



Sandia
National
Laboratories

Exceptional service in the national interest

Sandia Overview for Integratic Photonics MPW Programs

SAND2019-6366PE



Technology Partnerships with SANDIA NATIONAL LABORATORIES



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SAND2019-5161 C

SANDIA IS A FEDERALLY FUNDED
RESEARCH AND DEVELOPMENT CENTER
MANAGED AND OPERATED BY

National Technology & Engineering
Solutions of Sandia, LLC, a wholly
owned subsidiary of Honeywell
International Inc.: 2017 – present

Government owned,
contractor operated



SANDIA HAS FIVE MAJOR PROGRAM PORTFOLIOS



SANDIA's MESA COMPLEX

MESA= Microsystems Engineering, Science and Applications

Co-joined Fab Facility

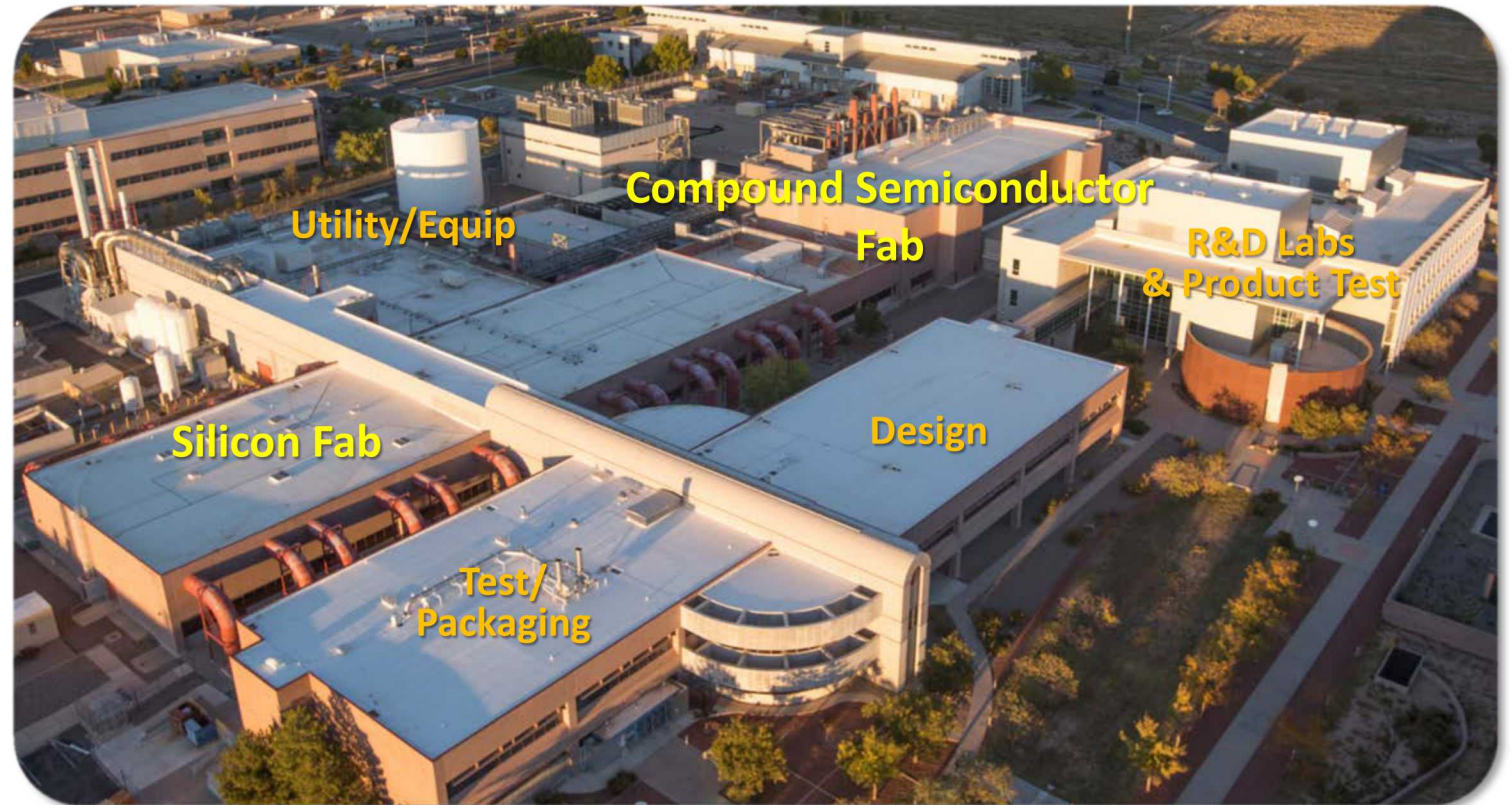
- Silicon Fab
- Compound Semiconductor Fab

Charter:

- design, develop, fabricate, qualify, and produce at low-volume for DOE applications
- conduct leading edge research

Currently dozens of products:

- ASICs, III-V SSICs, MEMS, FPAs, RFICs, Optoelectronics

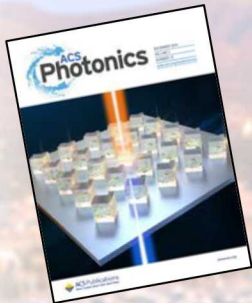


Co-located R&D and Production

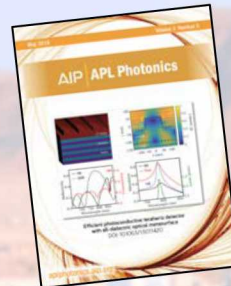
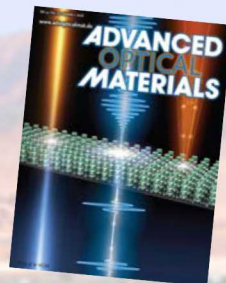
SANDIA's NATIONAL SECURITY PHOTONICS CENTER

Serve the nation as a center of excellence for national security photonics through scientific excellence and innovations and leading-edge integrated photonics solutions

- >60 photonics staff (plus postdocs and students) with expertise in device design, modeling, simulation, epitaxy, device fabrication, integration, assembly, and test
- Partnership with government agencies, industry, and universities
- Technology transfer to industry
- Areas of interests: communication, sensing, computing, imaging, quantum applications



Microsystems
Enabled
Photovoltaics



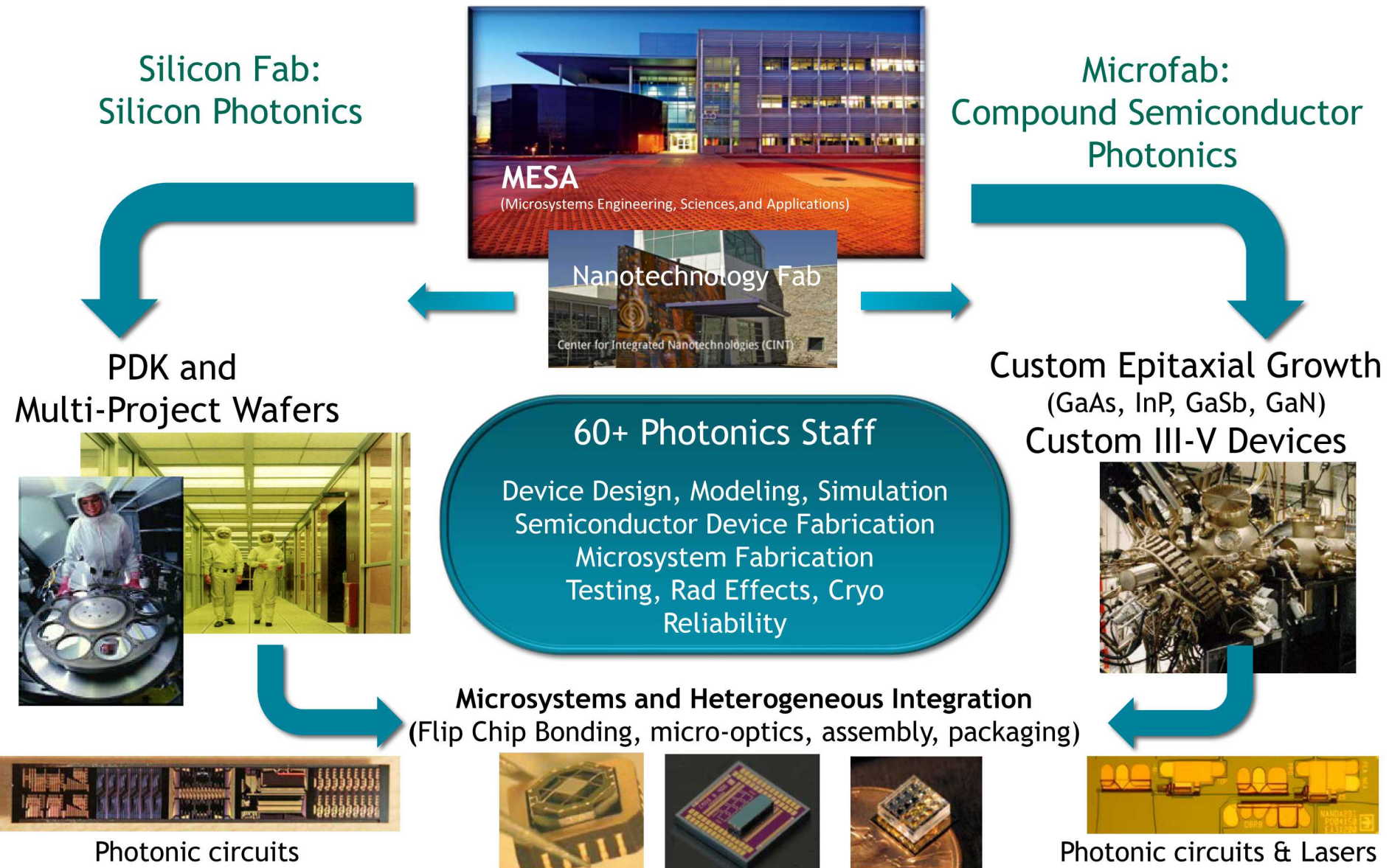
T-QUAKE
(Transceiver for
Quantum Keys
and Encryption)



