All-Optical Gate: Silicon-on-Insulator Waveguide, Ring Resonator, and All-Optical Modulation

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Abstract—**The outlook on Optical Interconnects replacing Metal Interconnects on ICs is promising. However some devices must be realized before implementing schemes of photonic circuits and systems. In this project we created a near-perfect silicon nanophotonics process at RIT. A ring resonator fabricated hear was shown to have a Quality-Factor of 10,000. We then demonstrated the ability of these resonant devices to act as a high-frequency optical switch.**

I. THE PROMISE OF NANOPHOTONICS

Nanophotonics is the field of manipulating light at the nanoscale. Much like electronics deals with controlling electrons/electricity, photonics deals with controlling photons/light. The applications are numerous: sensors, lasers, cavities, quantum optics, communications, and integrated optics (integrating optics with CMOS). This last sub-field is the main focus of this project, specifically in application for optical interconnects on CMOS.

Optical Interconnects have numerous advantages over traditional metal/electronic interconnects. Photons are orders of magnitude faster than electrons; optical interconnects have no parasitic capacitance, and multiple frequencies of light can be carried on a single waveguide at once, allowing for enormous bandwidth capabilities (THz). Integrated nanophotonic devices are also very compatible with current IC manufacturing as they utilize standard front-end CMOS processing techniques.

II. PROJECT SCOPE

The goal of this project was to develop a nanophotonics process on Silicon-on-Insulator (SOI). We fabricated two enabling devices for many nanophotonic systems: waveguides and ring resonators. A waveguide is a "wire" for light operating on the concept of total internal reflection. A ring resonator is a device used to hold and in some cases re-direct light from a waveguide at very specific frequencies. The measure of the quality of a resonator is described by a metric called Quality Factor (Q).

The process is very simple: electron-beam lithography, oxide etch, silicon etch, clad with oxide, polish, and test. However, none of these components were trivial, and ultimately this project came down to optimizing each of these processes. This entire process can be completed in one day, and ultimately was repeated numerous times until the best process was found.

III. RING RESONATOR FABRICATION

The first major accomplishment of this project was the correction of stitching issue with the e-beam lithography process. When writing the circular ring resonator, the beam scanned around the circle. At the first end, however, the charge remained in the substrate deflected the incoming beam and caused a distortion in the pattern. This was corrected by splitting the ring into concentric circles and writing these separately.

The second major accomplishment was the development of a brand-new sub-micron silicon etch. Previously, a fluorine etch was used but led to significant undercutting. A chlorine etch was created from scratch and tweaked throughout the quarter until it looked the best by eye (SEM). The ultimate goal was to find the best conditions for anisotropy, smooth sidewalls, and mask integrity.

The metric used to measured the quality of a ring resonator is called quality-factor and is inversely proportional to the width of a dip in intensity caused by the ring resonator. After testing, we determined the best ring resonator to have a Q of 10,065, over an order of magnitude better than our best device previous to the new chlorine etch (Q ~ 600).

IV. ALL-OPTICAL MODULATION

The ring performed well enough to lead to the third major accomplishment of this project: demonstrating all-optical modulation on devices fabricated at RIT. Pulses with a wavelength of 400nm were injected into the ring from the top and were absorbed by the silicon at a frequency of 76MHz. These pulses generated free-carriers which ultimately cause a shift in the resonance. This was done while probing the input of the device with a laser on the strongest resonance. This resonance shift caused the output of the ring (the probe) to mimic the signal of the 400nm pump, proving the concept of an all-optical gate. It was also demonstrated that the signal could be inverted, by tuning the probe wavelength to be on resonance at the carrier-injected state.

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