Edge Wavelength Selective Switch for Optical Access Networks

Evan D. Chansky[1*], Viviana Arrunategui-Norvick[1*], Takako Hirokawa[1†], L. Alberto Campos[2], Haipeng Zhang[2], Mu Xu[2], Zhensheng Jia[2], Clint L. Schow[1]

[1]*Electrical & Computer Engineering Department, University of California, Santa Barbara, Santa Barbara, CA 93106, USA*
[2]*Cable Television Laboratories Inc., 858 Coal Creek Circle, Louisville, CO 80027, USA*
[†] *Now associated with GLOBALFOUNDRIES, 400 Stone Break Rd Ext., Malta, NY 12020, USA*
**These authors contributed equally to this work*
Author e-mail address: evanchansky@ucsb.edu

Abstract: We demonstrate a novel C-band wavelength selective switch well equipped to handle the demands of scaling access at the edge. The 1x4 switch block has two drops per port with thermo-optic tuning. © 2022 The Author(s)

1. Introduction

Due to the ever-increasing growth in traffic, the optical access network has been going through significant changes. In addition, this access network, from having focused mostly on residential services, has become critical in carrying enterprise traffic as well as mobile backhaul. In metropolitan areas where the traffic demand is high, fiber and wavelength availability are at a premium. These likely denser areas also have a shortage of available conduits where it is expensive to trench new fiber paths. Therefore, service providers want to leverage their existing infrastructure as much as possible. This means efficiently populating their entire fiber wavelength spectrum with payload. As customers terminate service, these resources ideally must soon be taken by another customer so service providers need tools to facilitate a quick turnaround. The increase in enterprise connectivity and the increasing value of the traffic being carried is also prompting for higher reliability through redundant connectivity. All these trends point us towards greater management capabilities at the edge. Historically these requirements have existed in the regional and backbone portions of the network but not at the access or edge. Whereas wavelength manipulation in the backbone has been addressed by complex ROADMs, the needs in the access are different. The backbone networks are typically meshed whereas in the access the topologies are at most ring topologies (degree 2). The number of add/drop ports is also lower in the access. Furthermore, the shorter distances in the access leads to lower amplification requirements and enables the implementation of full duplex transport (same wavelength both directions) when carrying coherent signals [1].

Silicon photonics is especially appealing for this application due to its cost efficiency. With the increasing scale of devices at the edge, subtle differences in power consumption and loss are especially impactful [2]. MEMS switches have been shown to be capable of handling many ports [3], but without such requirements are not worth the added complexity and power consumption. Integrated ring resonator-based wavelength selective switches provide flexibility and meet the functionality required at the edge for a low complexity design. Thermo-optic tuning was chosen for its high tuning efficiency and low insertion loss.

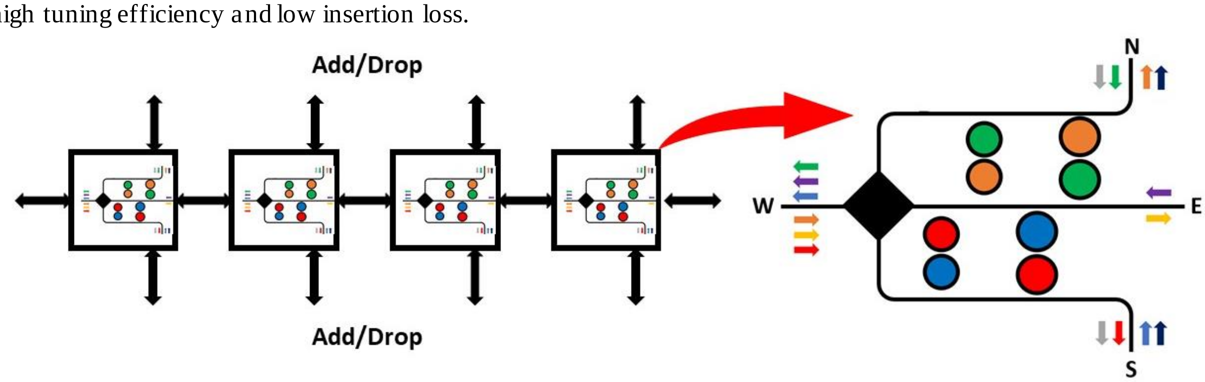

Fig 1. Switch architecture (a) complete 1x4 switch (b) individual switch block showing duplex color-coded paths with two wavelengths per port. Small and large rings are shown disproportionately different in size to highlight variety

This paper shows how the functionality needed at the access can be implemented through this technology. With remote and automated control of these wavelength selective switches, providers will be able to drastically lower the time in setting up new services and enable redundancy, all while better managing their wavelength inventory. This wavelength selective switch design addresses the low complexity, full duplex, and flexible configuration needs of the evolving access network.

