Reducing Mode-Transition Loss in Silicon-on-Insulator Strip Waveguide Bends

Hao Shen, Maroof H. Khan, Shijun Xiao and Minghao Qi *

Birck Nanotechnology Center, Purdue University, West Lafayette, IN 47906

The high-index-contrast in silicon-on-insulator (SOI) strip waveguides provides strong confinement of light and allows small bending radii [1]. Low propagation loss in straight waveguides [2], bends [2], and mircoring resonators [3] have been demonstrated. Waveguide bends with as small as possible bending loss and bending radius are highly desirable as they are indispensable for photonic integrated circuits (PIC) and the bending radius directly determines the integration density.

The total loss in bends includes both the radiation loss due to bending and mode-transition loss due to the mismatch in radius of curvatures between the bend section and straight section. A racetrack resonator (Fig. 1) can be viewed as two 180° degree bends and can be used to characterize the bending loss. Here we demonstrate a method to quantify and reduce such mode-transition loss in strip waveguide bends.

Fig.1 illustrates the fabricated racetrack resonator in an add-drop configuration. The fabrication procedure is documented in [3]. The waveguide width in both the racetrack and buses was set to 500nm. The bending radius was designed to be 4.5μm, in which case the radiation due to bending is very small [3]. The coupling gaps were 300nm at both sides. The gradual transition curve, shown in Fig. 1b and illustrated in Fig. 1c, is designed as a staircase. Nine straight waveguides, whose lengths linearly decrease from 100nm to 20nm, are arranged from left to right in Fig. 1c, and shifted downwards one by one at a 2nm step. The small minimum beam deflection step (2nm) of our electron beam lithography tool (Vistec VB6) allows such a fine gradual transition. The total length of the straight waveguide part, including the transition curve, is 1.6 μm (Fig. 1a). We also fabricated standard racetrack resonators, where the straight waveguide (1.6 μm in length) connects directly to the curved waveguide which has a bending radius of 4.5 μm. Except for the gradual transitions, these two racetracks have identical geometrical configurations and optical parameters. We also fabricated ring resonators of 5 μm radius, which yield a total perimeter that is the same as those of the racetracks. The ring resonator, having a uniform radius of curvature, does not suffer from mode-transition loss. Other parameters of the ring resonator are the same as those for the racetracks. For first order approximation, the difference in round trip losses among those resonators is a measure for the extra loss resulted from mode-transition loss.

The optical transmission spectra of the racetrack resonators with and without gradual transition curves are shown in Fig. 2a and 2b, respectively. Qualitatively, the higher extinction ratio, the lower loss in the drop port, as well as the narrower -3dB bandwidth in Fig. 2a all indicate a smaller propagation loss in the racetrack with gradual transition curves. Quantitatively, we use our recently proposed method [4] to calculate the optical propagation loss (or intrinsic Q value) in the resonators. This method is independent of the uncertainties form the fiber-to-waveguide coupling and cleaved waveguide facets. We first measured the microring resonators with 5μm radius on the same chip and get the

* corresponding author: Minghao Qi, 1205 W. State St, Rm 1297, West Lafayette, IN 47906
Email: *mqi@purdue.edu*

propagation loss due to scattering (*e.g.* from sidewall roughness) and radiation loss due to bending to be 0.012±0.0016 dB/round trip (3.7±0.5 dB/cm) at 1536nm. For the racetrack without gradual transition curves (Fig. 2b), the total propagation loss is 0.087±0.001 dB/round trip. As the perimeter of racetrack resonators were the same as that of the ring resonator with 5μm radius, they have roughly the same scattering loss due to roughness, and radiation loss due to bending. The additional loss is therefore caused by the mode-transition loss and calculated to be 0.076±0.002 dB/round trip or 0.019±0.0005 dB/transition (assuming 4 transitions/round trip). In the racetrack resonator with gradual transition curves (Fig. 2a), the mode transition loss is greatly reduced to 0.0046±0.0005 dB/transition. We note that the exact configuration for the gradual transition is not critical for the loss reduction. We tried different configurations and the results were similar.

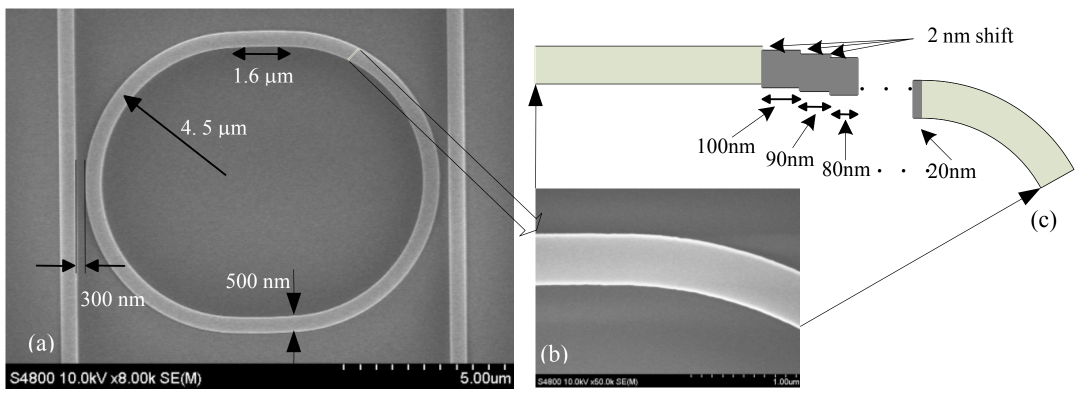

Fig.1. Scanning electron micrograph of the fabricated racetrack resonator with gradual transition between the straight waveguides and the curved ones (top view). (a) shows the geometry and (b) is the expanded view of the transition area. (c) illustrates the transition section that smoothly joins the curved and straight waveguides.

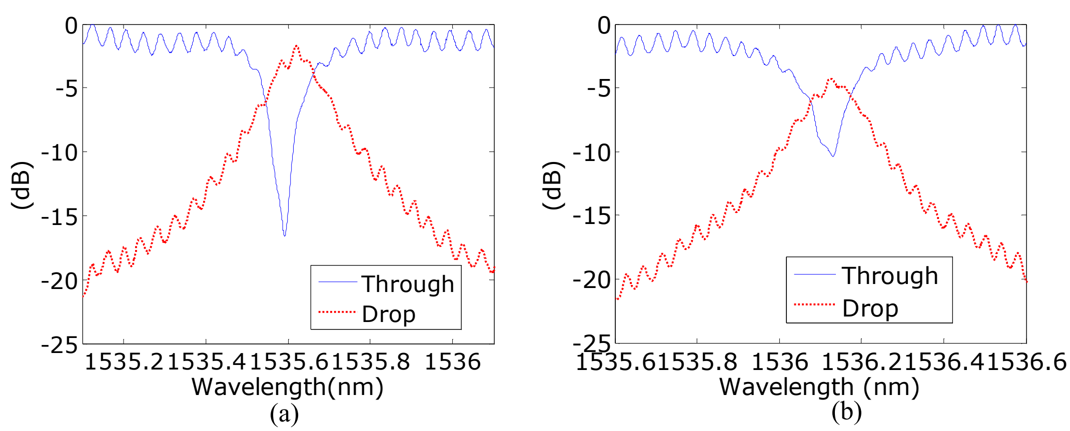

Fig.2: The comparison of one resonance peak of the racetrack resonator with (a) gradual transition curve and (b) direct connection between the straight and curved waveguides. The two racetracks otherwise have the same geometry and were fabricated on the same chip.

4. References

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