Abstract:
We report the first demonstration of a compact (20 µm x 40 µm), fast (7 ns), broadband (60 GHz of flat band) switch electrically driven by PIN diodes surrounding two coupled resonant cavities. The device operation is hitless, i.e. switch operation occurs with negligible (< -14 dB) perturbation on adjacent channels in a Wavelength Division Multiplexing (WDM) system. The two coupled cavities are responsible for the box-like filter shape while the PIN diodes enable free carrier injection to change the refractive index and provide switching operation.

Summary of Research:
We designed and implemented optical switches, key elements for enabling on-chip optical networks [1]. The main features of the device fabricated are its broadband characteristic and its hitless behavior. The former is important for robustness from on-chip temperature changes [2] and low distortion of high bandwidth signals [3], while the latter is important for on-chip optical networks where multiple wavelengths coexist in the system [1].

The device comprises two coupled optical cavities, responsible for the box-like filter shape, surrounded by p-doped and n-doped regions, which form a PIN diode for injecting free carriers in order to switch the data output by changing the refractive index [4]. The filter is realized by two ring resonators coupled to waveguides and to each other as shown in Figure 1a. A box-like transfer function (as in Figure 2a) can be obtained when the cavities share the same resonance wavelength and when the coupling between a cavity and its adjacent waveguide is much stronger than the coupling between cavities.

We realize hitless operation by controlling the optical path length of one of the cavities while leaving the optical path length of the other one unperturbed. When both cavities have the same resonance, light with wavelengths inside the filter bandwidth is directed to the drop port. When the refractive index of the right cavity is changed the resonances are not shared anymore, leading to an over-coupled system where the signal passes to the through port with central resonance on the
central frequency of the filter. The processing flow of the structure ensures that the diodes are electrically isolated for independent tuning of each cavity. We fabricate the device on an SOI substrate, with waveguides and cavities created by patterning and etching the top silicon layer and leaving a 40 nm slab throughout the chip. The diodes are made by doping slab regions around each cavity, leaving 250 nm x 450 nm waveguides. We achieve electrical isolation by removing the slab elsewhere, including between the cavities. The device is cladded with a 1 µm thick silicon oxide and has a 3 µm silicon oxide box underneath. Each cavity has a total length 2π·10 µm with 8 µm bend radius.

Broadband hitless switching behavior is demonstrated by measuring the dynamics of the spectrum as the switch is turned ON and OFF. This is done by monitoring the output power at the through and drop ports with an oscilloscope as we inject carriers to and extract carriers from the right cavity. We scan the input laser from 1547.3 nm to 1554.3 nm with steps of 0.05 nm and observe the spectrum dynamics.

In Figures 2 and 3 we show simulated (continuous line) and measured (dashed line) spectrum and time response for the through and drop ports. The drop port transmission changes by 9.8 dB when the switch is turned ON with a 1.46 V bias and 4.0 Vpp switching signal, and the through port transmission has a 16.6 dB change. When ON, the switch has a 2.8 nm resonance shift meaning an index change ∆n = 0.01 and a free carrier density of 6 × 10^{18} cm^{-3}. The contact resistance of the device is R_s = 437 Ω and the power consumed in ON state, considering a 0.7 V junction potential, is 17.4 mW.

Time constants related to device operation are obtained by fitting the theoretical model to the data measured. For a e^{-t} amplitude decay, the time constants for the switch are 7 ns for OFF-ON transition and 3 ns for ON-OFF transition.

From the data obtained and numbers above we demonstrate that at least an 80 ns window can be sustained with the switch ON with a 7 ns transient time. For a 10 Gbps signal going through the device it represents up to 710 bits. There is a trade-off between transient time and holding time of the switch, and it can be optimized for particular data architecture and stream sizes.

References:


