Microring Resonators in Silicon Photonic Circuits

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Abstract:

Microring resonators in silicon photonic circuits have, for the first time, been fabricated using equipment at the University of Colorado, Boulder. The fabricated rings have a free spectral range of 2.8 THz, and a quality (*Q*) factor of up to 31,000 has been observed.

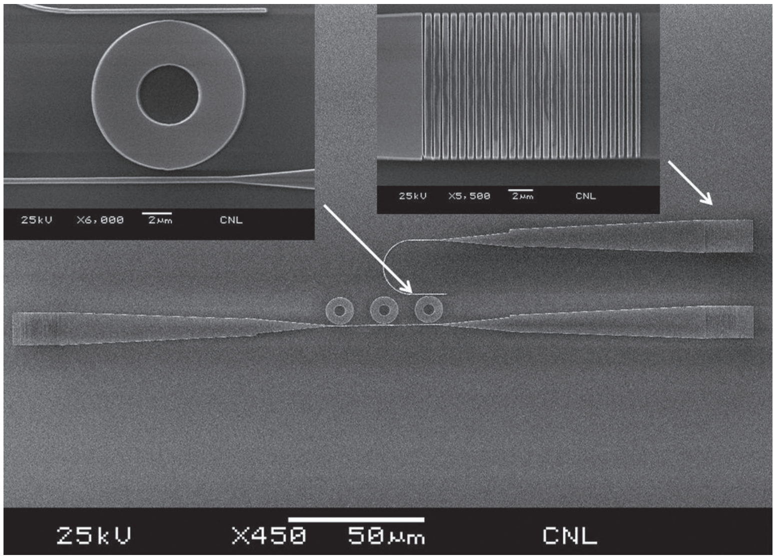

Figure 1: Scanning electron microscope image of the devices that were fabricated and tested. Light enters through the grating on the left side and comes out through one of the two gratings on the right side. From left to right, the three rings have coupling distances of 200, 350, and 500 nm. The rings have an outer radius of 5 μm and an inner radius of 2 μm.

Introduction:

Silicon (Si) photonics is an emerging technology that promises to allow for control of light on a compact chip analogously to how silicon microelectronics manipulates electricity. Si photonics may save the continued Moore's Law scaling of microelectronics by providing a solution to the energy efficiency problem faced by today's microelectronics. It will also potentially allow many table-top optical systems to be condensed onto a single chip. Microring resonators are ring-shaped, closed-loop optical waveguides with a radius on the order of a micron, which are capable of selecting a narrow frequency band of light from a spectrum. They work by being placed near a waveguide and coupling to the evanescent field. The light travels around the ring, and if an integer multiple of the wavelength is the same as the circumference of the ring, constructive interference occurs, while other wavelengths destructively interfere. The narrow resonant band is either transferred to another waveguide or lost to absorption and scattering while the remaining spectrum continues on the original path. This selectivity property causes microring resonators to be of interest to the telecom industry, where resonant microrings can be used as filters in wavelength-division multiplexed (WDM) communication systems. The project focus was to fabricate devices that incorporate microring resonators via electron beam lithography, and to characterize their optical frequency response, including bandwidth, quality factor (*Q*) and free spectral range (FSR).

Experimental Procedure:

The fabrication process of the devices began by spinning an ~ 150 nm thick layer of the polymer poly(methyl methacrylate) (PMMA) onto a silicon-on-oxide chip. The chip was placed inside a scanning electron microscope (SEM) that interfaces with the pattern layout program DesignCAD to cause the beam of electrons to write any desired shape using any dose of charge per area.

PMMA is normally used as a positive electron beam resist in the 100s of $\mu C/cm^2$ regime, but when the dose is increased to 10,000 or more $\mu C/cm^2$, the polymer cross-links where the pattern is written, causing the resist to become negative, which was desirable for the relatively long and narrow structures we were interested in fabricating (see Figure 1).

We then developed the sample in acetone for 40 seconds and used a reactive ion etching (RIE) process to etch all the way through the 220 nm thick Si layer to the oxide layer below.

