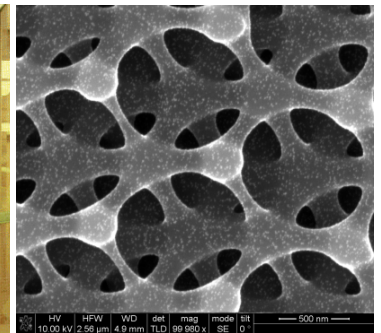
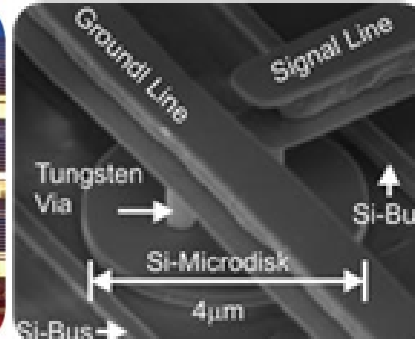


*Exceptional service in the national interest*



## 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.**

Sr. Manager: Microsystems Process Science & Technology Group

Defense Systems and Assessments S&T Products Program Manager

Microsystems Science, Technology & Components Center

[fbmccor@sandia.gov](mailto:fbmccor@sandia.gov) 505.284.1209 [www.sandia.gov/mstc](http://www.sandia.gov/mstc)



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# Center for Integrated Nanotechnologies: CINT

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

Molecular Foundry  
Lawrence Berkeley National Lab.

Center for Nanoscale Materials  
Argonne 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

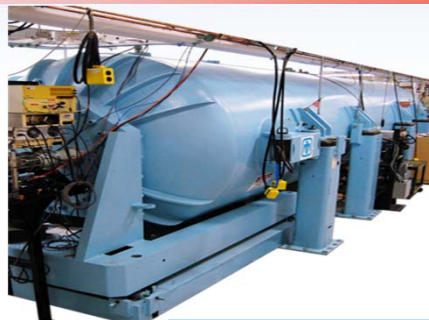
Soft, Biological, &  
Composite Nanomaterials

Theory & Simulation of  
Nanoscale Phenomena

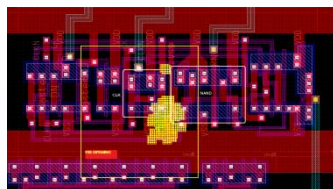
CINT User Proposals: <http://CINT.sandia.gov>

 Sandia National Laboratories

# THE ION BEAM LABORATORY



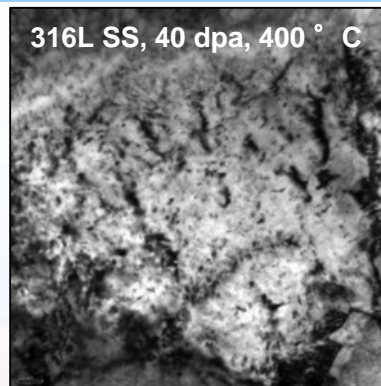
## Hostile Environments



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

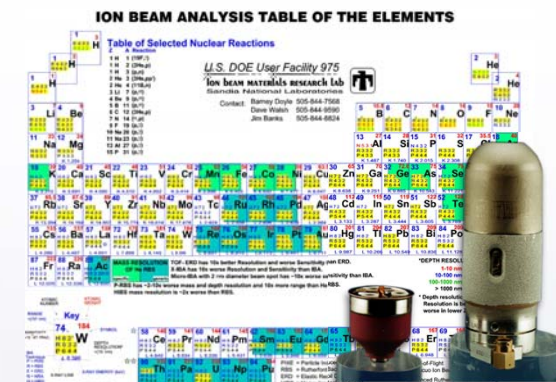
## Ion Beam Materials Modification

316L SS, 40 dpa, 400 ° C



- Single-ion implants for QIST
- Defect creation in Memristors
- Fusion reactor first wall design
- Novel Thermoelectric 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

1.9 MeV RFQ  
Accelerator

RadFX

Composition / IBA

100 keV  
NanoImplanter

In-situ  
TEM

Nano  
Implanter

Neutrons

~1eV Pulsed  
Laser  
Deposition

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

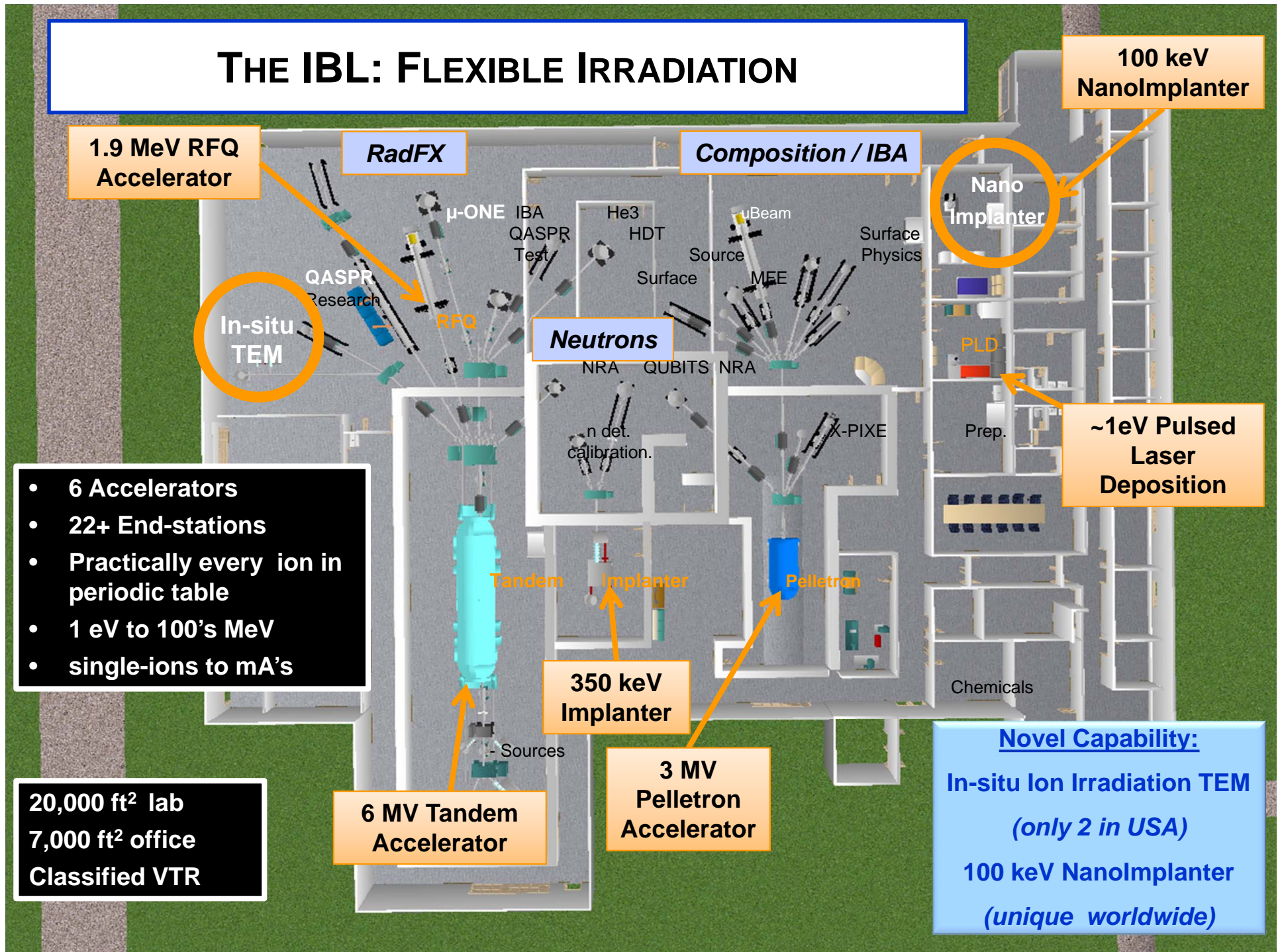
20,000 ft<sup>2</sup> lab  
7,000 ft<sup>2</sup> office  
Classified VTR

6 MV Tandem  
Accelerator

350 keV  
Implanter

3 MV  
Pelletron  
Accelerator

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



- 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

## Silicon Fabrication

Si

## Compound Semiconductor Fabrication

III-V

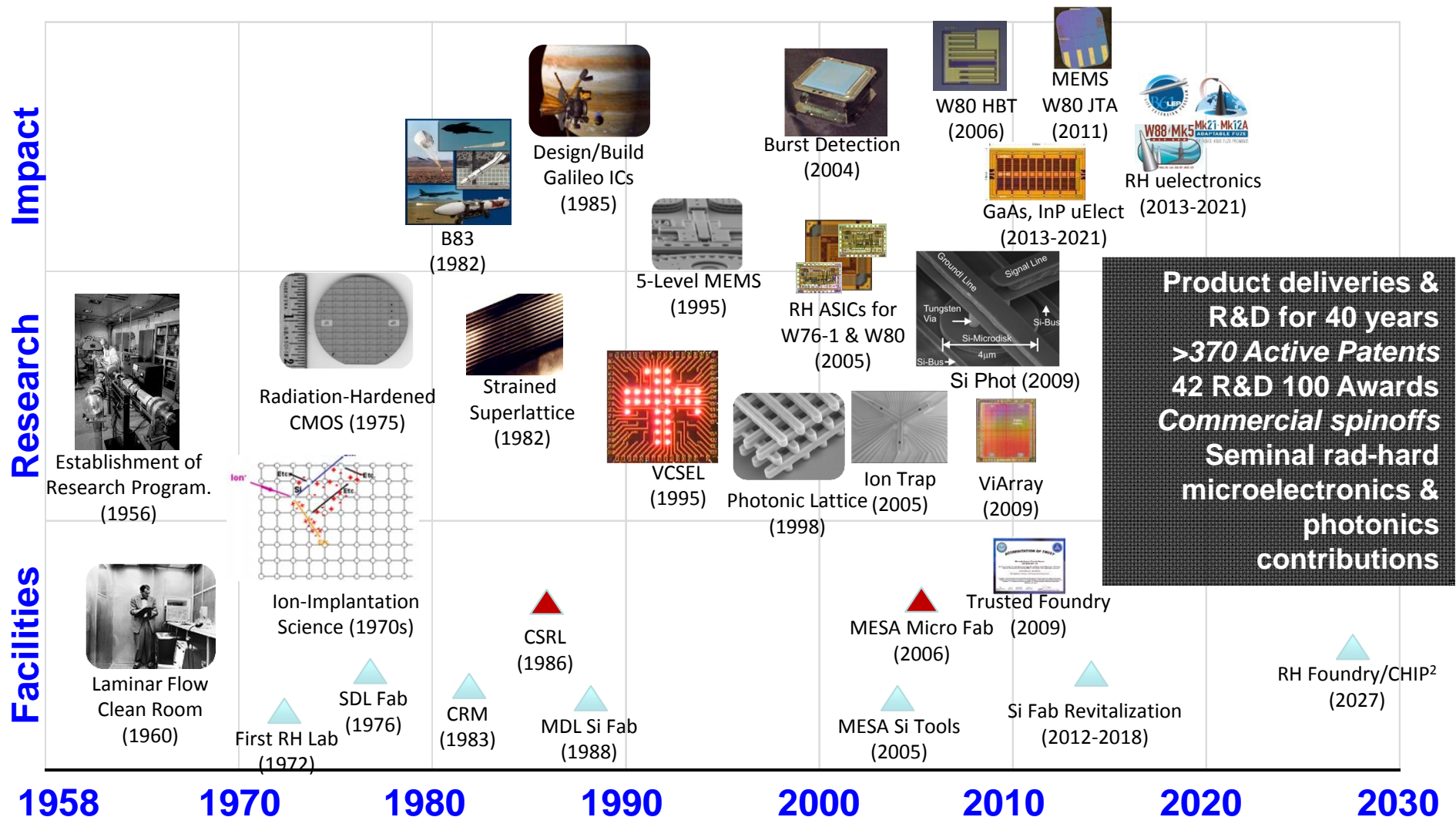
## Materials Research

- 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  $\mu$ Electronics
  - 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



