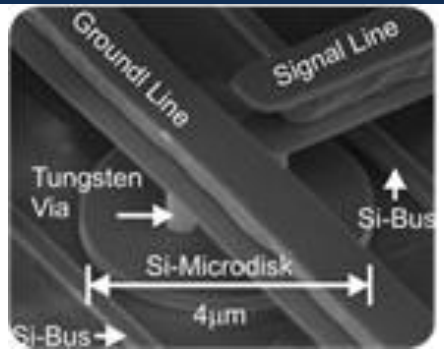
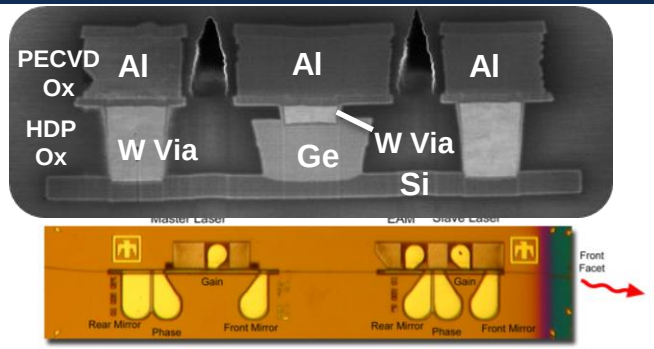
Exceptional service in the national interest

Sandia National Laboratories





Sandia National Laboratories and the Integrated Photonics Innovative Manufacturing Institute (IP-IMI)

F. B. (Rick) McCormick, Ph.D.
Sr. Manager: Microsystems Process Science & Technology Group
Microsystems Science, Technology & Components Center
fbmccor@sandia.gov 505.284.1209

Andrew Pomerene
Silicon Photonic Integration
R&D Science and Engineering
atpomer@sandia.gov 505.844.4788

http://www.sandia.gov/mstc/IPIMI

U.S. DEPARTMENT OF ENERGY | National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2011-0439P

Why Sandia and the IP-IMI?

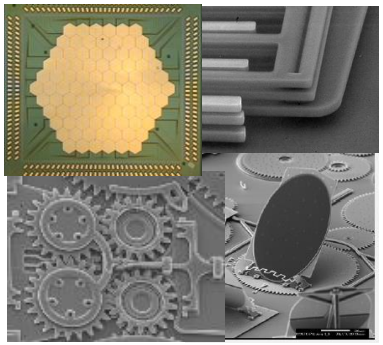
Sandia National Laboratories

- **Expertise**: >20 years in III-V & Silicon Photonics R&D:
  - Toolboxes for internal and contract R&D
- **Capability**: Large flexible Si & III-V R&D Fab, Production rigor:
  - 65kft^2 fab, 10 epi reactors, >60 photonics staff, (60% Ph.D.)
  - Here today, here tomorrow…(NW IC deliveries)
  - Secure environment & staff, robust info-control (TRUST)
- **History of Technology Transfer to Industry**:

Processes → Devices → Subassemblies → Systems

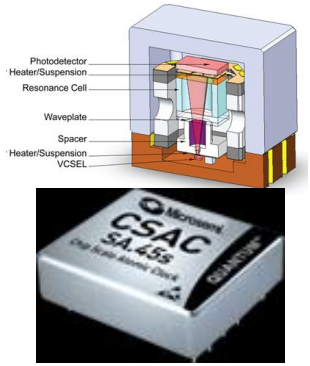
MEMS (Fairchild)

Transfer of Sandia's Summit IV™ MEMS technology. Network Photonics Optical MEMS



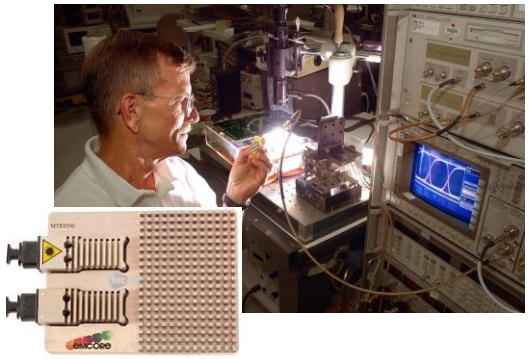
VCSEL CSAC (Microsemi)

Narrow λ temp-stable VCSEL for Chip-scale Atomic Clock (DARPA)