2009 Ultralow-
power Silicon
Microphotonic
Communication
Platform



SANDIA's NATIONAL SECURITY PHOTONIC CENTER

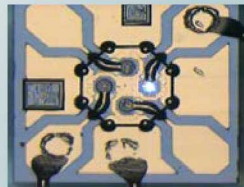


SANDIA's PHOTONIC MICROSYSTEMS

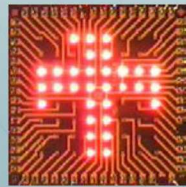
National Capabilities for Advanced Photonics R&D: design, model, fab, package, and test

Materials: Silicon, III-V (Phosphides, Arsenides, Antimonides, Nitrides), Lithium Niobate, Graphene, etc.

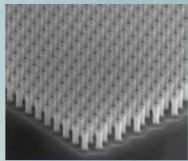
Sources



Single-Frequency
Tunable VCSELs



High Efficiency
VCSELs



Nanowire Laser



High power
GaAs laser

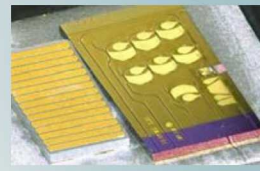
Control / Manipulation



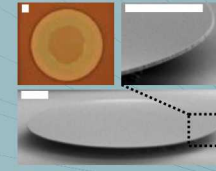
Resonant Optical
Modulator/Filter



Array Waveguide Grating
Channelizing Filter

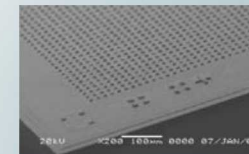


RF Channelizing Filter

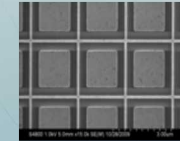


LiNbO3 Freq. Converter

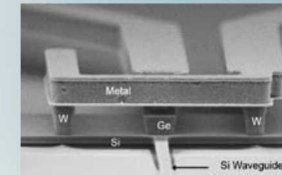
Detection



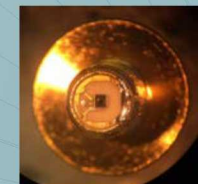
Infrared Detector



Plasmonic Perfect
Absorber



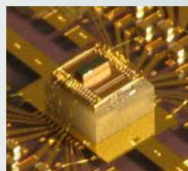
Germanium Detector
on Silicon



X-ray Detector

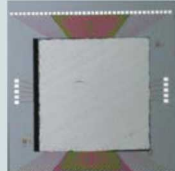
Heterogeneous Integration

III-V on CMOS

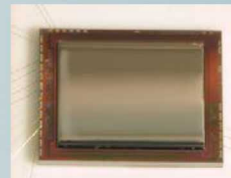


High-speed
Optical Transceivers

CMOS on
Si Photonics

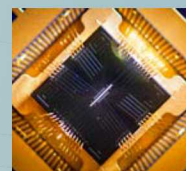


nBn on CMOS

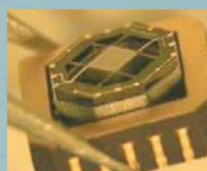


IR Focal Plane Array
w/ ROIC

Chip-scaled MicroSystems



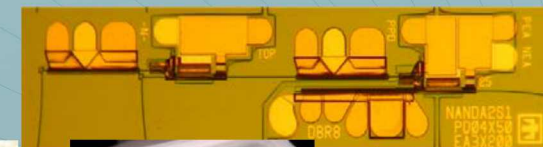
Quantum
Surface Ion Trap



Atomic
Clock



Quantum Key
Distribution Transceiver w/ microlenses



High-speed
All-Optical
Logic



Photovoltaics

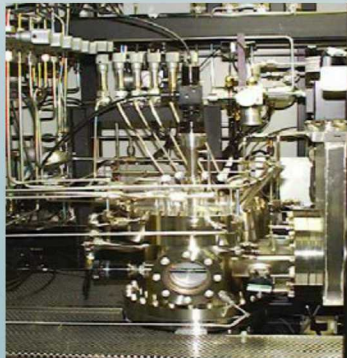
III-V OPTOELECTRONICS CAPABILITIES

Custom, trusted, low-volume, high-reliability products for harsh environments when industry is unwilling or unable to deliver

Custom Epitaxial Growth

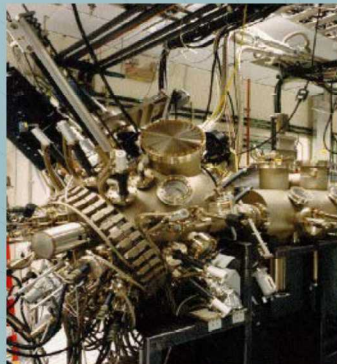
MOCVD:

As, P, Sb,
Ga, In, Al,
Zn, Si, Te,
N, H₂



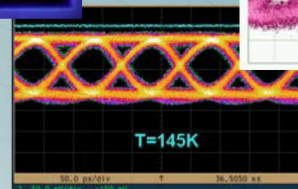
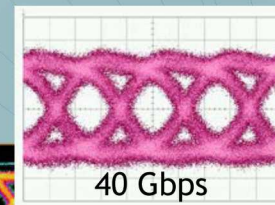
MBE:

Sb, Ga,
As, In, Al,
Si, Be, Te,
N, H₂



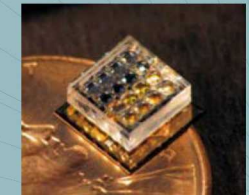
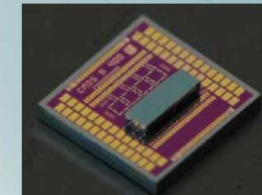
Device Design, Fabrication, and Characterization

- Device design, modeling, simulation
- TRL 1-6+: create, develop, prototype
- Fabrication: 16,600 sq. ft Class 10/100 Cleanroom
- Optical Comm testing to > 40 Gbps
- Cryo-testing
- Reliability and Rad Effects

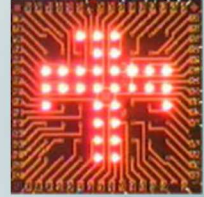


Microsystem Heterogeneous Integration

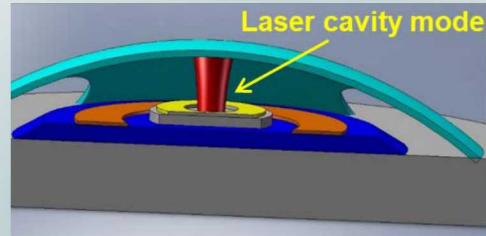
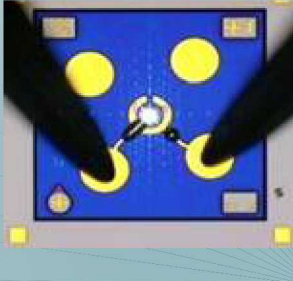
- Flip chip bonding
- Wafer level oxide bonding
- solder dam and bumps
- Grind, thin and polish
- Substrate removal
- Epoxy underfills
- AR coatings
- Micro-optics: diamond turning and molding
- Active alignment
- Dicing, scribe and break



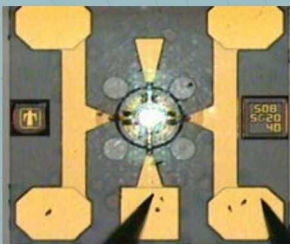
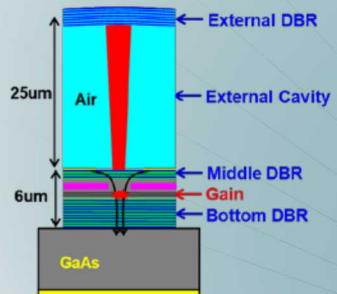
SANDIA's VCSEL RESEARCH and GaAs CAPABILITY