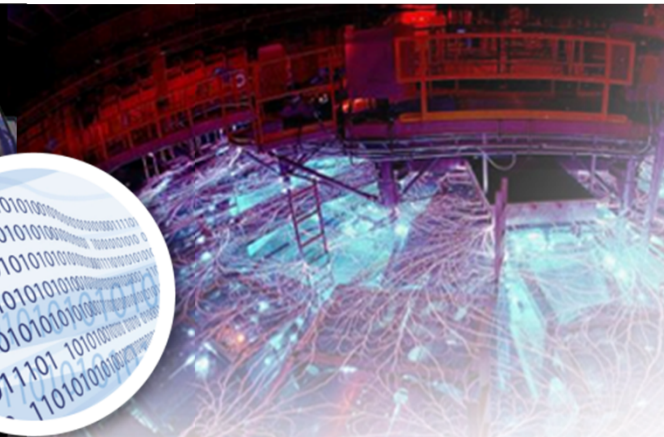
**MISSION: Invent and mature integrated circuit and microsystems technologies that provide differentiation and impact for NW and other national security missions**

# Strong Research Foundations Enable Mission Performance

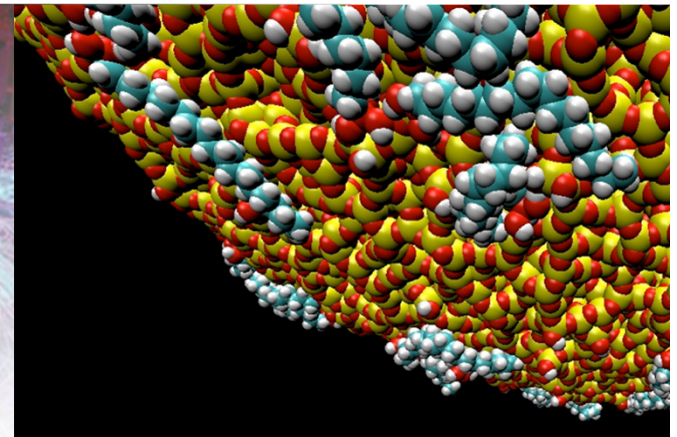
**Computing and  
Information Sciences**



**Radiation Effects and  
High Energy Density Science**

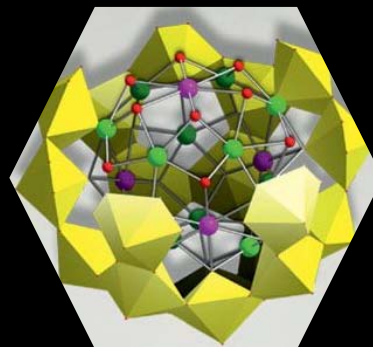
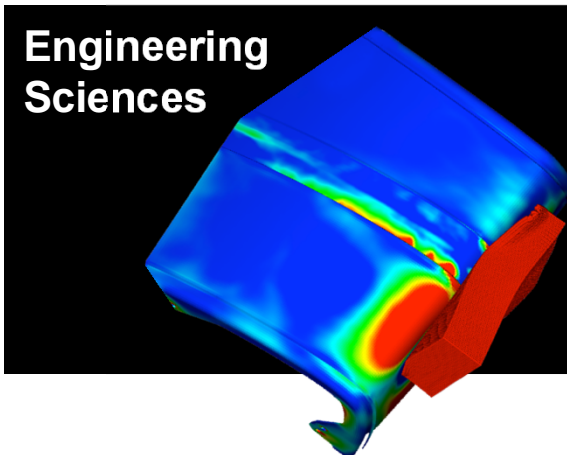


**Materials Science**

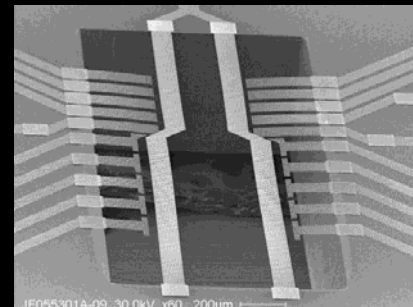


**Nanodevices and  
Microsystems**

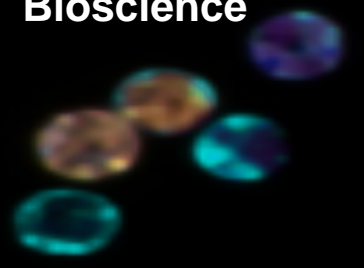
**Engineering  
Sciences**



**Geoscience**



**Bioscience**

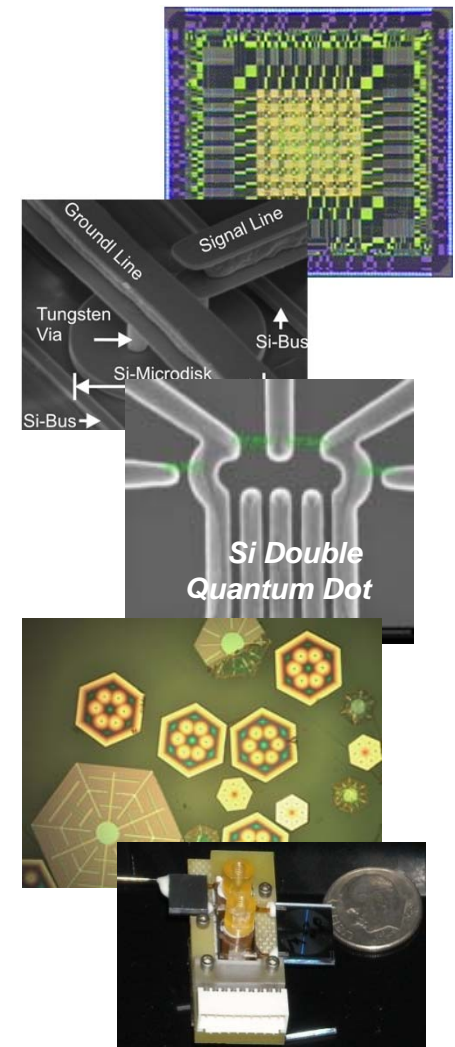


# Nanodevices and Microsystems

## Research Foundation Focus



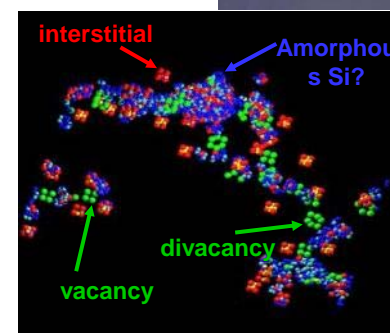
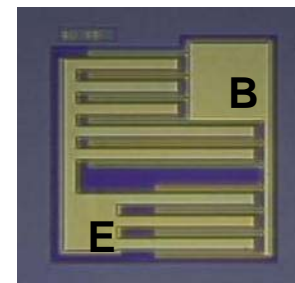
- **Trusted Radiation-Hardened Microelectronics:**
  - The development of concepts, devices and tools that enable the understanding and creation of fielded radiation-hardened microelectronics which are impervious to subversion.
- **Optoelectronics and Photonics of the Future:**
  - The discovery and 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.



