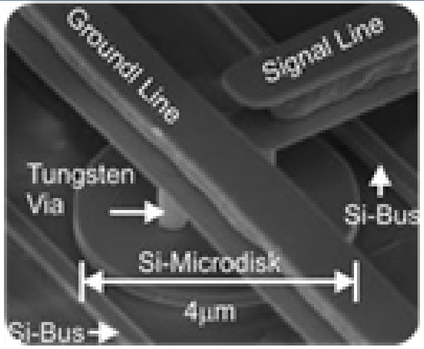
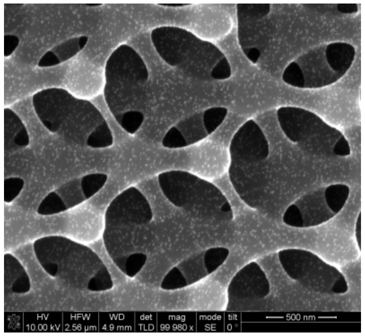
SAND2015-7188PE

Exceptional service in the national interest

Sandia National Laboratories





Nanodevices and Micro Technology: Sandia's MESA Complex and the Nanodevices and Microsystems Research Foundation

- Facilities & Capabilities
- Research Foundation Thrusts
- Technology Transition

F. B. (Rick) McCormick, Ph.D.
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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Center for Integrated Nanotechnologies: CINT

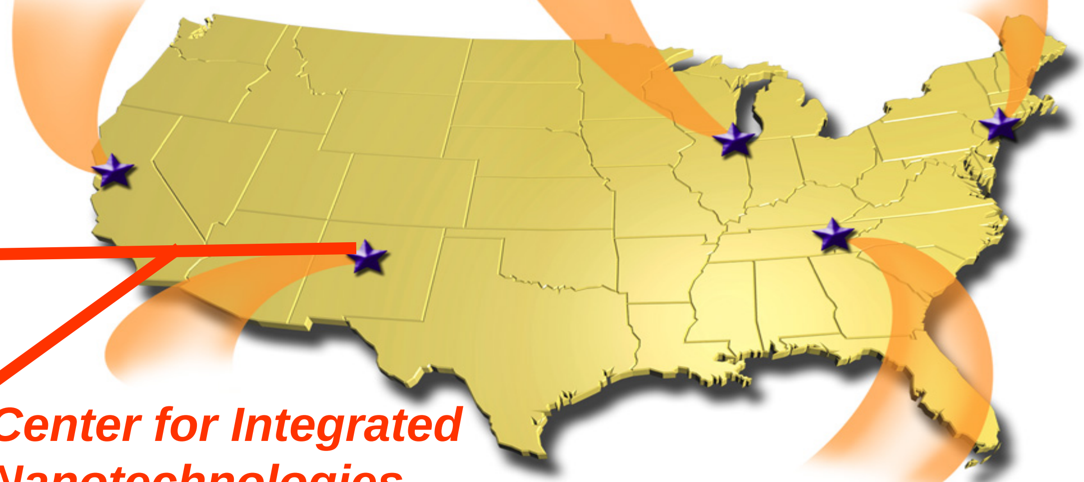
(One of five U.S. Dept. of Energy Nanoscience Centers)

Center for Nanoscale Materials
Argonne National Lab.

Molecular Foundry
Lawrence Berkeley National Lab.

Center for Functional Nanomaterials
Brookhaven National Lab.

Core Facility (Albuquerque)



CINT Gateway to Los Alamos
Nanomaterials / Biosciences

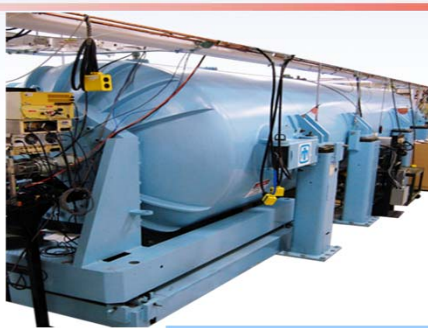
Center for Integrated Nanotechnologies
Sandia National Labs.
Los Alamos National Lab.

Center for Nanophase Materials Sciences
Oak Ridge National Lab.

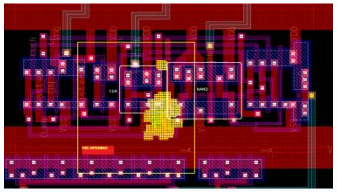
Nanophotonics & Optical Nanomaterials	**Nanoscale Electronics, Mechanics & Systems**
Soft, Biological, & Composite Nanomaterials	**Theory & Simulation of Nanoscale Phenomena**

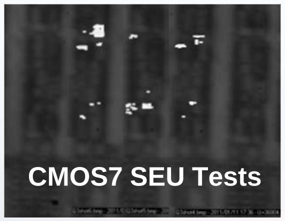
CINT User Proposals: http://CINT.sandia.gov

THE ION BEAM LABORATORY



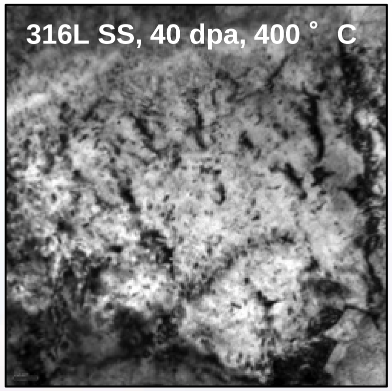
Hostile Environments





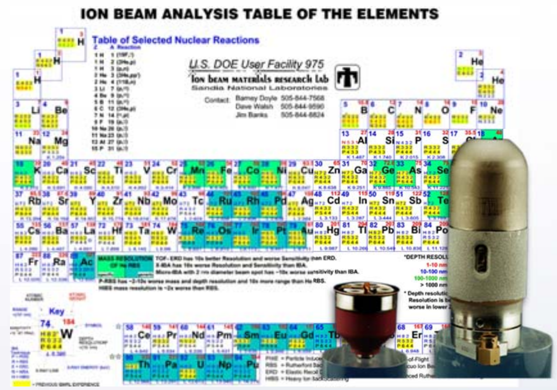
- Gate-level SEU: Rad Effects Microscopy (500nm)
- QASPR Pulsed Rad Effects over mm^2
- Mixed n & γ environment simulator
- IPEM & C-IPEM for REM thru metallization layers
- REM with EBSD, PL, SEM, optical microscope
- Novel Scintillator testing

Ion Beam Materials Modification



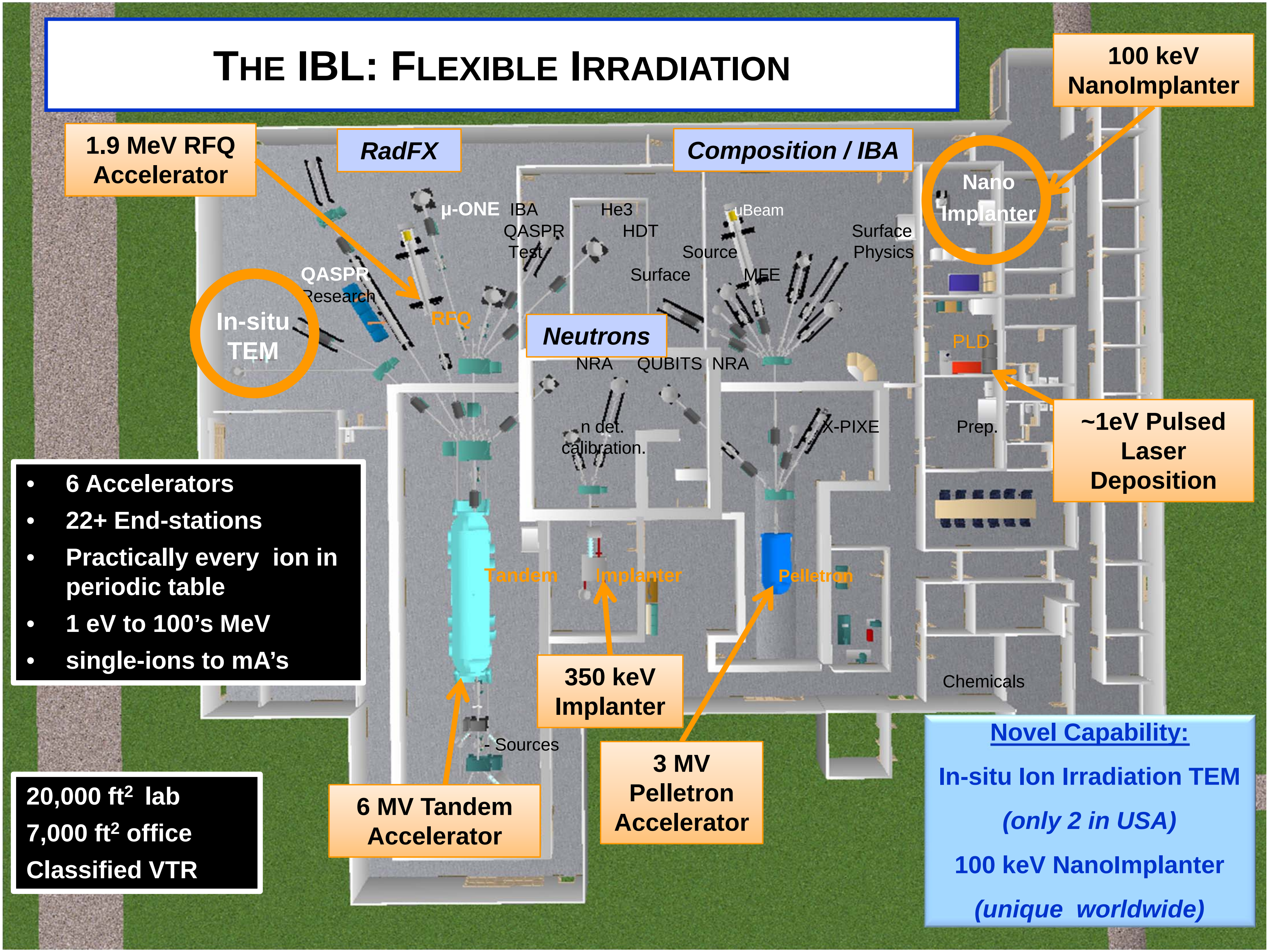
- Single-ion implants for QIST
- Defect creation in Memristors
- Fusion reactor first wall design
- Novel Therrmoelectric structuring
- Nuclear reactor materials design/aging
- Reactor fuel rod aging/burnup
- Novel nanomaterials synthesis & characterization

Ion Beam Analysis



- WR Certification of tritium in Neutron Tube targets
- D-T system to calibrate Pb probes (Sole US source)
- Neutron tube shot-life analysis
- Analysis of 3He, T, and H in NT targets
- Radiation Biology and Medicine

THE IBL: FLEXIBLE IRRADIATION



- 6 Accelerators
- 22+ End-stations
- Practically every ion in periodic table
- 1 eV to 100's MeV
- single-ions to mA's

20,000 ft^2 lab
7,000 ft^2 office
Classified VTR

Novel Capability:

In-situ Ion Irradiation TEM

(only 2 in USA)

100 keV NanoImplanter

(unique worldwide)