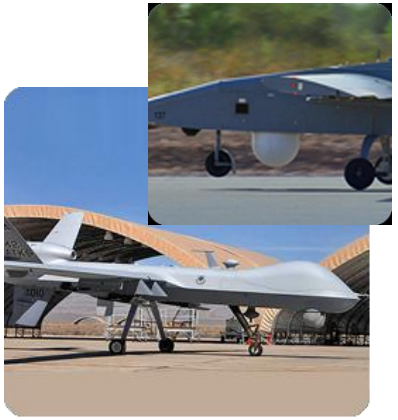
POM (EMCORE)

OC-192 Transponder Parallel Fiber Optic Module prototype development using VCSEL & PD arrays



SAR (General Atomics)

Copperhead & Lynx SAR (w/ GA Aero) on TigerShark & Predator UAVs (IED detector being transferred to Army)



What is Sandia National Lab?

Sandia National Laboratories

1950s	1960s	1970s	1980s	1990s	2000s	2010s
NW production engineering & manufacturing engineering	Development engineering Vietnam conflict	Multiprogram laboratory Energy crisis	Missile defense work Cold War	Post–Cold War transition Stockpile stewardship	Expanded national security role post 9/11	LEPs New START Evolving national security challenges

- DOE FFRDC: Initially Z-division of Manhattan Project (Non-nuclear Components, Weaponization of NEP)
- **National security tech transition**: Gov't Agencies (&/or Academia) ➔ SNL ➔ Industry
- DOE supports our "Strategic Partnership Projects" (with Industry & other gov't agencies (OGAs))
- Our Big 3: **Non-compete with Industry, Fairness of Opportunity, No Organizational Conflict of Interest**
- Managed by LMC, but see OCI above
- **CRADAs with many Defense Contractors, Many STTRs & SBIRs, BAA response teaming**
- **Experience handling sensitive & proprietary information**

Microsystems and Engineering Sciences Applications (MESA): 400,000 Sq-ft Complex with >650 Employees in Secure Facility

Sandia National Laboratories

- Trusted Digital, Analog, Mixed Signal & RF Integrated Circuits Design & Fabrication
- Custom IC Design
  - Secure microcontrollers
  - Sensor Readout ICs
  - Analog/Digital/RF
  - IBM Trusted Foundry
  - Tamper Resistant
- Micromachining
- RAD Effects and Assurance
- Failure Analysis, Reliability Physics
- Test & Validation
- 3-D Integration Features

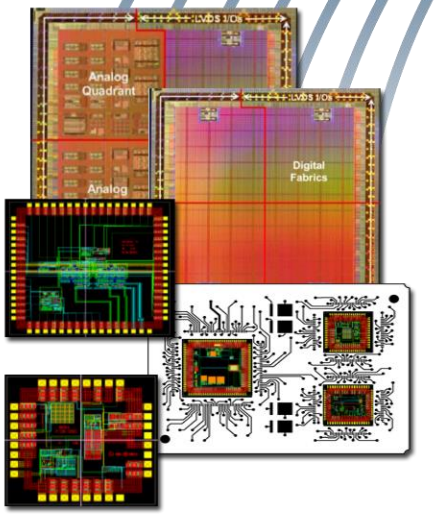
- Advanced Computation
- Modeling & Simulation
- COTS Qualification
- Advanced Packaging
- Custom Electronic Components
- System Design & Test

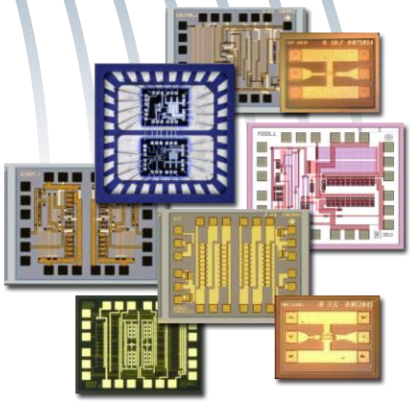
- Compound Semiconductor Epitaxial Growth (UV-THz)
- Photonics: Si & III-V
- MEMS, VCSELs, Plasmonics
- Specialized Sensors, FPAs
- Materials Science, Graphene
- Nanotechnology, Chem/Bio
- Heterogeneous-Technology Integration & Processing
- III-V Semiconductor Devices
  - Rad-Hard µElectronics
  - Rad-hard Optical Links
  - Solid-State RF Devices
  - GaN Power Electronics

MESA is an FFRDC-based development and production facility for any microsystem component or technology that cannot or should not be obtained commercially.

