only experiences scattering loss due to the roughness of one sidewall.

The through and drop ports spectra for the widened rings are shown in Fig. 2(a). Only offsets of α = 0 nm, 10 nm, and 20 nm are included for clarity. The lineshape of the widened microring was similar to the standard microring. At the through port, the extinction ratios (ERs) of the widened microrings were > 15 dB and were insensitive to α, while the ERs of the standard rings varied by several dB. At the drop port, the variations of the FWHM linewidths in the widened and standard rings were roughly identical within the experimental uncertainty. The spreads in linewidth appearing in both designs may be due to variations in the coupling coefficient and loss, since this variation was equally present in the widened and standard rings.

	λ_{res} (nm)	FSR (nm)	Loaded Q	ΔER (dB)	ΔFWHM (nm)	$d\lambda_{res}/d\alpha$ (nm/nm)	$d\lambda_{res}/d\alpha/FSR$ (nm^{-1})
Widened Ring	1548.1	8.7	10.0×10^3	-15 to -16	0.10 to 0.16	0.22	0.025
Standard Ring	1552.1	8.1	10.7×10^3	-13 to -16	0.13 to 0.17	0.54	0.067

Table 2: Comparison of resonator properties. The widened ring incorporates adiabatically widening bends, and the standard ring does not. Both devices use a coupling length of 4 µm and a coupling gap of 200 nm. ΔER and ΔFWHM are the spread of the ER at the through port and FWHM linewidth at the drop port over the range of α.

The sensitivity of resonant wavelength with dimensional offset, $d\lambda_{res}/d\alpha$, was found by a linear least-squares fit to the measured resonances [Fig. 2(b)]. The widened ring design reduces the resonance shift by a factor of about 2.5. Normalizing the resonance shift to the FSR, the widened ring was 2.6 times less sensitive to α than the standard ring. Fig. 2(c) shows $d\lambda_{res}/d\alpha/FSR$ is roughly constant over a broad wavelength range and that the experimental and our calculated values based on the round-trip phase ϕ_{RT} agree to within ~85%.The small discrepancy may be due to small differences in the nominal and actual (as fabricated) dimensions.



(a) (b) (c)

Figure 2: (a) Through (solid lines) and drop (dashed lines) port spectra for a widened ring for various nominally defined dimensional offsets. (b) Resonance wavelength shift as a function of the nominal dimensional offset. (c) The measured $d\lambda_{res}/d\alpha/FSR$ (solid lines) and analytic calculation based on $d\phi_{RT}/d\alpha/(2\pi)$ as a function of wavelength.

4. Conclusions

We have shown widened waveguides in microrings reduce the resonance wavelength shift due to waveguide width variations. The dimensional tolerance can be further improved using more tolerant couplers. Reducing the dimensional sensitivity improves the device yield and lowers the power consumption for post-fabrication tuning.

5. References

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