Adiabatic Resonant Microrings (ARMs) with Directly Integrated Thermal Microphotonics

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Abstract: A new class of microphotonic-resonators, Adiabatic Resonant Microrings (ARMs), is introduced. The ARM resonator geometry enables heater elements to be formed within the resonator, simultaneously enabling record low-power (4.4μW/GHz) and record high-speed (1μs) thermal tuning.

OCIS codes: (130.3120) Integrated optics devices; (230.5750) Resonators; (230.7370) Waveguides.

1. Introduction

Microring-resonator based filters and modulators have been proposed for communications within high performance computers with particular emphasis on reducing interconnect power consumption [1]. Recent demonstrations of ultralow power microphotonic modulators have exhibited power consumptions as low as 85fJ/bit (or 0.85mW) [2]. To overcome the large temperature variations induced by processor cores turning on-and-off, thermal control of the microring-modulators and filters is likely required. Optimized over-clad-style heaters have achieved 28μW/GHz tuning with a 6.4μs time constant [3]. Even with optimized over-clad-style heaters, in a processor with as little as ±10°C variation, the thermal control requirements for a microring exceed 5mW, dwarfing the power consumption of the modulator itself. In other applications, such as reconfigurable networks, rapid tuning is required. Therefore, it is desirable to simultaneously minimize power consumption while increasing tuning speed, two parameters generally at odds.

Here, we introduce a new resonator class, Adiabatic Resonant Microrings (ARMs), which enable contact to a microring-resonator without inducing radiation. In the thermal control application, ARMs enable heaters directly integrated within the resonator, thereby minimizing the heat capacity of the system, simultaneously enabling record low power (4.4μW/GHz) and record high-speed (τ = 1μs) thermal tuning.

2. Numerical Analysis

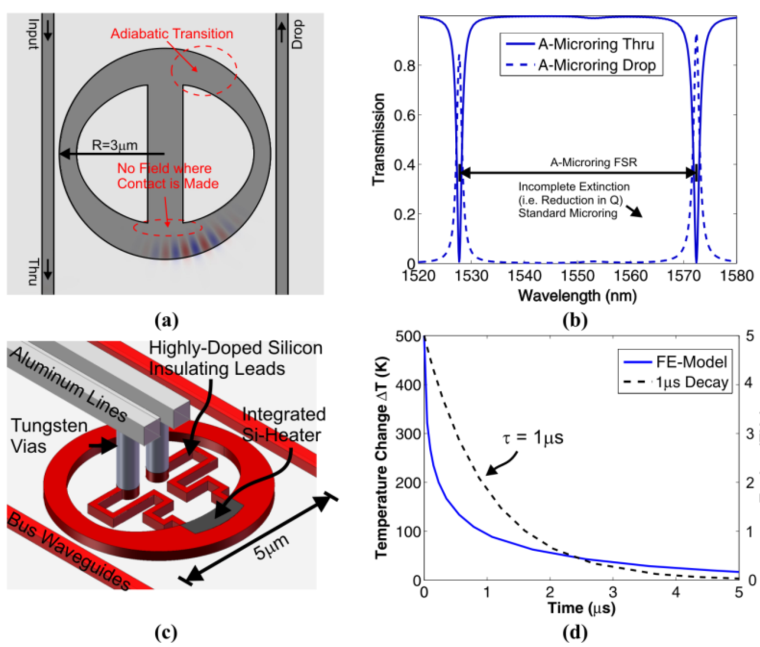

Figure 1 – (a) FD-TD simulation of an ARM-resonator, (b) spectrum response of the ARM-resonator from the FD-TD simulation demonstrating a large, uncorrupted FSR, (c) diagram of an ARM-resonator with integrated heaters, and (d) finite-element model of the temperature of the ARM-resonator as the heater is turned-off indicating a sub-1μs thermal time constant and 5μW/GHz tuning.