MESA manufactures strategic radiation-hardened trusted components for Nuclear Weapons

Sandia National Laboratories





Radiation Hardened ASICs
- **>25,000 deliveries**

Rad-Hard III-V µElectronics
- **>150,000 deliveries**

TRUST environment (NW, DMEA)

Strong Failure Analysis/Reliability

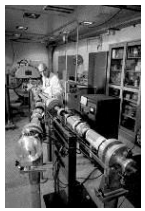
R&D enables and sustains Sandia's Radiation-Hardened Microelectronics/Microsystems Capability

Sandia National Laboratories

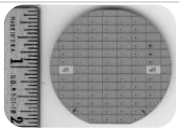
Impact

Research

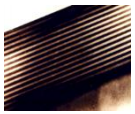
Facilities



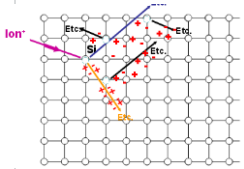
Establishment of Research Program. (1956)



Radiation-Hardened CMOS (1975)



Strained Superlattice (1982)



Ion-Implantation Science (1970s)

Laminar Flow Clean Room (1960)

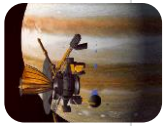
First RH Lab (1972)

SDL Fab (1976)

CRM (1983)

CSRL (1986)

MDL Si Fab (1988)

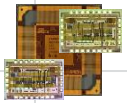


Design/Build Galileo ICs (1985)

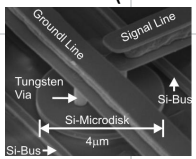
B83 (1982)

5-Level MEMS (1995)

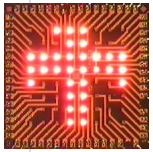
Burst Detection (2004)



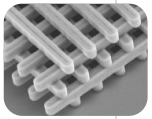
RH ASICs for W76-1 & W80 (2005)



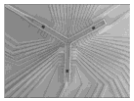
Si Phot (2009)



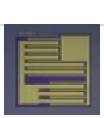
VCSEL (1995)



Photonic Lattice (1998)

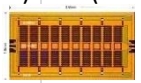


Ion Trap (2005)



W80 HBT (2006)

MEMS W80 JTA (2011)



GaAs, InP uElect (2013-2021)

RH uelectronics (2013-2021)

ViArray (2009)

Trusted Foundry (2009)

MESA Micro Fab (2006)

MESA Si Tools (2005)

Si Fab Revitalization (2012-2018)

RH Foundry/CHIP^2 (2027)

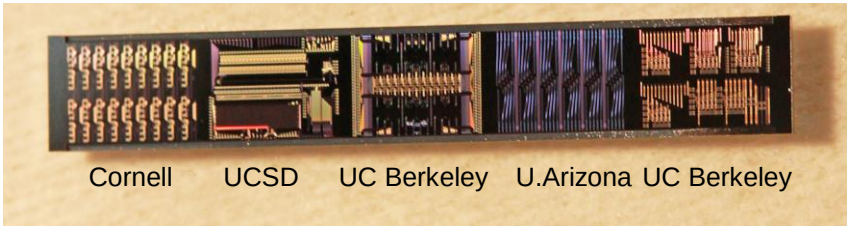
Product deliveries & R&D for 40 years
>370 Active Patents
42 R&D 100 Awards
Commercial spinoffs
Seminal rad-hard microelectronics & photonics contributions