VCSEL



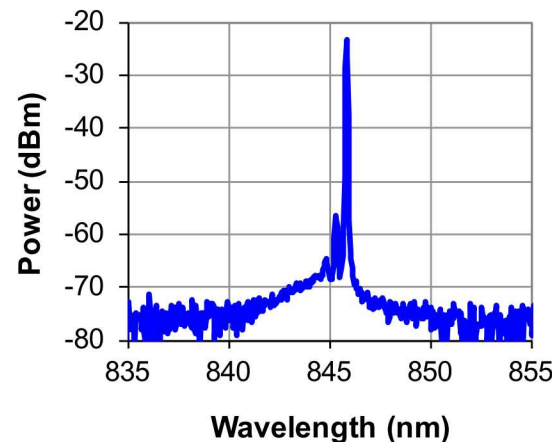
VECSEL Schematic



Narrow Line Width VECSEL

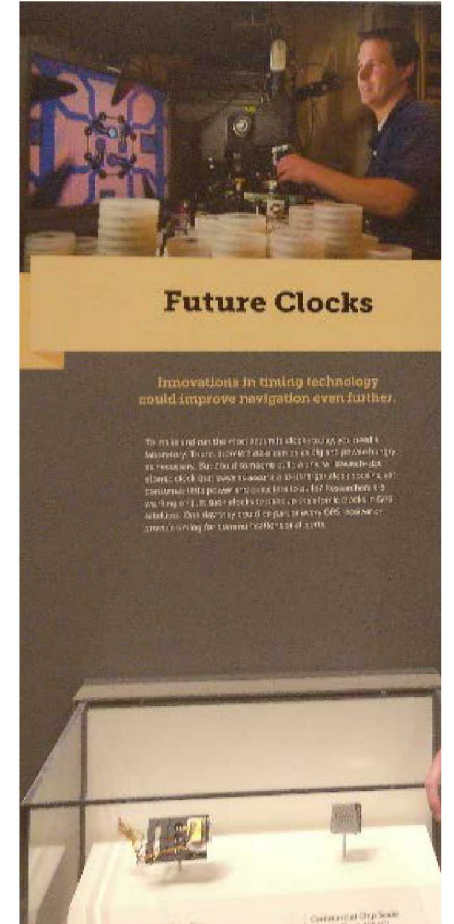
Sandia develops custom VCSELs & Photodiodes for emerging applications

- Innovative VCSEL research since 1990 with on going R&D and production
- Special VCSELs developed for atomic clocks
 - Narrow linewidth (<10MHz)
 - Technology transferred: Commercialized as a chip scale atomic clock, now manufactured Microsemi.
 - Current work focuses on VECSELs
- Custom VCSELs for high speed, high efficiency, cryogenics, and sensing



Chip Scale atomic clock technology transferred to industry

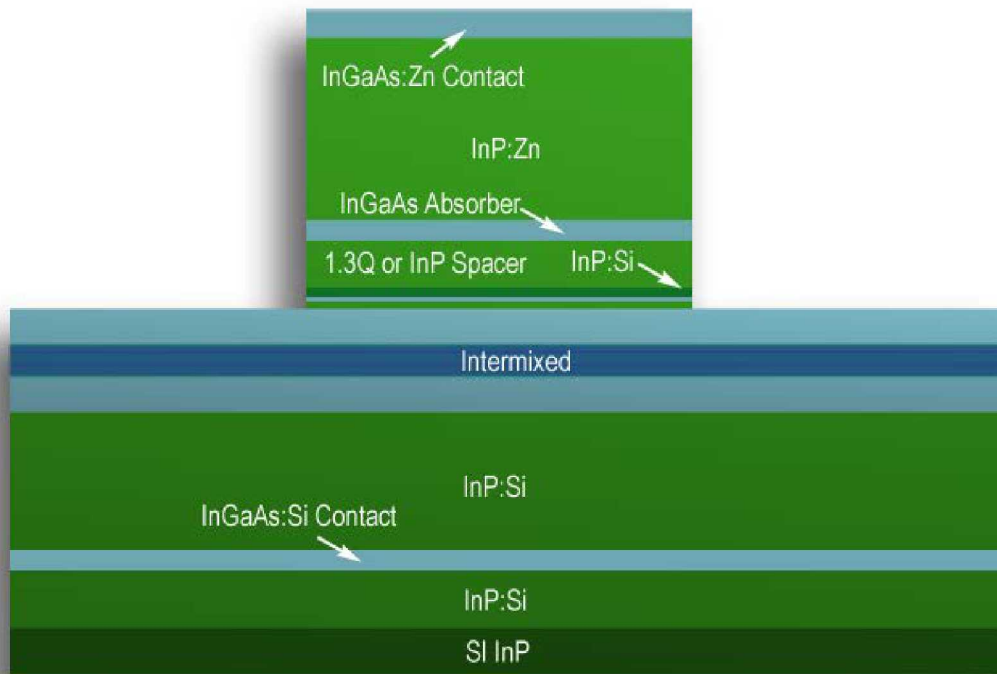
Smithsonian Air and Space Museum Exhibit
(Sandian Darwin Serkland (poster))



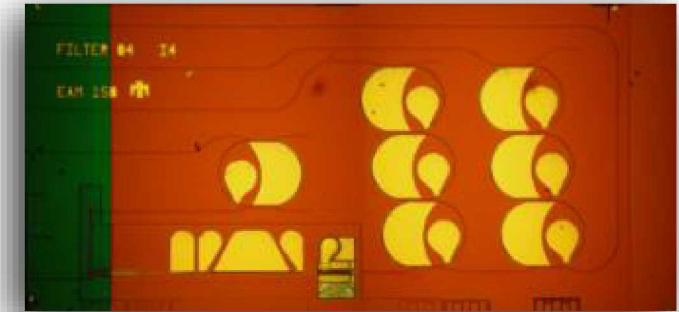
SANDIA's InP PIC CAPABILITY

InP-based Photonic Integrated Circuits

- Multiple band-edges by quantum-well-intermixing and/or regrowth
- Single and/or multiple epitaxial regrowth(s)
- Top-side n-type and p-type contacts
- Ridge, buried, and/or deep etch waveguide architectures



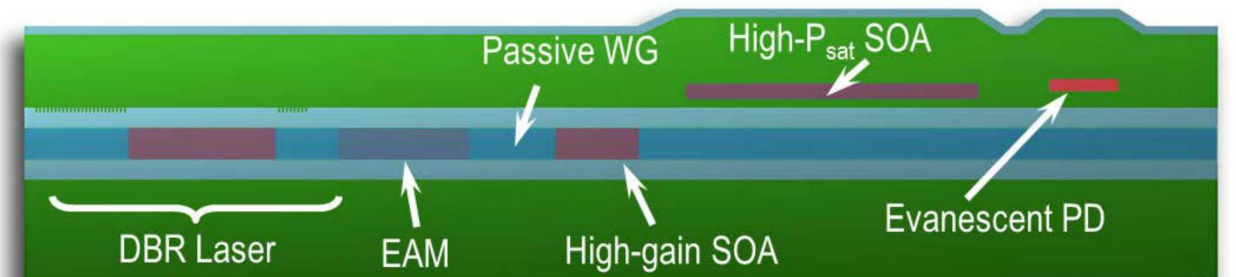
Device Cross-section (Lateral)



RF-Optical Channelizing Filter
1-20 GHz RF on C-Band Light



On-Chip Injection Locking
Enhanced Modulation > 50 GHz, C-Band



Device Cross-section (Longitudinal)

SANDIA's InP 'Design-Guided' Multi-project Wafer Runs

Sandia now offers an InP MPW program:

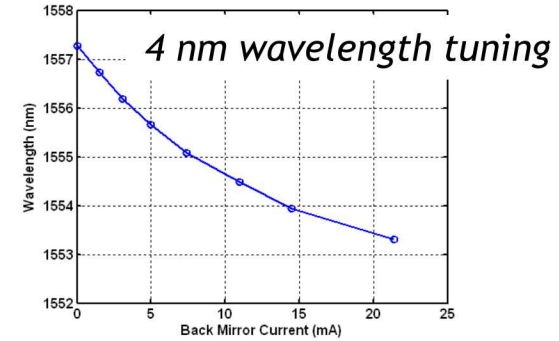
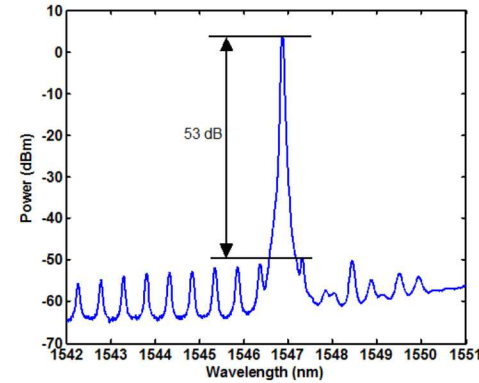
- Designs are being accepted through 9/2019 for the next run.

For more information:
email photonics@sandia.gov

Process		Tier 1	Tier 2	Tier 3
Description		One MOCVD regrowth	Two MOCVD regrowths	Full custom process
Lasers	Tunable (~5 nm)	YES	YES	YES
	Tunable (~40 nm)	YES	YES	YES
SOA	High Gain (dB/cm)	400	400	400
	High P _{sat}	NO	YES	YES
Detectors	R (A/W)	0.8	0.8	0.8
	P _{in} saturation (dBm)	15	15	15
	Bandwidth (GHz)	> 20	> 40	> 40
Wave-guide	Propagation Loss (dB/cm)	< 2	< 2	< 2
	Turning mirror loss (dB)	N/A	< 0.5	< 0.5
EA-Modulator	Length (μm)	125	125	125
	Efficiency (dB/V/cm)	800	800	800
	Loss (dB)	< 1	< 1	< 1
	Bandwidth (GHz)	> 20	40	40
MZ-Modulator	Electrode Length (μm)	250	250	250
	Efficiency (V _π)	2	2	2
	Loss (dB)	~1	~1	~1
	Bandwidth (GHz)	> 20	> 20	> 40
Phase Modulator	Length (μm)	200	200	200
	Efficiency (°/V)	20	20	20
	Loss (dB)	< 1	< 1	< 1
	Bandwidth (GHz)	> 20	> 20	> 40

