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Transparent high-data-rate optical transmission through broadband hitless bypass switches for chip-scale optical networks

M. S. Aras[1,*], A. Biberman[2,*], N. Ophir[2], A. Stein[3], S. Kocaman[1], R. Chatterjee[1], M. Yu[4], D. L. Kwong[4], K. Bergman[2], and C. W. Wong[1]

[1] Optical Nanostructures Laboratory, Columbia University, New York, NY 10027, USA
[2] Department of Electrical Engineering, Columbia University, 500 W. 120th Street, New York, NY 10027, USA
[3] Center For Functional Nanomaterials, Brookhaven National Laboratory, Upton, NY 11973, USA
[4] The Institute of Microelectronics, 11 Science Park Road, Singapore Science Park II, Singapore 117685, Singapore
[*] Equally contributed. Author email-address: ma2840@columbia.edu; cww2104@columbia.edu

Abstract: We demonstrate 10-Gb/s optical data channels through broadband hitless switches, with open eye-diagrams and error-free operation (BERs less than 10^{-12}). Both through- and drop-ports are measured in the hitless operation for transparent chip-scale optical networks.

OCIS codes: (250.6715) Switching; (230.3120) Integrated optics devices; (230.3990) Microstructure devices

1. Introduction and hitless switch implementation

Silicon photonics has been realized to provide outstanding performance in very broad range of applications such as short-haul communication, and on-chip global interconnection networks in multi-core microprocessors [1, 2]. The most pertinent advantages of silicon photonics are its large bandwidth, low energy consumption, and small footprint components. Furthermore, silicon photonics provides large index contrast, enabling highly confined, low-loss waveguides. In photonics, optical switches are one of the critical components for on-chip optical networks. Particularly, they are needed for high performance interconnects in multi-core microprocessors systems [2]. Previously, several switching techniques have been examined such as thermal heating [3], electro-optic switching [4], albeit requiring high power and not compatible with silicon. Recently, a non-blocking spatial hitless router was demonstrated [5], with switching from one input to various output ports. Here we demonstrate a hitless switch that can be implemented for tunable OADMs, where one can tune one (drop filter) wavelength -- resonance shifting -- without affecting all other wavelengths. A few switches were recently demonstrated [6 - 8]; our implementation is through a π-imbalanced Mach-Zehnder interferometer with oppositely-switched and cascaded directional couplers, perturbed with nanomechanical switches The hitless bypass switch enables: (1) binary on/off switching of the filters without any loss of data bits; and (2) filter reconfigurability without any loss of data bits by temporary transfer of data from the signal bus to a "bypass" bus, without disturbing all other wavelength channels. Numerical simulations through coupled-mode theory and complete 3D finite-difference time-domain have been performed to determine the hitless switch performance and operation [8].

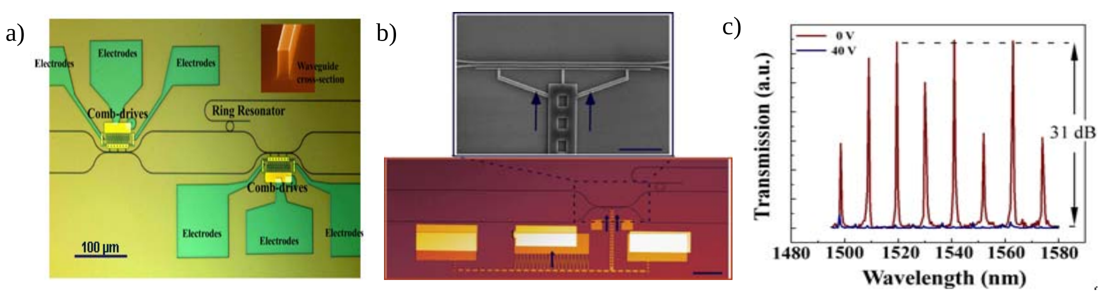

Figure 1. **a)** Optical image of complete hitless switch system with integrated electrodes. The perturbing dielectric switches the directional couplers and is driven MEMS-based comb-drive actuators. **b)** SEM and optical image of the fabricated sample of push-type system to displace perturbing dielectric close to directional coupler for high extinction ratios. **c)** Transmission spectrum from the drop port of the ring resonator in the perturbed and unperturbed cases. For the perturbed case (0V DC bias), light at the top portion of the hitless switch is dropped through the microring resonator. At 40V bias, the unperturbed condition is achieved and almost all light goes through the bottom portion of the switch and negligible amount of light gets dropped the microring resonator.