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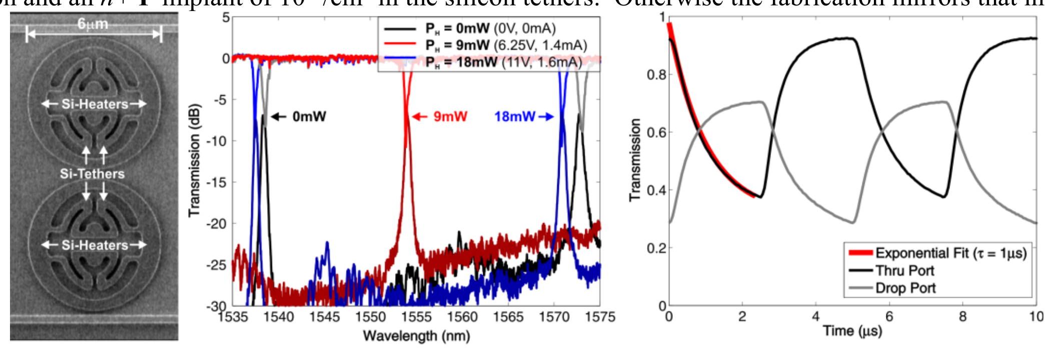
An Adiabatic Resonant Microring (ARM) is a microring-resonator for which the width of the microring waveguide is kept single-mode where the resonator is coupled to an external bus but is then widened adiabatically prior to making an interior contact for electrical or mechanical purposes. Maintaining single-mode operation in the coupling region ensures higher-order modes are suppressed. Widening the waveguide prior to electrical contact enables contact to be made where no electromagnetic field is present enabling nearly lossless (i.e. radiation-free) contact to the resonator as illustrated by the Finite-Difference Time-Domain (FD-TD) simulation of the ARM-resonator in Fig. 1a. FD-TD simulations, demonstrate that high-Q ($Q>10^5$) ARM resonators can be achieved in silicon with outer diameters as small as 4μm with a large, uncorrupted, Free-Spectral-Range (FSR) (Fig 1b).

To enable rapid ultralow power thermal tuning of an ARM-resonator, heaters can be introduced directly into the ARM-resonator by doping the widened waveguide portion of the resonator waveguide and then contacting the heater element with narrow silicon waveguide tethers (Fig. 1c). The narrow, winding, silicon tethers serve to thermally insulate the ARM-resonator from the highly thermally conductive tungsten vias. Finite element thermal models indicate that in a 5μm outer diameter ARM-resonator, sub-1μs thermal time constants can be achieved with a tuning power consumption of only 5μW/GHz (Fig. 1d).

3. Experimental Results

Second order 6μm diameter Adiabatic Resonant Microrings (ARMs) filters were fabricated with directly integrated heating elements in the geometry shown in the micrograph in Fig. 2a. The resonators were formed from an SOI wafer with an **As** implant to achieve an *n*-type doping level of $2\times10^{18}/cm^3$ in the heater region and an *n*+ **P** implant of $10^{20}/cm^3$ in the silicon tethers. Otherwise the fabrication mirrors that in [2].



(a) (b) (c)

Figure 2 – (a) Micrograph of the fabricated 2nd order ARM-filter with directly integrated heaters, (b) measured spectrum as a function of electrical power driven into each resonator demonstrating 4.4μW/GHz, and (c) temporal response of the ARM-resonator in the Thru and Drop ports of the ARM-filter resulting from a 200kHz 0.3V square-wave drive fit to a 1μs exponential decay (shown in red).

The resonators were tuned by applying a voltage across the resistive heating elements and the spectra were measured using a tunable laser, the results of which are shown in Fig. 2b. At dissipated power levels of 9mW and 18mW per resonator, wavelength shifts of 16nm and 32.85nm were achieved, respectively, corresponding to a tuning power of 4.4μW/GHz or less than 1mW for a ±10°C variation, a power commensurate with low-power modulators [2]. The thermal time constant was measured by applying a 200kHz, $0.3V_{pp}$, square-wave signal. The measured Thru and Drop port responses are plotted in Fig. 2c. The Thru response is fitted to a 1μs exponential decay with the close fit demonstrating a 1μs time constant.

4. Conclusions

Adiabatic resonant microring resonators have been demonstrated successfully, in an active application. By directly integrating heater elements into ARM-resonators, we simultaneously achieve record low tuning power (4.4μW/GHz) and speed (τ = 1μs), an improvement greater than a factor of 6 in each. Future applications of ARM resonators will include modulators, suspended microrings, and other active structures.

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5. References

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