Results and Conclusions:

A fiber laser was coupled into the left grating and out from the bottom right grating. The light coupled back into the laser was measured against the total power output of the laser to provide a measurement of the power extinction. The laser was swept from 1500 to 1620 nm in increments of 5 pm to obtain the plot shown in Figure 2. Each downward spike happened at a resonance where the rings removed light from the original waveguide and either transmitted it to another waveguide or lost it to radiation or absorption. The spectrum was fairly complicated by virtue of having three rings of differing coupling distances and also due to the fact that the rings were 3 μm wide and therefore capable of supporting multiple modes. There appeared to be two separate sets of resonances that each had a free spectral range of 2.8 THz.

A close-up view (Figure 3) revealed an additional structure present in the resonances. Namely, it was apparent that there were secondary and tertiary resonances that occurred in the vicinity of the central spike and that the central spike seemed to be made up of two closely-spaced resonances. It was likely that the secondary and tertiary resonances were higher-radial-order modes allowed by the large width of the rings.

The two closely spaced resonances are called doublets and are due to the breaking of degeneracy of clockwise and counter-clockwise propagating modes caused by imperfections in the rings, which break the rotational symmetry. However, there was not sufficient time for complete characterization of all modes in the spectrum. We did however measure the width of the central peak at the 3 dB point to be 50 pm and since it was centered at 1571.9 nm, it had a *Q* factor of 31,000, which was not much larger than the *Q* factor found in the other resonances.

In summary, fabrication of silicon photonic devices is now possible at the University of Colorado Boulder, and these devices have demonstrated a *Q* factor of 31,000.

Acknowledgements:

I would like to thank my entire lab group and especially my PI Dr. Miloš Popović and mentor Dr. Jeffrey Shainline for their tireless support and advice throughout the project. I would also like to thank the NSF for funding this research opportunity as well as the NNIN for offering and organizing the undergraduate research program.

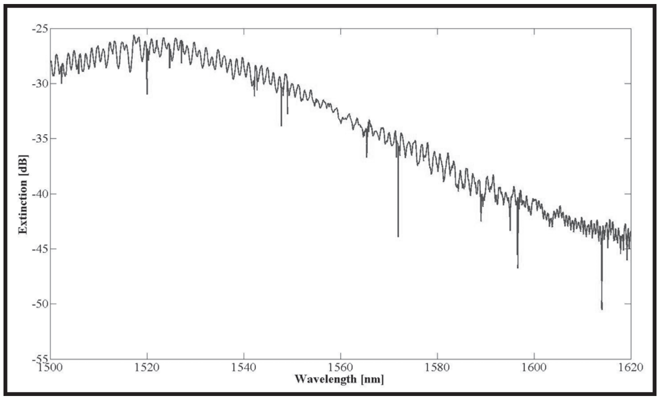

Figure 2: Spectrum sweep from 1500 to 1620 nm showing the resonance spikes due to the rings. Note that the y-axis is a dB scale.

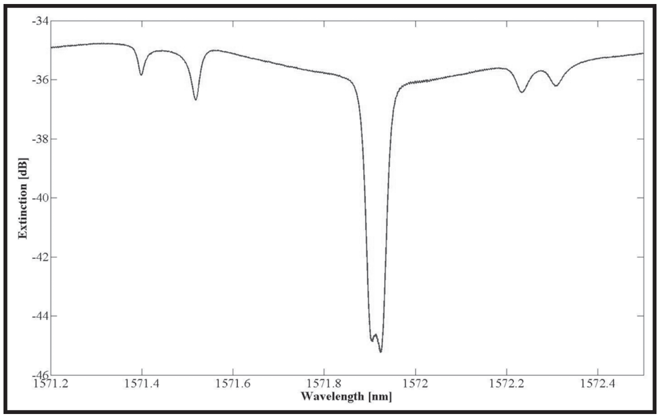

Figure 3: Zoomed in view of the resonance centered near 1572 nm. Secondary and tertiary resonances can be seen on either side of the central spike, which itself seems to be made up of two closely-spaced resonances.