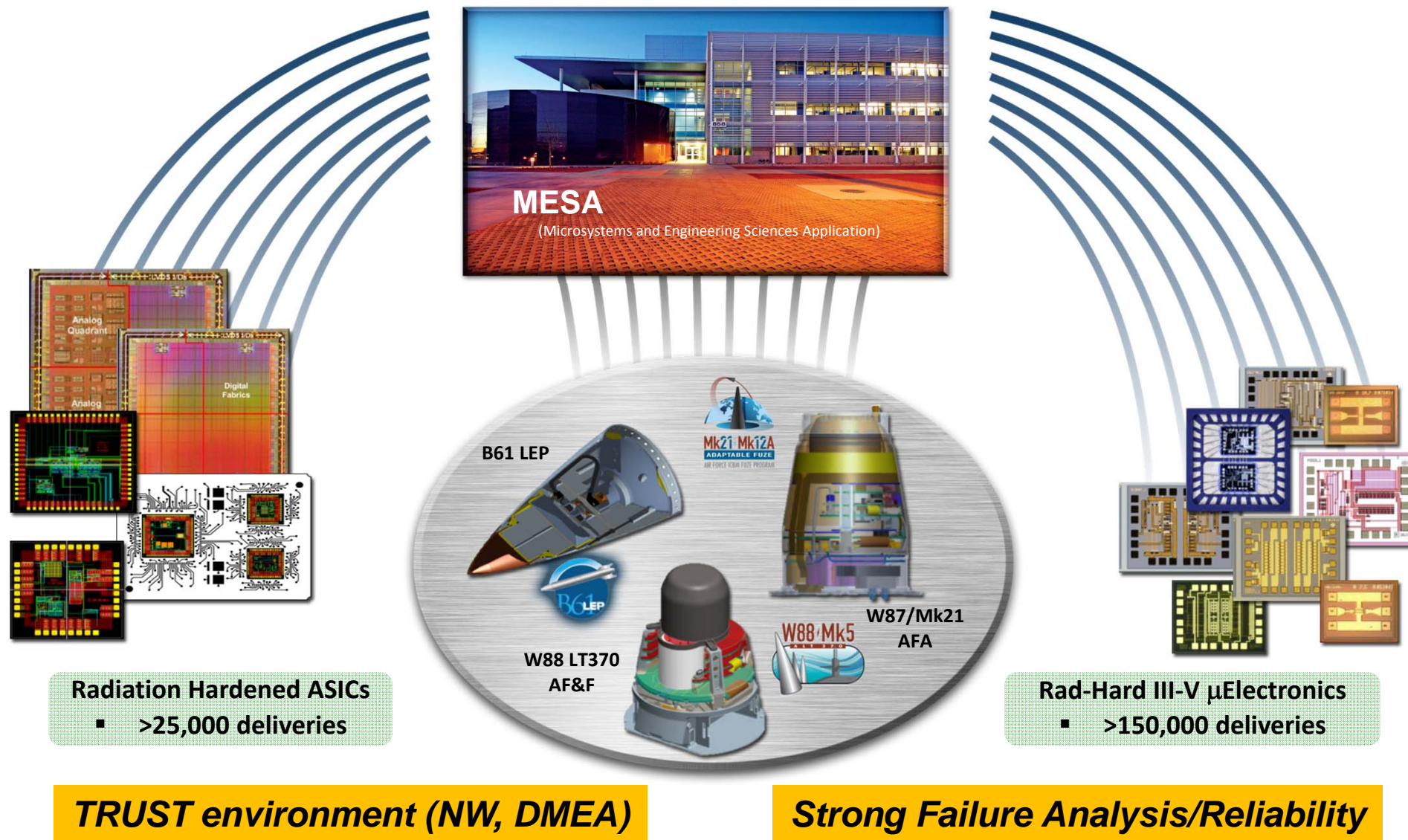
# Trusted Rad-Hard Microelectronics

***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



# Trusted Microfabrication Facilities

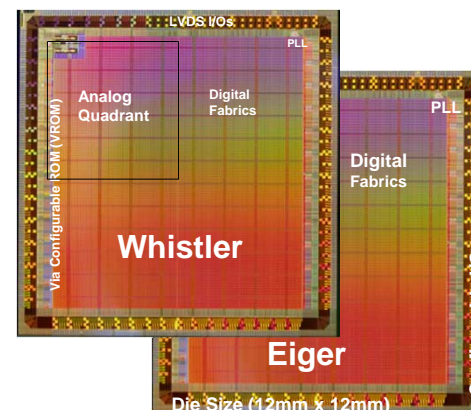
## Microelectronics Technology To Deliver Specialized ICs

### MESA Trusted Silicon Foundry

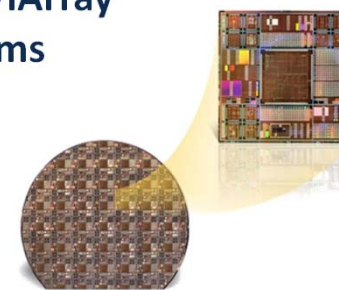
- Sandia is a certified DMEA Trusted Supplier Silicon Process Technology
- NNSA's primary supplier of custom rad-hard ICs for weapon life extension programs
  - 350nm Radiation Hardened CMOS
  - 3.3V, Silicon-on-Insulator
  - Mixed signal extensions
- Low Volume Mixed Signal Radiation Hardened ASICs
  - 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

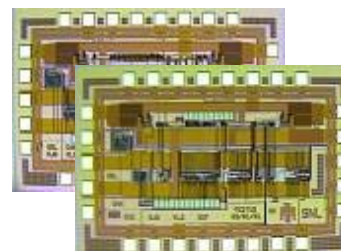
- Compound Semiconductor Epitaxial Growth
- Compound Semiconductor Discretes, IC's and Opto
- Mixed-Technology Integration and Processing
- Materials Characterization



**Rad-Hard ViArray Platforms**



**Low Cost Multi-Project Wafers**

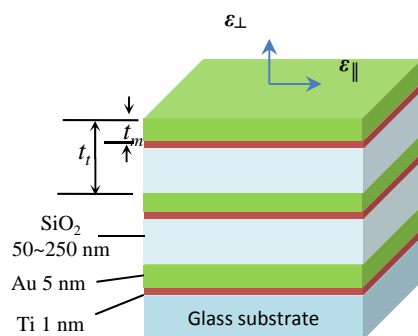


**Custom Rad-Hard Mixed Signal ASICs**

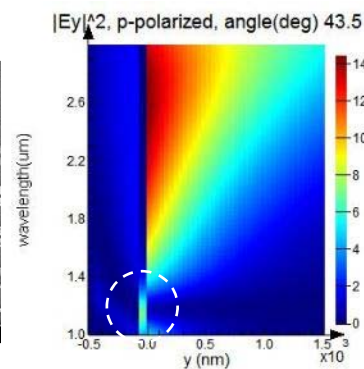
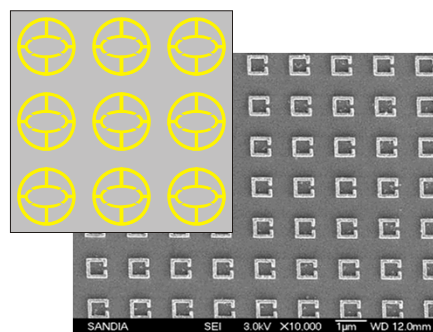
# Optoelectronics of the Future

