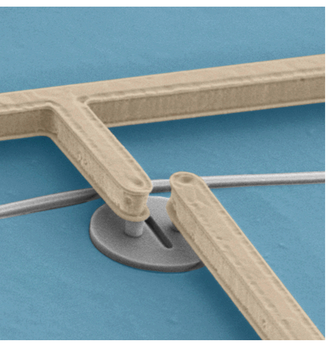
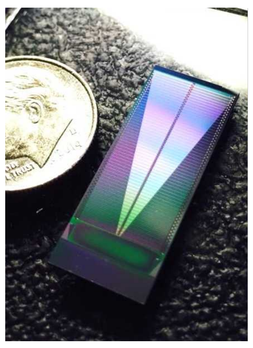
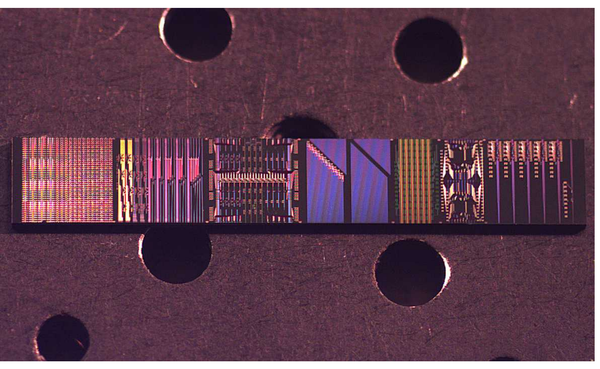
SAND2017-1842D

Silicon Photonics at Sandia





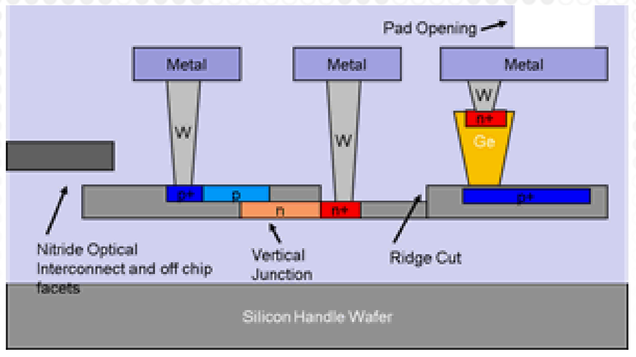


Role of Photonics at Sandia

- Collaborative Research and Innovative Solutions
- Not a Production Facility

Silicon Photonic Process at the MESA Facility

- 6 in. SOI wafers, 250nm device layer, 3 µm buried oxide layer
- Fully or partially etched silicon for rib or ridge waveguides
- 225nm low loss silicon nitride waveguide layer
- Selective area germanium epitaxy for photodiodes
- 4-6 ion implantation steps
- 1-2 aluminum metal layers



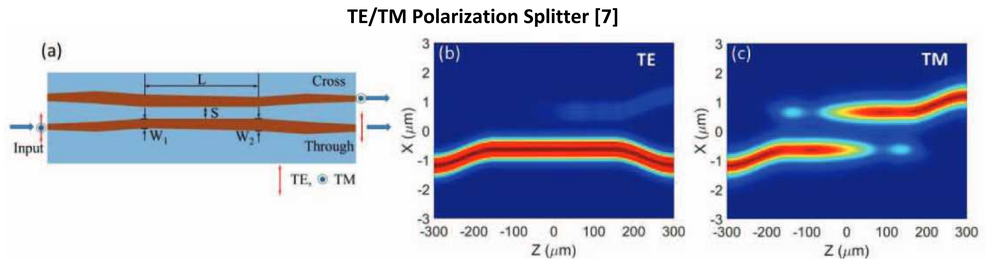
Sandia Designed & Tested Components Available Through PhoeniX Opto-Designer

