High quality optical microring resonators in Si_3N_4/SiO_2

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Abstract. *We have experimentally demonstrated high Q-factors strip waveguide resonators using the Si_3N_4/SiO_2 material platform at the wavelength of 1.31µm. The analyzed filters demonstrate high quality factors reaching 133,000. The dependence on resonator radii and coupling gap is also discussed.*

Introduction

The usefulness of integrated microring resonators has been demonstrated in numerous applications, including optical signal filtering [1], switching [2] and modulation [3], as well as biological and environmental sensing [4]. Usually silicon on insulator (SOI) is an attractive platform to make such photonic structures, featuring high index contrast ($\Delta n \approx 2$) between silicon and its oxide and therefore further leading to high integration and possible miniaturization of the photonic devices. However, the high optical index contrast makes the device highly sensitive to fabrication imperfections (e.g. sidewall roughness) [5]. The use of silicon nitride (Si_3N_4) instead of silicon permits reducing index contrast to $\Delta n \approx 0.5$, offering a higher tolerance to fabrication imperfections, while maintaining low cost and a reasonable level of integration [6].

In this paper we analyze silicon nitride microring resonators based on strip waveguides. According to the experimental results, the influence of ring resonator radius as well as the coupling gap is analyzed. Finally the high quality factor of the resonator is shown.

Design of the optical filters

The simplest topology of an optical filter based on a microring resonator is composed of a bus waveguide evanescently coupled to a single ring resonator presented in Fig.1.

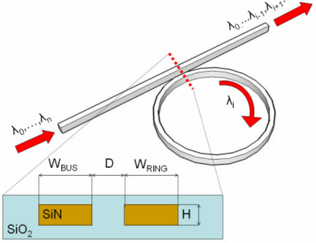


Fig.1. Schematic view of the wavelength selective filter with single bus waveguide side-coupled to the ring resonator

In the presented configuration, the device acts as a wavelength selective stop-band filter, where the resonant wavelengths are dropped to the resonator and do not propagate within the bus waveguide.

The considered geometry of the strip waveguide is the following: height H=300 nm, $W_{bus}=W_{ring}$=900 nm. The D gap ranges between 400 and 700 nm and the ring radius ranges between 80 and 120 nm.

Fig. 2 presents simulations of the fundamental mode profile of Si_3N_4 strip waveguide. The obtained effective index of a fundamental mode is equal to 1.59 and the group index of the mode equal to 1.913.

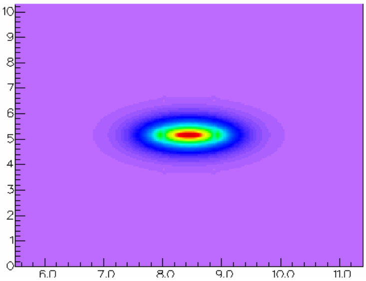


Fig.2: Simulation of a Si_3N_4 strip waveguide TE electrical field profile obtained at the wavelength of 1.31µm

Fabrication of experimental structures

A 3.3 µm thick silicon dioxide bottom cladding was grown on a silicon substrate by wet thermal oxidation at 1100°C. The 300 nm thick silicon nitride core layer was then deposited by LPCVD at 800°C from NH_3 and SiH_2Cl_2 precursors. A hard mask was patterned by electron beam lithography of PMMA, followed by a chromium evaporation and lift-off. The waveguide pattern was then transferred to the core layer by dry etching in a He/CF_4 plasma. Finally, the guides were covered by a 530 nm silicon dioxide top cladding by TEOS LPCVD at 720°C.

Fig.3 shows the SEM micrograph of the coupling section between the bus waveguide and the microring resonator.

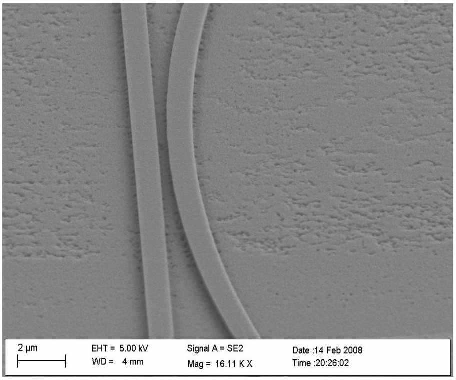


Fig.3. SEM micrograph of coupling section between a bus waveguide and a microring resonator

Experimental validation of test structures

The transmission spectra of fabricated test structures have been experimentally investigated by means of a micrometric optical setup and a tunable laser source.

Fig.4 shows the transmission spectrum of a strip waveguide microring resonator of radius R=90 µm and gap D=700 nm.