Inaugural Device Library

InP PIC Example: High-Speed Electrical-to-Optical (EO) Transmitter



InGaAsP Diode laser and modulator chip

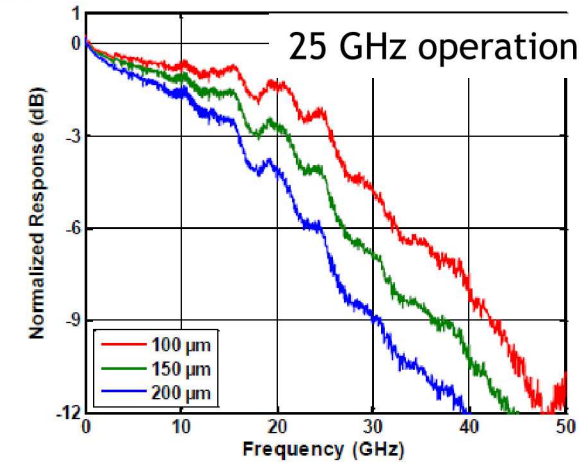
- DBR lasers
 - 6 mW fiber-coupled power
 - ~20 mW out from chip
 - 4 nm wavelength tuning
- EAMs
 - Efficiency ~19dB/V DC
 - Bandwidth 20GHz

Wavelength tuning

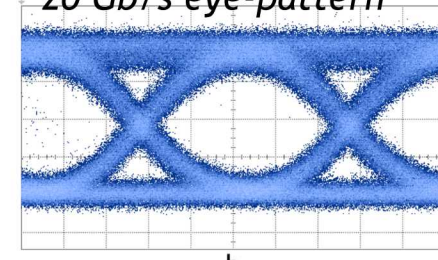
- Track filter frequencies
- Tune to WDM channels

Power for RF photonics
Wavelength agility

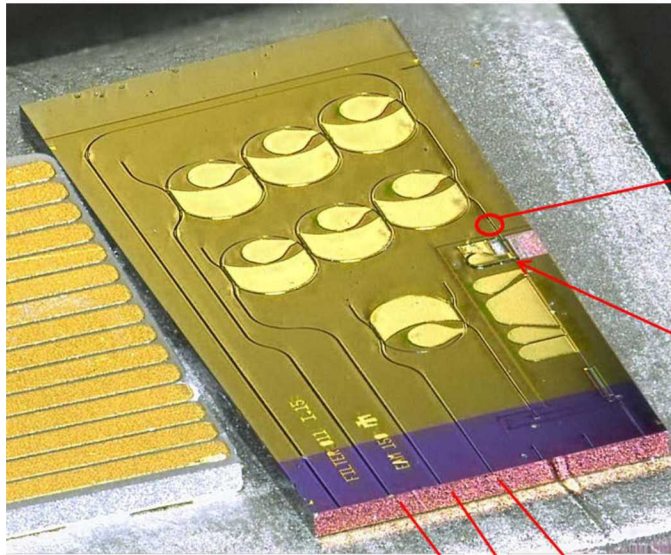
Scalable to mm-wave



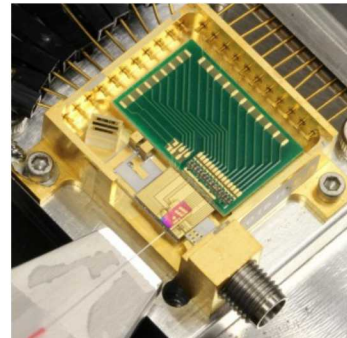
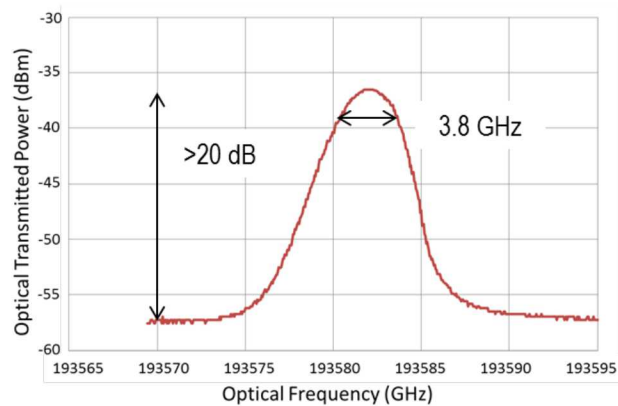
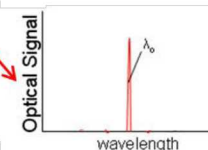
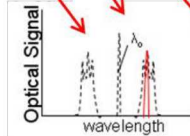
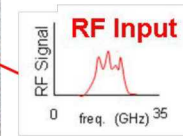
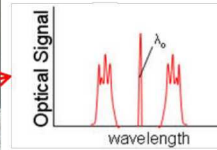
20 Gb/s eye-pattern



InP PIC Example: Optical RF Channelized Receiver



InGaAsP
Chip Size
3.5x1.5 mm



Analyze an RF signal for frequency content

- Filter outputs are spectral power density integrated over the filter bandwidth

Compact, highly functional photonic integrated circuits (PICs) features:

- 3-pole ring resonator filters
- Tunable over 10's GHz
- GHz-class pass bands
- 65 GHz free spectral range
- Integrated laser-modulator
- Signal to EAM provides the RF input
- Integrated extra filter for wavelength monitoring

SILICON PHOTONICS CAPABILITIES

- Leverage existing CMOS infrastructure (200mm SOI)
- Low Power, High Speed Devices
- Low Loss Optical Waveguides (<0.1 dB/cm)
- Two waveguide interconnect layers:
silicon and silicon nitride
- Selective Area Germanium Epitaxy for PIN/APDs
- 39 issued patents

Multi-project wafer runs

- Collaborative and custom work within or outside of MPW
- Academia, industry, other government entities
- Typical block size: 4 mm x 26 mm
- Three Deliverables:
 - 1) passive (Si+SiN), 2) Passive+ Active,
 - 3) Passive+ Active+ Germanium

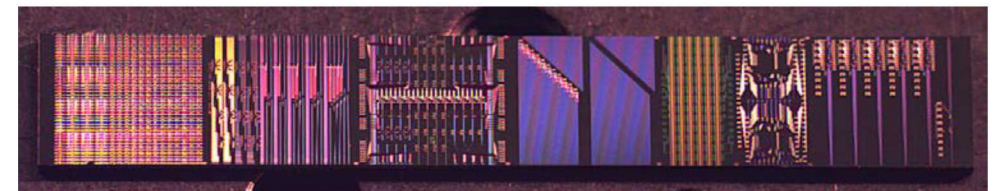
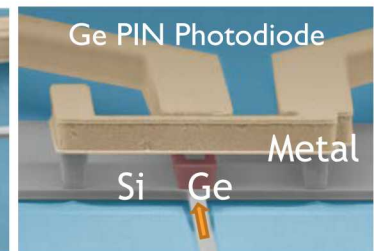
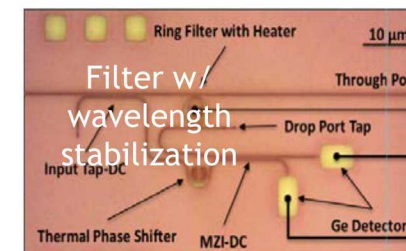
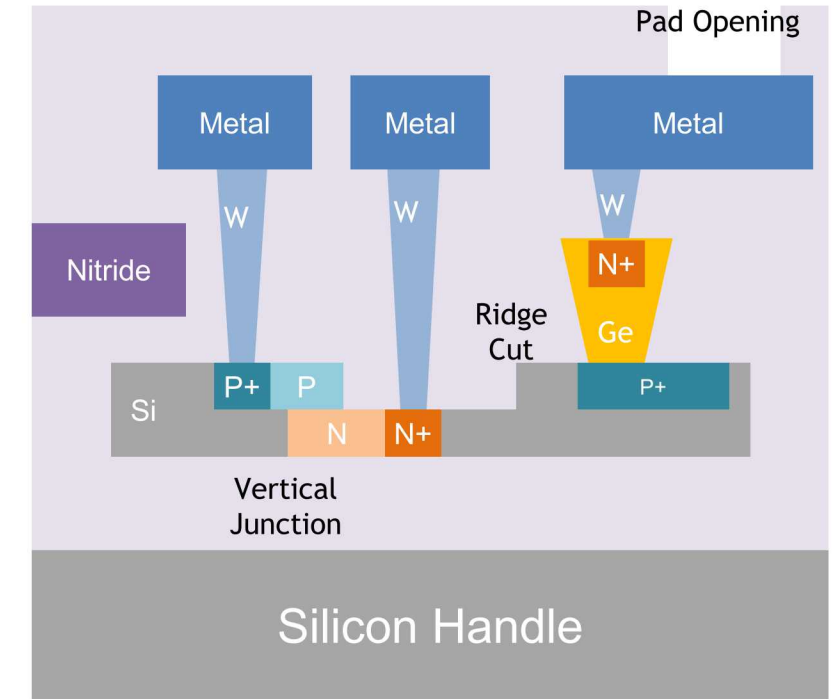


Image of MPW run, supporting Columbia, U of AZ, UC Berkeley, UCSD & Caltech

For more information:
email photronics@sandia.gov

SNL SILICON PHOTONICS LIBRARY

1st Rev. in Synopsis Optodesign Software)

