Microheaters for Thermo-Optic Tuning of Silicon Photonic Devices

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Abstract:

Silicon photonic devices have a broad range of uses, from chemical sensors to filters and modulators integrated with complementary metal oxide semiconductor (CMOS) microelectronics. As a result, these devices have applications that include future microprocessors, signal processing, biomedical devices, telecommunications, and more. A major drawback of silicon (Si) photonics is the sensitivity to device dimensions. Changing the width of a ring resonator by as little as a single atomic lattice will shift the resonant frequency by several gigahertz (GHz). This level of dimensional control is impossible in fabrication, so it is necessary to actively tune devices for operation. Because Si has a high thermo-optic coefficient, microheaters can be used to efficiently tune Si photonic devices and change their behavior. In this work, chromium microheaters were fabricated on top of a 1 μm-thick oxide cladding layer above microring resonators using photolithography and lift-off. Using a proportional-integral-derivative (PID) controller, the heaters were programmed to dissipate constant power over the rings and change their resonant frequencies. Robust heaters were demonstrated with a tuning ability of a full free spectral range and up to 60 GHz/mW.

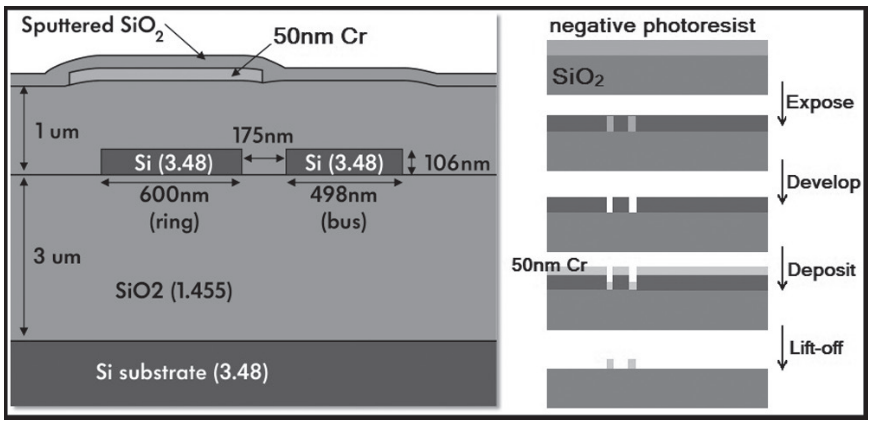

Figure 1, above: Cross section of the fabricated chip (left) and fabrication process (right).

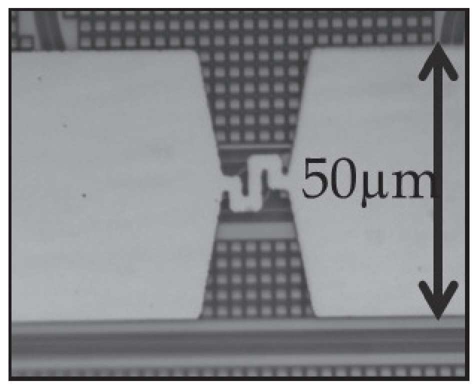

Figure 2, right: Chromium microheater on top of a microring resonator.

Introduction:

Microring resonators are Si photonic devices that act as filters. These devices drop light of a certain frequency, the resonant frequency of the ring, from a waveguide. The resonant frequency of the rings depends on the geometry of the rings as well as the index of refraction of Si. Because silicon's index of refraction depends on temperature, microheaters can actively change the resonant frequency of microring resonators. It is of interest to produce power-efficient tuning, i.e. produce as large a wavelength tuning as possible with a given amount of dissipated power, which is possible in Si photonics because of the large thermo-optic coefficient of Si, and the micron-scale size of the devices that need to be heated to a high temperature.

The goal of this project was to fabricate microheaters and demonstrate thermal tuning of microring resonators.

Methods:

A metal had to be chosen before the dimensions of the heaters were determined. The candidates were titanium and chromium because they are affordable metals with high resistivity.

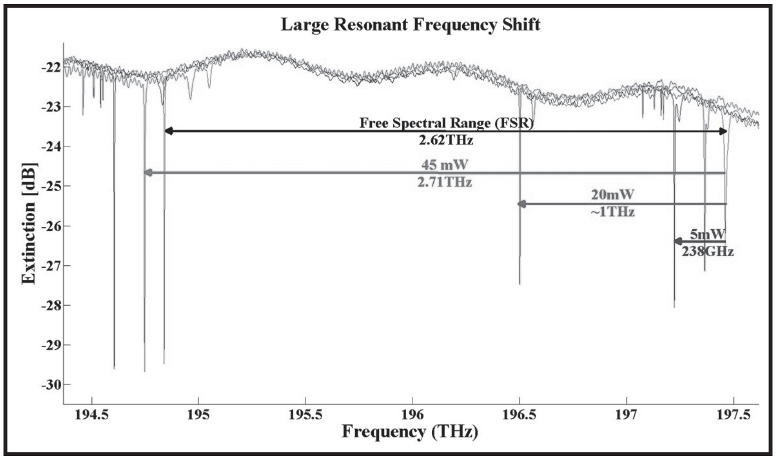

Figure 3, above: Tuning past a full FSR of a microring. The resonant frequency at ~ 197.5 THz is the resonant frequency of the ring at room temperature.

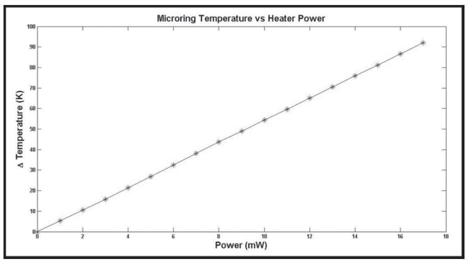

Figure 4: Change of temperature at the ring as a function of the power dissipated by the heater. Power was incremented by 1 mW from 0-17 mW.

Out of both metals, titanium has the highest resistivity (4.2 × 10^{-7} Ωm at 20°C), but it also oxidizes quickly. Thus, we chose chromium because it would yield more robust heaters. Figure 1 shows the cross section of the fabricated chip as well as the fabrication process of the heaters.

We started with chips that had the rings, waveguides, and the 1 μm SiO_2 cladding, which protected the waveguides from metal contamination [2]. Optical photolithography and lift-off were then used to fabricate the heaters on top of the SiO_2 cladding. The desirable resistance of the heaters was 500 Ω to 10 kΩ. Devices with a wire thickness of 50 nm and widths from 1.5 μm to 3 μm were fabricated in order to get heaters with desirable resistance that covered the area of the rings. Figure 2 shows one of the fabricated devices.

To test the heaters, a probe station and a PID controller, written in LabVIEW, were used. The PID controller measured the current going through the heater and the voltage drop. With this feedback, the PID controller changed the voltage across the heater so that it reached the desired steady state. Light was then coupled into the chip and a sweep of 1500 nm to 1590 nm wavelength was taken to determine the resonance of the ring.

A sweep was taken while dissipating constant power over the heater and the shift in resonance was measured.

Results and Conclusions:

First, an optical transmission wavelength sweep was taken while dissipating power from zero milliwatts (mW) to 17 mW across the heater with a step size of 1 mW. Since the resonant frequency of this ring changed by ~ 10.7663 GHz/K and the thermo-optic coefficient of silicon was nearly constant over this range (23°C-123°C), the temperature of the ring could be determined as a function of power dissipated [1].

Furthermore, a linear relationship between the change in temperature of the ring and the power dissipated by the heater is shown in Figure 4. This was expected because of the near-constant thermo-optic coefficient with temperature, and the fact that thermal diffusion itself was a linear process (like an RC electrical circuit), the heater covers the whole top area of the ring. Thus, the temperature should drop linearly across the 1 μm SiO_2 cladding.

It was important for the heaters to be efficient and be able to tune the rings over a large range of frequencies. Figure 3 shows the tuning of a ring past its free spectral range, FSR, the difference between adjacent resonant frequencies. This was all the tuning necessary for this ring since tuning past the FSR was not necessary — one could simply use the adjacent resonance's passband beyond a one-FSR detuning. Also, a 50 GHz/mW to 60 GHz/mW tuning efficiency was measured.

Considering the desired resonant frequency of a microring can be off by a few hundred gigahertz after it is fabricated, the microring can be tuned to its desired response with a few milliwatts dissipated by the heater. Furthermore, complex multiple-ring devices, like higher order filters, typically have slight (a few gigahertz) mismatches between ring frequencies. These can be compensated with sub-milliwatt power in the microheaters.

Acknowledgements:

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References:

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[2] T. Barwicz, M. A. Popovic, F. Gan, M. S. Dahlem, C. W. Holzwarth, P. T. Rakich, E. P. Ippen, F. X. Kartner, and H. I. Smith, "Reconfigurable silicon photonic circuits for telecommunication applications", Proc. SPIE 6872, 68720Z-1-12 (2008).