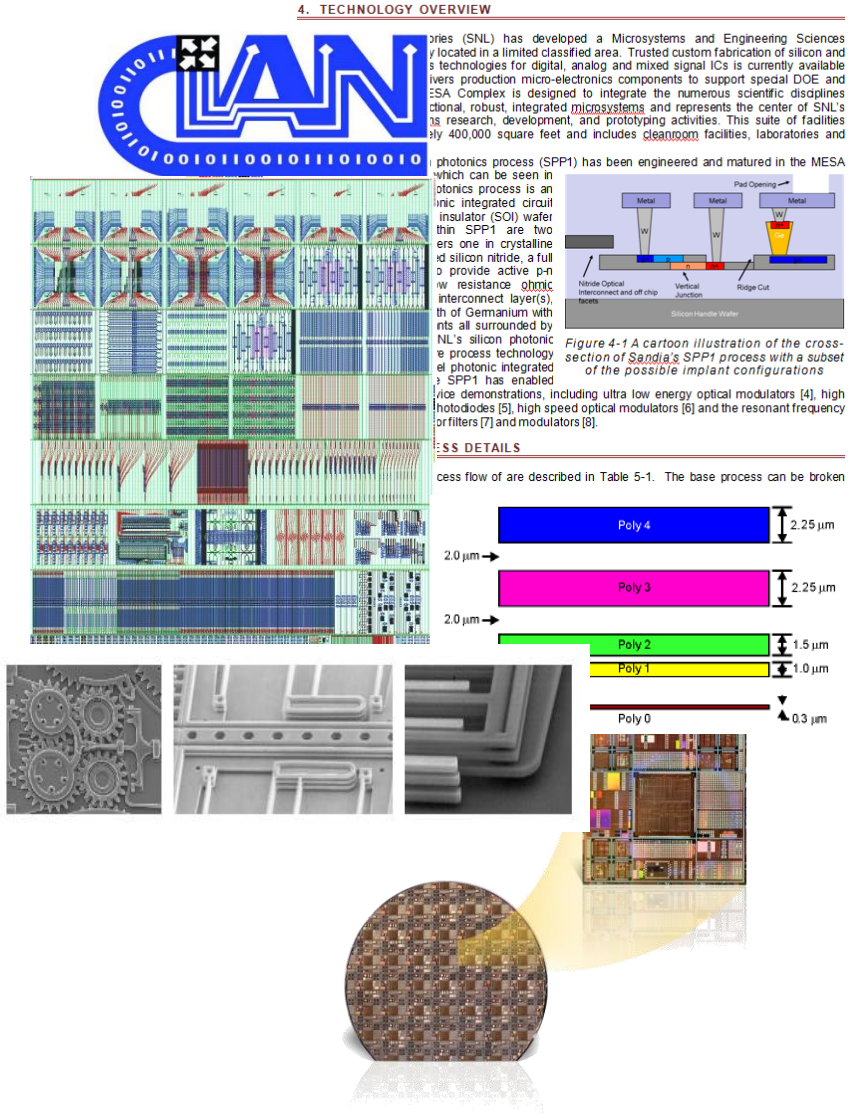
1958 1970 1980 1990 2000 2010 2020 2030

MISSION: Invent and mature integrated circuit and microsystems technologies that provide differentiation and impact for NW and other national security missions

Sandia and MPW Fabrication

- **SUMMIT V: 5 layer polysilicon MEMS process**
  - Developed design manual, DRC, many MPWs over the last decade
- **CMOS7 Electronics:** Rad-hard, mixed-signal ASIC/ViaArray: 0.35um, 3.3V core, 3.3V I/O, Cadence, MPWs since 2009
- **SPP1 Silicon Photonics Process:**
  - 250nm Si/3000nm BOx
  - fJ/bit mods, 45 GHz dets, filters, etc.
  - SiN 2-layer guides/xovers
  - Design manual, initial DRC, pilot MPW runs

