A single microring resonator for measuring waveguide losses

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Abstract: We present a compact, single microring resonator with a tunable coupler to measure waveguide losses. The method is demonstrated by extracting the propagation losses of 550 nm and 600 nm wide SOI rib waveguides.

Designing micro-ring resonators (MRRs) with certain bandwidths/quality factors for various applications such as quantum and nonlinear optics, telecommunications, analog signal processing, and biosensing applications requires knowledge of the waveguide propagation loss, α_{dB} (in dB/cm), *a priori* in the design process [1]. Methods to measure the propagation loss include the cut-back [2], direct camera imaging of the decay length [3], using a straight waveguide with air-terminated endfacets as a Fabry-Pérot interferometer [4], or using weakly-coupled MRRs [5, 6]. Among these methods, MRRs provide the largest propagation loss measurement range, are insensitive to fiber-chip coupling/alignment errors, and has the smallest footprint. However, since the MRR through-port transmission equation is invariant upon interchanging t (the coupler's lossless through transmission) and α (the combined loss in both the coupler and the MRR cavity, which includes α_{dB}) [7], additional methods are required to uniquely determine t and α [7]. Several methods to measure both parameters have been reported [1], however, they either require the use of expensive tools, consume large footprints, or make the measurements susceptible to fabrication errors. Here, we show how t and α can be separated using a single and compact MRR with a tunable coupler. We demonstrate the method by extracting the propagation losses of 550 nm and 600 nm silicon-on-insulator (SOI) wide rib waveguides.

Fig. 1(a) illustrates the mask layouts of the coupling-tunable MRR. This design preserves the compact, round MRR structure, thus minimizing mode mismatch losses that could otherwise have been introduced [5]. To tune the coupling to the MRR's cavity, a TiN heater is placed above the longer arm of the tunable coupler. The lengths of the tunable coupler arms are selected such that $L_1 = L_2 + \pi R$, where L_2 is the length of the shorter arm of the tunable coupler that is shared with the ring, and L_1 is the length of the longer arm. We use the same arc radius, R, for each curved section of the tunable coupler's longer arm, and θ was calculated accordingly. To approximate a straight waveguide, while maintaining a compact footprint, we simulated the waveguide cross-section shown in Fig. 1(b) in Lumerical MODE solutions to get the radiation loss as function of the MRR radius, for $W = 550$ nm and 600 nm (see Fig. 1(b)). Setting $R = 20\,\mu$m results in negligible radiation loss ($\ll 10^{-4}$ dB/cm). The coupling-

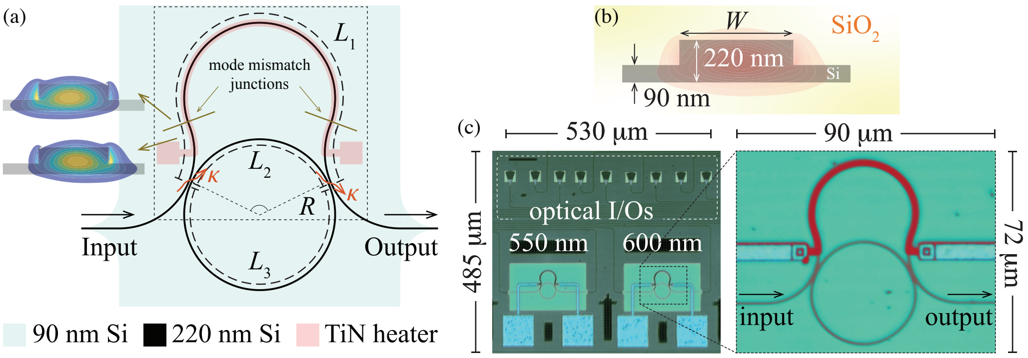
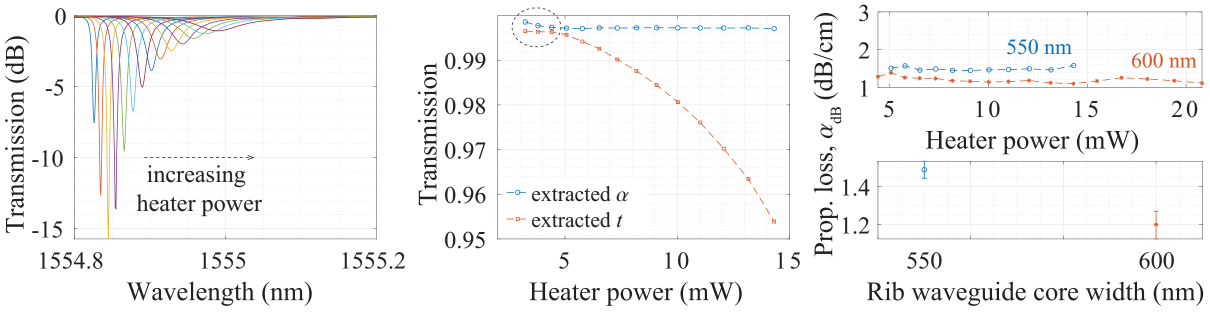


Fig. 1: (a) Schematic of the coupling-tunable MRR with the design parameters indicated; the junctions at which the oppositely rotating arcs meet is also indicated. (b) Cross-section of the MRR's rib waveguide formed with a 90 nm-thick slab in 220 nm-thick Si waveguide core. (c) Optical microgragh of the fabricated coupling-tunable MRRs. The inset shows a zoomed-in view of a single device.