2. Device Design

Singular switch blocks are built around one crosspoint to pass light through or across the main East/West throughput which can then be coupled away to North/South add/drop ports. Since the entire switch is duplex, all directionality is reversible as shown in Fig. 1(a). This photonic integrated circuit (PIC) was fabricated in a GlobalFoundries 90nm Silicon Photonics process. Micro-ring resonators (MRRs) were designed to be thermally tuned by integrated resistive silicon heaters and were arranged in a second-order serial combination to increase the full width half maximum (FWHM) of each resonance. Ring-bus coupling gaps are 405 nm and ring-ring coupling gaps are 705 nm. To ensure optimal coupling, each MRR in the pair has individual tuning control. Each MRR shape is a racetrack for higher-coupling straight regions with Bezier curves instead of circular for lower waveguide loss [5]. To minimize required thermal tuning and therefore power consumption, each path was designed with a large and small MRR pairs to have offset natural resonances spaced within a single free spectral range (FSR). The large MRRs have a slightly longer straight region but the same Bezier curves as small MRRs. This implementation has been shown in [4] for a crossbar switch and was optimized for this edge architecture. East, West, and South ports are accessed through edge couplers, while North ports are accessed via grating couplers due to space constraints. The PIC footprint shown in Fig. 2 is 1.6 mm by 2.2 mm and is dominated by the edge coupler V-grooves, as the switch itself is a 0.4 mm tall 3×12 array of bond pads (32 signal pads for each MRR and 4 ground pads).

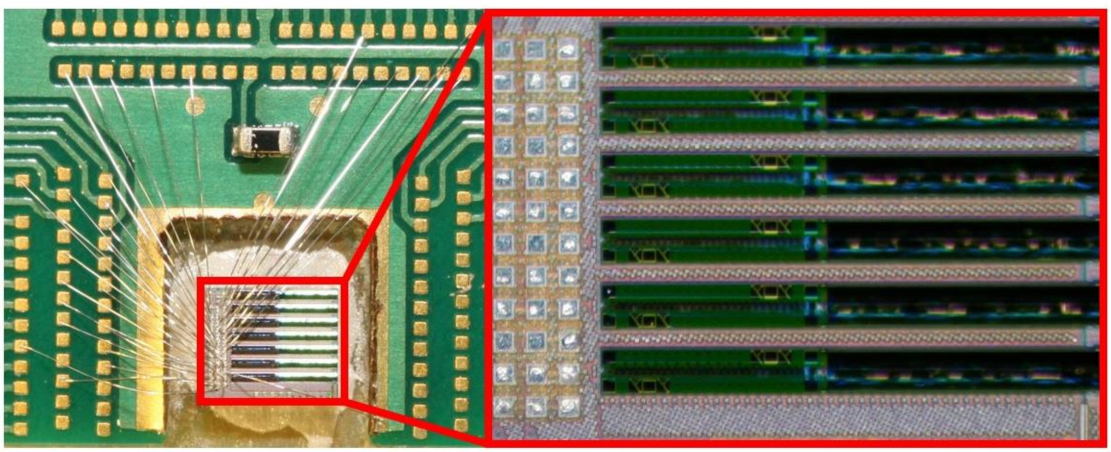

Fig. 2 Assembled and wirebonded device on PCB with closeup of PIC. Chip footprint is dominated by edge couplers

3. Results and Discussion

The PIC was wirebonded to a custom designed printed circuited board (PCB) alongside a thermistor for temperature control. For the purposes of this paper the first block was coupled with individual single mode fiber. MRR structures provide an FSR of around 18 nm, with ample width for the two drops per port. Individual add/drop resonances have a FWHM of 0.97 nm (119 GHz) for the large rings and 1.44 nm (179 GHz) for the small rings with an extinction of 40 dB for both. The large rings had an average resistance of $861 \pm 33\,\Omega$ and small rings had $719 \pm 48.5\,\Omega$. The tuning efficiency was approximately 45GHz/V with 2.5 GHz/V tuning crosstalk as shown in Fig. 3(a) for tuning of small MRRs and was similar for large MRRs. Such crosstalk should be accounted for when tuning both ring pairs but does not introduce any optical crosstalk of transmitted signals to the well separated properly biased resonances in Fig. 3(b). To tune the entire FSR, 8V is sufficient, though tuning midway between adjacent resonances is best for switch operation to avoid mode splitting. Operation with a thermo-electric cooler (TEC) temperature controller did not limit crosstalk for larger biases. On future generations, increasing the pitch of ring elements can minimize thermal crosstalk, and a larger ground plane can limit any possible electrical crosstalk. Additionally, on-chip wavelength locking can be integrated [6]. Note that in Fig. 3(b) unbiased small rings overlap with the natural resonance of large rings, so that consistent loss is achieved when biased to a separate resonance.

