

Monolithically Fabricated Subwavelength Grating Filters for O-band MUX/DEMUX Applications

Francis O. Afzal¹, Bo Peng², Shuren Hu², Kevin Dezfulian², Karen Nummy², Andy Stricker², Abdelsalam Aboketaf², Crystal Hedges², Dave Riggs², Ken Giewont² and Sharon M. Weiss¹

¹Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, Tennessee 37235, USA

²GlobalFoundries, Hopewell Junction, NY 12533, USA

Corresponding author: francis.afzal@vanderbilt.edu

Abstract: We demonstrate low loss (-1.2dB), high extinction ratio (-30dB) and single-source thermal tunability of the first silicon add/drop subwavelength grating filters fabricated at a CMOS foundry, using a commercial, monolithic silicon photonics technology from GlobalFoundries.

OCIS codes: (050.6624) Subwavelength structures (220.0220) Optical design and fabrication (130.7408) Wavelength filtering devices

1. Introduction

Commercial interconnects require high performance and low cost to be competitive. Hence, it is not sufficient to only achieve key performance metrics, including data bandwidth, signal loss and energy consumption, but it is also necessary to design for manufacturability. As optical interconnects are outperforming electrical interconnects in an increasing portion of the market, it is crucial to realize nanophotonic devices which push interconnect performance higher while maintaining commercial scalability.

A major benefit of optical interconnects is their capacity for wavelength division multiplexing (WDM), which enables larger data bandwidth through encoding information channels onto separate wavelengths of light. To realize WDM capabilities, filters for splitting and combining wavelength channels must be reliably implemented and achieve sufficiently low signal loss to be feasible for integration in photonic integrated circuits (PICs). Many solutions exist for optical MUX/DEMUX filtering, including well-established platforms such as arrayed waveguide gratings (AWGs), Echelle gratings, cascaded Mach-Zehnder interferometers (MZIs) and coupled rings [1-3]. While these devices utilize larger feature sizes which are readily compatible with commercial photolithography, shortcomings in metrics such as channel shape, channel width, insertion loss and tuning requirements either make them unsuitable for many commercial applications or leave much room for improving performance or implementation. Research on add/drop subwavelength-grating (SWG) filters shows potential to advance WDM performance with highly versatile channel widths, flat-top responses, low crosstalk and low insertion loss in a serially cascadable platform; however, the small feature sizes of SWG filters are typically realized using electron beam lithography, which is incompatible with commercial fabrication [4-6]. Moreover, most prior work with add/drop SWG filters has been conducted in the C-band while the industry standard for datacenter applications is O-band operation. Investigating the performance and manufacturability of SWG filters in the O-band is critical for enabling one of the most versatile and compact filtering platforms available to make low-loss, flat-top channels needed to meet IEEE 400GBASE datacom standards for CDWM and DWDM. Towards this goal, we demonstrate the first add/drop SWG filters manufactured in a CMOS foundry using a tape-out on the monolithic silicon photonics technology at GlobalFoundries (GF).

2. Design Method

Devices were designed using the 90WG technology available at GF. To realize a SWG filter in this technology, we implemented a straight silicon ridge waveguide side-coupled to a SWG waveguide. This configuration was chosen as it has demonstrated good performance in the C-band [5] and can be implemented with elements in GF's product design kit. Figure 1(a) illustrates the device design, where the bus ridge waveguide evanescently couples to the SWG waveguide, contra-directionally dropping a single frequency channel into the SWG waveguide. The center of the channel dropped into the SWG filter by first order diffraction is determined by the equation:

$$(1) \quad \lambda_{drop} = \Lambda(n_{wvg} + n_{swg}),$$

where λ_{drop} is the center of the drop channel, Λ is the pitch of the SWG, n_{wvg} is the effective index of the forward propagating bus waveguide mode, and n_{swg} is the effective index of the backward propagating SWG mode [4].

Lumerical FDTD and MODE solutions were used to simulate the 90WG front-end-of-line material stack around a patterned silicon device layer. The effective indexes, n_{wvg} and n_{swg} , were computed using standard techniques with MODE solutions [4]. The filter was engineered to have a large difference between n_{wvg} and n_{swg} to push side-band

reflections out of the operating window and a minimum feature size of $\sim 150\text{nm}$ to obey design rules. The pitch was used to tune the channel position in the O-band and the overall filter footprint was $\sim 0.002\text{mm}^2$.