(a) (b) (c)

Fig. 2: (a) The through-port optical spectrum of the coupling-tunable MRR with $W = 550$ nm at various heater bias. (b) The extracted t and α (from Fig. 2(a)) using the method described in [7]. t and α are interchanged when the MRR is under-coupled (indicated by a dotted circle). (c) Top plot: extracted α_{dB} (using Eq. (1)) across heater powers for each MRR. Bottom plot: the averaged losses (indicated with markers) and the $\pm\sigma$ (indicated with bars) of the propagation loss measurements for the various heater powers, for each waveguide rib width.

tunable MRRs were fabricated at the A*STAR IME foundry in Singapore, using 193 nm-deep UV lithography. An optical micrograph is shown in Fig. 1(c).

To measure α_{dB}, first, the heater is biased at various values using a source-measuring unit (Keithley 2602B), which tunes the power coupling to the MRR's cavity. The MRR through-port transmission spectrum is then measured using a tunable laser (HP 81682A) and a photodetector (HP 81635A) (as shown in Fig. 2(a) for the resonances around 1550 nm wavelength, of the MRR with $W = 550$ nm), and from each optical spectrum, t and α are extracted according to the method described in [7] (as shown in Fig. 2(b)). This method can be applied to the device presented here if the point couplers are designed with very small power coupling coefficients ($\kappa^2 < 0.1$, which, results in < 0.1 dB/cm error in the extracted α_{dB}). Thus, in our design, we selected point coupler gaps of 200 nm for both MRRs, which using 3D-FDTD simulations, resulted in $\kappa^2 = 0.088$ and 0.056 for the MRRs with $W = 550$ nm and 600 nm, respectively. Because the method described in [7] does not uniquely determine α and t, we assign α to be the larger value among the two solutions given by Equation (25) in [7], which results in an interchange between α and t when the MRR is under-coupled. We thus interchange α and t when the MRR is under-coupled (indicated by the dotted circle in Fig. 2(b)). α_{dB} can then be obtained by solving,

$$\alpha^2 = 10^{-(3\pi R\alpha_{dB}+2\alpha_m)/10}\kappa^2 + 10^{-\pi R\alpha_{dB}/5}(1-\kappa^2), \tag{1}$$

where α_m is the mode-mismatch loss (in dB) due to the two opposing bend orientations forming the longer arm of the tunable coupler (see Fig. 1(a)). α_m is calculated using the overlap integral of the two oppositely propagating bent mode TE-field patterns (simulated using the FDE solver in Lumerical MODE), where $\alpha_m = 0.027$ dB and 0.031 dB for the MRRs with $W = 550$ nm and 600 nm, respectively, at 1550 nm wavelength. We then use the simulated κ^2 and α_m and solve Eq. (1) to calculate α_{dB} at each heater bias. The results are shown in Fig. 2(c) (top plot), and the averaged losses are 1.49 ± 0.04 and 1.20 ± 0.07 dB/cm for $W = 550$ nm and 600 nm, respectively, as shown in Fig. 2(c) (bottom plot). The error bars in Fig. 2(c) (bottom plot) indicate the $\pm\sigma$ (standard deviation) of the propagation loss measurements at the various heater powers.

We have proposed a compact solution to measure the propagation loss in optical waveguides and implemented it to measure the propagation losses of SOI rib waveguides with 550 nm and 600 nm rib widths. The method developed here is tolerant to fiber-chip coupling/alignment errors and can measure on-chip dB scale losses. Compared to prior arts, this device has a small footprint, which makes it easy to be incorporated as a general calibration device for photonic integrated circuits.

References

1. W. Bogaerts, et al., Laser & Photonics Rev. **6**, 47–73 (2012).
2. P. K. Tien, Appl. optics **10**, 2395–2413 (1971).
3. P. T. Rakich, Ph.D. thesis, Massachusetts Institute of Technology (2006).
4. R. Walker and R. Goodfellow, Electron. Lett. **19**, 590–592 (1983).
5. M. Popović, Ph.D. thesis, Massachusetts Institute of Technology (2008).
6. H. Shoman, et al., Opt. Express **27**, 26661–26675 (2019).
7. W. McKinnon, et al., Opt. express **17**, 18971–18982 (2009).