Ultra-high Q and finesse all-pass microring resonators on Silicon-on-Insulator using rib waveguides

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***Abstract*— Low-loss rib waveguides on Silicon-on-Insulator are used to demonstrate ultra high-Q and finesse all-pass microring resonators with record finesse of 1100 and Q of 613000.**

Key words— Microring resonators, Silicon-on-Insulator (SOI)

I. Introduction

Microring resonators are considered to be key components for integrated photonics, especially in high-index contrast platforms such as Silicon-on-Insulator (SOI). Many promising applications have been demonstrated on this high-yield high-volume platform ranging from data communications, optical interconnects, bio-sensing and non-linear applications [1]. Each application has their own specifications with respect to the coupling between the mircoring and the bus waveguide, but in general one needs a low-loss cavity and thus low-loss waveguides. Although low-loss (~2dB/cm) [1] deep-etched waveguides on SOI using the quasi-TE mode with negligible bending loss for radii up to 5µm [ref] have been demonstrated, the performance of microring resonators is limited by resonance-splitting induced by backscattering [1]. The origin of backscattering can be found in the vertical sidewall roughness of the waveguide. By using the quasi-TM mode which has less overlap with the vertical sidewall roughness the backscattering can be significantly reduced. Another approach to minimize the overlap of the quasi-TE mode with this vertical sidewall roughness is to optimize the waveguide dimensions [2] or use partially etched rib waveguides the waveguides [3]. In this paper, these rib waveguides are optimized and result in lower scattering as well as low bending loss. We demonstrate critically coupled microring resonators with loaded Q factors of 613000 and a finesse of 1100 which is approximately a twofold improvement over previous reported results [4].

II. Design and fabrication

Our design is based on a SOI platform exhibiting a 220nm silicon device layer on a 2µm thick buried oxide layer. We choose a shallow etch step of 70nm. The waveguide width is next to the etch depth, an important design parameter to minimize the bending loss. This loss can be simulated using a 2D mode solver (e.g. Fimmwave Photon Design, UK). As expected a smaller bending loss for a wider waveguide, as a result of the better confinement is found. Simulations reveal that for a radius of 25µm the quasi-TE mode the bending loss of 500nm, 600nm and 700nm wide waveguide is respectively 17.3, 3.1 and 0.81dB/cm. The quasi-TM mode is not supported in these rib waveguides. To compare the bending losses for the different waveguide widths, microring resonators with a radius of 25µm and 50µm were fabricated. Using fiber grating couplers, TE-polarized light is coupled into this all-pass microring resonator.

III. Experiments and results

The performance of microring resonators is commonly expressed as the intrinsic Q (Q_i) which represents the number of oscillations of the field before the circulating energy is depleted to 1/e of the initial energy and thus represents the losses in the cavity using (1) with n_g the groups index of the mode.

$$\alpha\left[\frac{dB}{cm}\right] = \frac{4.3*2\pi n_g}{\lambda[cm]Q_i} \tag{1}$$

The 3dB bandwidth of a single resonance is then broadened by the coupling towards the ring, expressed in terms of the loaded Q (Q_l) and the Q of the coupling towards the ring (Q_c).

$$\frac{1}{Q_l} = \frac{1}{Q_i} + \frac{1}{Q_c} \tag{2}$$

For large gaps or low coupling towards the microring Q_l evolves into the intrinsic Q_i. This behavior is shown in Fig.1, where the mean Q_l of all resonances in a wavelength range from 1520nm to 1560nm per ring is plotted for varying gap and this for rings with a fixed waveguide width of 500nm, 600nm and 700nm and a radius of 25µm and 50µm respectively. From this figure one can see that for the small waveguide width of 500nm and the smallest radius of 25µm, the Q is converging to a poor Q_i of 50000. For a radius of 50µm, this Q drastically increases to 500000 indicating that the bending loss was indeed the limiting factor for Q which agrees with the trend of the bending loss simulations. The Q of microring resonators with a waveguide width of 600nm with a radius of 50µm is approximately the double than the ones of 25µm which shows that even for this waveguide width the bend loss is not negligible. For a width of 700nm, this difference between the two radii becomes smaller showing that the bend loss is significantly reduced.