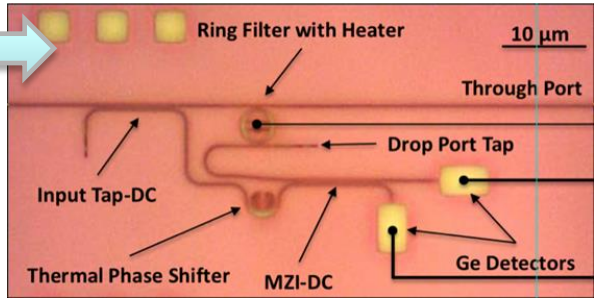


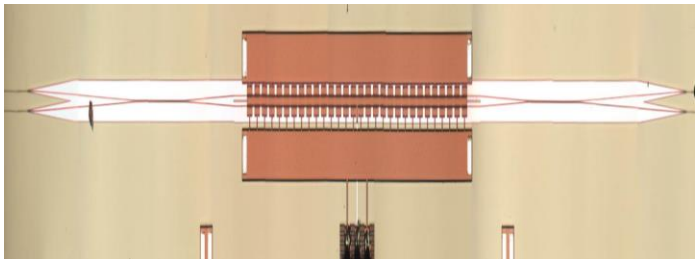


Trusted Advanced Pathfinder Products: Si Photonics

Sandia National Laboratories

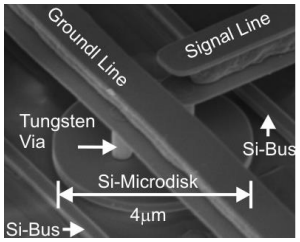
2014	*balanced homodyne resonant wavelength stabilization > 55C*
2013	*Si Photonics MPW (CIAN NSF ERC)*
2012	*24 GHz Si TW MZM*
2011	*45 GHz Ge Detector*
2010	*3 fJ/bit resonator modulator, 1V-cm MZM*
2009	*wavelength tunable rings over 35 nm*
2008	*2.4 ns Wavelength selective switch*
2007	*MicroDisk resonator infrared detector*
2005	*Si_3N_4 low-loss waveguides*
2000	*SiON / SiO2 (Clarendon Photonics)*
1990s	*Si PhC & Optical MEMS*