- ***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

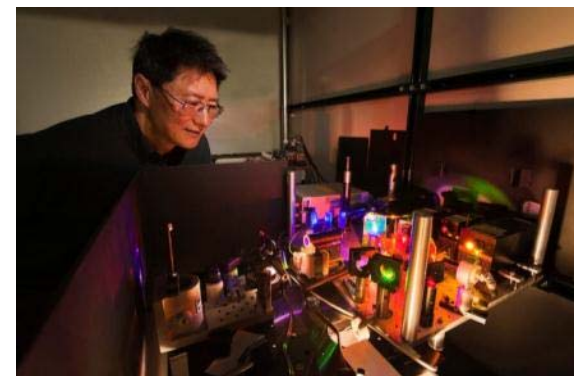
**Epsilon Near Zero**



**Metamaterials & Plasmonics**



**SSL By Lasers**



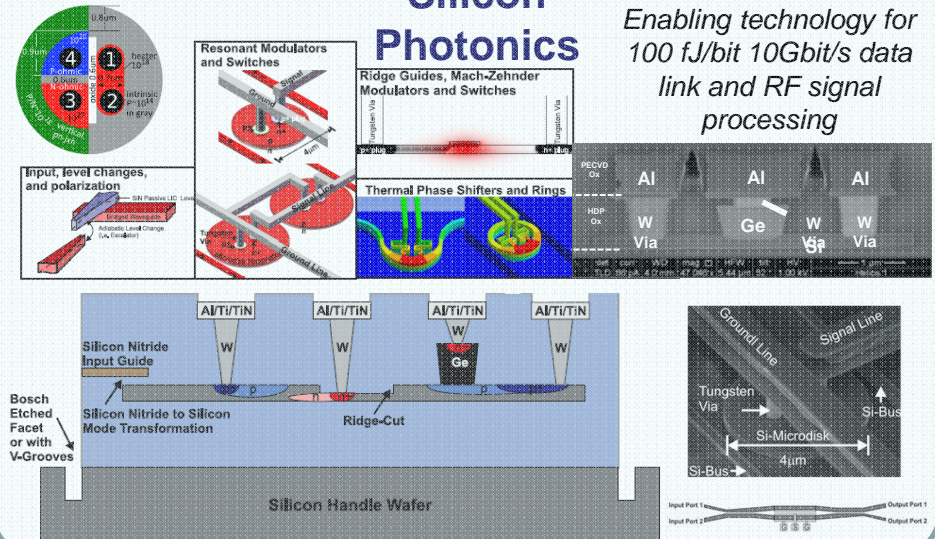
# Applied Photonics Microsystems

## 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

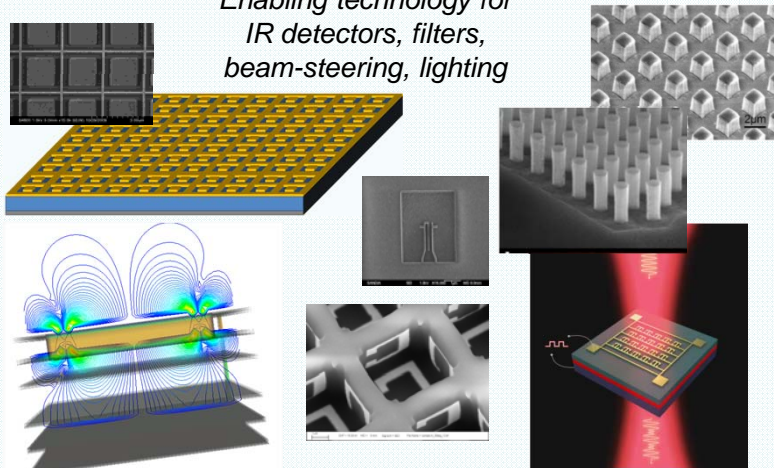
## Silicon Photonics

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



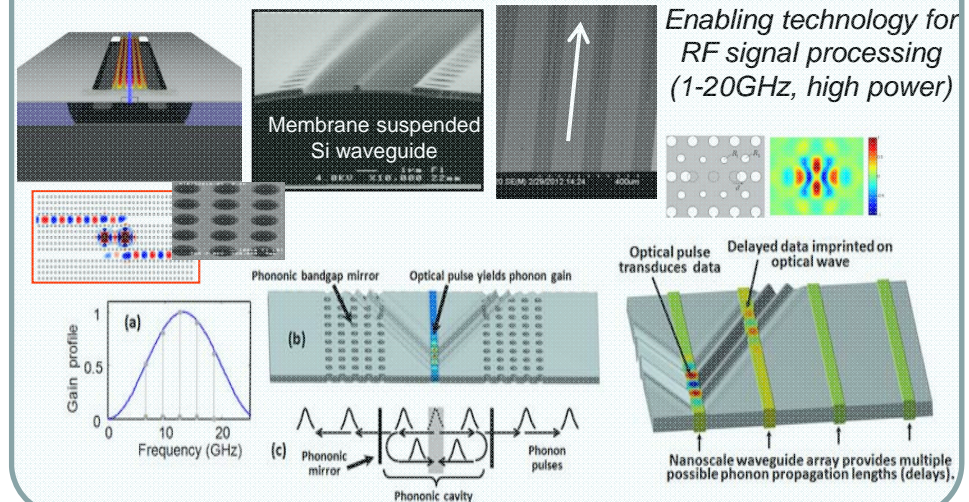
## Nano-photonics

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

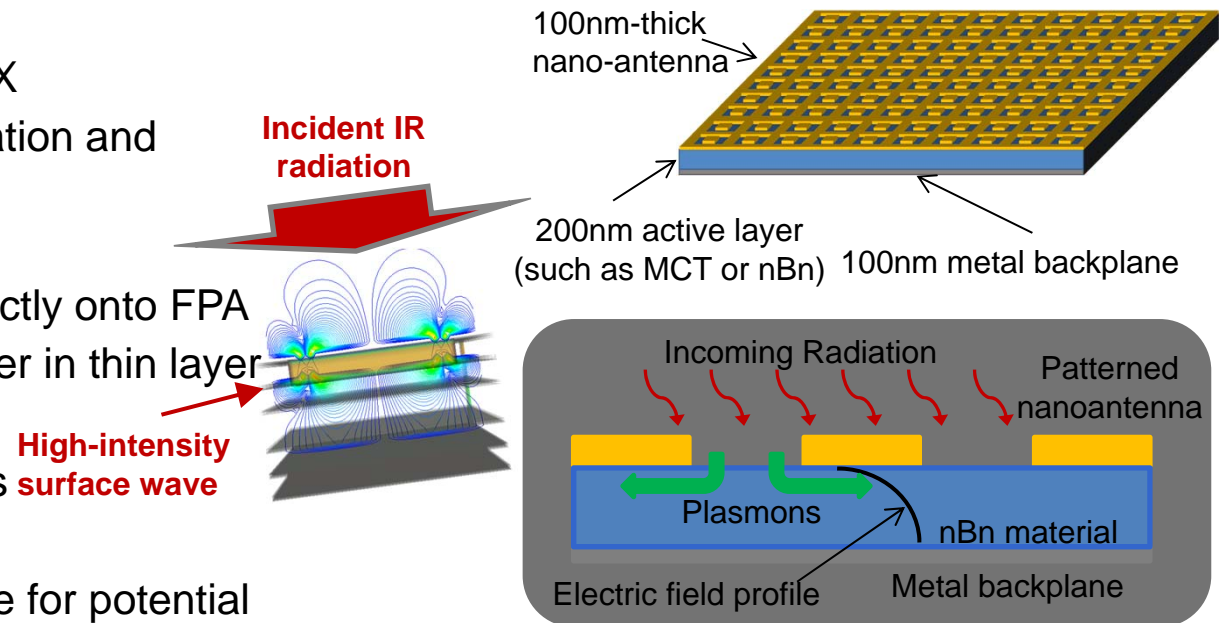
## Approach:

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

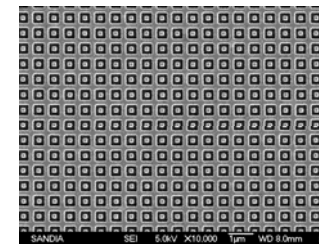
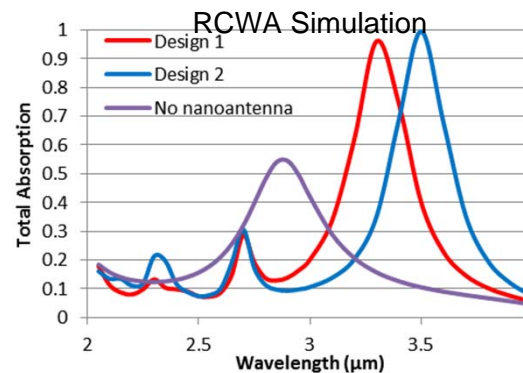
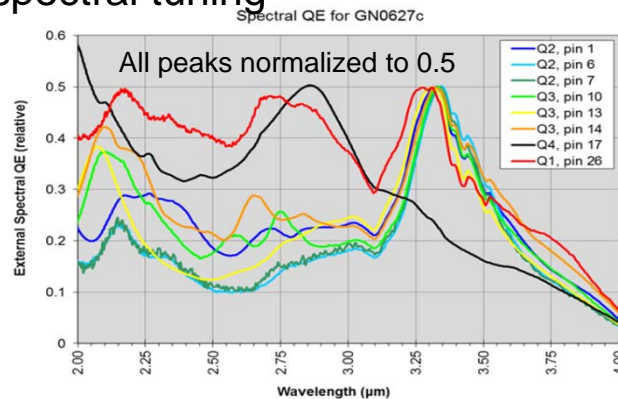
## Accomplishments to Date:

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

## One FPA pixel with integrated nanoantenna

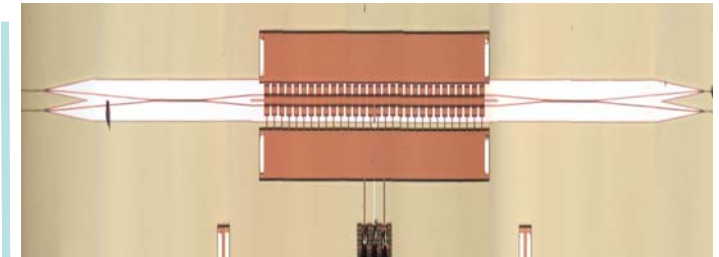
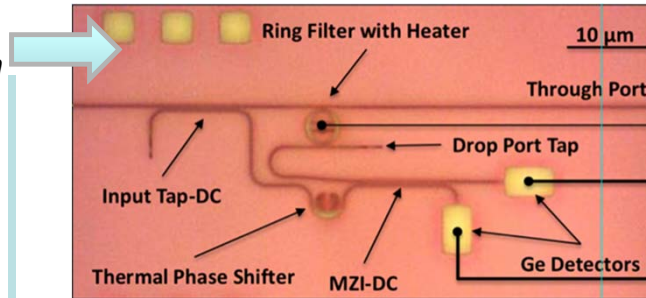


## Wide band filter simulation

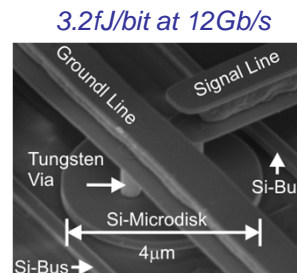


# Si Photonics

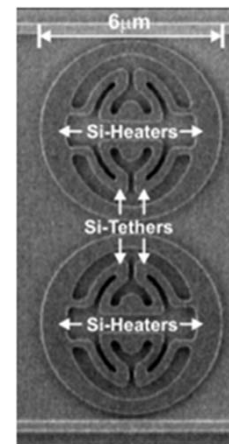
- 2014 *balanced homodyne resonant wavelength stabilization > 55C*
- 2013 *Si Photonics MPW (CIAN NSF ERC)*
- 2012 *24 GHz Si TW MZM*
- 2011 *45 GHz Ge Detector*
- 2010 *3 fJ/bit resonator modulator, 1V-cm MZM*
- 2009 *wavelength tunable rings over 35 nm*
- 2008 *2.4 ns Wavelength selective switch*
- 2007 *MicroDisk resonator infrared detector*
- 2005 *Si<sub>3</sub>N<sub>4</sub> low-loss waveguides*
- 2000 *SiON / SiO<sub>2</sub> (Clarendon Photonics)*
- 1990s *Si PhC & Optical MEMS*



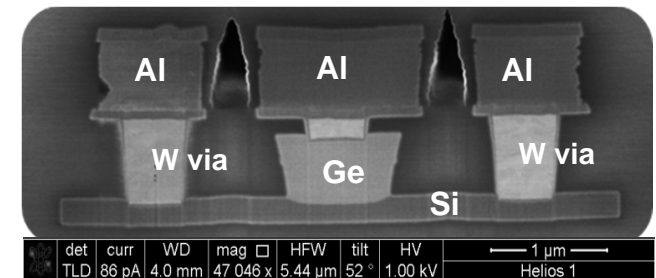
**24 GHz 0.7V-cm Travelling Wave MZI Modulator**



**Resonant Optical Modulator/Filter**

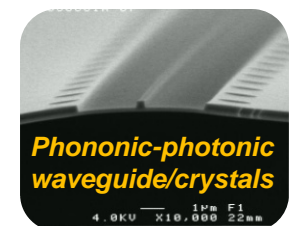


**Tunable Resonant Filter**



**45 GHz High-speed Ge Detector on Si**

**MEMS process for additional capability**

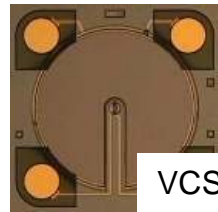


# III-V Photonics

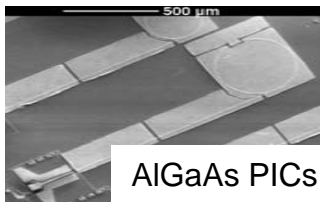
2010s



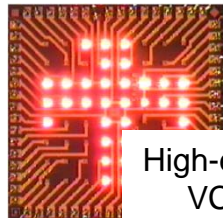
InGaAsP PICs



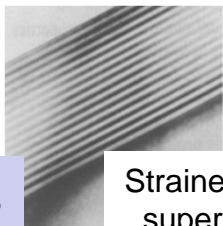
VCSEL+ PD



AlGaAs PICs



High-efficiency  
VCSELs

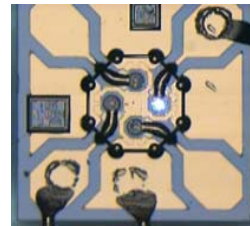


Strained-layer  
superlattices

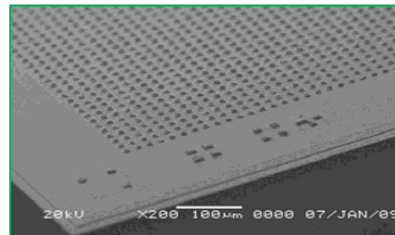
1980s



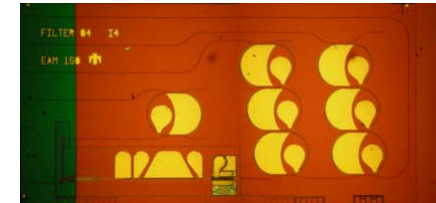
On-Chip Injection Locking  
Enhanced Modulation > 50 GHz, C-Band



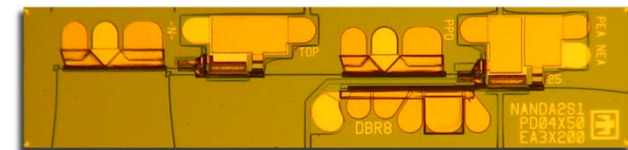
Single-Frequency Tunable VCSELs,  
For atomic spectroscopy and sensors



