Low Power Thermal Tuning of Second-order Microring Resonators

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Abstract: Efficient thermal tuning of 36pm/K and 60μW/GHz is shown for high-index-contrast silicon nitride second-order filters. Their compact size, large free-spectral range, low tuning power, and silicon compatibility make these resonators attractive for photonic integration.

OCIS codes: (230.5750) Resonators; (120.6810) Thermal effects

Microring resonators can be used as tunable filters, wavelength switches, add-drop multiplexers, converters and modulators [1-3]. Most photonic applications require resonators with large free-spectral range (FSR) and low loss. Thus, requiring rings to be fabricated with high-index-contrast material. Silicon as well as silicon nitride (SiN) optical waveguides are becoming integral components for optical systems because of the advantages of high-index contrast and compatibility with silicon integrated circuits (IC) [3].

Thermal tuning has been reported for various ring resonator structures. Polymers have very low thermal conductivity and high thermo-optic coefficients, thus thermo-optic tuning of polymer rings is very efficient. InP/InGaAsP microrings fabricated with waferbonding using polymer (BCB) has been tuned with power consumption of 26μW/GHz [4]. Microrings made of polyimide are tuned with 50μW/GHz showing total tuning range of 9.4nm [5]. However, microrings made of materials compatible with CMOS processing are preferred. A single SiN ring has been reported with a tuning range of 20pm/K and tuning power of 400μW/GHz [6]. Here we show efficient thermal tuning for SiN second-order filters using tuning power of 60μW/GHz. This is the first report of low power efficient thermal tuning for a high-order microring resonator.

Second-order filters are fabricated with silicon-rich silicon nitride (n = 2.2) cores and silicon oxide (SiO_2) as a lower cladding and hydrogen silsequioxane (HSQ) as the upper and side cladding. Both the lower and upper claddings have comparable refractive indices of nearly 1.45 at 1.55μm. Hence, single-mode waveguides have submicron dimensions. HSQ was chosen as the upper cladding because of its gap filling property which was needed to fill in the high aspect-ratio gap between the ring and laterally coupled bus waveguide.

The ring diameter of 16μm (Fig. 1), with group index of 2.3, gives a large FSR of 20nm. The rings are fabricated with 3dB bandwidth of 50GHz. Low drop loss (1.5dB) has been obtained for the ring resonator. Fabrication and design details for the resonator are described in Ref. [7]. The resonant wavelength is tuned via the temperature dependence of the refractive index of the waveguide. The thermo-optic coefficient ($\Delta n/\Delta T$) is temperature as well as wavelength dependent. At 1.55 μm, the thermo-optic coefficients for SiN and SiO_2 are 4e-5 K^{-1} and 1.5e-5 K^{-1} respectively. From equation 1, the theoretical tuning range for the waveguide is calculated to be 27pm/K.

$$\frac{\Delta\lambda}{\Delta T} = \frac{\lambda_o}{n_{group}}\left(\frac{\Delta n_{eff}}{\Delta T}\right) = \frac{\lambda_o}{n_{group}}\left(\frac{\Delta n_{eff}}{\Delta n_{core}}\frac{\Delta n_{core}}{\Delta T} + \frac{\Delta n_{eff}}{\Delta n_{clad}}\frac{\Delta n_{clad}}{\Delta T}\right) \qquad (1)$$

Optimized thin film metal heaters (100nm) are fabricated on top of the cladding to locally change the temperature of the resonator. One of the key parameters under consideration in the design of the heaters is the power dissipation per GHz of tuning. Finite-element thermal simulation (FEMLAB) gives the temperature profile for the filter with chromium heaters on top showing approximately one dimensional heat flow with very low thermal cross-talk. The upper cladding of 1.5μm ensures optical isolation of the resonator from local heaters on top. Simulations show long heaters with high thermal impedance are appropriate in order to minimize power dissipation for thermal tuning. Fig. 2 shows three different heater designs with various resistance and tuning power. The total tuning power for the finalized heater design is 60μW/GHz with a tuning range of 150GHz for 40K change in the ring temperature.

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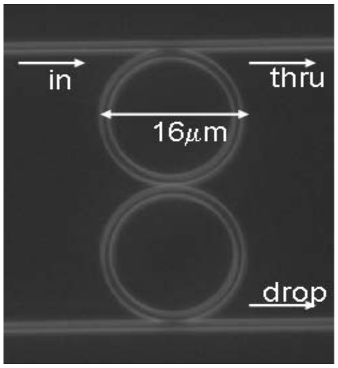

Fig. 1. Top view of the second-order filter.