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

Sandia National Laboratories

Silicon Fabrication

Compound Semiconductor Fabrication

Materials Research

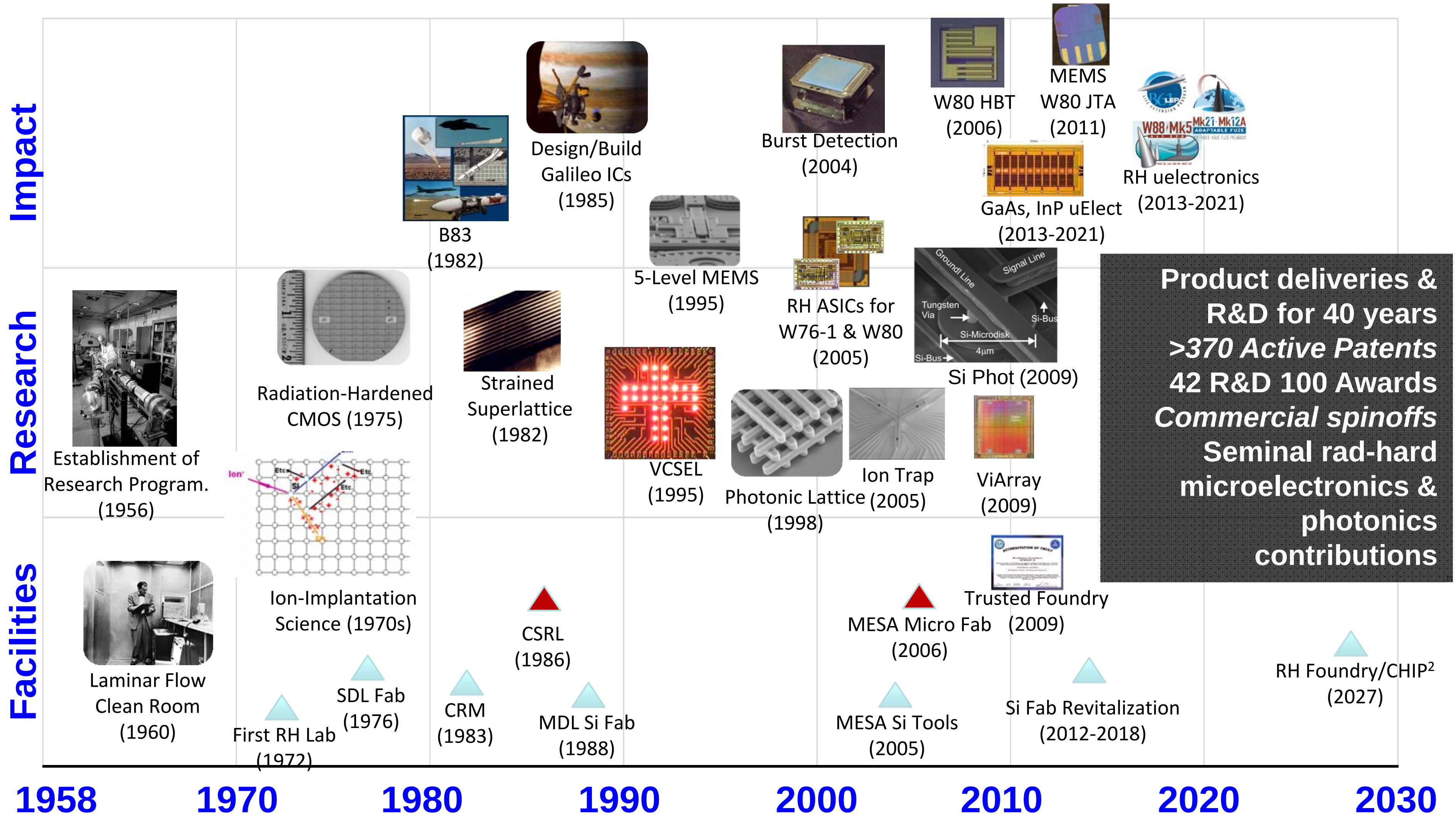
- Trusted Digital, Analog, Mixed Signal & RF Integrated Circuits Design & Fabrication
- Custom IC Design
  - Secure microcontrollers
  - Sensor Readout ICs
  - Analog/Digital/RF
  - IBM Trusted Foundry
  - Tamper Resistant
- Micromachining
- RAD Effects and Assurance
- Failure Analysis, Reliability Physics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

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



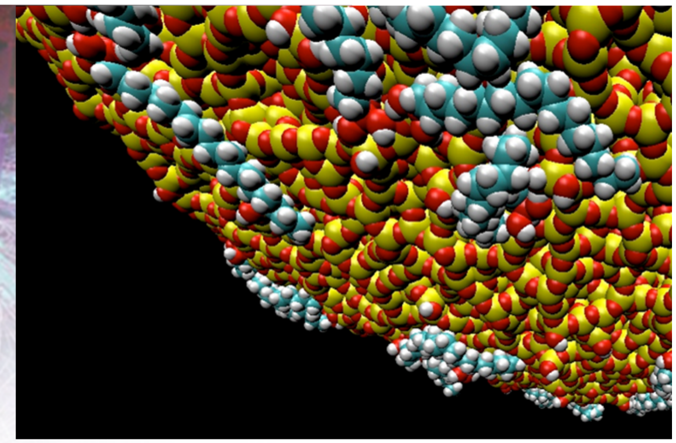
MISSION: Invent and mature integrated circuit and microsystems technologies that provide differentiation and impact for NW and other national security missions

Strong Research Foundations Enable Mission Performance

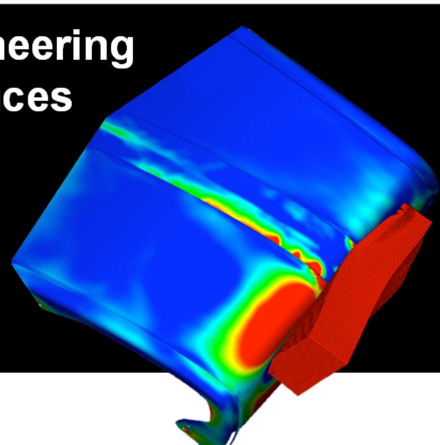
Computing and Information Sciences

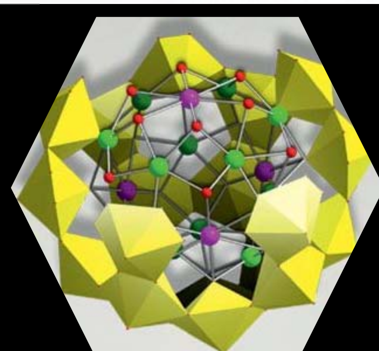
Radiation Effects and High Energy Density Science

Materials Science



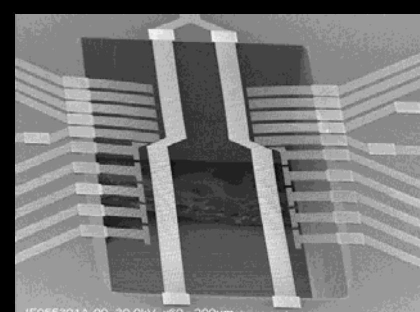
Engineering Sciences



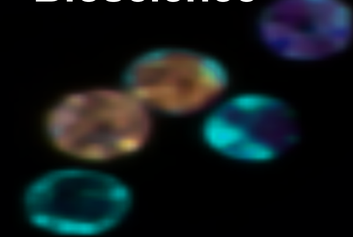


Geoscience

Nanodevices and Microsystems



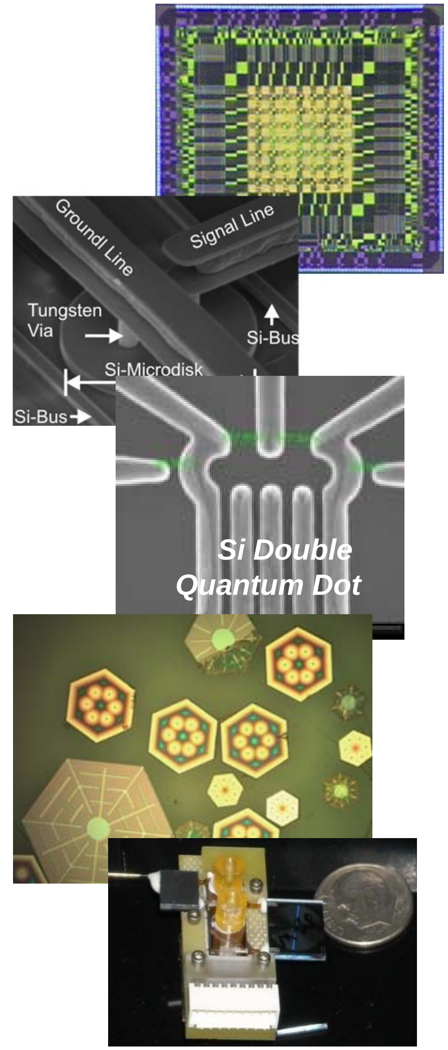
Bioscience



Nanodevices and Microsystems Research Foundation Focus

Sandia National Laboratories

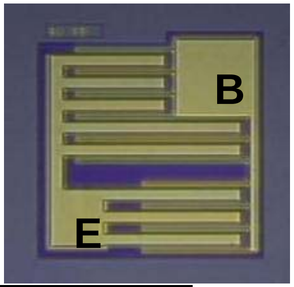
- **Trusted Radiation-Hardened Microelectronics:**
  - The development of concepts, devices and tools that enable the understanding and creation of fielded radiation-hardened microelectronics which are impervious to subversion.
- **Optoelectronics and Photonics of the Future:**
  - The discovery and creation of advanced optoelectronics, at the nanoscale and microscale, which provide new functionality.
- **Ultraportable Multi-function Sensor Systems:**
  - The development of nanoscale and microscale concepts, devices and systems that enable portable physical, chemical, biological, radiation, nuclear materials, and explosives detection that exceed current limitations in selectivity, sensitivity, and robustness.
- **Beyond Moore Technologies:**
  - The development of nanoscale and microscale concepts, devices, tools and systems that continue performance improvements beyond Moore's Law.
- **Nanoscale and Microscale Enabled Performance:**
  - Discover and exploit new functionality that results from phenomena that are unique to the nanoscale and microscale.

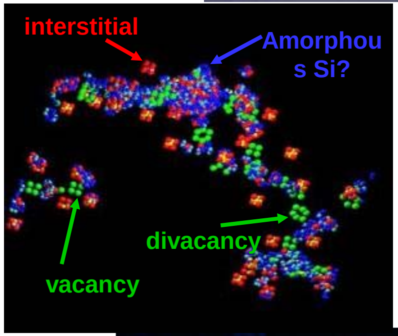


Trusted Rad-Hard Microelectronics

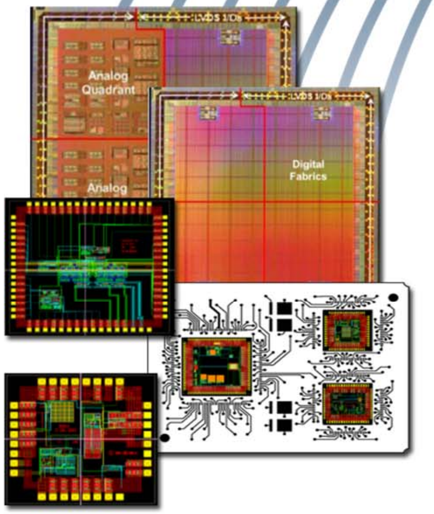
The development of concepts, devices and tools that enable the understanding and creation of fielded radiation-hardened microelectronics which are impervious to subversion.

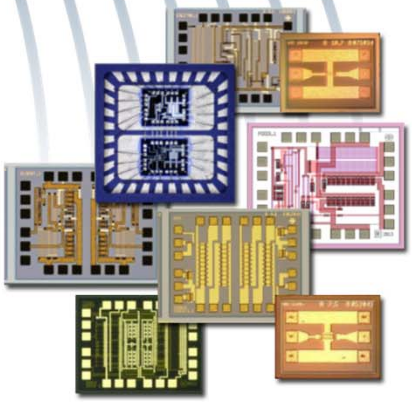
- Trusted Rad-hard microelectronics and microsystems for future LEPs
- Trusted electronics for cyber and high consequence national security missions
- “Science of Trust”
- Nano- and microscale structures and signatures
- New materials and device architectures which reduce susceptibility to radiation effects





MESA manufactures strategic radiation-hardened trusted components for Nuclear Weapons





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

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

TRUST environment (NW, DMEA)

Strong Failure Analysis/Reliability

Trusted Microfabrication Facilities

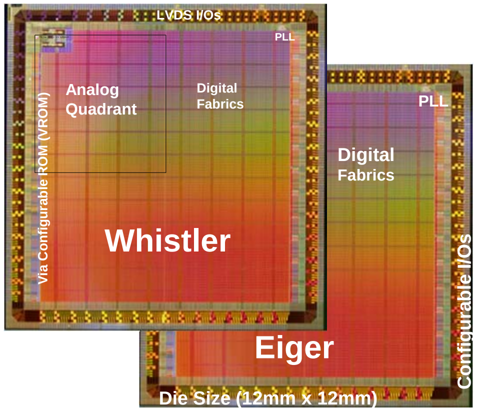
Microelectronics Technology To Deliver Specialized ICs

MESA Trusted Silicon Foundry

- Sandia is a certified DMEA Trusted Supplier Silicon Process Technology
- NNSA's primary supplier of custom rad-hard ICs for weapon life extension programs
  - 350nm Radiation Hardened CMOS
  - 3.3V, Silicon-on-Insulator
  - Mixed signal extensions
- Low Volume Mixed Signal Radiation Hardened ASICs
  - Low Cost Multi-Project Wafer Program (MPW)
  - Quick Turn Structured ASIC ViArray Platforms
  - Low Volume Production ASICs
- Supports silicon bulk *and* silicon surface micromachining