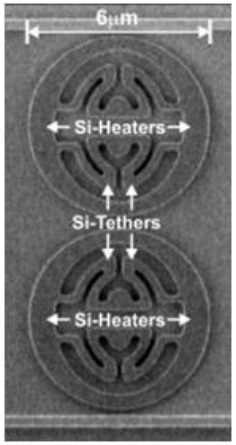


24 GHz 0.7V-cm Travelling Wave MZI Modulator

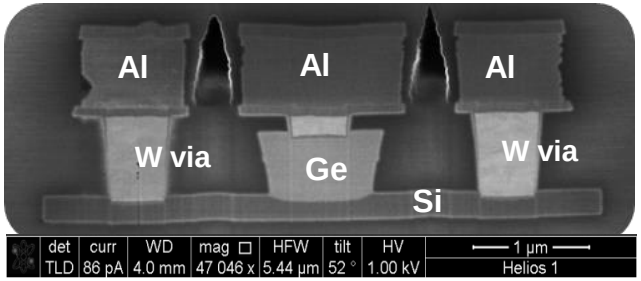
3.2fJ/bit at 12Gb/s



Resonant Optical Modulator/Filter

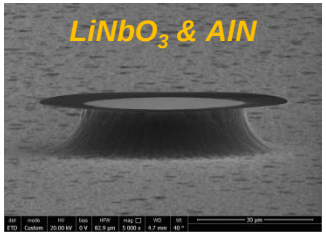


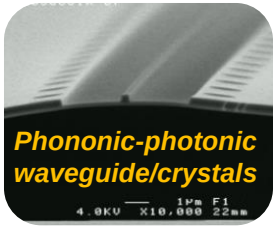
Tunable Resonant Filter



45 GHz High-speed Ge Detector on Si

MEMS process for additional capability



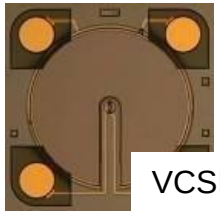


Trusted Advanced Pathfinder Products: III-V Photonics

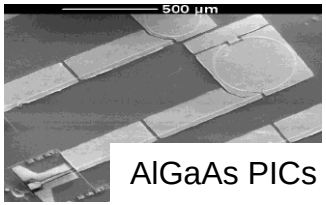
Sandia National Laboratories

2010s

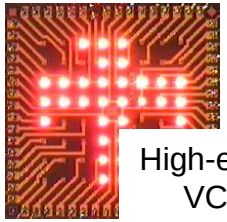
InGaAsP PICs



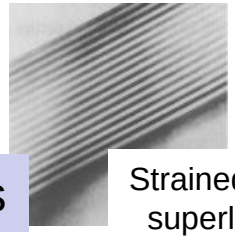
VCSEL+ PD



AlGaAs PICs

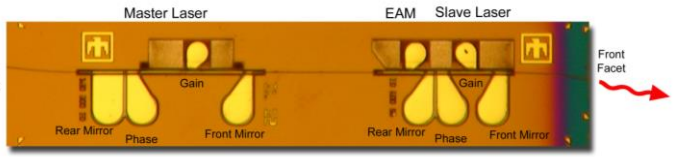


High-efficiency VCSELs

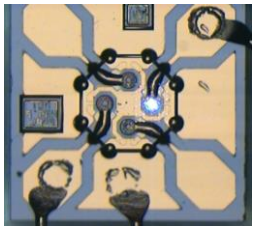


Strained-layer superlatices

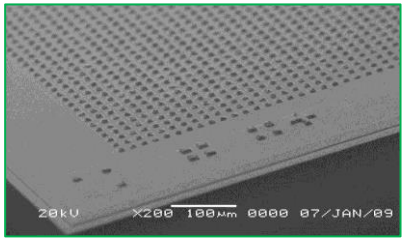
1980s



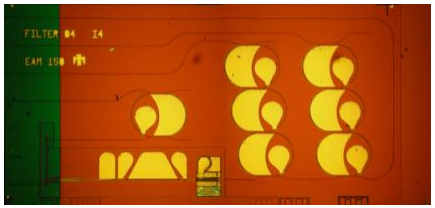
On-Chip Injection Locking
Enhanced Modulation > 50 GHz, C-Band



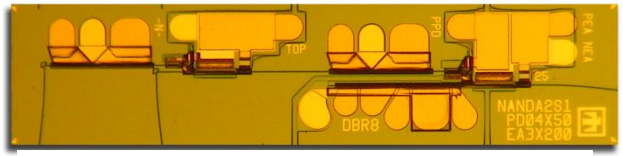
Single-Frequency Tunable VCSELs,
For atomic spectroscopy and sensors



nBn FPAs in the SWIR, MWIR and LWIR, leveraging novel III-P and III-Sb materials



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



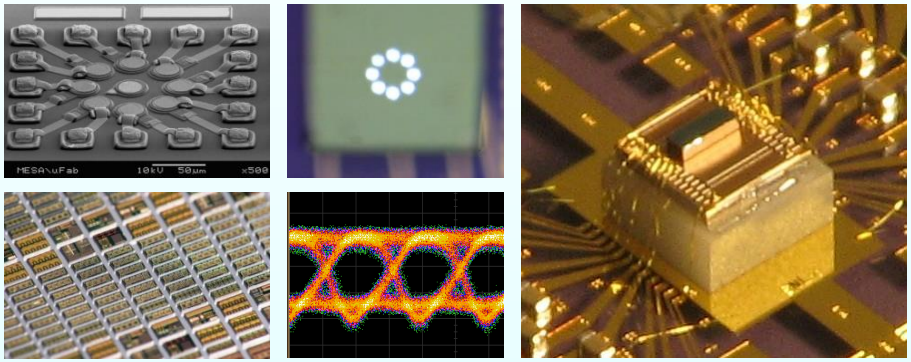
All-Optical Logic at >40 Gb/s, C-Band

- **Foundational Capabilities**
  - **III-V compound semiconductor epitaxy, microfabrication, integration**
  - **Device physics, modeling, simulation**
  - **Microelectronics/optoelectronics, and complex mono/hetero-circuits**
- **Prove, Advance Technology Readiness Level, Productize**
  - **TRL1-6+: create, develop, prototype**
  - **NNSA QMS/QC-1-10; trusted**
- **Trusted, low-volume, high-reliability products for harsh environments**