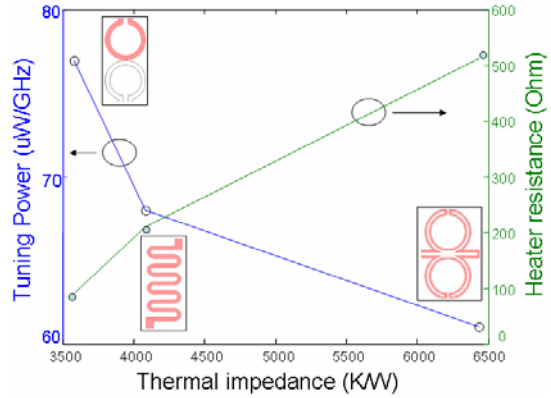

Fig. 2. Heater designs with different thermal impedance and tuning power.

To confirm the tuner designs before cladding deposition, we performed initial measurements on second-order filters with air as the upper cladding using external heaters. The change in center wavelength (Fig. 2) is approximately 36pm/K. Due to slight variation in the group index of the waveguide with air cladding as compared to the HSQ cladding, the experimental tuning range is different from the theoretical value.

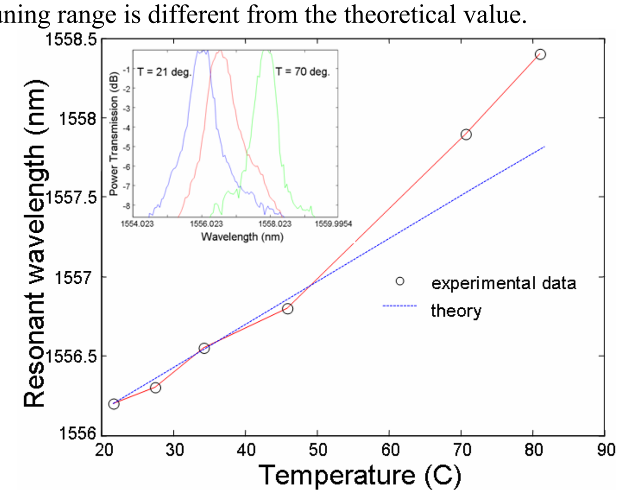

Fig. 2. Thermal tuning for the second-order filter is observed by changing temperature of the rings. Total shift of 2.2nm is seen due to heating the rings from 21°C - 81°C. Inset shows the drop port spectra.

The 3ω technique, as explained in Ref. [8], has been used to validate the thermal impedance of the heater structures. In this work, we present thermal tuning for post fabrication trimming of high-index-contrast microring resonators for stable and precise resonant frequency control. A large tuning coefficient of 36pm/K is achieved for small area SiN rings with large free-spectral range. Tuning powers approaching the best polymer microring devices can be realized with optimized heater designs on SiN microrings.

References:

[1] M. Nawrocka, T. Liu, X. Wang, "Tunable silicon microring resonator with wide free spectral range", *Applied Physics Letters*, 89 (2006).

[2] R. A. Soref, "Silicon-Based Optoelectronics", *Proc. of the IEEE*, Vol. 81, No. 12, Dec (1993).

[3] B. E. Little, "Advances in Microring Resonators", Invited Talk, *Integrated Photonics Research Conference*, 2003.

[4] I. Christiaens, D. Van Thourhout, R. Baets, "Low-power thermo-optic tuning of vertically coupled microring resonators", *Electronics Letters*, Vol. 40, No. 9, April (2004).

[5] Y. Kokubun, "Wavelength Selective Integrated Device by Vertically Coupled Microring Resonator Filter", *IPAP Books* 2, (2005) pp. 303-316.

[6] D.H. Geuzebroek, E.J. Klein, H. Kelderman, F. S. Tan, D.J.W. Klunder, A. Driessen, "Thermally Tunable, Wide FSR Switch based on Micro-ring Resonators", *Proceedings Symposium IEEE/LEOS Benelux Chapter*, (2002) Amsterdam

[7] T. Barwicz, M.A. Popović, P.T. Rakich, M.R. Watts, H.A. Haus, E.P. Ippen, H.I. Smith, "Microring-resonator-based add-drop filters in SiN: fabrication and analysis", *Optics Express*, Vol. 12, No. 7 (2004).

[8] D.G. Cahill, H.E. Fischer, T. Klitsner, E.T. Swartz, R.O. Pohl, "Thermal conductivity of thin films: Measurements and understanding", *J. Vac. Sci. Technol.* Vol. A 7, No. 3, May/June (1989).