2. Nanofabrication and high-data-rate measurement setup

The hitless switch is designed with 500-nm $\times$ 250-nm cross-sectional waveguides in a silicon-on-insulator material system, and fabricated either with electron-beam or deep-UV lithography . The integrated electrodes are patterned through electron-beam lithography, and transmission characterizations performed at Columbia. For high-data-rate maesurements, the setup is illustrated in Figure 2 and consists of a tunable laser externally modulated with a 10-Gb/s non-return-to-zero (NRZ) on-off-keyed (OOK) signal, encoded using a pseudo-random-bit-sequence (PRBS) of length 2^{31}-1, generated by a pulse pattern generator. The pump, operating near 1550 nm wavelengths, is externally modulated using pulse pattern generator (PPG). After leaving the modulator,

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the pump signals are coupled into the waveguide from a tapered fiber. After exiting the chip, the signals go through a polarizer, selecting the transverse-electric-like polarization, and are collimated and collected into a fiber. The probe then propagates through an EDFA, a tunable grating filter (λ), a tunable attenuator, and is received by a high-speed receiver with a trans-impedance amplifier/limiting amplifier (TIA/LA) pair. Probe signal is analyzed with digital communication analyzer (DCA) and a bit-error-rate (BER) tester (BERT) that is synchronized to the PPG through a 10-GHz clock. A fraction of the pump and probe power is tapped-off before the filter for examining spectral analysis.

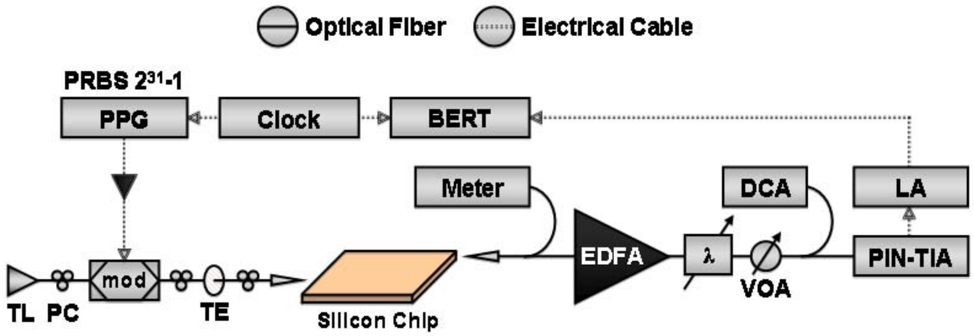

Figure 2. Experimental setup for 10-Gb/s optical channel and BER measurement.

3. Experimental results and analysis

As shown in Figure 3a, we recorded eye diagram for both through- and drop-port outputs with almost distortionless transmission at a 10-Gb/s data rate input. Furthermore, we observed error-free operation on both outputs. Additionally, 20-dB extinction ratio was achieved on the hitless switch drop port. The insertion loss was estimated to be about 20-dB, even without optimized fiber-chip-fiber couplers. The microring resonator for this specific measurement at the 1551.02-nm drop channel has a *Q* of 2,325 (linewidth of 0.667 nm), allowing a 82 GHz bandwidth for our measurements (albeit with lower channel density in the C-band). The absence of signal degradation at 10-Gb/s is promising for the scaling up of our bitrate measurements to 100-Gb/s in the hitless switch for chip-scale optical interconnects and networks for advanced communications.

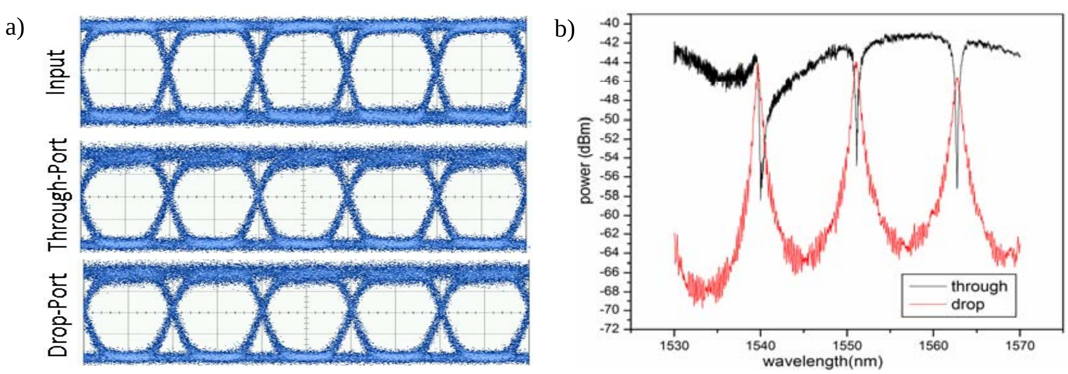

Figure 3. a) 10-Gb/s eye diagrams recorded using DCA without applying voltage (comb-drives actuators not activated). b) Transmission of through (black) and drop (red) output ports taken using experimental setup (Figure 2).

4. Conclusion

We have demonstrated high data-bit-rate transmission through the chip-scale integrated hitless bypass switch. We observed error-free operation (BERs of less than 10^{-12}) on both through- and drop-ports and recorded open eye diagrams with corresponding minimal signal distortion on both output ports. Current studies involve the complete filter add/drop through integrated actuations for network on-chip demonstrations. .

5. References

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