Thermal Effects in Silicon Based Resonant Cavity Devices

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Abstract:

CMOS process-compatible silicon photonic devices provide the possibility of monolithic integration with standard CMOS chips. They are, however, very sensitive to changes in temperature. In this project, we fabricated high-index contrast ring resonators on a silicon-on-insulator (SOI) platform and characterized the changes in resonance of these devices due to changes in temperature.

Introduction:

Silicon based photonic devices and circuits are attractive due to their fabrication compatibility with the CMOS process and possibility of monolithic integration on CMOS chips [1, 2]. Various photonic devices including micro-ring resonators [3] and high-Q cavities [4] have been demonstrated on SOI substrates.

Silicon-based ring resonators, such as the one shown in Figure 1, can act as ultra-compact add-drop switching devices [5]. The resonance condition of the ring resonator is given by the following equation.

$$C\lambda = 2\pi r$$
$$\lambda = \lambda_0/n$$

where C is an integer, λ_0 is the wavelength of light in free-space, n is the refractive index of the medium, and r is the radius of the ring. At the resonant wavelength, the light circulates in the ring and is either scattered out or absorbed, resulting in less light transmitted at the output. This drop in transmission at the resonant wavelength, as displayed in Figure 2, can be used to make optical modulators on Si [6].

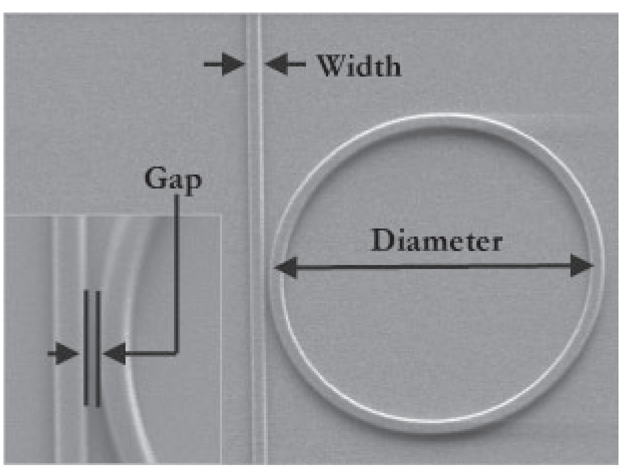

Figure 1: Ring resonator fabricated on silicon, with a ring radius of 12 µm and gap of 250 nm.

The refractive index (n) of silicon changes with temperature (T), as represented by the thermo-optic effect in silicon:

$$\Delta n/\Delta T = +1.8\text{x}10^{-4}\ K^{-1}$$

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Moreover, the resonant wavelength λ is a function of the refractive index n ($\lambda = \lambda_0 / n$).

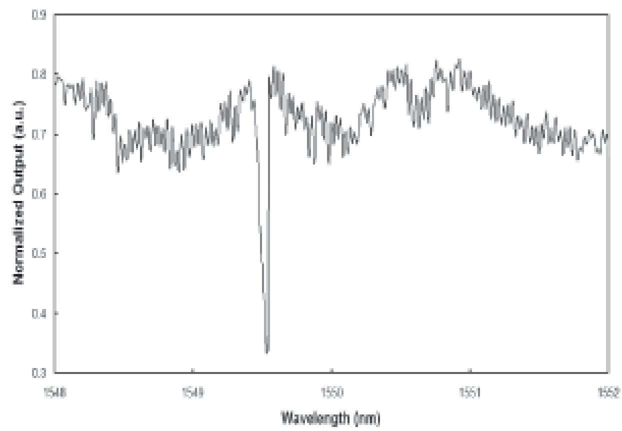

Figure 2: Transmission spectrum at room temperature using TE mode.

Fabrication Process:

We fabricated an Si ring resonator closely spaced from a waveguide with two bends to distinguish light coupled with the input and light transmitted to the output. There were 32 of these devices on the chip. All the waveguides were approximately 300 nm tall and 450 nm wide. The ring diameter was varied from 12 µm to 40 µm and was spaced 200 nm to 300 nm from the waveguide. The SEM of a fabricated ring resonator on a SOI platform is shown in Figure 1.

For the fabrication process, negative e-beam resist called FOX-12 was spun on a Silicon On-Insulator (SOI) wafer. The pattern was exposed using e-beam lithography with a 2 nA current and pixel step of 3. After developing in 300MIF, an Inductively Coupled Plasma (ICP) etcher was used to etch through the silicon layer.

The potential challenge with using a positive resist was large area exposure and high exposure time. The challenge encountered with using negative resist was slanted side walls, later found to be the cause of noisy output and subsequently undistinguishable resonances. The slanted side walls were mixing the TE and TM polarizations at the bends of our single-mode waveguides. Increasing the etch-chamber pressure from 22 mTorr to 30 mTorr and ICP power from 800 W to 850 W on the ICP etcher reduced the side wall slant.

In order to examine thermal effects on resonances, the input wavelength was swept from 1548 nm to 1552 nm using a tunable laser. A polarization controller was used to select TE or TM polarization of the input light. The light from the fiber was coupled with the waveguide. A lens was placed between the output end of the device and a power meter, in order to focus the output light into the detector. The device rested on a temperature controller used to heat the device. Furthermore, resonance shifts for 5°C increments between 25°C and 45°C were observed.

Results and Conclusions:

It is evident from Figure 2 that a resonance occurs at 1549.782 nm at room temperature (~ 25°C). Figure 3 illustrates how the resonances shift with a temperature increase. Based on this data, a linear relationship between the temperature and resonant wavelength was established, as represented in Figure 4. In conclusion, a 0.1 nm (± 0.01 nm) shift of the resonance wavelength occurs for every 1°C (± 0.05°C) change of the chip.

Future:

Now that the thermal effect on resonances has been characterized, the next step is to reduce and perhaps even eliminate these thermal effects. One suggested method is to add strain to the optical medium, with the ideal relationship being $\Delta n/\Delta T + \Delta n/\Delta P = 0$.

Using either tensile or compressive strain within the optical waveguides, the change in refractive index due to strain can be made to compensate for the change in refractive index due to temperature changes [7].

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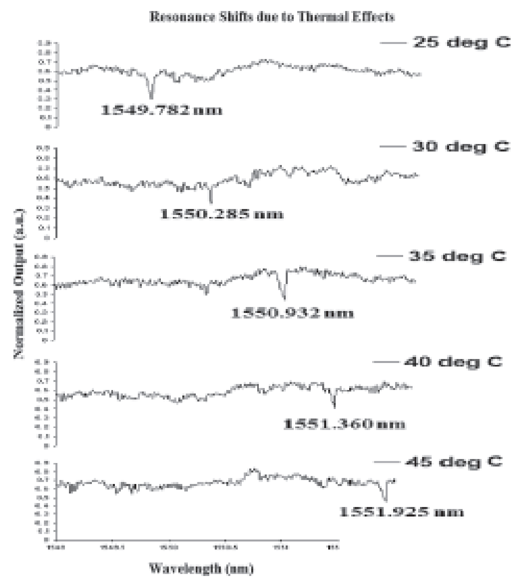

Figure 3, above: Transmission spectra with increasing temperature.

Figure 4, below: Linear relationship between temperature and resonant wavelength.