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



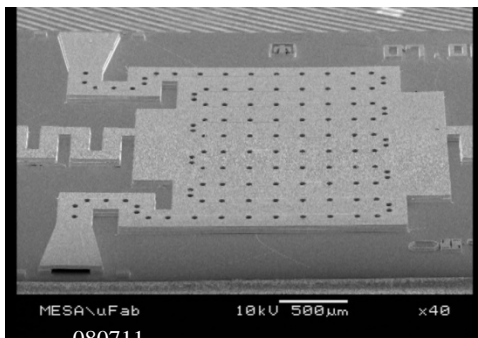
RF-Optical Channelizing Filter  
1-20 GHz RF on C-Band Light



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

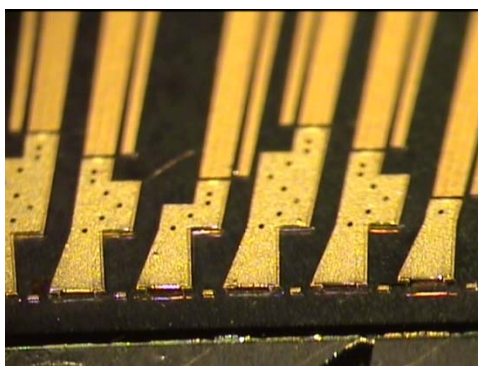
- Foundational Capabilities
  - III-V compound semiconductor epitaxy, microfabrication, integration
  - Device physics, modeling, simulation
  - Microelectronics/optoelectronics, and complex mono/hetero-circuits
- Prove, Advance Technology Readiness Level, Productize
  - TRL1-6+: create, develop, prototype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

# THz Integrated Devices



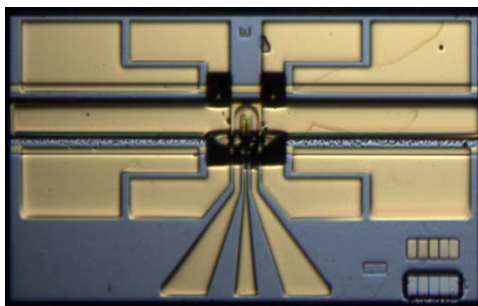
- **Micromachined rectangular waveguides:**

- 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



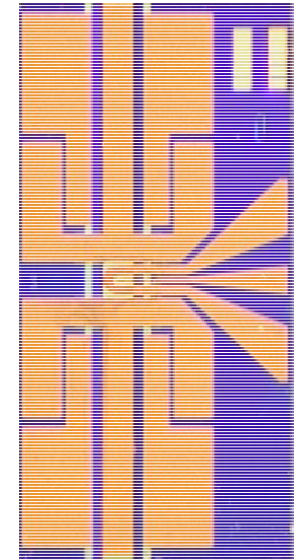
- **THz QCL Integrated with Schottky receiver:**

- Compact heterodyne receiver / transceiver on-chip
- Novel tool to explore laser dynamics
- Enables novel functions (phase imaging, vibrometry, ...)

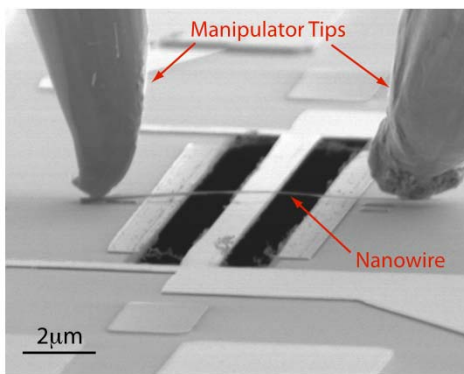
# Ultraportable Multi-function Sensor Systems

- ***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

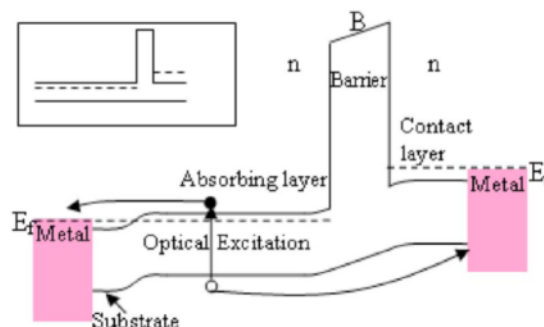
QCL-based Mid-IR Transceiver



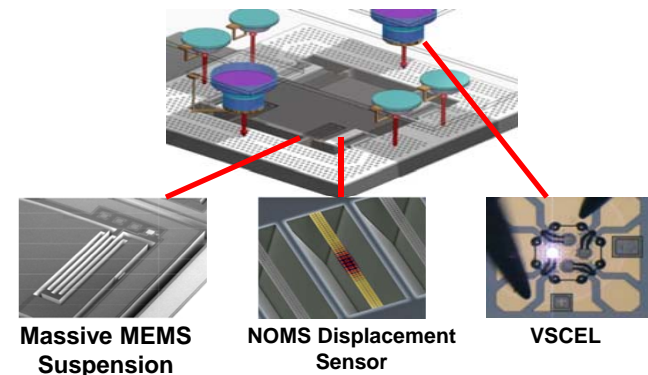
Nanoscale Calorimetry



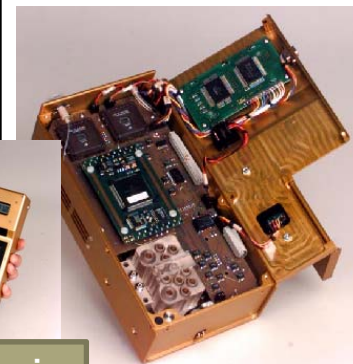
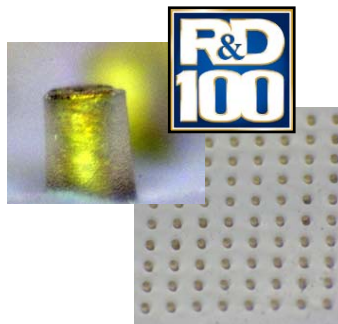
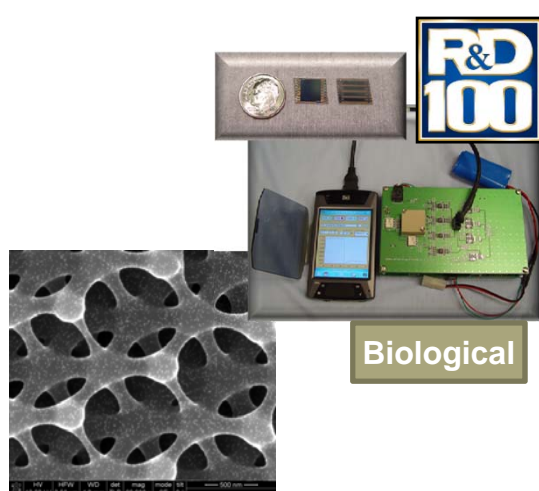
nBn IR Detector



Accelerometer:  
100nG/rtHz, 10kHz



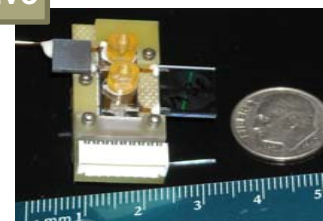
# Example Remote & Proximate Sensor Capabilities



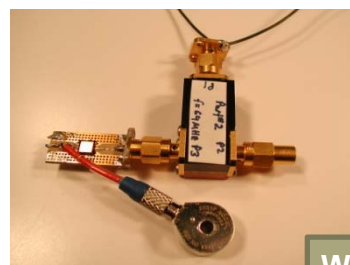
Chemical/explosive



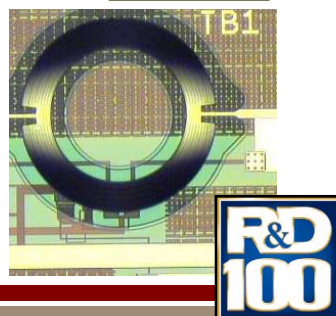
EM



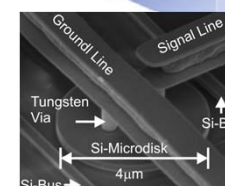
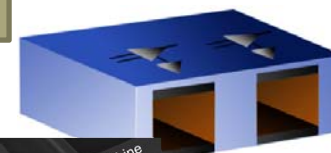
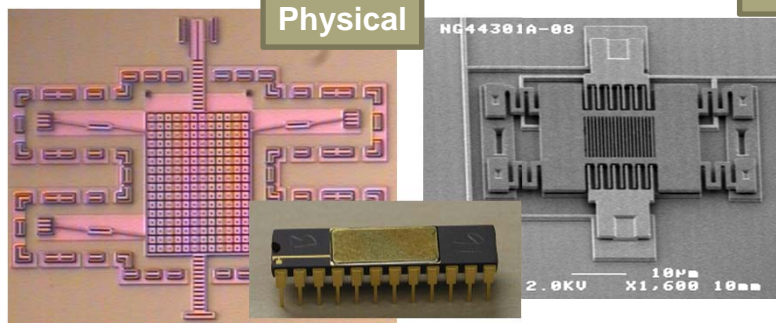
Radiation