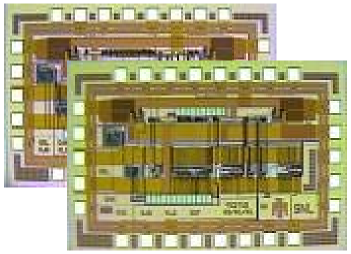
MESA MicroFab

- Compound Semiconductor Epitaxial Growth
- Compound Semiconductor Discretes, IC's and Opto
- Mixed-Technology Integration and Processing
- Materials Characterization



Rad-Hard ViArray Platforms

Low Cost Multi-Project Wafers

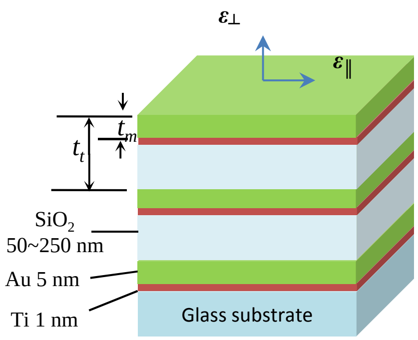


Custom Rad-Hard Mixed Signal ASICs

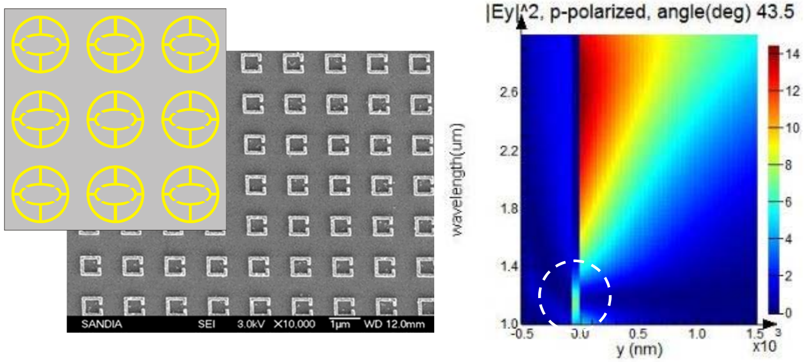
Optoelectronics of the Future

- ***The discovery and creation of advanced optoelectronics, at the nanoscale and microscale, which provide new functionality.***
  - High-speed, low-power secure communication
  - Low noise, high sensitivity FPAs
  - Solid-state lighting
  - Understanding and control of light-matter interactions for advanced sources and detectors

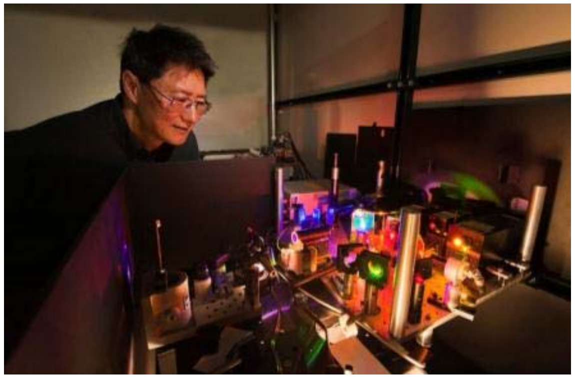
Epsilon Near Zero



Metamaterials & Plasmonics



SSL By Lasers



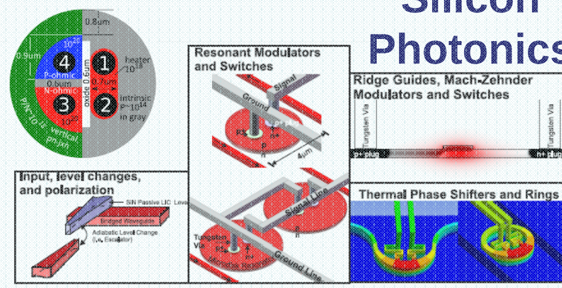
Applied Photonics Microsystems

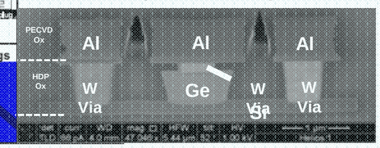
Main Research Thrusts

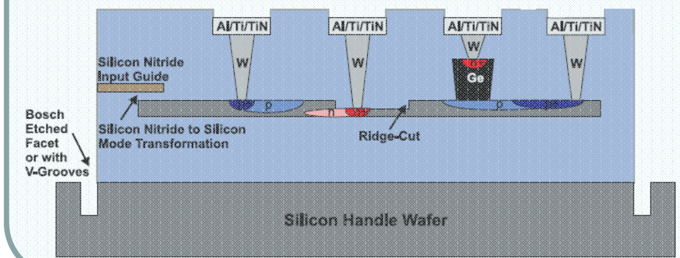
- **Silicon Photonics**
  - Optical Interconnects (waveguides, modulator, filter, switches)
  - Si Germanium detectors
  - Integration (with high-speed or rad-hard CMOS, III-V lasers)
  - RF photonics; mid-IR photonics
- **Nano-photonics**
  - Plasmonics (nano-antennas, emitters, sensors, energy harvesting)
  - Tunable and passive IR metamaterials (dielectric resonators, filters)
  - Solid-state Lighting (III-nitrides, nanowire lasers, strong-coupling)
- **Nano-Optomechanics / Phononics**
  - Nonlinear signal processing
  - RF waveform generation (oscillator, filter)
  - Phononic crystals: thermal management, quantum networks

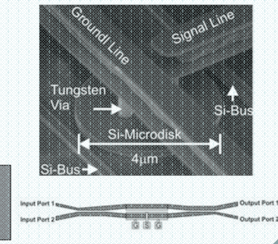
Silicon Photonics

Enabling technology for 100 fJ/bit 10Gbit/s data link and RF signal processing



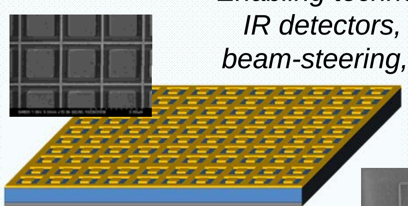


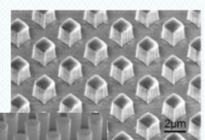


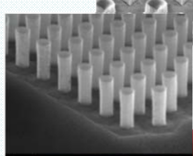


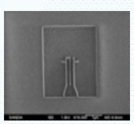
Nano-photonics

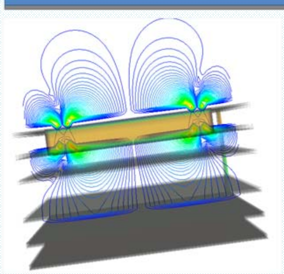
Enabling technology for IR detectors, filters, beam-steering, lighting

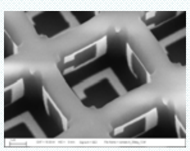


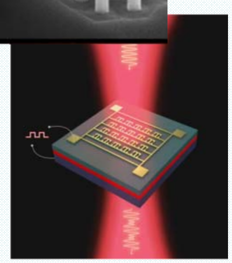






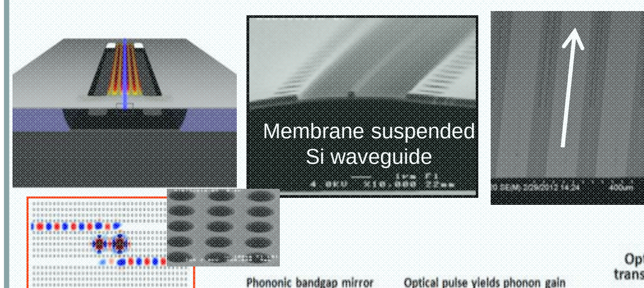


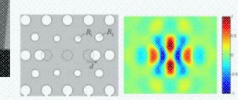


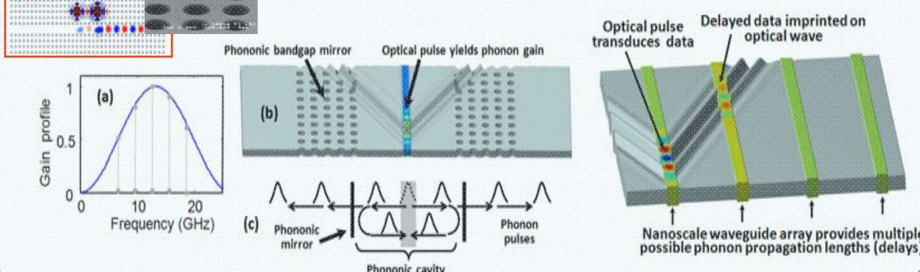


Nano-Optomechanics

Enabling technology for RF signal processing (1-20GHz, high power)







Nanoantenna-Coupled Infrared Focal Plane Array

Goal:

- FPA size/weight improvements for multiple detector platforms
- Reduce dark current by over 10X
- Integrated pixel-by-pixel polarization and spectral filtering capability

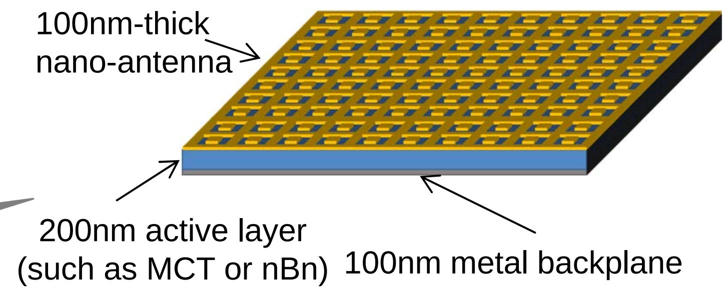
Approach:

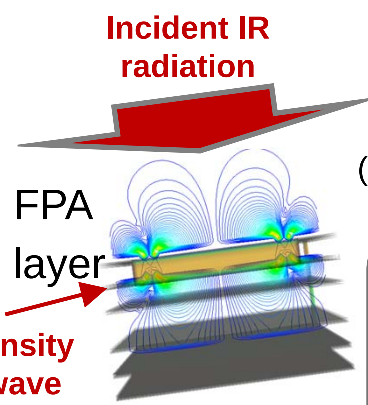
- Integration of nano-antenna directly onto FPA
- Nanoantenna concentrates power in thin layer

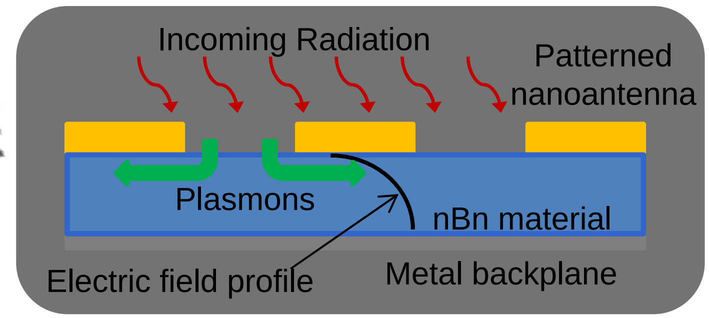
Accomplishments to Date:

- Integrated with InAsSb detectors
- Measured detector performance
- Integrated with Bilayer Graphene for potential real-time spectral tuning

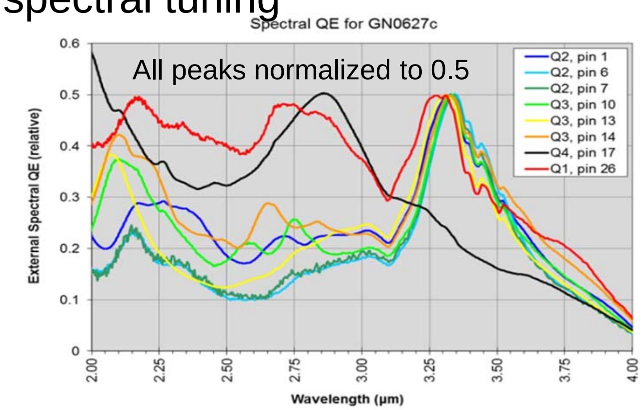
One FPA pixel with integrated nanoantenna