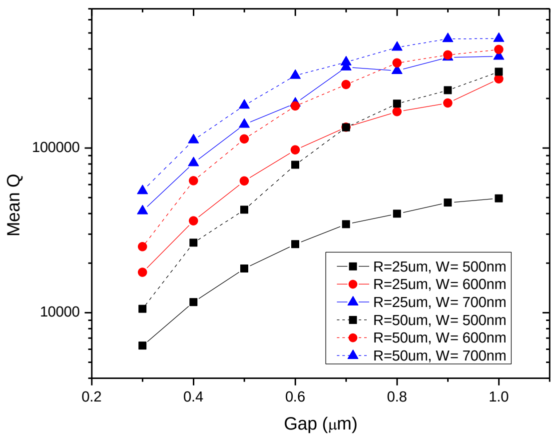

Figure 1: The mean Q_l over all resonances per ring between 1520nm and 1560nm as a function of gap for varying waveguide width (W) and radius (R).

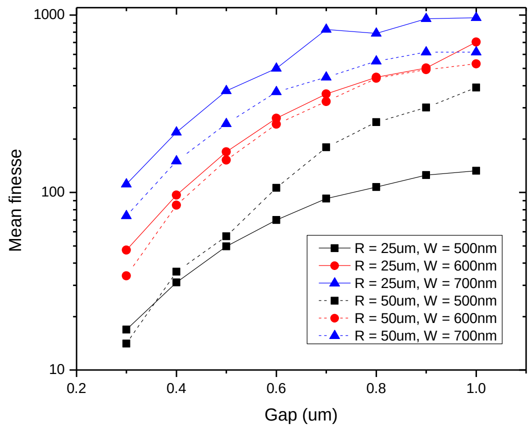

Figure 2: The mean finesse over all resonances per ring between 1520nm and 1560nm in function of gap for varying waveguide width (W) and radius (R).

In a next experiment the finesses of the different rings are compared. The finesse is defined as the Q divided by the free-spectral-range and is a measure for the round trip loss. Its mean value over all resonances per microring is plotted in Fig. 2 for the same varying set of parameters. For a microring with 700nm waveguide width, the finesse for a radius of 50µm is indeed the half of the finesse for a 25µm radius indicating that the waveguide loss is equal for both bending radii or consequently that the bending loss is negligible. For the smaller waveguide widths of 500nm and 600nm, the finesse for the larger bending radius is respectively larger and equal than the smaller bending radius indicating a decreasing bending loss for increasing waveguide width. When the coupling becomes large, such as in the case with waveguide width 500nm and small gaps (<0.5µm) the coupling factor is too large and hiding an effect of Q_i following (2).

Due to the ultra-high Q that reaches easily >100000, any small portion of backscattering results in resonance splitting (±10pm) and degrades the performance. Since this backscattering process is wavelength dependent, some peaks are not affected and show very good performances for either a high Q or finesse in the critically coupled regime such as plotted in Fig. 3. Ring 1 is a microring resonator with waveguide width of 0.7µm, radius of 25µm and gap 0.7µm demonstrating a Q of 417000, an ultra-high finesse of 1100 and an extinction ratio of 17dB. This record finesse enables a whole new set of applications. For example, the enormous finesse, a measure of the Purcell factor, could significantly reduce the threshold in Raman lasers. Other examples include ultra-dense WDM applications, sensing and delay lines.

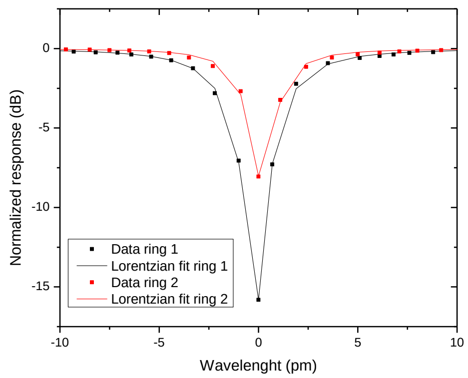

Figure 3: Illustration of two critically coupled microring resonators with a Lorentzian fit. Ring 1: R=25µm, gap=0.7µm, width=0.7µm, around 1550nm. Ring 2: R=50µm, gap=0.7µm, width=0.7µm, around 1530nm.

IV. CONCLUSIONS AND OUTLOOK

Low-loss rib waveguides on Silicon-on-Insulator are optimized and used to demonstrate all-pass microring resonators with a record finesse of 1100 and Q of 613000. This record finesse could enable a whole new set of applications such as reduced threshold in Raman lasers, ultra-dense WDM applications, sensing and delay lines.

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