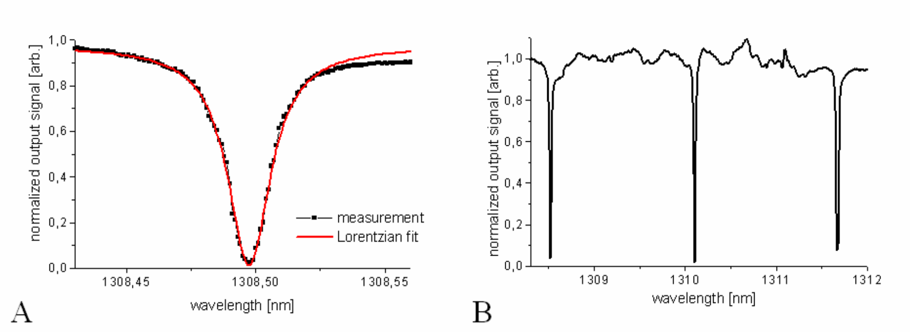


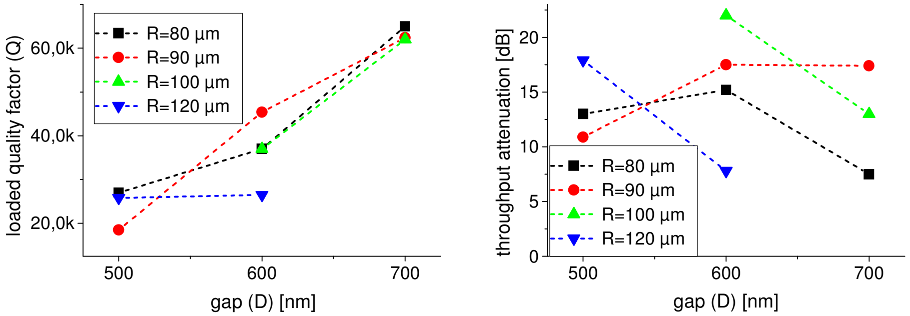
Fig.4. Transmission spectrum of a wavelength selective filter based on Si_3N_4 ring resonator. a) close-up on the resonant peak, b) the free spectral range of the filter

The normalized transmitted power has been measured in the wavelength range 1308.400–1305.570 nm with a step of 1 pm, so as to resolve the extremely narrow resonance peak of the filter (Fig.5a). The peak shows a resonance wavelength of 1308.497nm ± 10^{-3}nm and a full width at half maximum (FWHM) of 17pm, corresponding to a loaded (measured) quality factor (Q) of 77,000 and the intrinsic quality (Q_i) of 133,000. The extinction ratio reaches 15.9 dB. The free spectral range (FSR) of the filter has also been characterized experimentally by enlarging the wavelength range of the measurement to 1308.25–1312.00 nm with a step of 10pm (Fig.5b). Three resonant peaks are observed at 1308.50 nm, 1310.07 nm and 1311.68 nm, respectively, giving an average FSR of 1.59 nm ± 0.01 nm. These measurement results allow calculating the effective group index of the strip waveguide resonator mode that is equal to 1.91 that is in good agreement with the theoretical investigations.

Fig.5 depicts dependence of measured filter parameters on resonator radii and coupling gap between bus waveguide and microring.

In the case of resonators with radius between 80 µm and 100 µm, the loaded quality factor strongly depends on the coupling gap between resonator and bus waveguide. Indeed for the gaps ranging between 500 nm and 700 nm, the quality increases with the gap increment reaching more than 60000. It can be explained with lower coupling losses. In the case of the resonators with 120 µm radius, the quality does not exceed 30000 and only slightly depends on coupling gap. This could be explained by dominating propagation losses being the limitation of quality factor. In contrary for the resonators of radii between 80 µm and 90 µm bending losses dominates as the quality increases with radius increment.

A similar observation can be made when the throughput attenuation of the filters is analyzed. In the case of resonators with radii varying from 80 up to 100 µm it reaches the highest value (exceeding 15dB) for the coupling gap of 600 nm. In the case of the resonator with 120 µm, where coupling is weaker due to more open bend the highest attenuation is obtained for the smallest analyzed gap of 500 nm.



a) b)

Fig.5. Comparison of the loaded quality factor (a) and throughput attenuation (b), for filters with different resonator radii and coupling gaps

Conclusion

We have demonstrated wavelength selective filters with high quality factors from microring resonators based on silicon nitride strip (Q_i=133,000) waveguides. We discussed the influence of the filter parameters such as resonator radius and coupling gap on the quality factor of the filters.

Acknowledgments

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