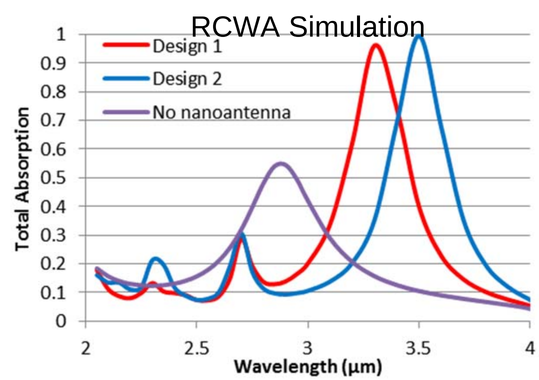


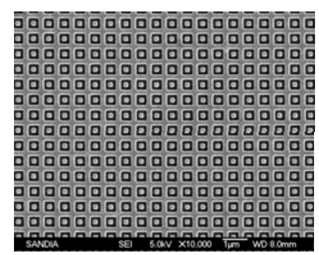




Wide band filter simulation

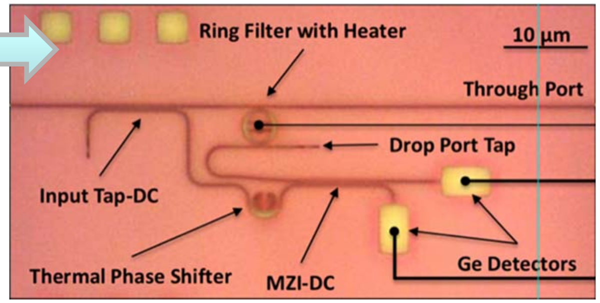


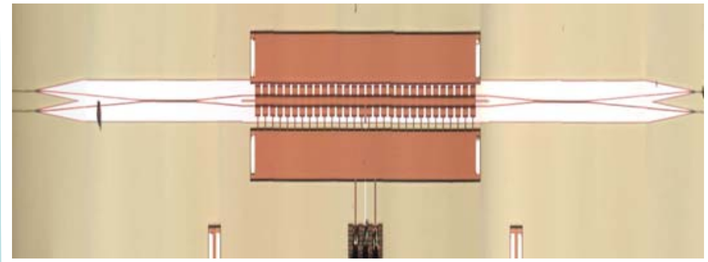




Si Photonics

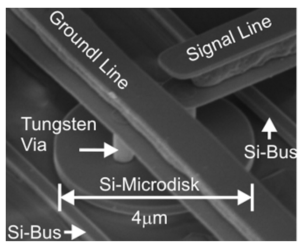
2014	*balanced homodyne resonant wavelength stabilization > 55C*
2013	*Si Photonics MPW (CIAN NSF ERC)*
2012	*24 GHz Si TW MZM*
2011	*45 GHz Ge Detector*
2010	*3 fJ/bit resonator modulator, 1V-cm MZM*
2009	*wavelength tunable rings over 35 nm*
2008	*2.4 ns Wavelength selective switch*
2007	*MicroDisk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



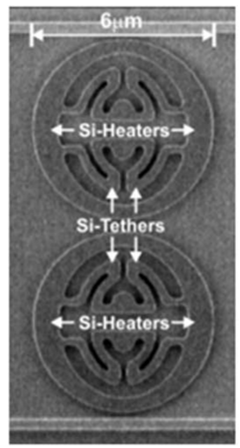


24 GHz 0.7V-cm Travelling Wave MZI Modulator

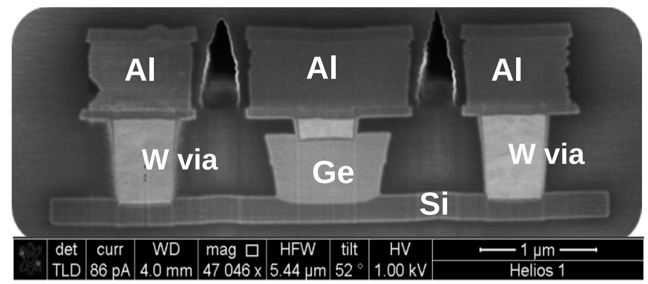
3.2fJ/bit at 12Gb/s



Resonant Optical Modulator/Filter

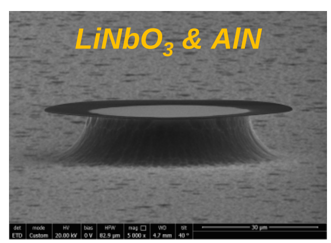


Tunable Resonant Filter



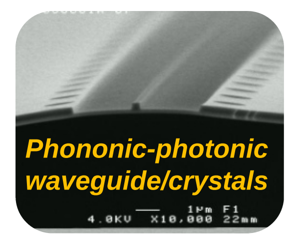
45 GHz High-speed Ge Detector on Si

MEMS process for additional capability



$LiNbO_3$ & AlN

Suspended Si/SiN resonators

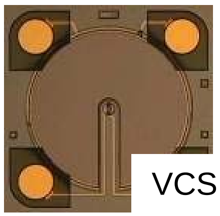


Phononic-photonic waveguide/crystals

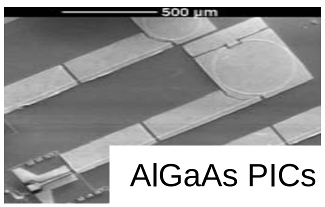
III-V Photonics

2010s

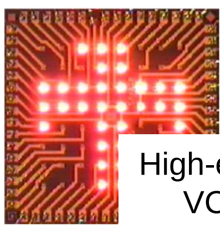
InGaAsP PICs



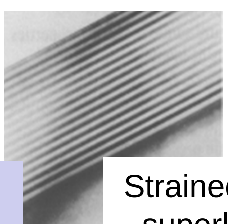
VCSEL+ PD



AlGaAs PICs



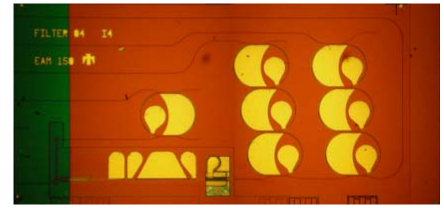
High-efficiency VCSELs



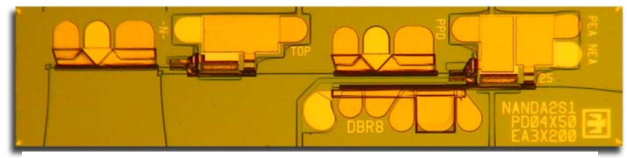
Strained-layer superlattices

1980s

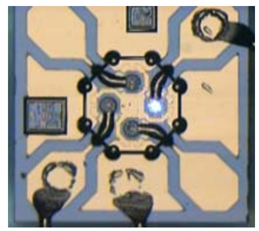
On-Chip Injection Locking
Enhanced Modulation > 50 GHz, C-Band



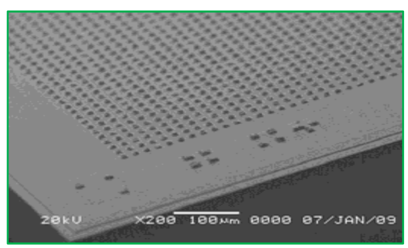
RF-Optical Channelizing Filter
1-20 GHz RF on C-Band Light



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



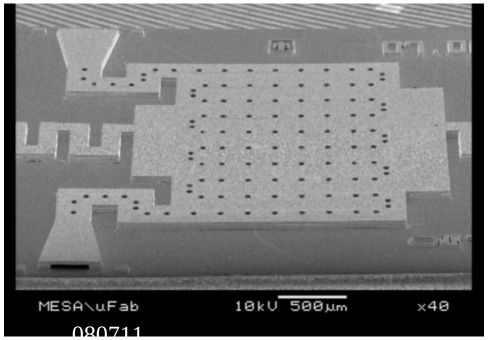
Single-Frequency Tunable VCSELs,
For atomic spectroscopy and sensors

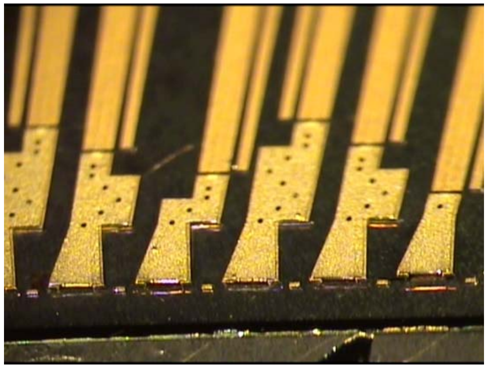


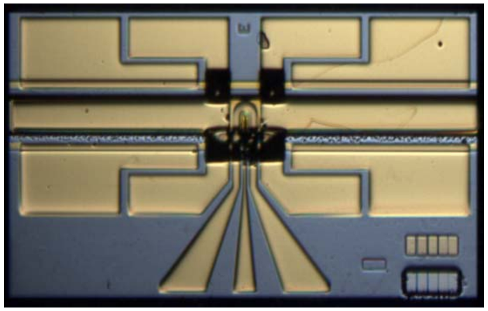
nBn FPAs in the SWIR, MWIR and LWIR,
leveraging novel III-P and III-Sb materials

- 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

THz Integrated Devices





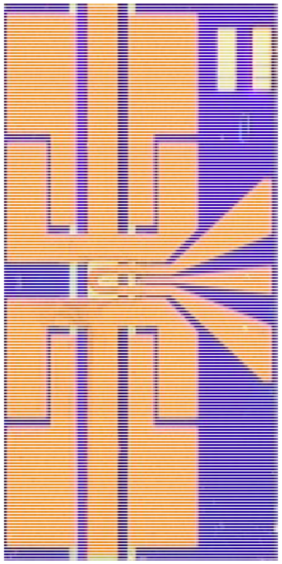


- **Micromachined rectangular waveguides:**
  - Waveguides route signals around chip.
  - Components (Splitters / Combiners / Couplers)
  - Horn Antennas / vertical emitters
- **Waveguides coupled to active lasers:**
  - Waveguides route laser output around chip
  - Horn antennas improve free space beam patterns
  - E-plane bends enable vertical emission
  - Enables laser facet impedance engineering
- **THz QCL Integrated with Schottky receiver:**
  - Compact heterodyne receiver / transceiver on-chip
  - Novel tool to explore laser dynamics
  - Enables novel functions (phase imaging, vibrometry, ...)

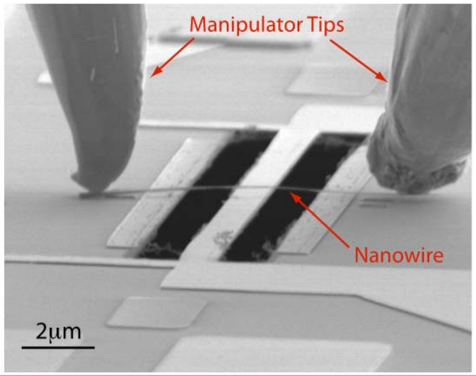
Ultraportable Multi-function Sensor Systems

- ***The development of nanoscale and microscale concepts, devices and systems that enable portable physical, chemical, biological, radiation, nuclear materials, and explosives detection that exceed current limitations in selectivity, sensitivity, and robustness.***
  - Multifunction (CBRNE, physical) lab/sensor on a chip
  - Compact, high-reliability, rad-hard sensors
  - Exploration of new physical mechanisms for detection