Trusted Advanced Pathfinder Products: Heterogeneous Integration

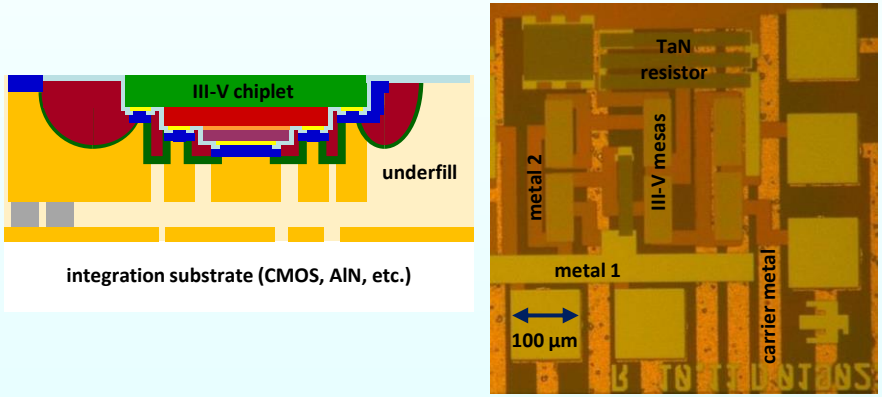
Sandia National Laboratories

Optical Data Communications



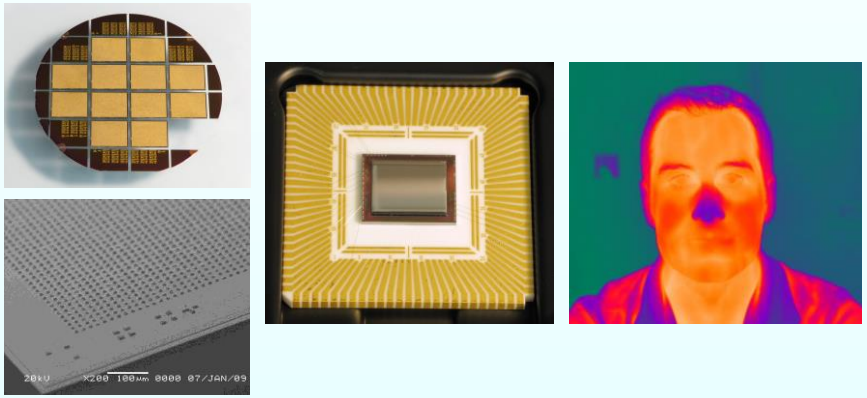
- GaAs- and InP-based devices: VCSELs, modulators, photodiodes
- dense integration onto 32-nm and 45-nm CMOS

Heterogeneous III-V/CMOS Microelectronics



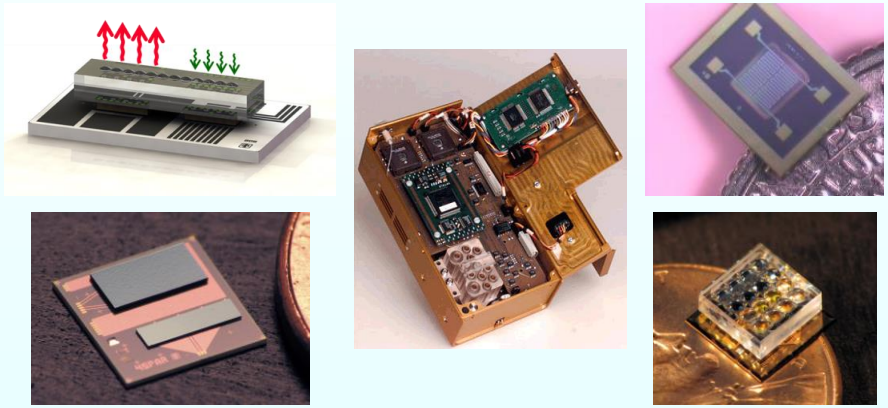
- complementary integration of GaAs and InP microelectronics
- III-V microelectronics circuitry on CMOS ASICs

IR Imagers for Remote Sensing



- nBn InAs/GaSb MWIR/LWIR detector arrays for large-format FPAs
- 10µm indium bump bonding, underfill, thinning, AR coating
- hybridization to silicon ROICs with >99.99% interconnect yield

Optical and MEMS-based Microsensors

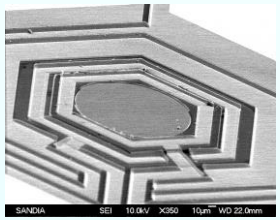
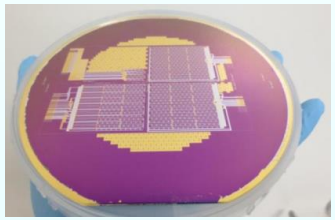
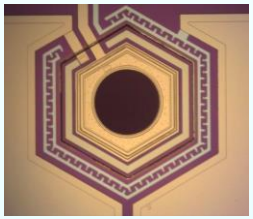


- chemical and bio sensors using MEMS and SAW devices
- g-hard optical microsensors with in-house photonics
- hybrid device integration with custom micro-optics

Trusted Advanced Pathfinder Products: Heterogeneous Integration

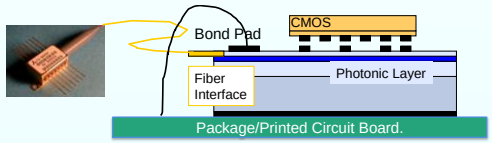
Sandia National Laboratories

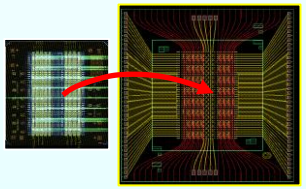
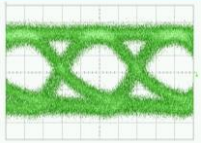
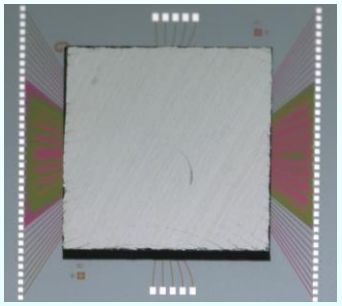
Microsystem-Enabled Photovoltaics