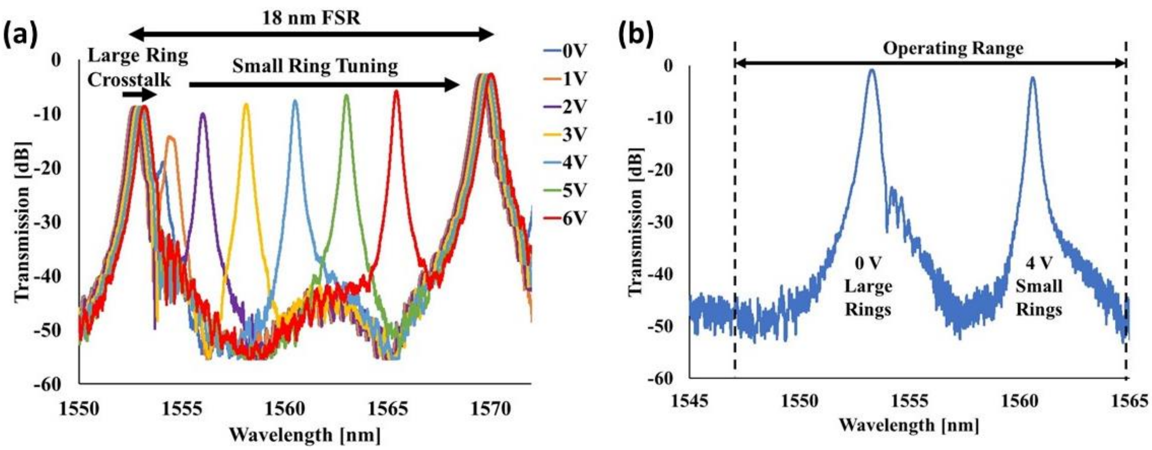

Fig. 3 (a) Tuning efficiency and crosstalk (b) wavelength allocation for two drops per port within operation region

Fiber coupling varied between measurements, so the spectral data in Fig. 3 were calibrated to include only on-chip losses. Permanent fiber-attach would eliminate the need for calibration and would resolve wavelength dependent coupling losses that could hinder perfectly flat tuning. We have been able to achieve 9.6 dB loss on an edge coupler to edge coupler test structure also on-chip, although these same PDK edge couplers have achieved 1.3 dB/coupler with proper packaging [7]. The insertion loss was found to be 0.8 dB per drop which is consistent with past designs measuring 0.4 dB per MRR. Other test structures on-chip did not yield, so individual contributions to total insertion loss cannot be determined at this time. Tuning the rings to reach the equally spaced wavelength allotment in Fig. 3(b) required a power consumption of 48.6 mW from the required bias voltages and the corresponding MRR resistances.

4. Conclusion

We have implemented and demonstrated a novel architecture for wavelength selective switching that is compatible with the demands of expanding edge networks. Continued testing of this design will seek to characterize the device from a system perspective and to demonstrate real-time switching of duplex WDM signals. A complete assembly including a fiber array and custom driver will be utilized in future testing.

Acknowledgements

The authors would like to thank K. Giewont, A. Stricker, K. Nummy, D. Riggs, K. Dezfulian, T. Letavic, N. Cahoon, and M. Peters at GlobalFoundries for their support and assistance. The authors would also like to thank Alethea Butler-Nalin for her wirebonding expertise.

References

[1] Z. Jia, M. Xu, J. Zhang, H. Zhang, L. A. Campos, and C. Knittle, "Demonstration of Low-Latency Coherent Optical Connectivity for Consolidated Inter-Hub Ring Architecture," in Optical Fiber Communication Conference (OFC) 2020, OSA Technical Digest (Optical Society of America, 2020), paper Th3A.2.

[2] Y. Ma, I. Clarke, and L. Stewart, "Recent Progress on Wavelength Selective Switch," in *Optical Fiber Communication Conference (OFC) 2020*, OSA Technical Digest (Optical Society of America, 2020), paper M3F.1.

[3] T. Hirokawa et al., "A Spectrally-Partitioned Crossbar Switch with Three Drops Per Cross-Point Controlled with a Driver," 2019 IEEE Photonics Conference (IPC), 2019, pp. 1-2, doi: 10.1109/IPCon.2019.8908418.

[4] C. L. Manganelli et al., "Large-FSR Thermally Tunable Double-Ring Filters for WDM Applications in Silicon Photonics," in IEEE Photonics Journal, vol. 9, no. 1, pp. 1-10, Feb. 2017, Art no. 6600310, doi: 10.1109/JPHOT.2017.2662480.

[5] T. J. Seok, J. Luo, Z. Huang, K. Kwon, J. Henriksson, J. Jacobs, L. Ochikubo, R. S. Muller, and M. C. Wu, Silicon photonic wavelength cross-connect with integrated mems switching. APL Photonics, 4(10):100803, 2019.

[6] Khope, A. S., Netherton, A. M., Hirokawa, T., Volet, N., Stanton, E. J., Schow, C., ... & Alferness, R. C. (2017, July). Elastic WDM optoelectronic crossbar switch with on-chip wavelength control. In *Photonics in Switching* (pp. PTh1D-3). Optical Society of America.

[7] B. Peng et al., "A CMOS compatible monolithic fiber attach solution with reliable performance and self-alignment", in Proc. Opt. Fiber Commun. Conf. Exhibi., San Diego, CA, USA, May 13, 2020

[8] N. Dupuis et al., "A 4×4 electrooptic silicon photonic switch fabric with net neutral insertion loss," J. Lightwave Technol., 38 (2), 178 –184 (2020). https://doi.org/10.1109/JLT.2019.2945678 JLTEDG 0733-8724