22 Passive Devices

- Si rib and ridge waveguides (including transitions, auto routing, phase aware routing)
- Nitride waveguides (si to nitride transitions)
- Si rings [6] (standard, adiabatic, cascaded)
- Grating couplers (1D & 2D)
- Edge couplers (silicon, SiN)
- Waveguide crossings (nitride over silicon)
- Beam splitters (amplitude and polarization, MMI, adiabatic and directional couplers)

20 Active Devices

- Disk modulators (different size, dopants)
- Disk modulators and filters with heaters (int. & ext.)
- Ring modulators (adiabatic)
- Thermal phase shifters
- Thermal and electro-optic traveling wave MZM
- Ge PIN detectors

Design Tools & Features

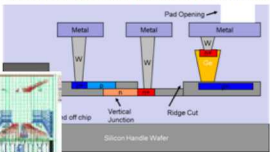
- Design Guide
- Library (GDS/Scripted)

SNL Silicon Photonics Design Manual

4. TECHNOLOGY OVERVIEW

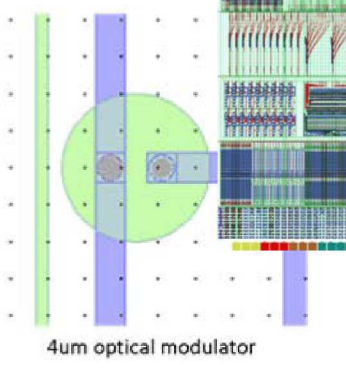
Sandia National Laboratories (SNL) has developed a Microsystems and Engineering Sciences Applications (MESA) facility located in a limited classified area. Trusted custom fabrication of silicon and radiation-hardened process technologies for digital, analog and mixed signal ICs is currently available through MESA, which delivers production micro-electronics components to support special DOE and DOD programs. The MESA Complex is designed to integrate the numerous scientific disciplines necessary to produce functional, robust, integrated microsystems and represents the center of SNL's investment in microsystems research, development, and prototyping activities. This suite of facilities encompasses approximately 400,000 square feet and includes cleanroom facilities, laboratories and offices.

More recently, a silicon photonics process (SPP1) has been engineered and matured in the MESA facility, a cross section of which can be seen in Figure 4-1. The silicon photonics process is an electro-optical silicon photonic integrated circuit platform built on silicon on insulator (SOI) wafer technology. Included within SPP1 are two waveguide interconnect layers on a crystalline substrate.



A cartoon illustration of the cross-section of the SPP1 process with a subset of possible implant configurations. low energy optical modulators [4], high modulators [6] and the resonant frequency

5-1. The base process can be broken



4um optical modulator

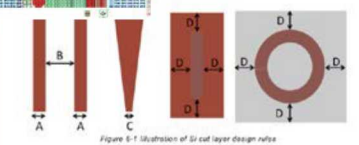




Figure 5-1: Illustration of Si cut layer design rules

Device Library

Contents Search

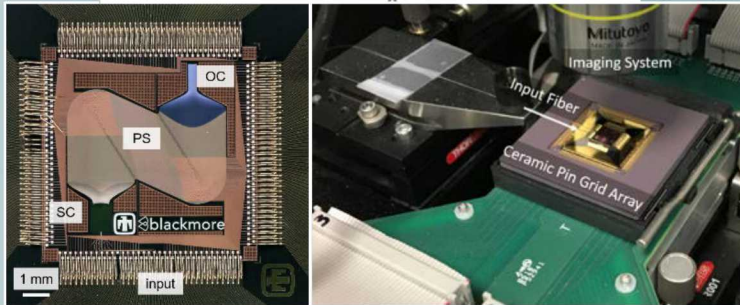
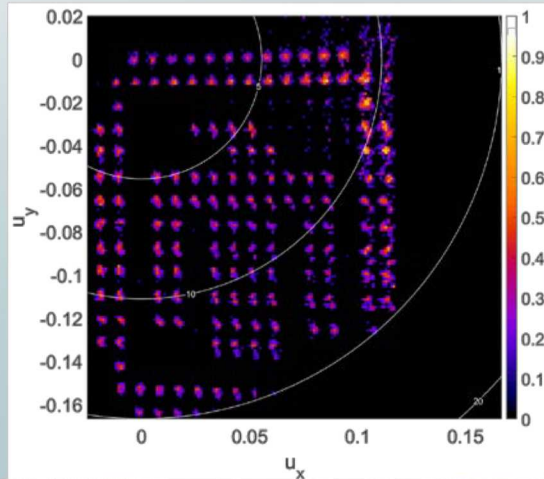
- Database
- SANDIA
 - Transitions
 - sandiaSiRidge_SiRib
 - sandiaSiRib_SiRidge
 - sandiaSi_SiN4
 - sandiaSiN4_Si
 - Crossings
 - sandiaCrossingSi_SiN4
 - Phoenix
 - Splitters&Combiners
 - sandiaMMI2x2
 - sandiaMMI1x2
 - sandiaMMI2x1
 - Miscellaneous
 - px_automatic_instance
 - Specifics
 - sandia_smartStraight
 - Fibercouplers
 - pxFocusingGrating_Coupler
 - Splitters&Combiners
 - sandiaDirectionalCoupler
 - sandiaAdiabatic3dB_splitter_RIB
 - sandiaAdiabatic3dB_splitter
 - Miscellaneous
 - SandiaPassive_MZI
 - Polarization Components
 - sandiaPolarization_SplitterRotator
 - Fibercouplers
 - sandia_1D_Grating_Coupler
 - sandia_2D_Grating_Coupler
 - sandia_Si_EdgeCoupler
 - sandia_SiN4_EdgeCoupler
 - Contacts
 - sandiaDC_Pad
 - sandiaGSG_Pad
 - Filters
 - sandiaModeFilter
 - sandiaMicroringFilter
 - sandiaMicroringFilter_orderN
 - sandiaAdiabaticRingTunableFilter
 - Modulators
 - sandiaMicroDiskModulator
 - sandiaSmallMicroDiskModulator
 - sandiaMicroDiskHeaterModulator
 - sandiaThermalMZM
 - sandiaEOMMZM
 - sandiaTWMZM
 - PhaseShifters
 - sandiaThermalPhaseShifter
 - Detectors
 - sandiaPhotoDiodr
 - PDA-BB
 - Crossing
 - BaseDesign

SYNOPSYS®

Image of MPW run, supporting Columbia, U of AZ, UC Berkeley, UCSD & Caltech

* Synopsis may provide other generic components in addition.

CHIP-SCALE OPTICAL BEAM STEERING



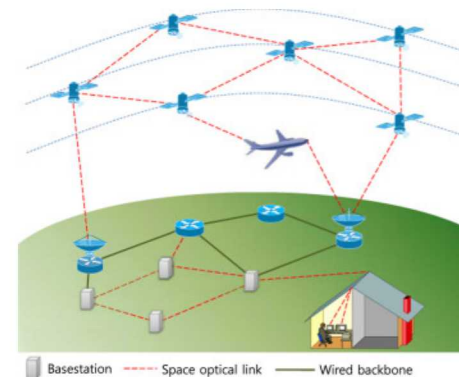
Phase Optimization of Si Photonics
2D Electro-optic Phased Array
(CLEO -Thur May 9 JTh2A.39)

2D Silicon Photonic Optical Beam Scanner

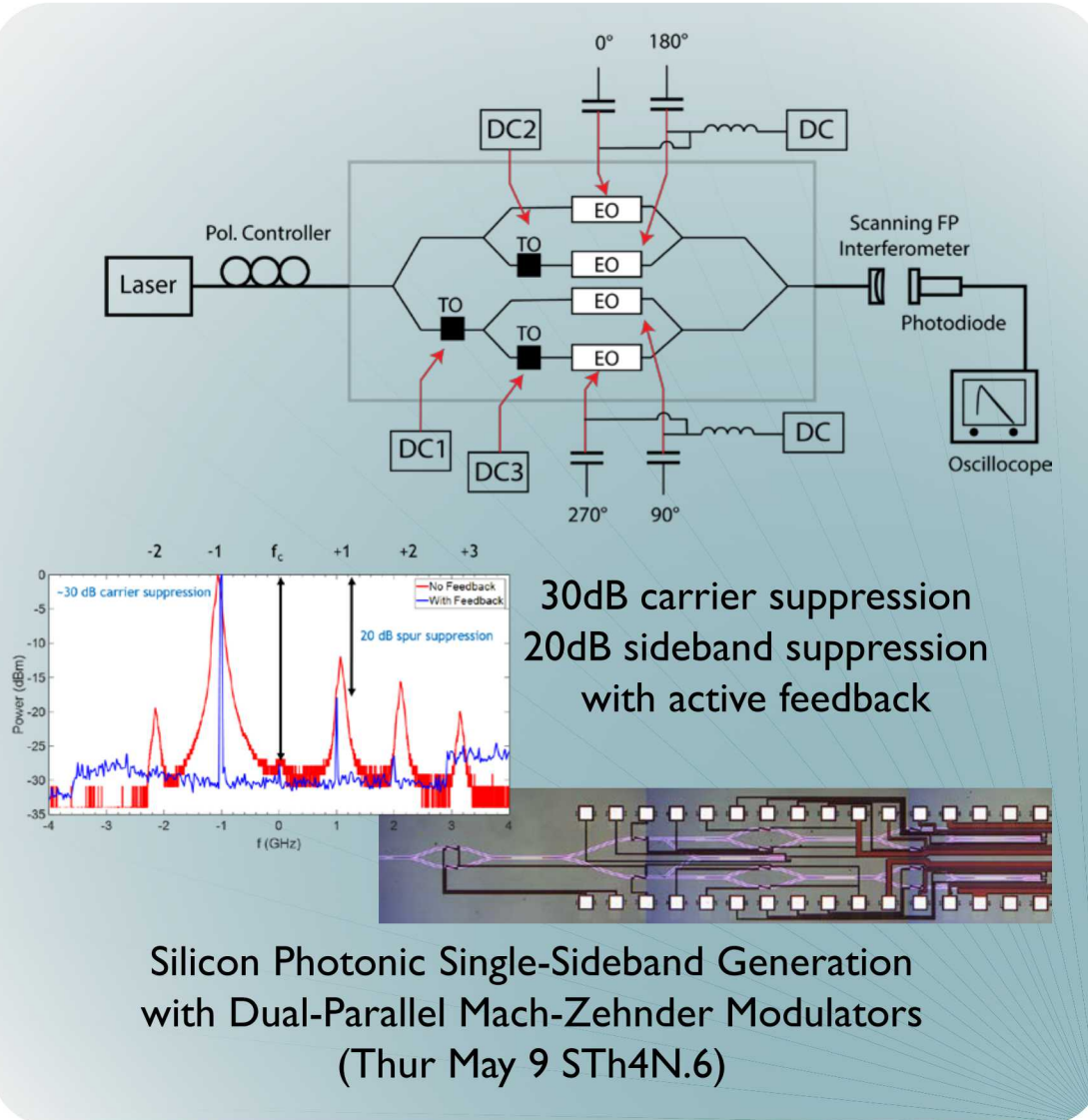
- Electronic (low-power EO phase shifter) and wavelength steering
- field of view: $24^\circ \times 10^\circ$; divergence angle: $0.3^\circ \times 0.3^\circ$
- 256 independent channels with 3-mm pitch
- Area: 750mm x 750mm with high fill factor

Applications

- Imaging and sensing
- Free-space communication



SILICON PHOTONICS OPTICAL SINGLE-SIDEBAND MODULATOR



Frequency shifting/conversion for many applications

- high-resolution spectroscopy
- dense wavelength division multiplexed (D-WDM) networks
- atom interferometry / quantum sensing

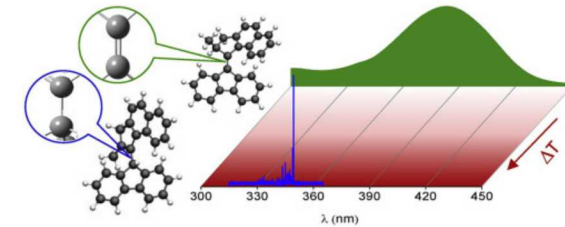


Photo Credit: Tetrahedron, 73(33, pp. 4887-4890, Aug 17, 2017

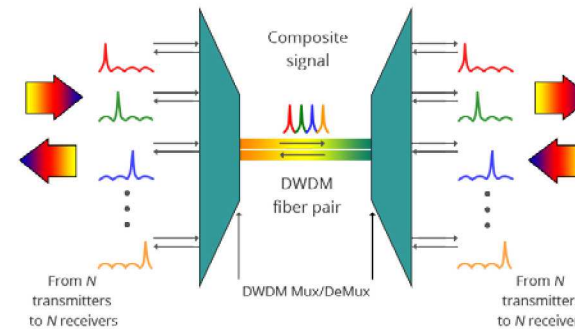


Photo Credit: <https://community.fs.com/blog/an-overview-of-dwdm-technology-and-dwdm-system-components.html>

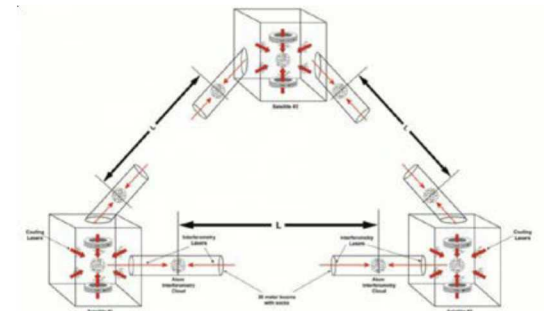
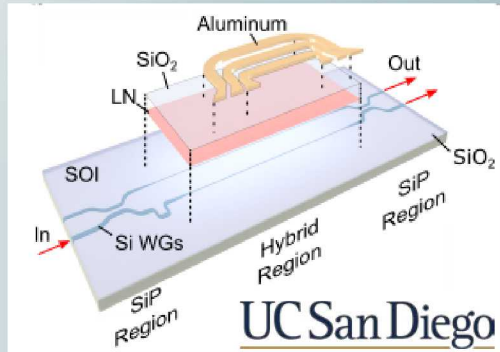


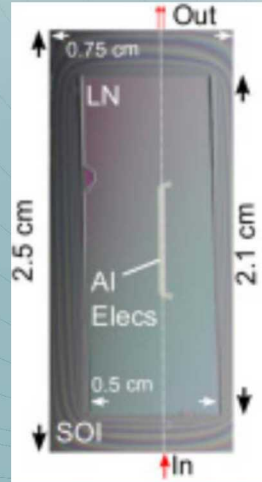
Photo Credit: <https://www.nasa.gov/content/atom-interferometry-for-detection-of-gravity-waves-a/>

INTEGRATED SILICON PHOTONICS for RF SIGNAL PROCESSING

Optics Express 26 (18), 23728-23739, July 2018



Lithium Niobate on Silicon
100+GHz Bandwidth demonstrated

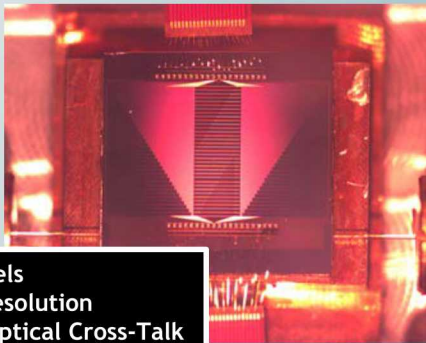


Photonic processing of RF signals provides significant reduction in SWAP-C for high frequency applications (>40 GHz)

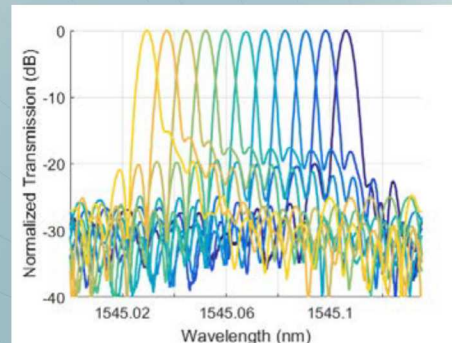
Applications in space and avionic platforms for electronic warfare and situational awareness

- Frequency up/down-conversion
- Antenna remoting
- RF over fiber
- Wide-band channelization
- Low loss RF delay lines

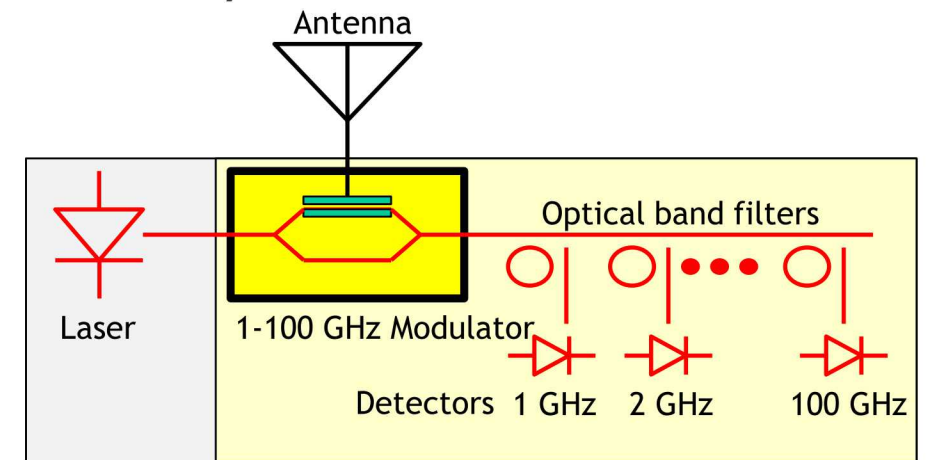
Optics Express 25 (6), 6320-6334, Mar. 2017



11 Channels
<1 GHz Resolution
<-15 dB Optical Cross-Talk
1.1 cm² Total Area

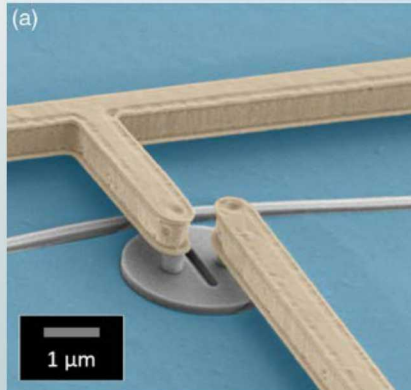


1st Demo of 1GHz RF Channelization in a Si Photonics Array Waveguide Grating

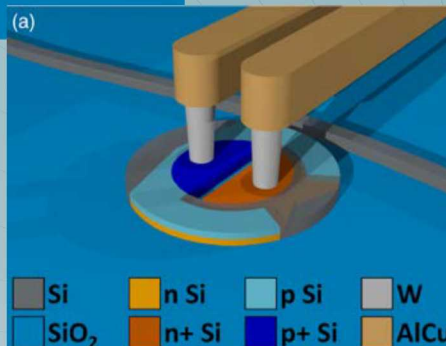
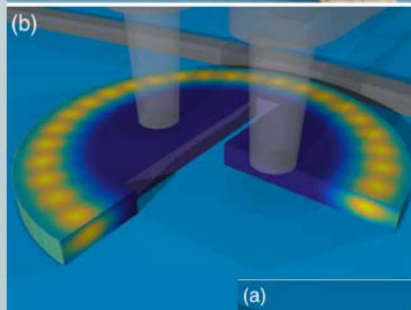


Example integrated wide-band channelizer

CRYOGENIC OPTICAL INTERCONNECT

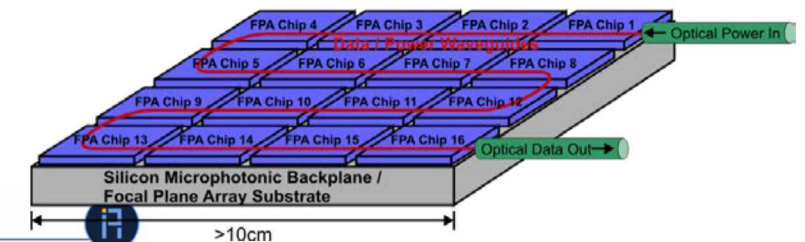


Optica 4, 374-382 (2017)

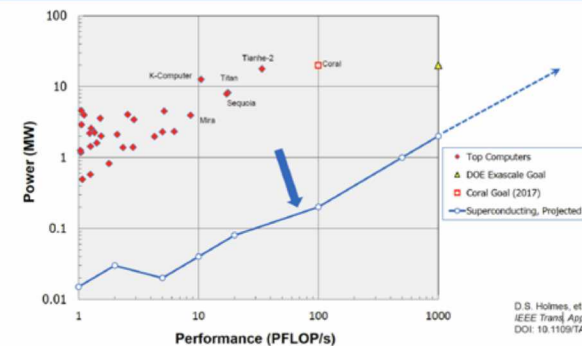


High-speed low-power resonant modulator operating at cryogenic temperatures (50K, 4K, and below)

- Superconducting Computing
- Optical backplane for focal plane array



DARPA Superconductor computing looks promising



D. B. Holmes, et al.
IEEE Trans Appl Supercond
DOI: 10.1109/TASc.2013.2244634

DARPA Interconnect Requirements (Superconductor HPC)

Desirable architectural metrics for supercomputers designed for floating-point-intensive applications

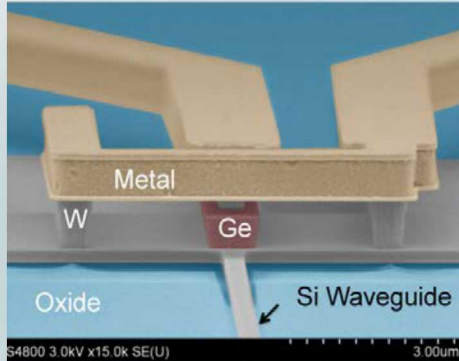
- Main memory: 0.1 to 1 B s/FLOP
- Main memory latency (access time): < 100 cycles
- Main memory data access rate: 1 B/FLOP
- Input/Output data rate: 10^{-5} to 10^{-3} B/FLOP
- Parallelism: fewer processors is generally better

	1	10	100	1,000
I/O data rate ^a (Tbit/s)	0.8	8	80	800
Channels ^b , 20 Gbit/s	80	800	8,000	80,000
Power leads	c	c	c	c
Input data	c	c	c	c
Cache memory access	18 mW	180 mW	1.8 W	18 W
Main memory access	9 mW	90 mW	0.9 W	9 W
Output data	10 mW	100 mW	1.0 W	10 W
Drivers, eSFQ-to-DC ^d	0.024	0.24	0.002	0.024
Ribbon cable to 40 K ^e	8.3	83	0.83	8.3
VCSEL array at 40 K ^f	0 ^g	0 ^g	0 ^g	0 ^g
Interconnects, total	0.1 W	1 W	10 W	100 W
I/O budget	0.4 W	3 W	30 W	300 W

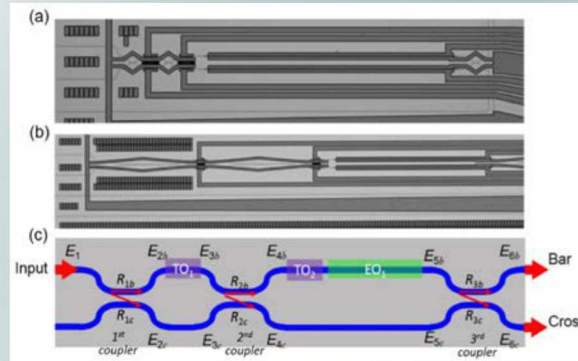
^a Specified using the mid-range I/O data rate (10^{-5} B/FLOP) (8 bit/B).
^b Channel capacity is 2 times the specified I/O data rate.
^c No estimate made. ^d [47].
^e Vertical-cavity surface-emitting laser (VCSEL) heat load is less than refrigerator intermediate stage capacity, so no effect on 4 K capacity.

D. Scott Holmes DARPA MTO Program Manager
2nd Photonics and Electronics Technology for Extreme-scale Computing (rePETE) Workgroup presentation 2019-05-02

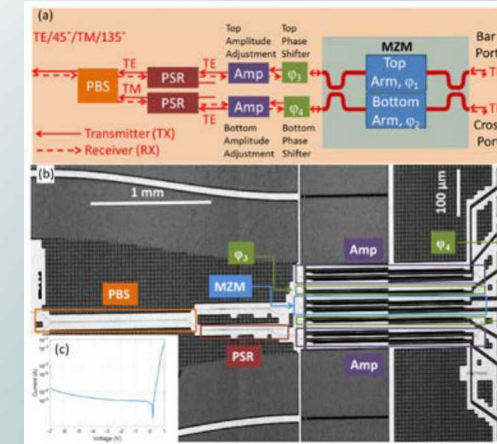
INTEGRATED PHOTONICS for QUANTUM COMMUNICATION



Geiger-mode APD
for single photon detection



High-speed (10GHz) high-extinction ratio (>65dB)
silicon amplitude modulator for CV QKD & Q-Sensing



Phys. Rev. X 8 (021009), 1-12, April 2018



T-QUAKE
(Transceiver for
Quantum Keys
and Encryption)

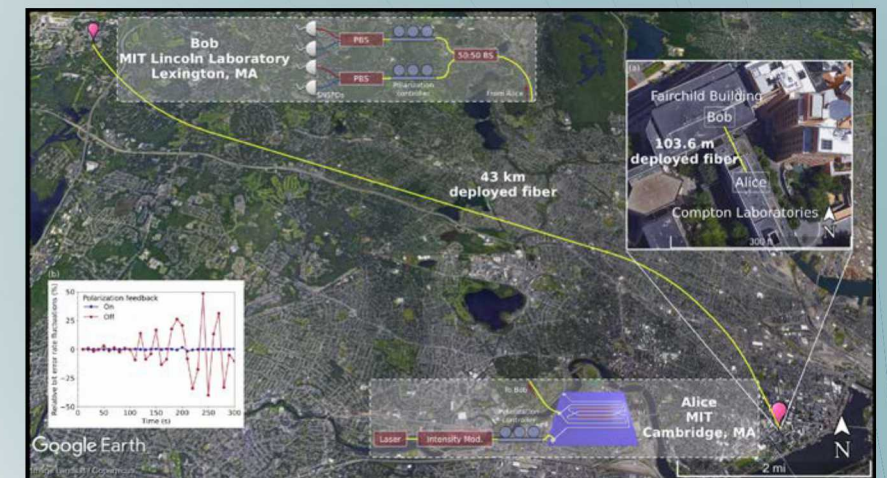
Sandia's silicon, III-V, alumina, lithium niobate heterogeneously integrated photonic platforms enable compact microsystems for telecom. and visible wavelengths

Many foundational building blocks for advancing quantum science have been or are being developed

- detectors, modulators, frequency converter, amplifiers, optical transceivers, etc.