Wireless

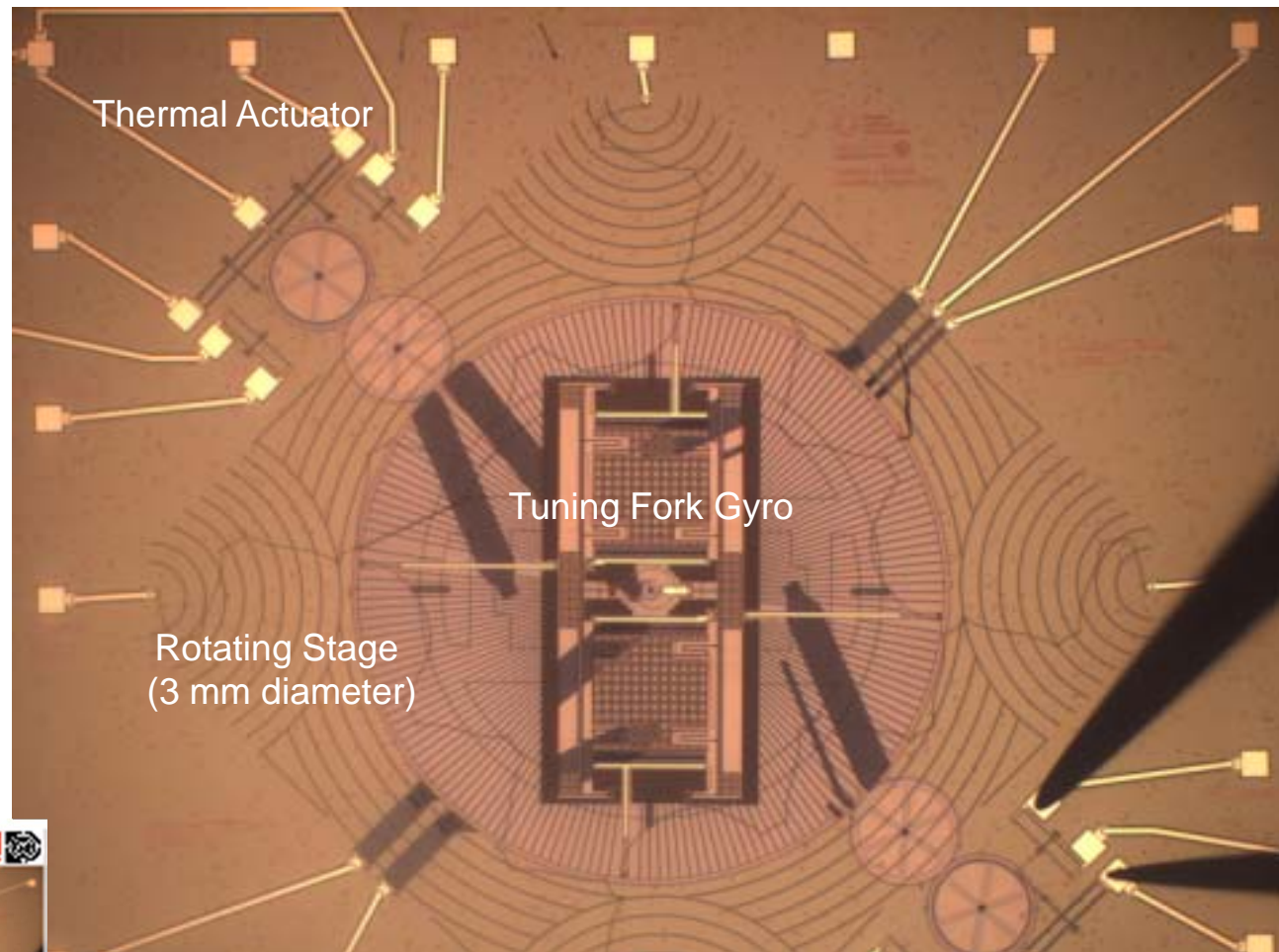


Physical



# SUMMiT Today: PASCAL

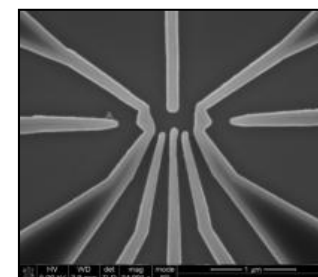
## *DARPA MicroPNT Project: Primary and Secondary Calibration on Active Layer (PASCAL)*



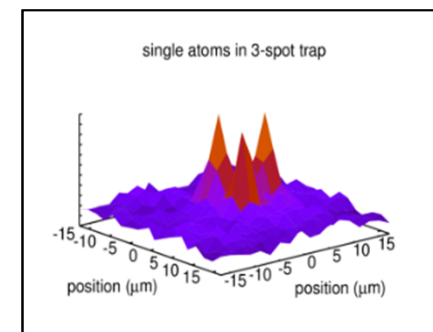
# Beyond Moore Technologies

***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.

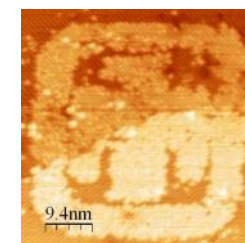
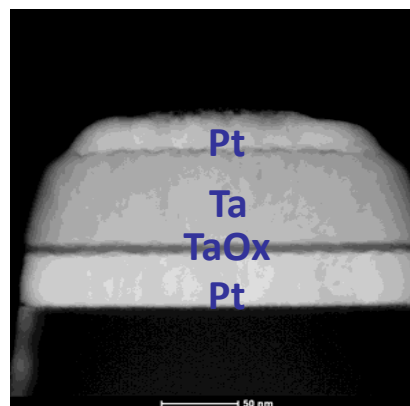


*Silicon double-QD qubit*

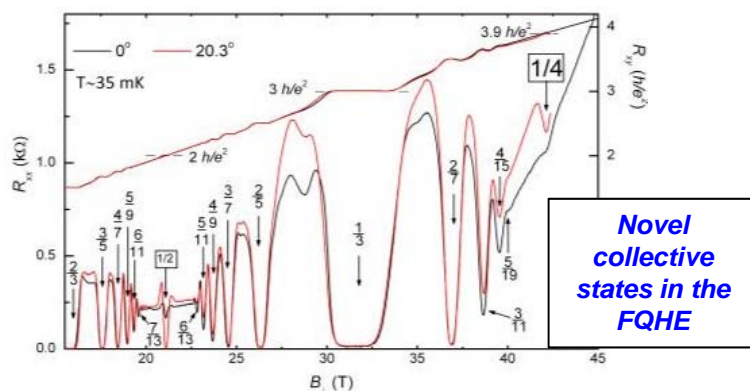


*Three Cs atoms in a 3-node trap*

*TaOx Memristor*



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



# Quantum Information Processing Over \$30M of investments at Sandia



## LDRD Grand Challenge: Quantum Information Science and Technology (FY08-10; ~ \$13.4M)



- Long-term problem:
  - Quantum computing can in principle provide exponential speed-up over classical computing, but to date the hardware components of such a system do not exist.
- Approach:
  - Develop logical
  - Demonstrate
  - Measure
  - Develop
  - Fabricate
  - Tested
- Accomplish:
  - Design
  - Sensitive
- Follow-on Architect

**AQUARIUS™**  
Adiabatic quantum architectures in ultracold systems

Dr. Andrew J. Landahl • Principal Investigator  
Dr. Steven M. Rinaldi • Project Manager

**Quantum computing 101**  
Quantum computers promise to take computing to its ultimate quantum-mechanical limit, just as lasers did for light. Multiple applications in fields like energy, medicine, and optimization are already known. The primary roadblock to development is exceptional noise sensitivity. On paper, the adiabatic quantum architecture is expected to dramatically improve robustness by maintaining a quantum computer in its lowest-energy configuration. Understanding whether this robustness is borne out in practice is an important QIST question.

Post-doc Paul Pomonis adjusts Sandia's first quantum computer, capable of processing a single quantum bit (qubit). The computer processes information stored in an optically trapped ion in a 100-micron-scale ion trap in an ultra-high vacuum chamber.

**QIST**  
Quantum Information Science

Malcolm S. Carroll • Principal Investigator  
Thomas D. Terman • Project Manager

**Project Accomplishments**

- Developed fabrication and measurement techniques for silicon quantum bit (qubit) using double quantum dots
- Developed end-to-end design (qubits to quantum circuit) for error corrected logical qubit with Si double quantum dot hardware
- Developed modeling tools to guide the fabrication, measurement, and assessment of Si qubit and circuits.

**Recent accomplishments**

- Demonstrated spin qubit in Si
- Neural systems
- Electronics integration

**More than 24 scientific articles, 50 invited talks, and coverage in mass media**

**Experimental work started under QIST GCLDRD is continuing under external funding**

**Quantum Circuit**

**Physical Qubit**

**Classical Interface**

**Logical Qubit**

World's first single electron charge sensing in SiMOS system

- Quantum Information Processing at Sandia enabled by 2 GC LDRDs

**Beyond Moore Computing RLT Research Challenge**

- Objective:
  - Versatile, scalable, energy efficient HPC
  - New devices, architecture, algorithms
  - Existing software; scientific computing through "big data"
- Application Focus:
  - Embedded to autonomous systems
  - National Security through commercial applications
- Challenges:
  - Devices, logic circuits, interconnects, memory, software, architecture, energy efficiency
  - Leverage material Science, device physics, heterogeneous integration, computer architectures, algorithms...

**Device Structure:** Pt (10 nm), Ta (100 nm), TaO<sub>x</sub> (20 nm), Pt (10 nm). O<sup>+</sup> leave behind vacancies switching region.

**CMOS Circuitry:** De-Sensitized Memory Array, Pulse Generators, Read Out Circuitry, CMOS Circuitry, De-Sensitized Memory Array.

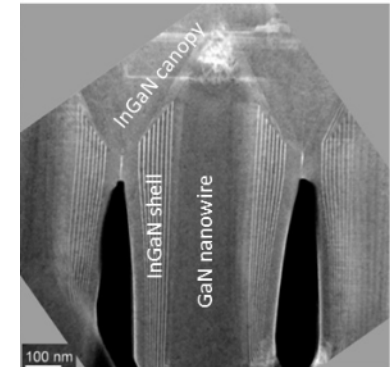
**NOT TO SCALE**

Sandia National Laboratories

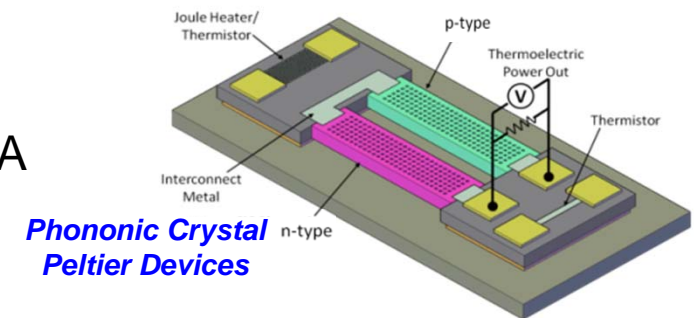
# Nanoscale- and Microscale-Enabled Performance



**Strain-relaxed InGaN Core-Shell Nanowires for PV**

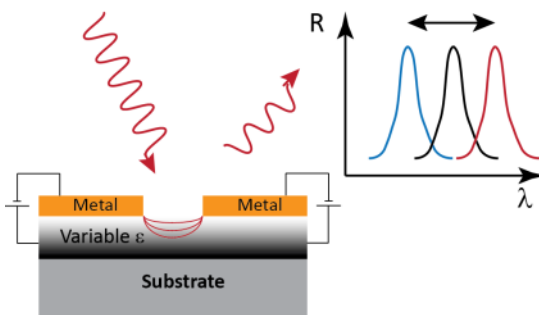


- ***Discover and exploit new functionality that results from phenomena that are unique to the nanoscale and microscale.***
  - Enable technology surprise
  - nm-to-cm 3D Surface Enhanced Raman
  - Phononic enabled filters and communication
  - Metamaterials
  - 2-D Materials: Bilayer Graphene Tunable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