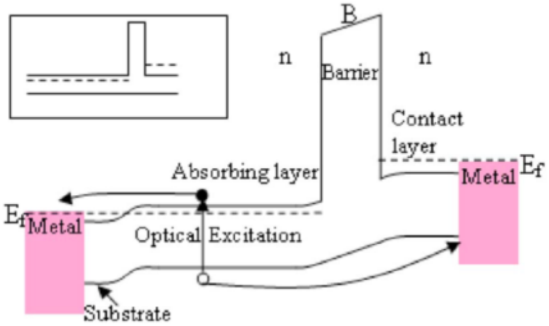
QCL-based Mid-IR Transceiver



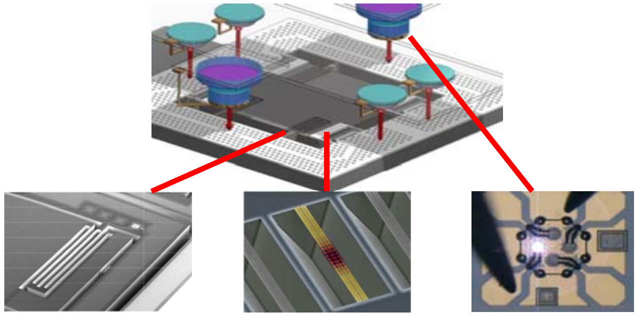
Nanoscale Calorimetry



nBn IR Detector



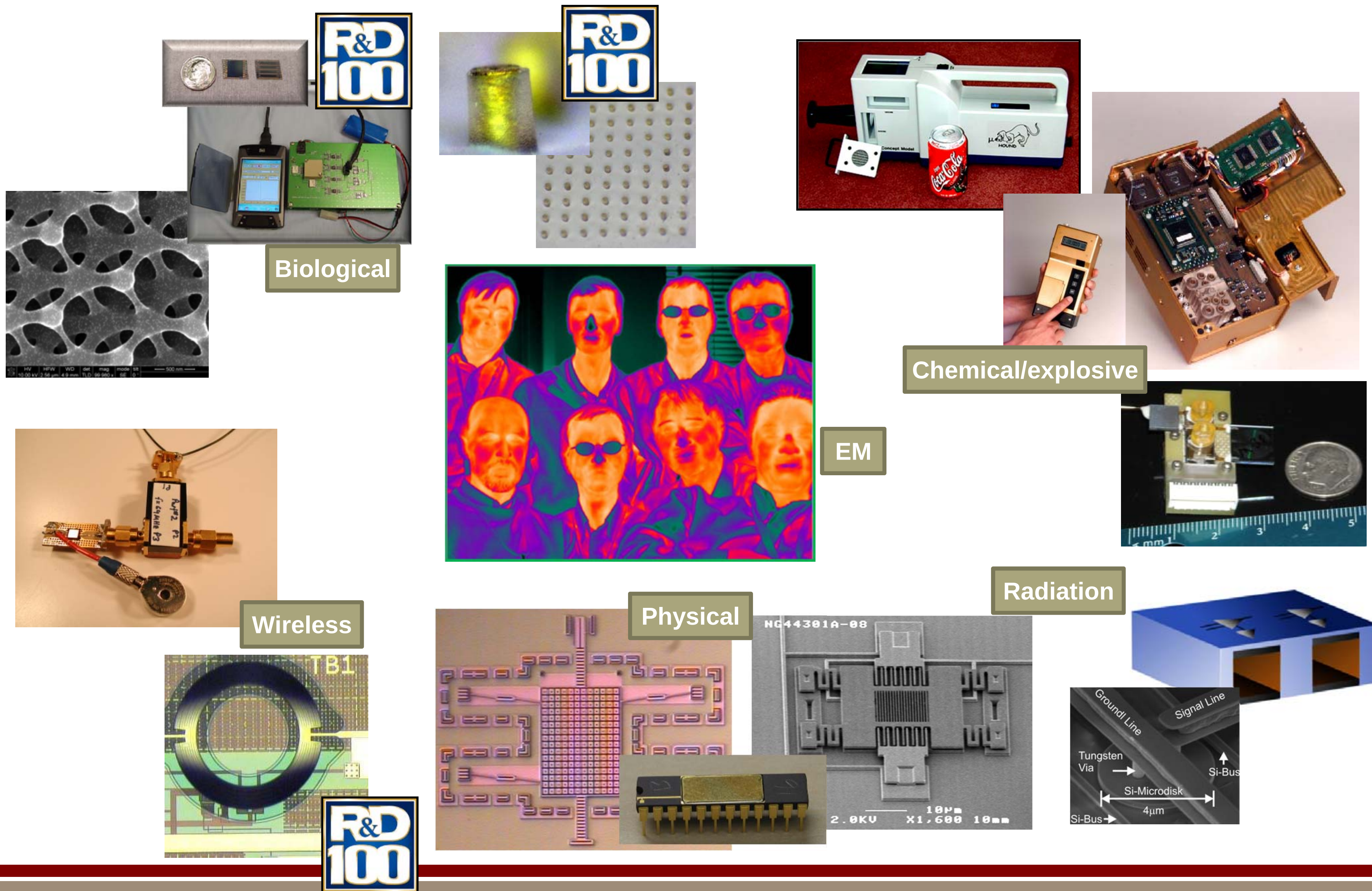
Accelerometer: 100nG/rtHz, 10kHz



Massive MEMS Suspension | **NOMS Displacement Sensor** | **VSCEL**

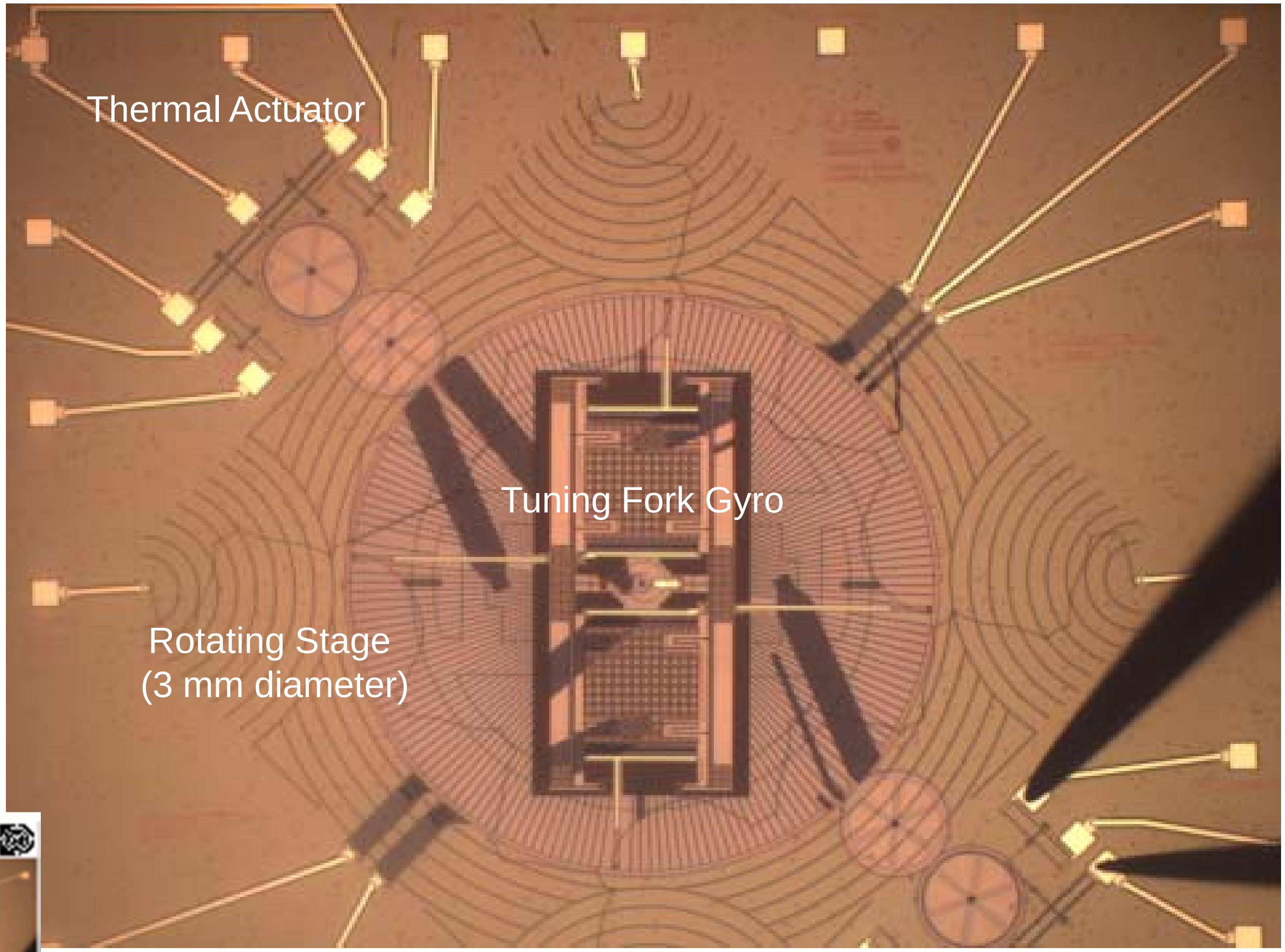
Sandia National Laboratories

Example Remote & Proximate Sensor Capabilities



SUMMiT Today: PASCAL

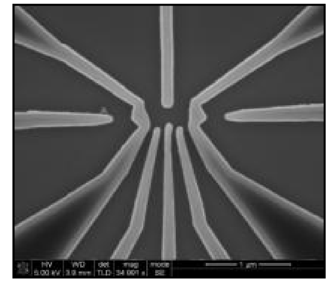
DARPA MicroPNT Project: Primary and Secondary Calibration on Active Layer (PASCAL)



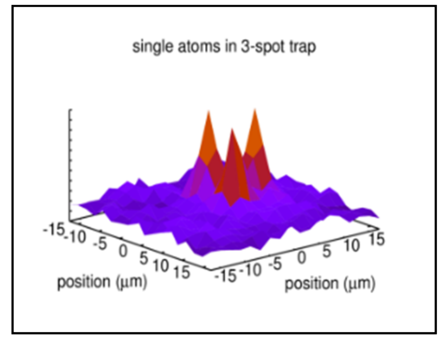
Beyond Moore Technologies

The development of nanoscale and microscale concepts, devices, tools and systems that continue performance improvements beyond Moore's Law.

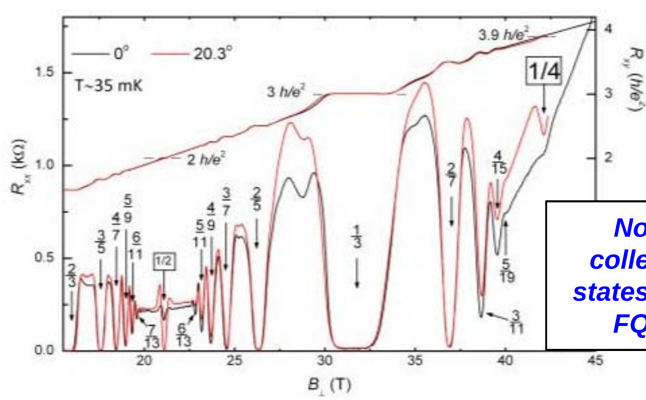
- Exascale: co-design of advanced computing hardware/software architectures for HPC
- Quantum Information Processing
- Quantum Communication
- Novel materials and operating principles: graphene, memristors, superconducting devices, topological insulators, etc.