Alumina ring
filter /waveguide
for visible
wavelength

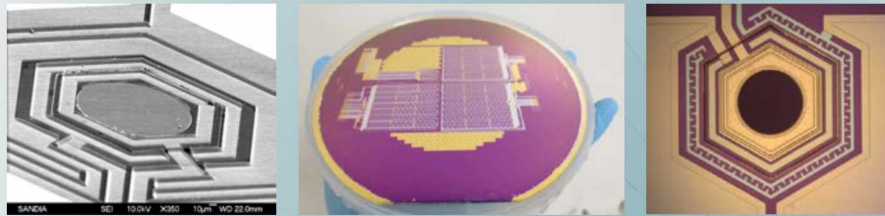


High-speed polarization-based DV QKD
field tests (BB84) demonstrated

*FedBizOpps Announcement: Technology Commercialization Opportunity:
Partnership Opportunity for On Chip QKD Technology Development:
16_462 9/29/2016*

HETEROGENEOUS INTEGRATION CAPABILITIES

Microsystem-Enabled Photovoltaics

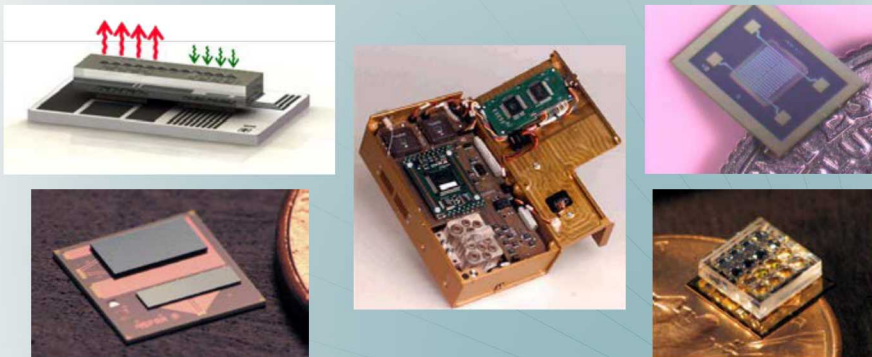


- wafer-level bonding for multi-junction solar cells
- InGaAsP/InP and InGaP/GaAs devices on silicon
- dielectric interfaces with III-V substrate removal
- integration with collection optics

Heterogeneous integration enables miniaturization with independent material and device optimization

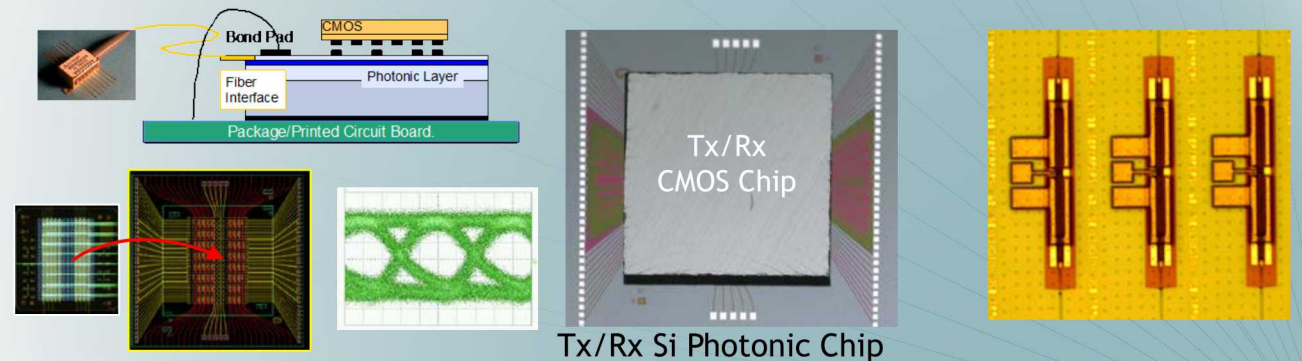
- Integration of LiNbO₃ and III-V Lasers on Silicon Photonics
- Non-traditional materials such as Al₂O₃, Epsilon-Near-Zero In₂O₃ and CdO, graphene
- Integration of CMOS with InGaAsP/InP, InGa/GaAs, Silicon Photonics, and other materials

Optical and MEMS-based Microsensors



- chemical and bio sensors using MEMS and SAW devices
- g-hard optical microsensors with in-house photonics
- hybrid device integration with custom micro-optics

CMOS / Silicon Photonics / III-V Integration



- silicon photonics on high-speed silicon ASIC
- independent optimization of electronics & photonics
- Gain and laser sources on silicon

Photonics Partnerships

Examples of industry and academia partnerships

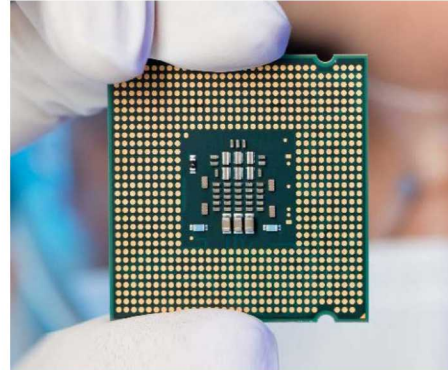


HISTORY OF TECHNOLOGY TRANSFER SUCCESS



Cleanroom

Sandia's invention of the original modern-day cleanroom led to \$50 billion worth of laminar-flow cleanrooms being built worldwide within only a few years.



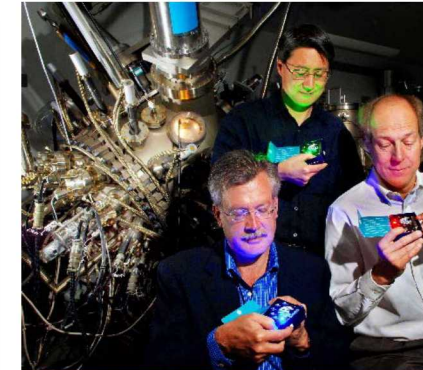
Microelectronics & Semiconductors

Sandia helped revolutionize the semiconductor industry by licensing LIVA/TIVA, VCSEL, EUVL, and 3D-stacking technologies to some of the world's leading semiconductor manufacturing companies.



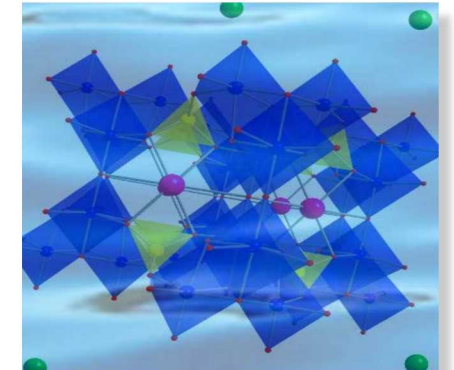
Decon Foam

A Sandia-developed chemistry for neutralization of chem/bio warfare agents that was first used for the anthrax attacks of 2001, is now being used by multiple companies for rapid decontamination applications.



Solid State Lighting

Sandia's early R&D of solid-state lighting has helped establish a global industry for LED/OLED technologies in which improved efficiencies could lead to \$120B in estimated annual global energy savings.



Crystalline Silico-titanate (CST)

Sandia's CST technology was used by UOP, LLC to remove radioactive material from more than 43 million gallons of contaminated wastewater at Japan's damaged Fukushima Daiichi nuclear power plant.



Synthetic Aperture Radar (SAR)

Sandia has worked extensively with General Atomics to deploy Sandia's SAR systems for the US military and other customers. One version of the technology has been uncovering IEDs in Afghanistan and Iraq since 2009.

COLLABORATION WITH SANDIA

Federal agencies can engage in an interagency agreement with NNSA to obtain the Labs' unique services under Sandia's management and operating contract with DOE/NNSA.

Non-federal entities may enter into a variety of technology partnerships agreements with Sandia:

- Commercial License Agreement
 - ~40 Silicon photonics patents
 - >60 III-V patents
 - >15 metamaterials patents
- Cooperative Research and Development Agreement (CRADA)
- Strategic Partnership Projects/Non-Federal Entity (SPP/NFE) Agreement

BLACKMORE SENSORS AND ANALYTICS

"Working with Sandia has provided Blackmore a window into the future of beamscanning technology for autonomous vehicle lidar. Sandia is helping us to realize practical technology solutions to present technology challenges."

— Stephen Crouch
CIO
Blackmore Sensors and Analytics, Inc.

Smaller Imaging System a Big Improvement for Self-Driving Cars

CHALLENGE
Autonomous vehicles, or cars that drive radar to see other cars, people, and the and reflected light—rely on mechanical parts. These moving parts add weight on autonomous vehicles would be no. This would help lidar slim down from a car components.

COLLABORATION
Blackmore Sensors and Analytics is part driving systems. The company is a pioneer in licensing Sandia's chip-scale optical technology.

Sandia's ability to design, simulate, fabricate, and test integrated silicon photonics technology is a key component of Blackmore's advanced lidar technology for commercial autonomous vehicles.

SOLUTION
The integrated chip technology simplifies the manufacturing process, allowing large scale production at a significantly lower cost with reduced production times. Sandia is currently perfecting the fabrication and packaging process, which will be transferred to a commercial foundry for mass production when complete. Fabrication of prototype chips is being conducted at Sandia's Microsystems and Engineering Sciences Applications (MESAP) Complex.

IMPACT
Unlike lidar systems that rely on mechanical parts to steer a laser beam, the Sandia-developed optical array integrates beamsteering onto a single chip, allowing Blackmore to produce a compact lidar system with significantly reduced power requirements, increased longevity and improved durability. The integrated chip technology leverages the decades of photonics innovations by researchers at Sandia's National Security Photonics Center (<https://www.sandia.gov/nscphotonics/>).

PARTNERSHIP TYPE: Cooperative Research and Development Agreement (CRADA) and License
GOAL: Developing a chip-scale lidar system for use in commercial autonomous vehicles.



Sandia's Microsystems and Engineering Sciences Applications (MESA) for silicon photonics, III-V photonics, CMOS, and compound-semiconductor device fabrication, and heterogeneous integration

**Sandia
National
Laboratories**

Learn about Photonics at Sandia:

National Security Photonics Center

sandia.gov/mstc/nspc

**Avalanche
Photodetector**

**QKD
Transceiver**

**AWG RF
Channelizer**

IR FPA with ROIC

**Photovoltaics
w/microlenses**

3-D Metamaterials

**III-V on Silicon
Optical Amplifier**

Collaborate with us!

Visit us:

- @ CLEO Booth 1324
- On-line: sandia.gov/mesa/nspc

Email contact:

- Photonics@sandia.gov

Career Opportunities for staff and students:

- www.sandia.gov/careers