- 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

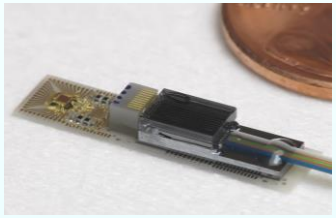
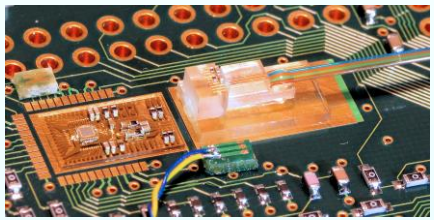
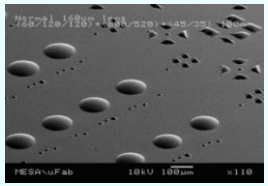
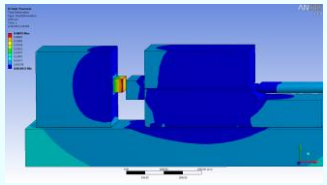
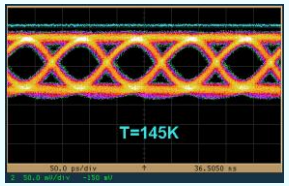
High Performance Computing



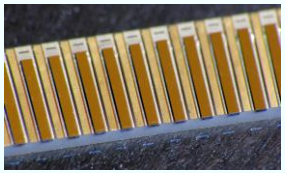
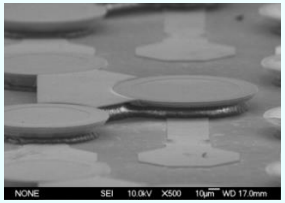
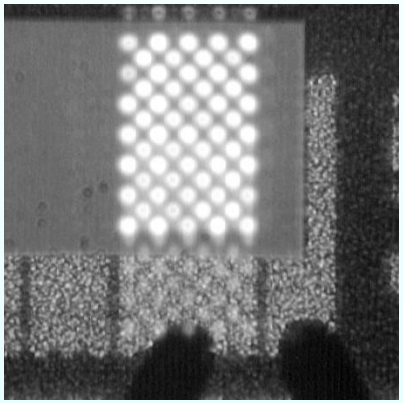
- silicon photonics on high-speed silicon ASIC
- independent optimization of electronics & photonics

Extreme Environment Applications

- custom photonics, optics, electronics for cryogenic interconnects
- advanced optoelectronics and integration for radiation hardness

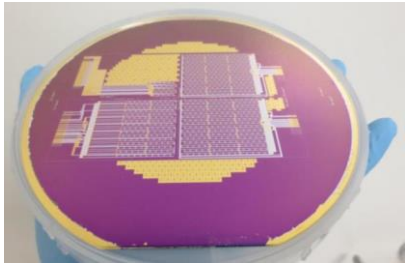
High Performance Photonics

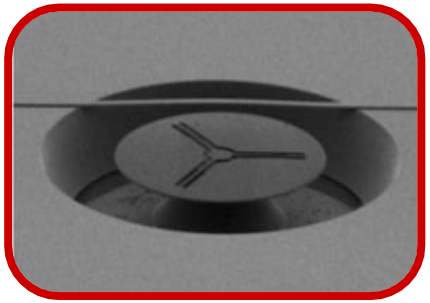




- high-power emitters on AlN and diamond
- RF packaging for high-speed test and measurement

Potential Roles and Engagement within The IP-IMI

- **Trusted Tech Transition:** ITAR, sensitive projects
- **Novel Materials, Devices, or process integration:**
  - Items outside primary scope of Institute?
- **Extra Fab/MPW and Test capacity**
  - Unique failure analysis and reliability tools also available





Engagement

- DOE supporting National Lab involvement in strategy and project development for *ALL* teams.
- We are available for:
  - Telecons & briefings at team meetings
  - Hosting visits to Sandia

Very strong teams have formed: What gaps can we help fill?