Silicon double-QD qubit

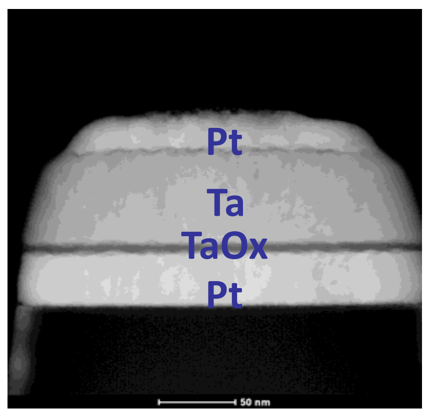


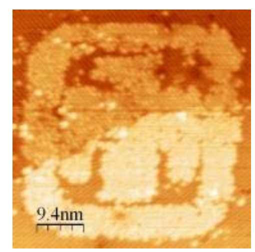
Three Cs atoms in a 3-node trap



Novel collective states in the FQHE

TaOx Memristor

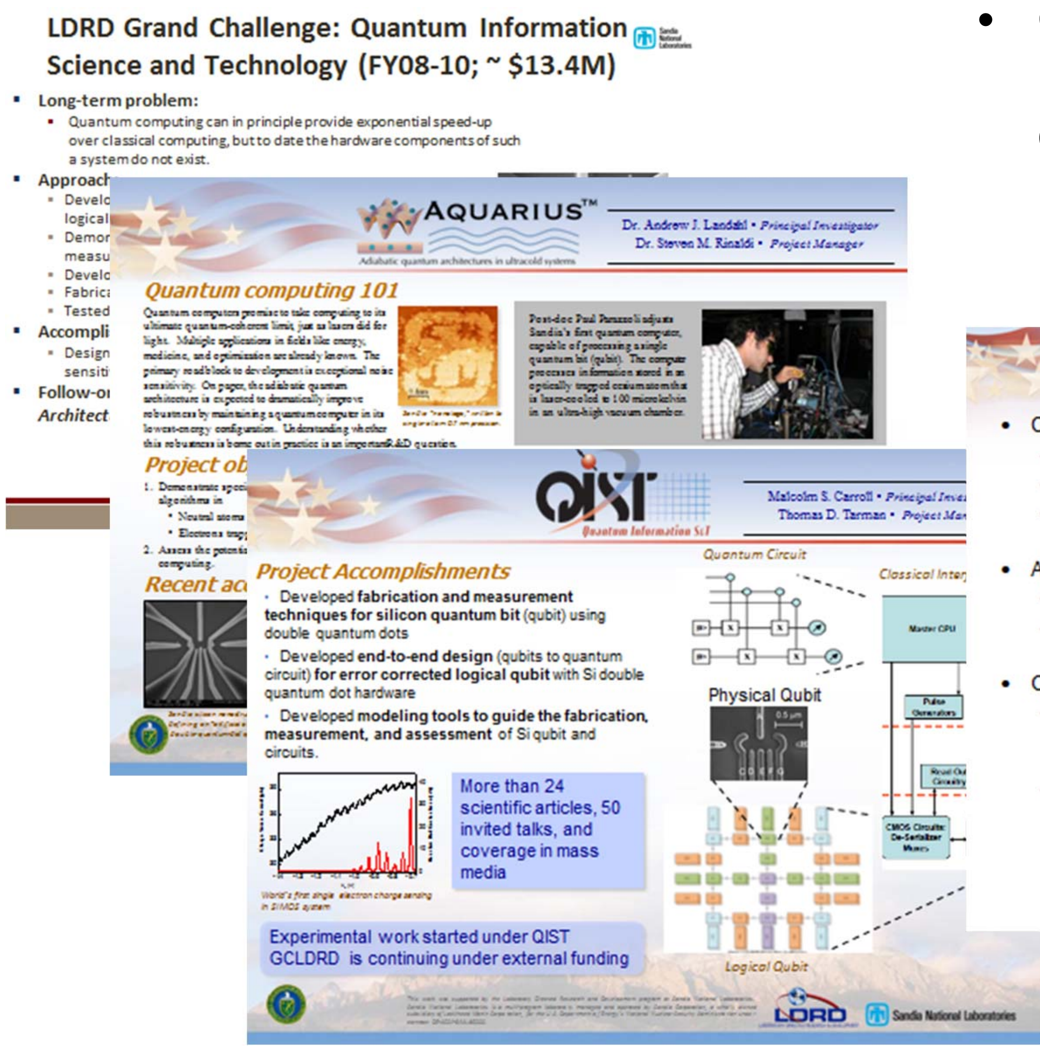




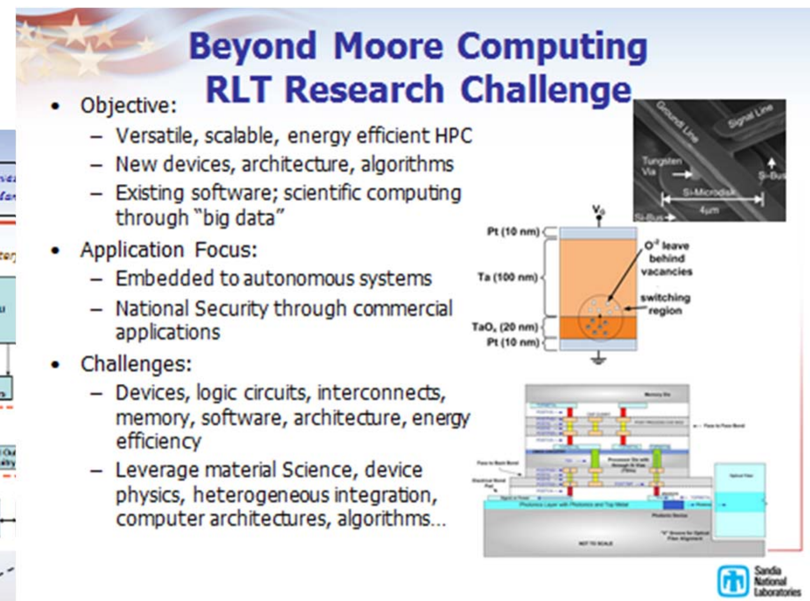
Sandia "nanologo," written to single-atom 0.7 nm precision.

Quantum Information Processing
Over $30M of investments at Sandia

Sandia National Laboratories



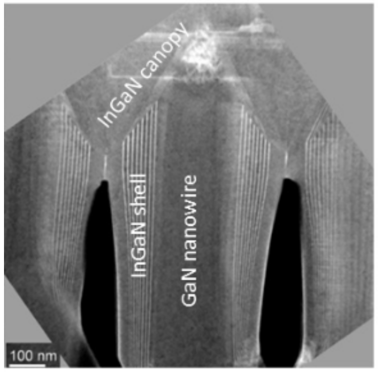
- Quantum Information Processing at Sandia enabled by 2 GC LDRDs

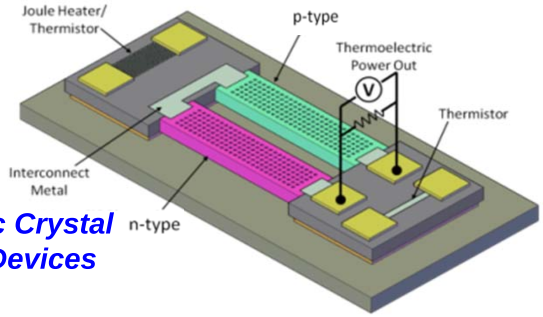


Nanoscale- and Microscale-Enabled Performance

- ***Discover and exploit new functionality that results from phenomena that are unique to the nanoscale and microscale.***
  - Enable technology surprise
  - nm-to-cm 3D Surface Enhanced Raman
  - Phononic enabled filters and communication
  - Metamaterials
  - 2-D Materials: Bilayer Graphene Tunable FPA

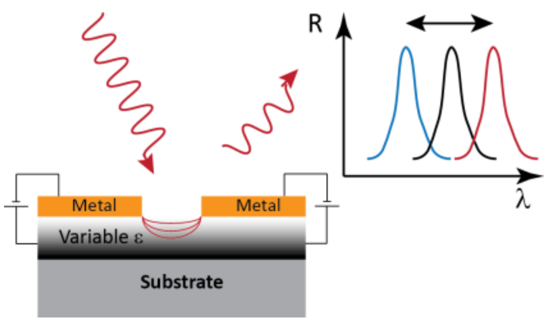
Strain-relaxed InGaN Core-Shell Nanowires for PV



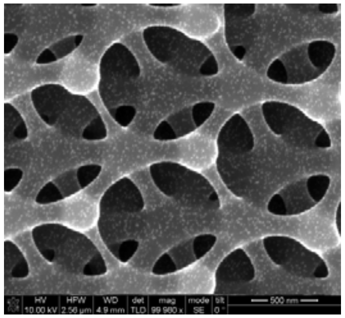


Phononic Crystal Peltier Devices

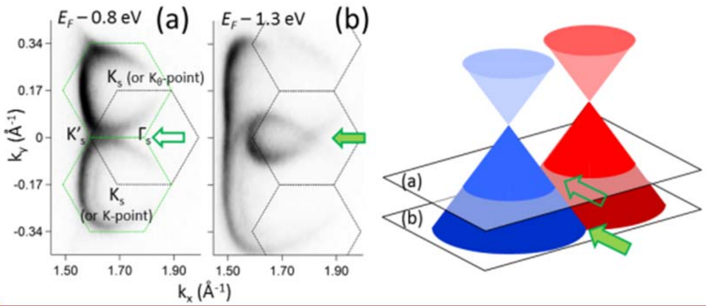
Metamaterial-based tunable optical filter



Pyrolized Carbon Interference Litho 3D SERS substrates



Optical Properties of Twisted Bilayer Graphene

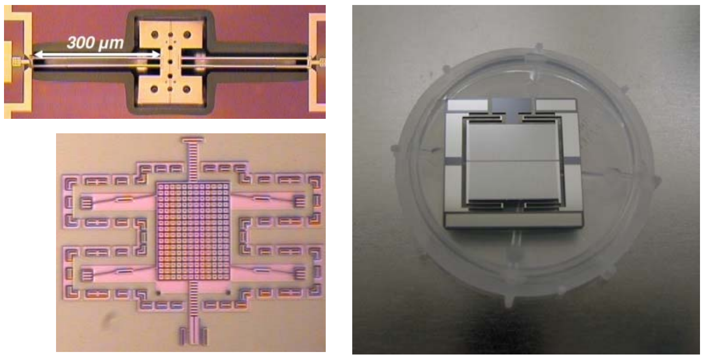


Sandia's Current MEMS Portfolio

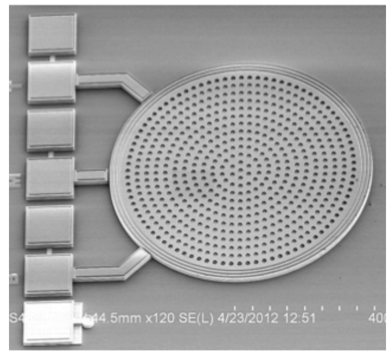
Sandia National Laboratories

Exploratory research and advanced development for MEMS technologies, devices, and systems for national security.

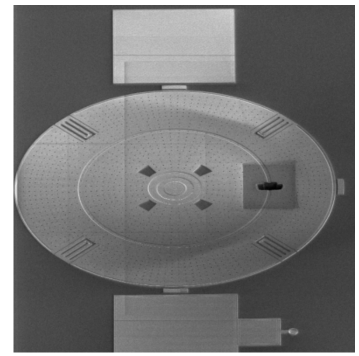
Inertial Sensors



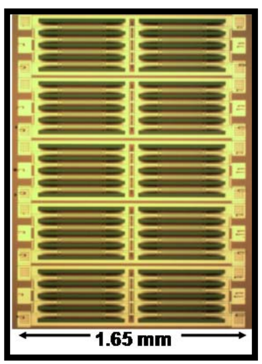
Pressure Sensors



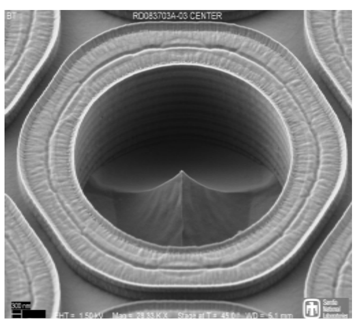
Microfluidic Actuators



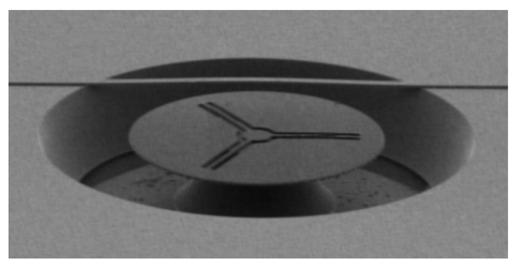
Electronics



Vacuum Electronics



Photonics and Waveguides

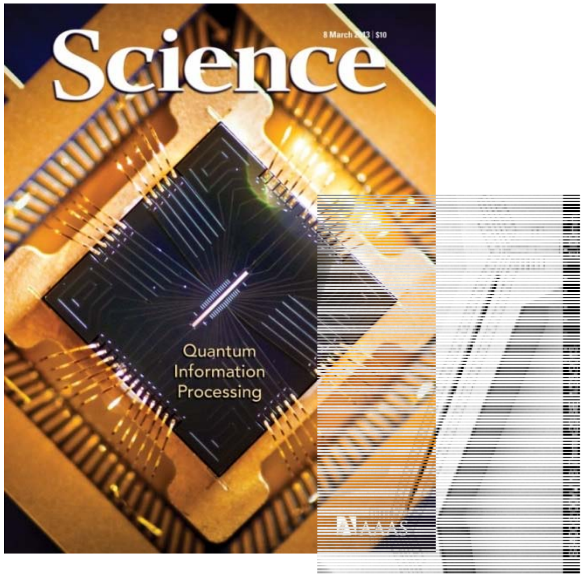


Photovoltaic Cells

Quantum technologies and applications

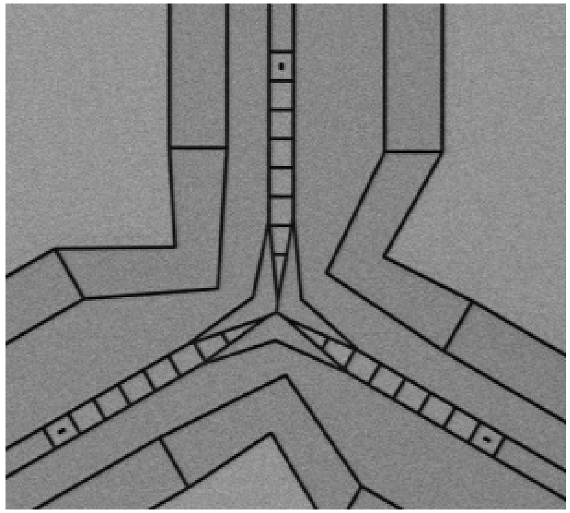
Sandia National Laboratories

Quantum Information Processing



- 2008: Sandia's 1st "workhorse" trap
  - Used worldwide
  - Quantum operations
- 2013: Sandia's latest surface ion trap
  - Bowtie shape enables improved control of ions & quantum operations