Passive	Qty	Si Ridge	Si Rib	Nitride	Optimal Performance
Waveguides (Si Ridge, Si Rib, Nitride)	**3**	**X**	**X**	**X**	Si Ridge – <0.7 dB/cm single mode Si Nitride – <3 dB/cm single mode
Edge Couplers	**2**	**X**		**X**	<1 dB/facet Insertion Loss (UHNA Fiber + Index Matching Fluid)
Grating Couplers (1D, Polarization Split, Focusing)	**3**	**X**		**X**	<5dB Peak Insertion Loss
Ridge ↔ Rib Transition	**1**	**X**	**X**		
Ridge ↔ Nitride Transition	**1**	**X**		**X**	
Nitride over Si Crossing	**1**	**X**		**X**	<-44 dB Crosstalk [4]
MMI Couplers	**3**	**X**		**X**	
Adiabatic Couplers	**2**	**X**	**X**	**X**	
Directional Couplers	**1**	**X**			
Polarization Splitter & Rotator	**2**	**X**			
Mode Filter	**1**	**X**			
Micro-Ring Filters (Standard, Adiabatic, Cascaded)	**3**	**X**	**X**	**X**	<1 nm → 75 nm FSR, Q >100,000
Active					
Ge Photodetector	**1**	**X**			>0.8 A/W @ 1.5µm, up to 45 GHz 3dB cut-off [1]
Electro-Optic Mach-Zehnder Modulator	**3**	**X**			
Traveling Wave EO Mach-Zehnder Modulator	**4**	**X**	**X**		24 GHz 3dB cut-off, 0.7Vcm Vπ*L [5]
Thermo-Optic Mach-Zehnder Modulator	**3**	**X**			12.7 mW/pi, >20dB Extinction [2, 3]
Thermo-Optic Phase Shifter	**2**	**X**			12.7 mW/pi [2]
Thermally Tunable Micro-Ring Filter	**3**	**X**			
Electro-Optic Micro-Disk Modulator	**2**	**X**			10GHz/12.5 Gbps, <1V drive
EO Micro-Disk Modulator w/ Thermal Tuning	**2**	**X**			10GHz/12.5 Gbps, <1V drive, 21.3µW/GHz Thermal Tuning [6]

Passive Devices

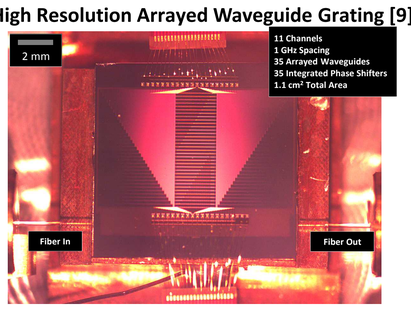
- Multiple types of low loss waveguide
- Edge or grating coupled
- Adiabatic, directional and MMI splitters
- Polarization splitting and rotation

TE/TM Polarization Splitter [7]

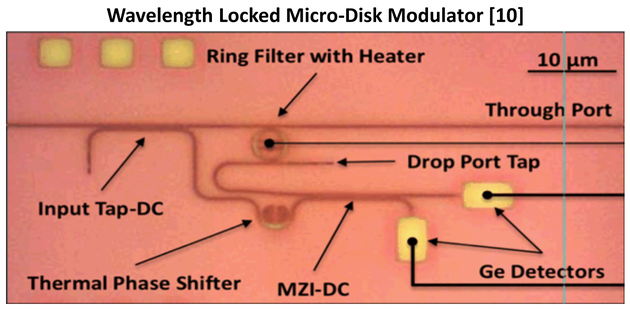


Systems Integration

High Resolution Arrayed Waveguide Grating [9]



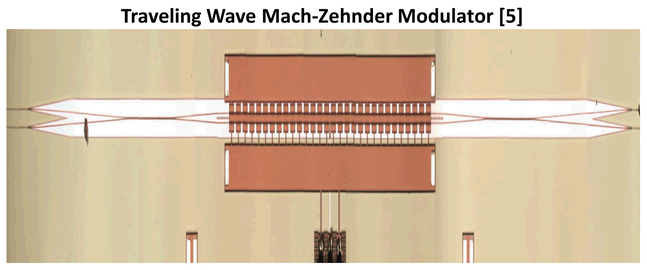
Wavelength Locked Micro-Disk Modulator [10]