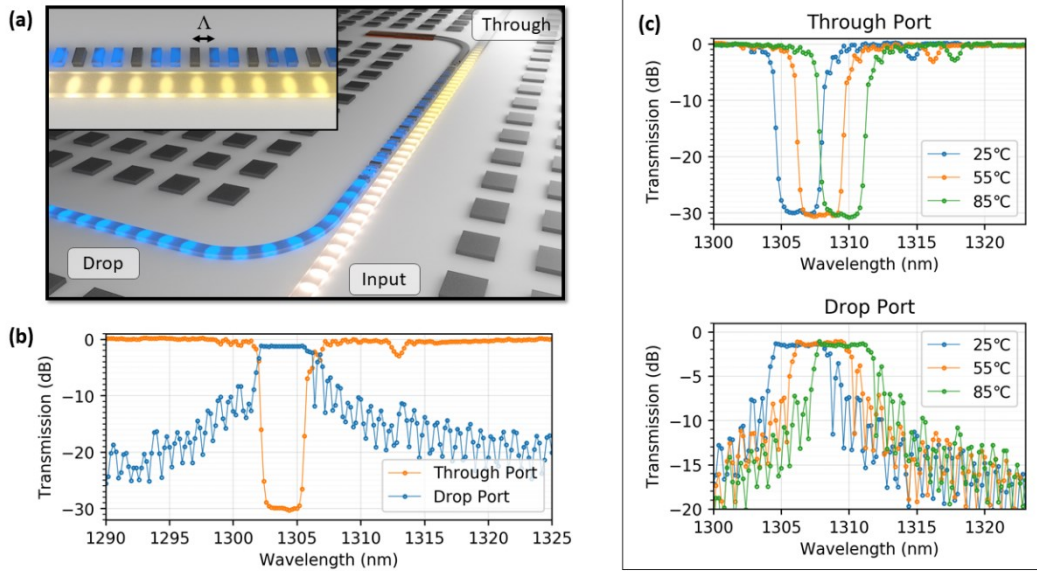


Figure 1: (a) Illustration of SWG filter design with zoomed in inset showing the coupled bus waveguide and grating. (b) Experimental data showing transmission in through and drop ports of a SWG filter fabricated at GF. (c) Transmission at the through port (top) and drop port (bottom) of a fabricated SWG filter at varying chuck temperatures.

3. Experimental Results

The experimental transmission at drop and through ports of fabricated filters is shown in Fig. 1(b,c). The comparison between the drop and through ports shows a flat-top drop channel response with low insertion loss of -1.2dB and a high extinction ratio of $\sim 30\text{dB}$ in the through port. The 3dB channel width is seen to be $\sim 5\text{nm}$.

As active heater tuning is standard in many commercial photonic devices, the thermal response of the SWG filters was tested. Eqn. (1) dictates the drop position is based solely on the pitch and effective index. Hence, the channel position should shift without a spectral shape change. Figure 1(c) shows that by heating the wafer chuck from 25°C to 85°C , the drop channel position can be moved $\sim 4\text{nm}$ without changing the channel shape. This has the potential to significantly reduce MUX/DEMUX heater tuning complexity when compared to interferometric filtering devices, such as AWGs and cascaded MZIs, which often require many heaters and tuning of all channels simultaneously to optimize channel shapes and position. As wafer heating was used in Fig. 1(c), the device temperature may be lower than the chuck temperature indicated. Furthermore, inclusion of integrated heaters may enable increased tunability.

4. Conclusions

We demonstrate manufacturability of SWG filters with a compact footprint ($\sim 0.002\text{mm}^2$), low insertion loss (-1.2dB), high extinction ratio ($\sim 30\text{dB}$) and flat-top response with a 3dB channel width of $\sim 5\text{nm}$ using CMOS foundry fabrication. It is anticipated that incorporating more advanced design techniques will further improve the performance metrics of SWG filters achievable with foundry fabrication, enabling the creation of dense photonic circuits and meeting the standards for the next generation of high performance interconnects.

5. References

- [1] P. Dong, "Silicon photonics integrated circuits for wavelength-division multiplexing applications," *IEEE Journal of Selected Topics in Quantum Electronics* **22** 6100609 (2016)
- [2] C. Sciancalepore, R. J. Lycett, J. A. Dallery, S. Pauliac, K. Hassan, J. Harduin, H. Duprez, U. Weidenmueller, D. F. G. Gallagher, S. Menezo and B. Ben-Bakir, "Low-crosstalk fabrication-insensitive echelle grating multiplexers and passives for the silicon photonics toolbox," *Proceedings Volume 9365, Integrated Optics: Devices, Materials, and Technologies XIX* 936508 (2015)
- [3] S. Dwivedi, P. De Heyn, P. Absil, J. Van Campenhout and W. Bogaerts, "Coarse Wavelength Division Multiplexer on Silicon-On-Insulator for 100 GbE," *2015 IEEE 12th International Conference on Group IV Photonics (GFP)* 15556427 (2015)
- [4] H. Yun, M. Hammood, S. Lin, L. Chrostowski, and N. A. F. Jaeger, "Broadband flat-top SOI add-drop filters using apodized sub-wavelength grating contradirectional couplers," *Opt. Lett.* **44**, 4929-4932 (2019).
- [5] B. Naghdi and L. R. Chen, "Silicon photonic four-channel optical add-drop multiplexer enabled by subwavelength grating waveguides," *IEEE Photonics Journal* **10** 6601510 (2018).
- [6] B. Naghdi and L. R. Chen, "Spectral engineering of subwavelength-grating-based contradirectional couplers," *Opt. Express* **25** 25310 (2017)

This work was funded in part by the National Science Foundation through a GOALI grant (ECCS1809937).