Optical Silicon Routing Devices for Active Optical Networks-on-Chip

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Abstract:
Utilizing silicon microring resonators as filtering elements for lightwave communications, we built a variety of switch-based systems for numerous applications. We developed various networking devices as well as a high-order optical signal filtering structure that could be used to create a faster and denser communication system between electronic processors, as well as being tunable to adjust for fabrication inconsistencies. The devices are fabricated on SOI wafers using Si as the waveguide material and SiO2 as the optical cladding. The ring resonators used are on the order of 10-20 µm.

Summary of Research:
Optical filtering devices, such as high quality factor (Q) ring resonators, have been shown to provide novel functionalities on chip [1,2]. These nanoscale structures, however, critically depend on the various dimensions of the design in order to function properly. Unfortunately, fabrication at this scale is still prone to considerable deviation. In a resonating structure the Q as well as the resonant wavelength of the device are parameters that can change due to these variations; in a multiple resonance structure more complex transmission functions can be drastically distorted.

To restore a damaged transmission function or networking device, we require dynamically adjustable filters that can be retuned after fabrication. Manipulating the resonance condition of the microrings gives us the freedom to modify the spectral characteristics of the filter. Individual tuning of each device can thus help us retune a complex arrangement requiring many rings to work in tandem. In the case of large networking devices such as the optical network router seen in Figure 1, each of the rings needs to be tuned a certain amount to move an optical signal from one of the inputs to one of the outputs. The device is based on a 4 × 4 hitless router, meaning that four signals can be simultaneously routed to the four outputs without incurring any line contention [3]. This work is yet to be published.

In another device seen in Figure 2, we use the idea of coupling rings serially to manipulate a complex-order filter, which could also be used in an optical network to operate on signals by wavelength. By coupling two tunable rings together in an EIT-like configuration, we can go beyond just tuning the resonant wavelength and also dynamically change the bandwidth of the filter [4]. Finally, coupling multiple two-ring sets of these rings to a single waveguide allows us the flexibility of complete filter design, and improves our ability to create our own custom spectrum. To demonstrate the performance and flexibility of the fabricated system we show in Figure 3 the transmission function of three different filters. A ramp, a band-pass and a double band-pass function. These are all dynamically created using the same four ring-pair device. This work was presented at the 2008 CLEO Conference [5].

The tuning of the rings is done thermo-optically using metal heaters located above each individual ring. The heaters are electrically controlled and conductively change the temperature of the silicon. Changing the temperature alters the refractive index of the material, in this case nSi for silicon, by the experimentally verified relation between index and temperature dnSi/dT = 1.86 × 10-4K-1 [6]. The change in nSi modifies the effective path length around each ring, and with it the resonance
condition \(2\pi n_{\text{eff}} = m \lambda\) where \(m\) is an integer, and \(n_{\text{eff}}\) is the effective index based on \(n_{\text{Si}}\).

Fabrication is done on an SOI substrate with a 240 nm silicon layer on 3 \(\mu\text{m}\) buried oxide. We use 450 nm wide rectangular Si waveguides defined using e-beam lithography, etched by reactive ion etching (RIE) and clad by a 1 \(\mu\text{m}\) plasma enhanced chemical vapor deposition (PECVD) oxide layer. The oxide is planarized using chemical mechanical polishing (CMP) to avoid pinching and other variations when depositing the metal. The heaters and contact pads are then fabricated from nickel and gold, respectively, above the cladding layer using an e-beam masking, electron-gun (E-gun) evaporation and lift-off process. The thickness of the nickel is 100 nm with a 5 nm Ti adhesion layer.

**References:**