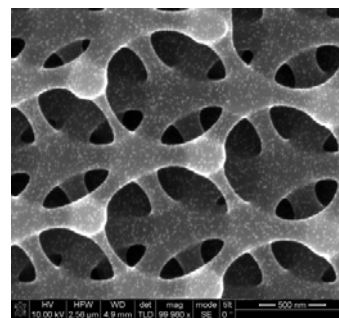


**Phononic Crystal Peltier Devices**

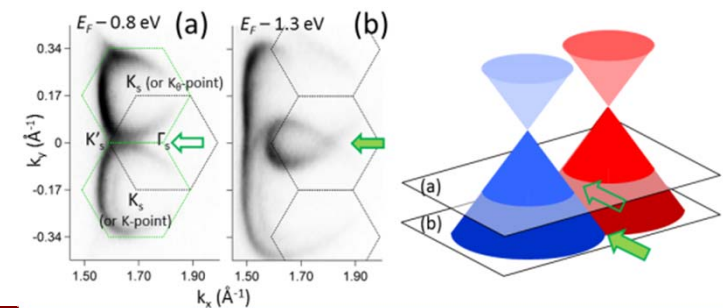
**Metamaterial-based tunable optical filter**



**Pyrolyzed Carbon Interference Litho 3D SERS substrates**



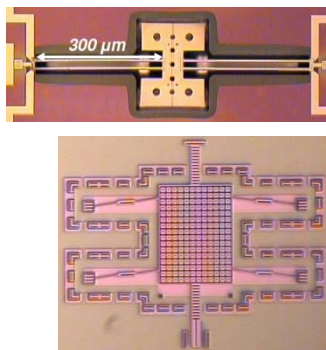
**Optical Properties of Twisted Bilayer Graphene**



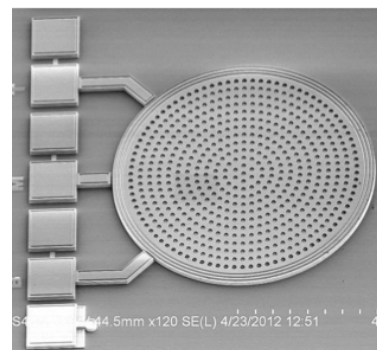
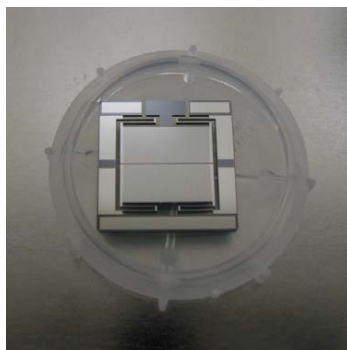
# Sandia's Current MEMS Portfolio

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

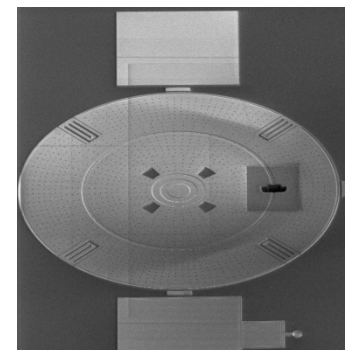
**Inertial Sensors**



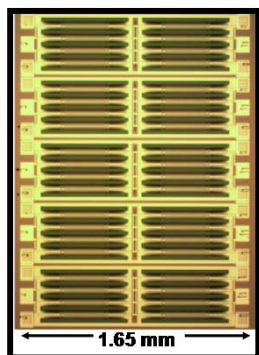
**Pressure Sensors**



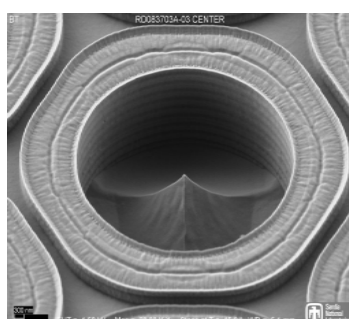
**Microfluidic Actuators**



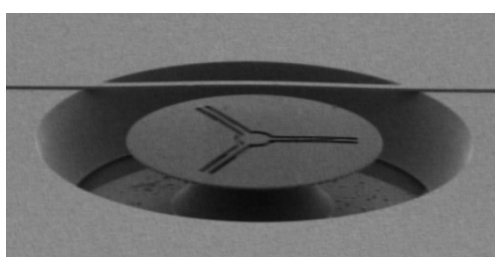
**Electronics**



**Vacuum Electronics**



**Photonics and Waveguides**



**Photovoltaic Cells**

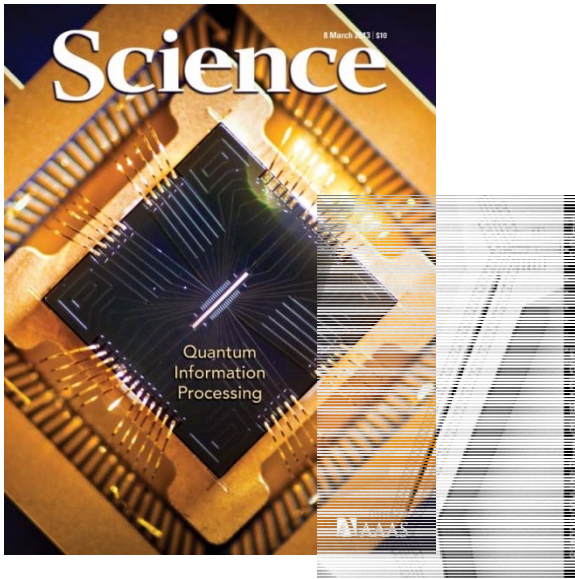




Sandia  
National  
Laboratories

# Quantum technologies and applications

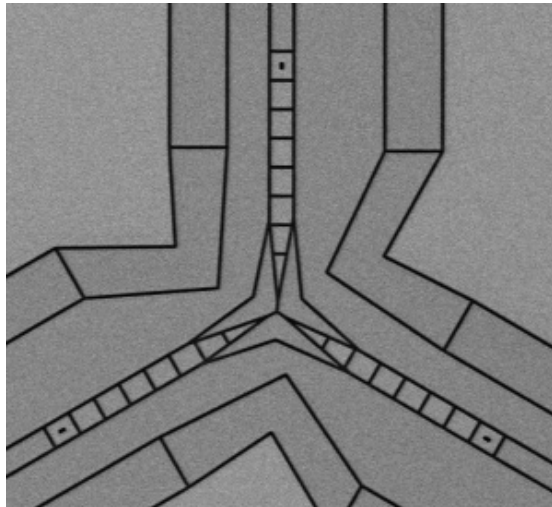
## Quantum Information Processing



- 2008: Sandia's 1<sup>st</sup> “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

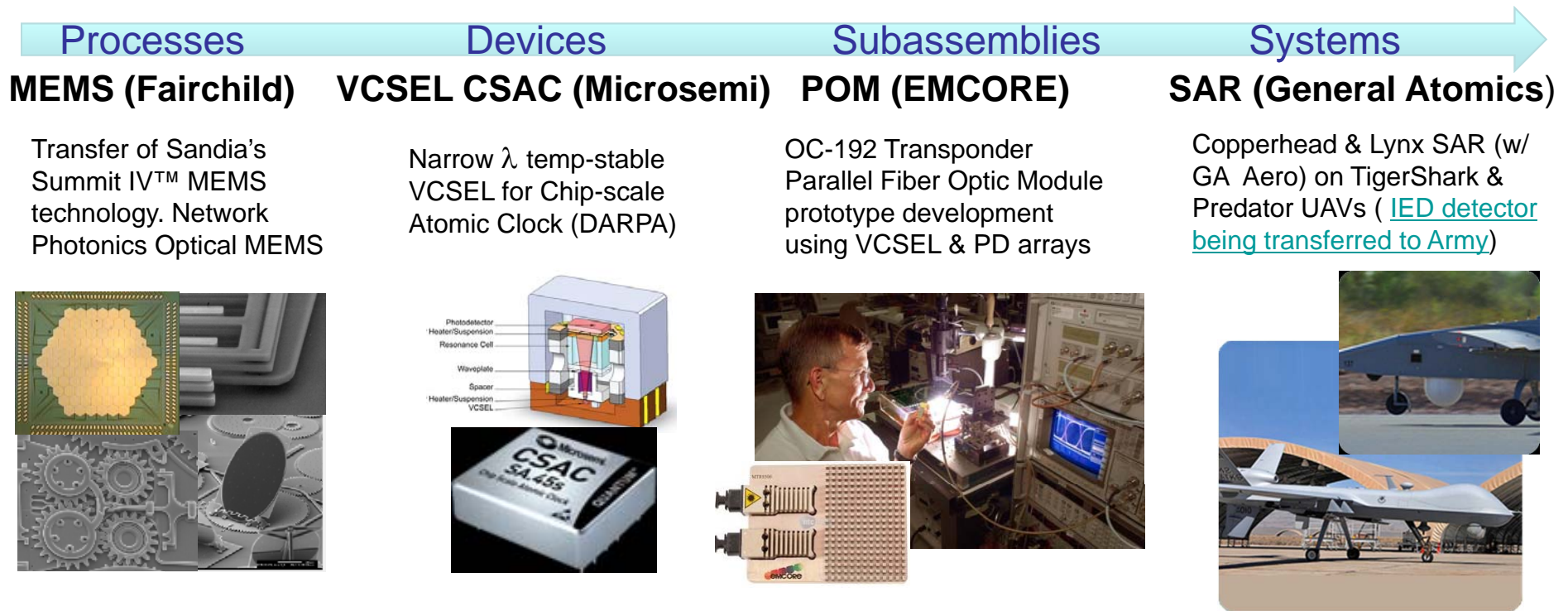


Tiny trapped-ion clock:

- 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

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



# Technology Transition: innovation and application

Vertical Cavity  
Surface  
Emitting Lasers  
Intellectual  
Property

Led  
To

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

Including



Chip-Scale  
Atomic Clock

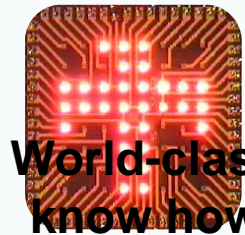
 Symmetricom®



Product!