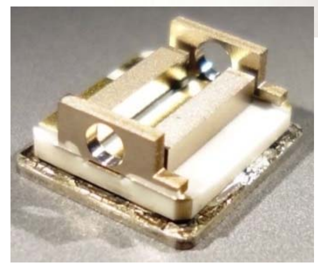
Advanced surface ion trap concepts



The world's most advanced Y-junction trap:

- "Railroad switch" for ions
- Designed for reordering of ions with minimal disturbance
- Made for David Wineland at NIST/Boulder

Accurate time-keeping with ions



Tiny trapped-ion clock:

- Small size (5 cc) and low power (50 mW)
- Excellent long term stability (loses 32 ns in 1 month)
- Clock prototype passed demanding testing at NIST for 49 days

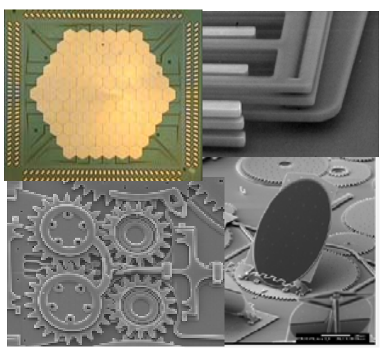
Technology Transition: innovation and application

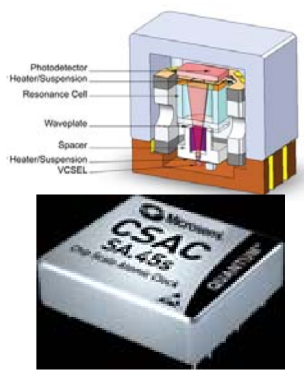
Sandia National Laboratories

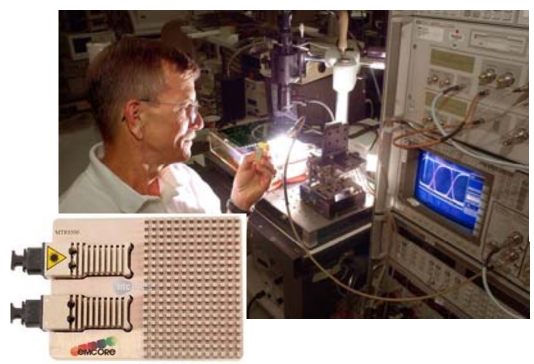
- **<u>Expertise</u>**: >40yrs R&D: μelectronics, MEMS, Photonics, Quantum
    - Toolboxes for internal and contract R&D
- **<u>Capability</u>**: Large flexible Si & III-V R&D Fab, Production rigor:
    - 65kft^2 MESA fab, CINT, IBL, >600 staff
    - Here today, here tomorrow…(NW IC deliveries)
    - Secure environment & staff, robust info-control (TRUST)
- **<u>History of Technology Transfer to Industry</u>**:

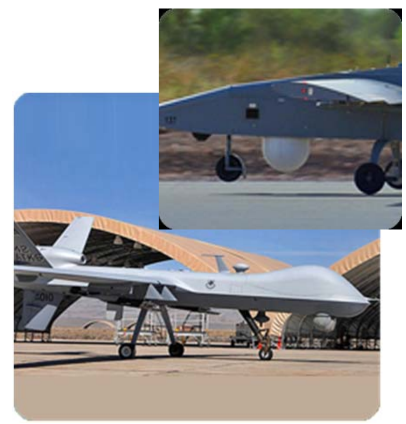
Processes → Devices → Subassemblies → Systems

Processes	Devices	Subassemblies	Systems
MEMS (Fairchild)	**VCSEL CSAC (Microsemi)**	**POM (EMCORE)**	**SAR (General Atomics)**
Transfer of Sandia's Summit IV™ MEMS technology. Network Photonics Optical MEMS	Narrow λ temp-stable VCSEL for Chip-scale Atomic Clock (DARPA)	OC-192 Transponder Parallel Fiber Optic Module prototype development using VCSEL & PD arrays	Copperhead & Lynx SAR (w/ GA Aero) on TigerShark & Predator UAVs (IED detector being transferred to Army)









Technology Transition: innovation and application

Sandia National Laboratories

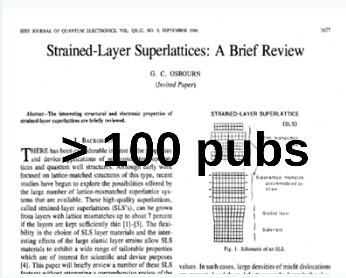
Vertical Cavity Surface Emitting Lasers Intellectual Property


United States Patent [19] Hadley et al.

[11] Patent Number: 5,903,590

[45] Date of Patent: May 11, 1999

[54] VERTICAL-CAVITY SURFACE-EMITTING LASER DEVICE


Strained-Layer Superlattices: A Brief Review

G. C. OSBOURN

(Invited Paper)

Led To

Licenses
Spinoff (e.g., Mode)
CRADAs (e.g., Emcore)
WFOs
Reputation

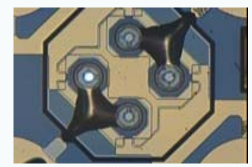
Including

DARPA

Chip-Scale Atomic Clock

Symmetricom

DRAPER LABORATORY



Product!

ROI

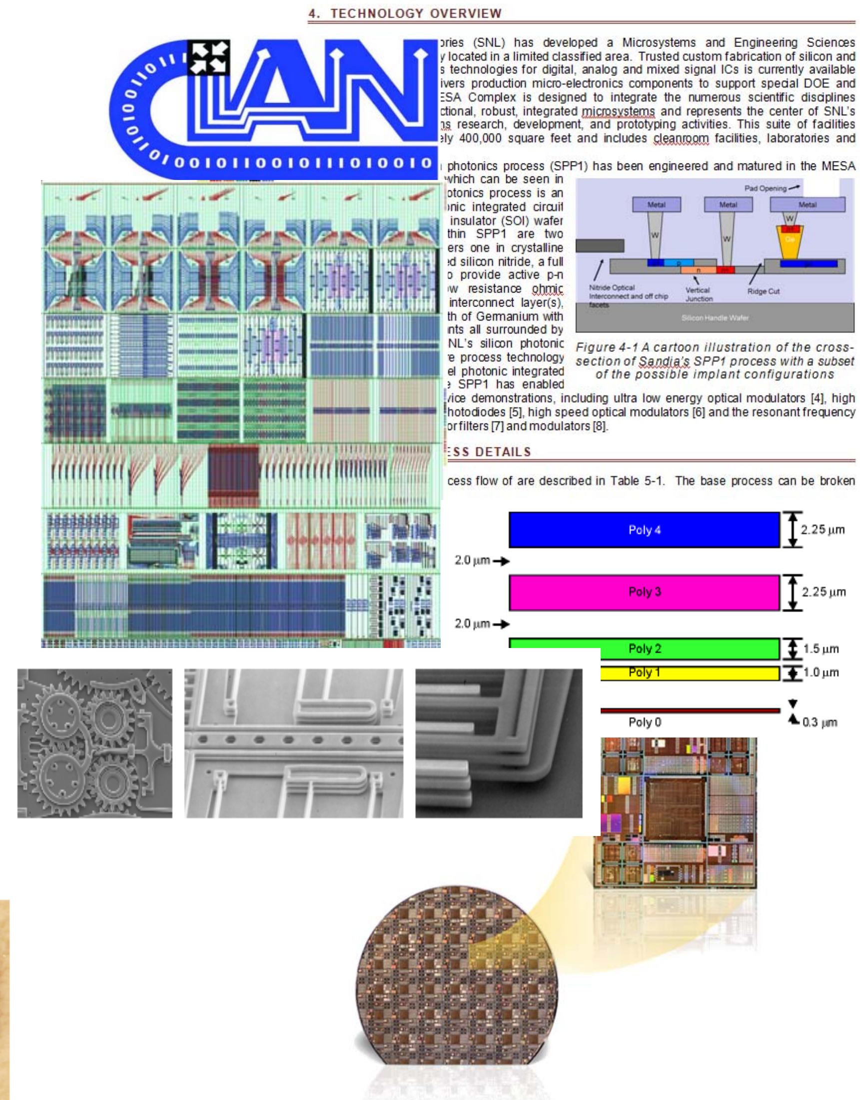
- CSAC project funds DARPA:
- VCSEL license to Finisar
- DARPA VCSEL follow-on projects
- Strategic partnerships with Draper and Symmetricom
  - Non-VCSEL projects, VP-level engagement/site visits
- **National value: low-power clock for GPS denied navigation**

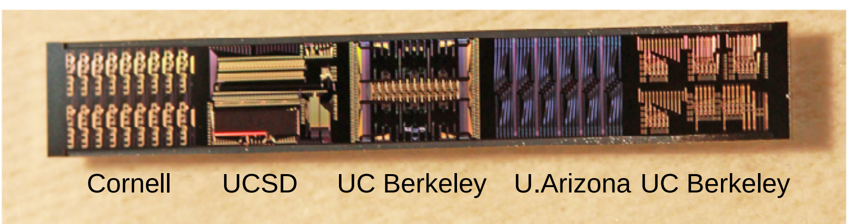
Sandia and Multi-Project Wafer Fabrication

- **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

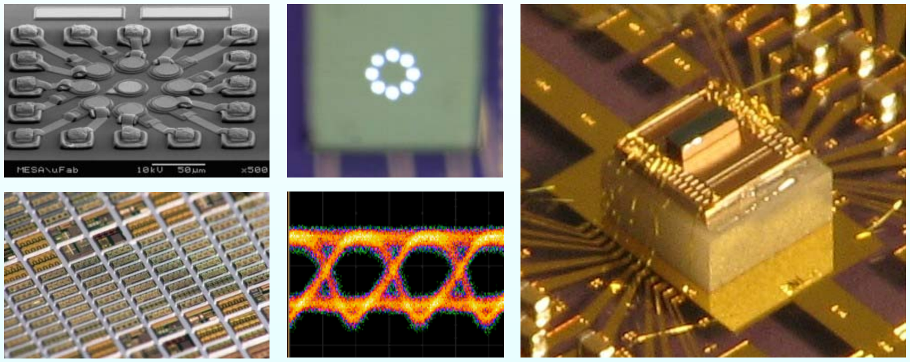




Trusted Pathfinders: Heterogeneous Integration

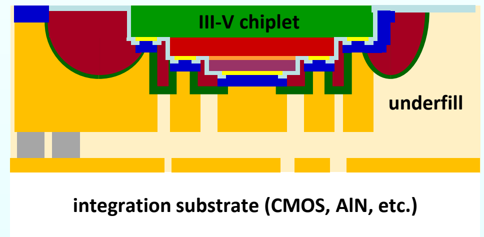
Sandia National Laboratories

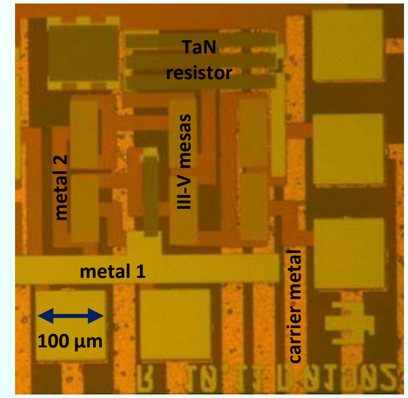
Optical Data Communications



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

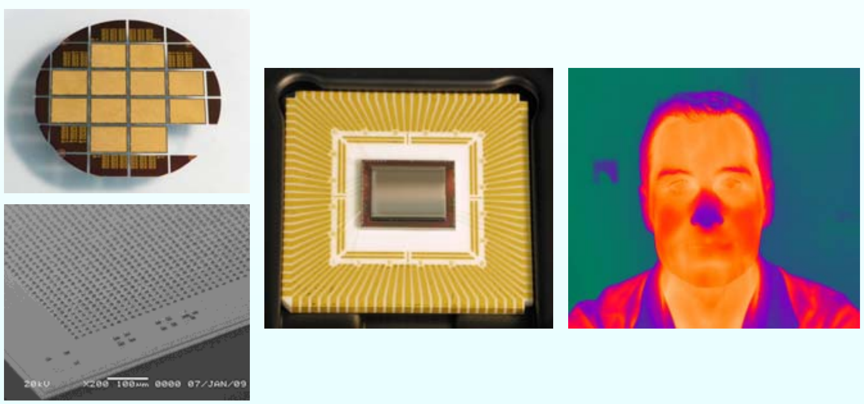
Heterogeneous III-V/CMOS Microelectronics