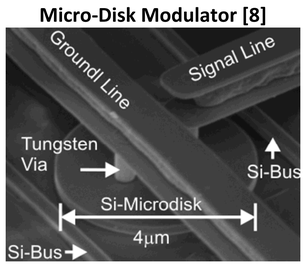
Active Devices

- High speed micro-disk and Mach-Zehnder modulators
- Thermo-optic modulators and phase shifters
- Thermal tuning of micro-rings and disks
- Germanium PIN photodiodes;

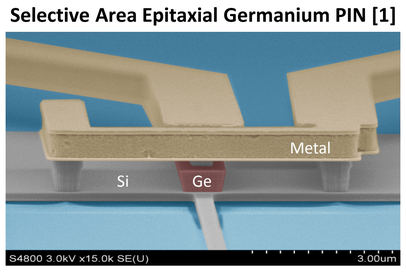
Traveling Wave Mach-Zehnder Modulator [5]



Micro-Disk Modulator [8]



Selective Area Epitaxial Germanium PIN [1]



Preliminary MPW Run Schedule

April, 2017 (Passive & Active Delivery Only)
October, 2017 (Passive, Active & Ge Delivery)
January, 2019 (Passive, Active & Ge Delivery)

Target Delivery After Tape Out

Passive Silicon – 2 Months
Active Silicon – 4 Months
Active Silicon & Ge – 8 Months

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[1] C. T. DeRose, D. C. Trotter, W. A. Zortman, A. L. Starbuck, M. Fisher, M. R. Watts, and P. S. Davids, "Ultra compact 45 GHz CMOS compatible Germanium waveguide photodiode with low dark current," *Opt. Express* **19**, 24897-24904 (2011)
[2] M. R. Watts, J. Sun, C. DeRose, D. C. Trotter, R. W. Young, and G. N. Nielson, "Adiabatic thermo-optic Mach–Zehnder switch," *Opt. Lett.* **38**, 733-735 (2013)
[3] C. T. DeRose, M. Watts, R. W. Young, D. C. Trotter, G. N. Nielson, W. Zortman, and R. D. Kekatpure, "Low Power and Broadband 2 X 2 Silicon Thermo-Optic Switch," in *Optical Fiber Communication Conference/National Fiber Optic Engineers Conference 2011*, paper OThM3.
[4] A. M. Jones, C. T. DeRose, A. L. Lentine, D. C. Trotter, A. L. Starbuck, and R. A. Norwood, "Ultra-low crosstalk, CMOS compatible waveguide crossings for densely integrated photonic interconnection networks," *Opt. Express* **21**, 12002-12013 (2013)
[5] C. T. DeRose, D. C. Trotter, W. A. Zortman, M. R. Watts, "High Speed Travelling Wave Carrier Depletion Silicon Mach-Zehnder Modulator," in *Optical Interconnects Conference, 2012*, paper WC6.
[6] C. T. DeRose, R. Kekatpure, A. Starbuck, A. Pomerene, A. L. Lentine, "A CMOS Compatible External Heater-Modulator," in *Optical Interconnects Conference, 2014*, paper MC3
[7] H. Cai, N. Boynton, A. L. Lentine, A. Pomerene, D. C. Trotter, A. L. Starbuck, P. Davids, C. T. DeRose, "An Adiabatic/Diabatic Polarization Beam Splitter," in *Optical Interconnects Conference, 2016*, paper WC3
[8] M. R. Watts, W. A. Zortman, D. C. Trotter, R. W. Young, and A. L. Lentine, "Vertical junction silicon microdisk modulators and switches," *Opt. Express* **19**, 21989-22003 (2011)
[9] M. Gehl, D. C. Trotter, A. Starbuck, A. Pomerene, A. L. Lentine, C. T. DeRose, "Active phase correction of high resolution silicon photonic arrayed waveguide gratings," *Opt. Express* (Accepted Feb. 2017)
[10] J. A. Cox, A. L. Lentine, D. C. Trotter, A. L. Starbuck, "Control of integrated micro-resonator wavelength via balanced homodyne locking," *Opt. Express* **22**, 11279-11289 (2014)

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