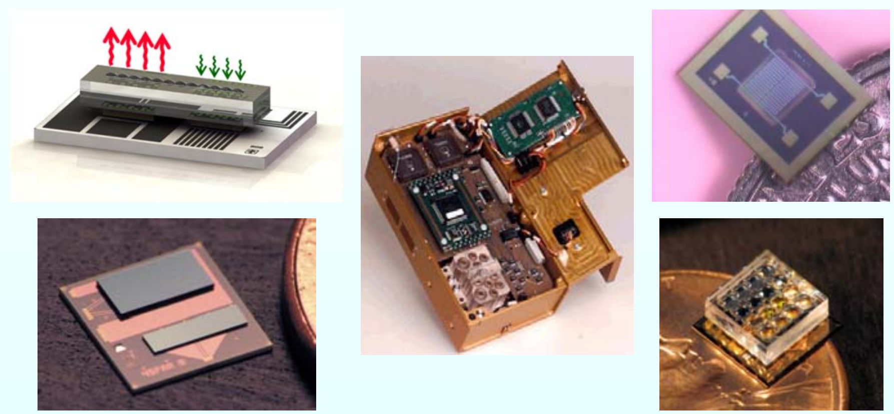
- complementary integration of GaAs and InP microelectronics
- III-V microelectronics circuitry on CMOS ASICs

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

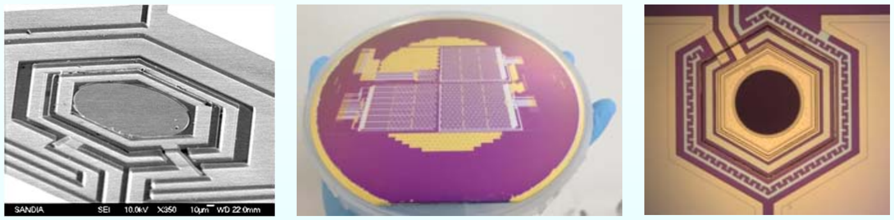


- chemical and bio sensors using MEMS and SAW devices
- g-hard optical microsensors with in-house photonics
- hybrid device integration with custom micro-optics

Trusted Pathfinders: Heterogeneous Integration

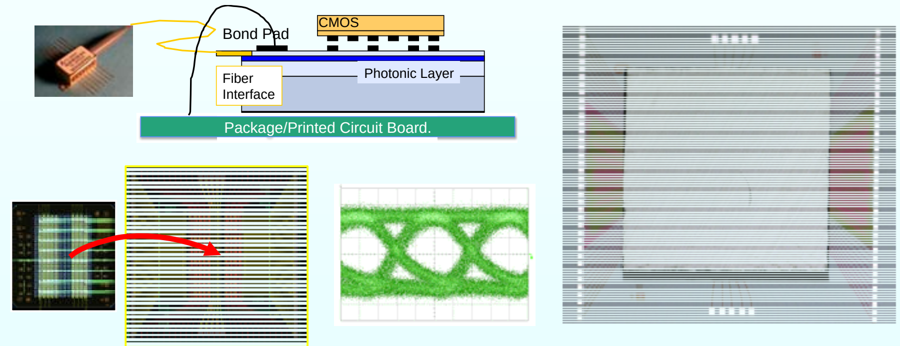
Sandia National Laboratories

Microsystem-Enabled Photovoltaics



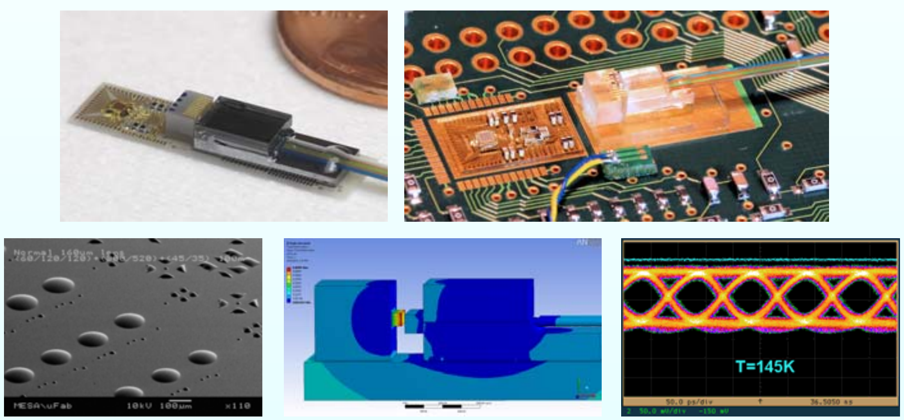
- wafer-level bonding for multi-junction solar cells
- InGaAsP/InP and InGaP/GaAs devices on silicon
- dielectric interfaces with III-V substrate removal
- integration with collection optics

High Performance Computing



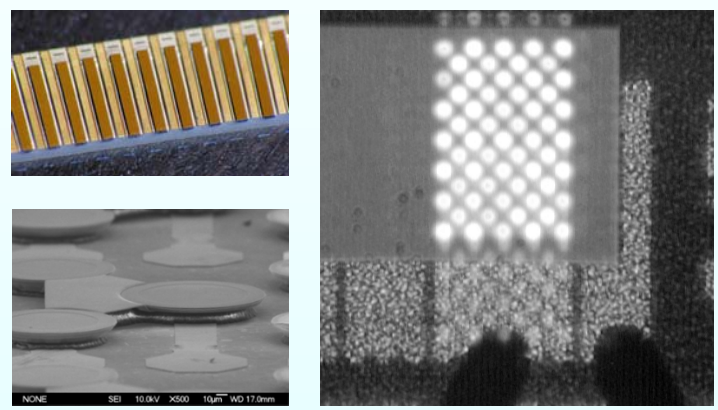
- silicon photonics on high-speed silicon ASIC
- independent optimization of electronics & photonics

Extreme Environment Applications



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

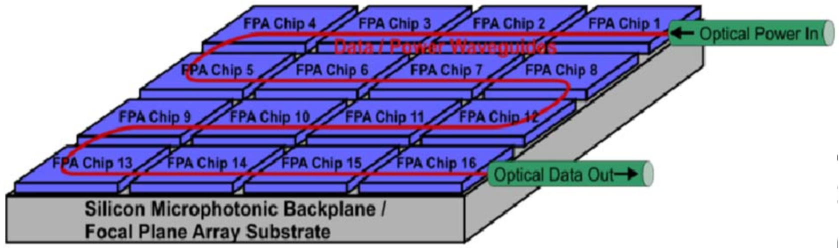
High Performance Photonics

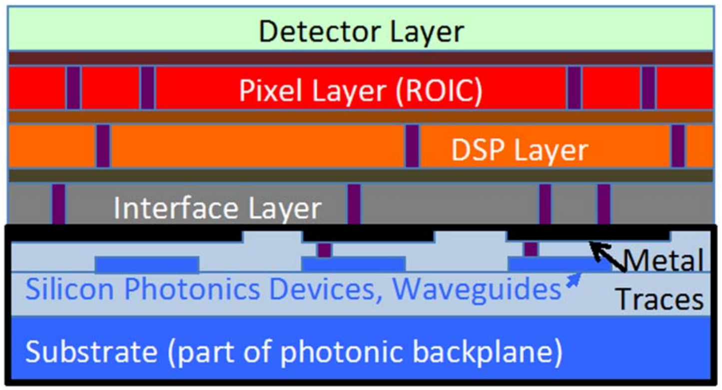


- high-power emitters on AlN and diamond
- RF packaging for high-speed test and measurement

$220M+ Integrated Photonics Institute for Manufacturing Innovation

DOE (EERE & NNSA) and DSA support to engage Teams and Gov't Agencies ➔ <u>Sandia in FOA, Brief at Proposer's Day (Mfg.gov), Written into final 3 Team's full proposals (NY, FL, CA)</u>





<u>Potential Roles for Sandia</u>:
- **Foundry, T&E, Failure Analysis, TRUST work within the IP-IMI**
- **Direct engagements with OGA customers on TRUST, Tech surprise and related topics**
- **Direct engagements with interested DoD and Defense contractor customers**
- **Increased engagements with Universities**

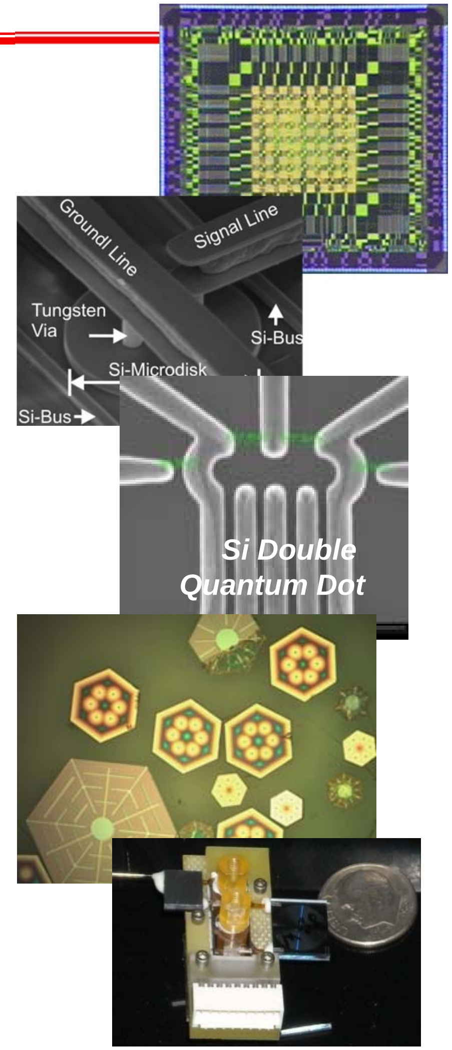
Nov 5	**FOA released**
Dec 19	Deadline for concept papers (received by 3pm ET)
Jan 30, 2015	Invitations for full proposals sent to teams
March 31	Deadline for full proposals (received by 3pm ET)
April 27	DOD may perform site visits during week of April 27
May 8	Evaluation notifications sent week of May 8
May 29	Negotiations completed on or about May 29
June 22	Award issued on or about June 22
July 15	Beginning of stand-up period; tooling, fab facility, staffing, roadmap, market survey
2017	End of stand-up period. IP-IMI will start contracting device technology development projects: DOD requirements, programs of record, prime contractors
2021	End of direct federal funding, beginning of self-sufficiency

<u>PROJECT AREAS</u>

<u>Integrated photonic manufacturing processes for:</u>
1. **High-speed digital data communication (Data Centers, HPC)**
2. **Analog RF applications (EW, EP, ECM, EMI/EMP)**
3. **Integrated photonic sensors (physical, chemical and/or biological)**
4. **Another key technology**

Nanodevices and Microsystems Research Foundation Focus

- **Trusted Radiation-Hardened Microelectronics:**
  - **The development of concepts, devices and tools that enable the understanding and creation of fielded radiation-hardened microelectronics which are impervious to subversion.**
- **Optoelectronics and Photonics of the Future:**
  - **The discovery and creation of advanced optoelectronics, at the nanoscale and microscale, which provide new functionality.**
- **Ultraportable Multi-function Sensor Systems:**
  - **The development of nanoscale and microscale concepts, devices and systems that enable portable physical, chemical, biological, radiation, nuclear materials, and explosives detection that exceed current limitations in selectivity, sensitivity, and robustness.**
- **Beyond Moore Technologies:**
  - **The development of nanoscale and microscale concepts, devices, tools and systems that continue performance improvements beyond Moore's Law.**
- **Nanoscale and Microscale Enabled Performance:**
  - **Discover and exploit new functionality that results from phenomena that are unique to the nanoscale and microscale.**



Sandia National Laboratories