ROI



World-class  
know how

United States Patent	
Hayley et al.	5,903,590
Patent Number:	May 11, 1999
Date of Patent:	
[10] VERTICAL CAVITY SURFACE-EMITTING LASER DEVICE	
[11] Inventors: G. Ronald Hayley, Kevin L. Lee, Jeffrey S. Wang, Kent D. Chappo, et al. of Albuquerque, NM	
[12] Attorney: [13] 01/01/99	
[14] 01/01/99	
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29 patents

Strained-Layer Superlattices: A Brief Review  
G. C. OSBORNE  
(United Paper)

THERE has been a remarkable increase in the number of papers published on strained-layer superlattices (SLS) in the last few years. This is due to the fact that SLS have been found to have a wide range of properties which are of interest for scientific and device purposes. In this paper we review a number of these SLS properties without attempting a comprehensive review of the field.

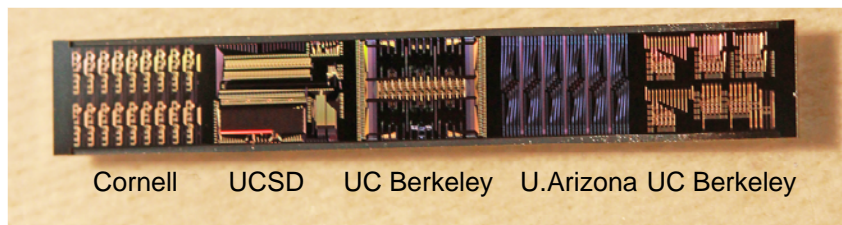
> 100 pubs

- 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**

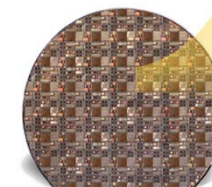
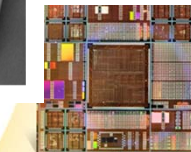
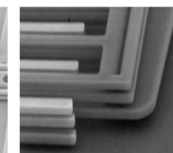
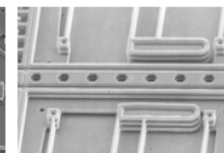
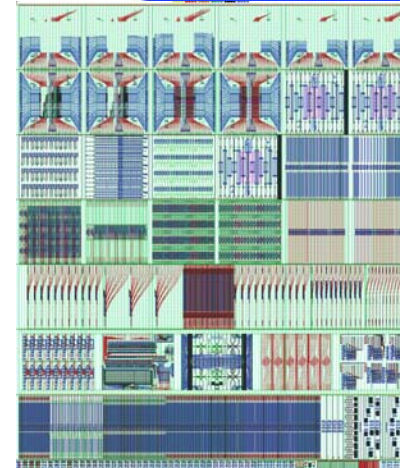
# Sandia and Multi-Project Wafer Fabrication



- **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



#### 4. TECHNOLOGY OVERVIEW



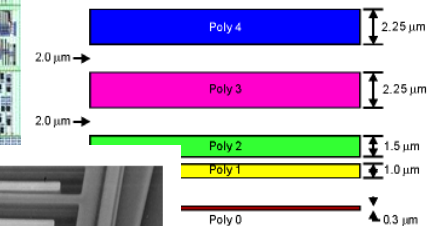
ories (SNL) has developed a Microsystems and Engineering Sciences facility located in a limited classified area. Trusted custom fabrication of silicon and technologies for digital, analog and mixed signal ICs is currently available. It offers production micro-electronics components to support special DOE and ESA Complex is designed to integrate the numerous scientific disciplines of microelectronics, including design, fabrication, and testing. The facility is a national, robust, integrated microsystems and represents the center of SNL's research, development, and prototyping activities. This suite of facilities occupy 400,000 square feet and includes cleanroom facilities, laboratories and

photonics process (SPPI) has been engineered and matured in the MESA fab which can be seen in photonics process is an insulator (SOI) wafer thin SPPI are two layers one in crystalline silicon nitride, a full p-w resistance **phonic** interconnect layers), in of Germanium with nts all surrounded by NL's silicon photonic process technology el photonic integrated

Figure 4-14 A cartoon illustration of the cross-section of Sandia's SPPI process with a subset of the possible implant configurations

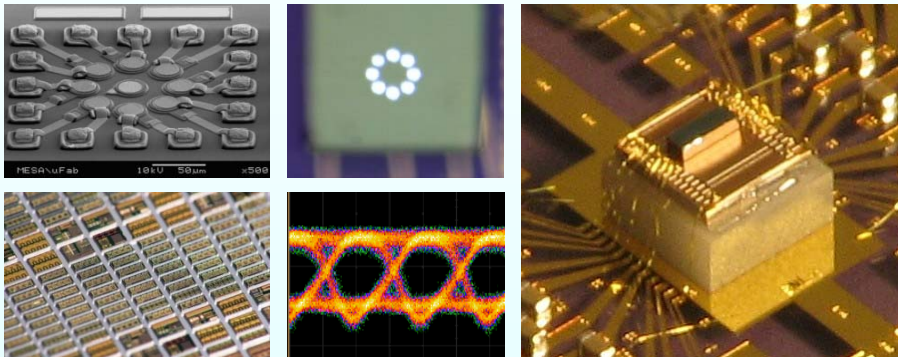
## LESS DETAILS

cess flow of are described in Table 5-1. The base process can be broken



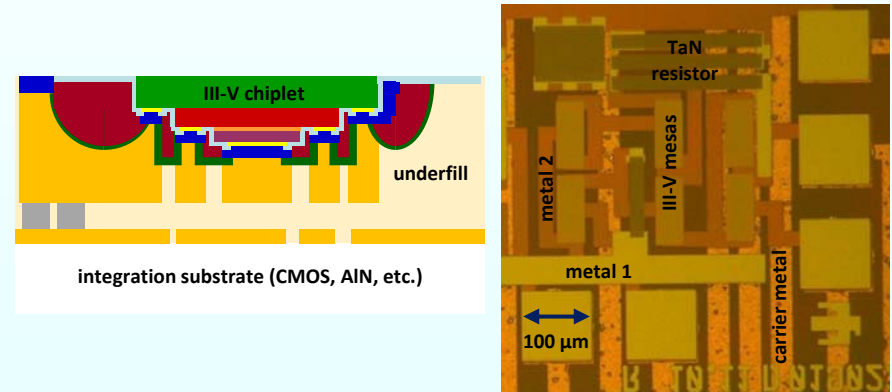
# Trusted Pathfinders: Heterogeneous Integration

## Optical Data Communications



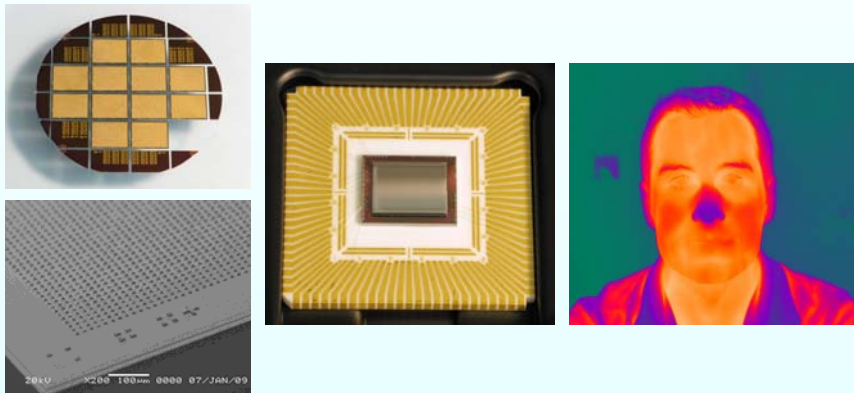
- GaAs- and InP-based devices: VCSELs, modulators, photodiodes
- dense integration onto 32-nm and 45-nm CMOS

## Heterogeneous III-V/CMOS Microelectronics



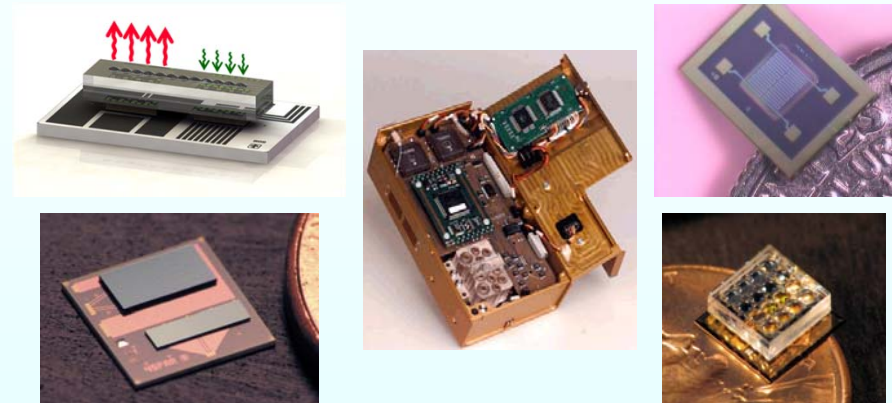
- complementary integration of GaAs and InP microelectronics
- III-V microelectronics circuitry on CMOS ASICs

## 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

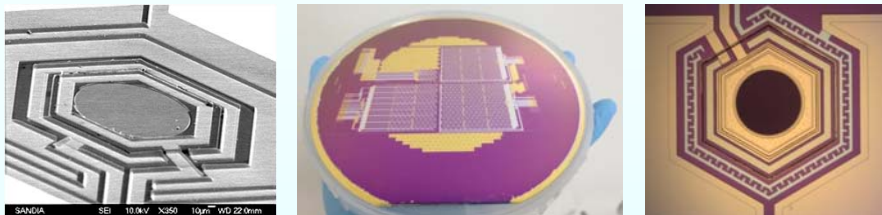
## Optical and MEMS-based Microsensors



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

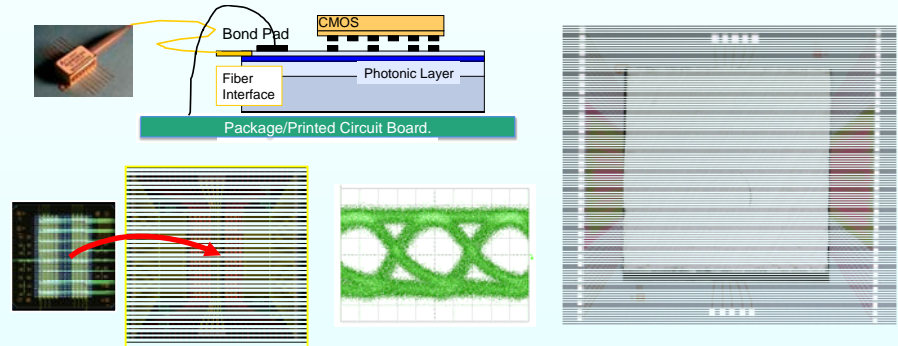
# Trusted Pathfinders: Heterogeneous Integration

## Microsystem-Enabled Photovoltaics



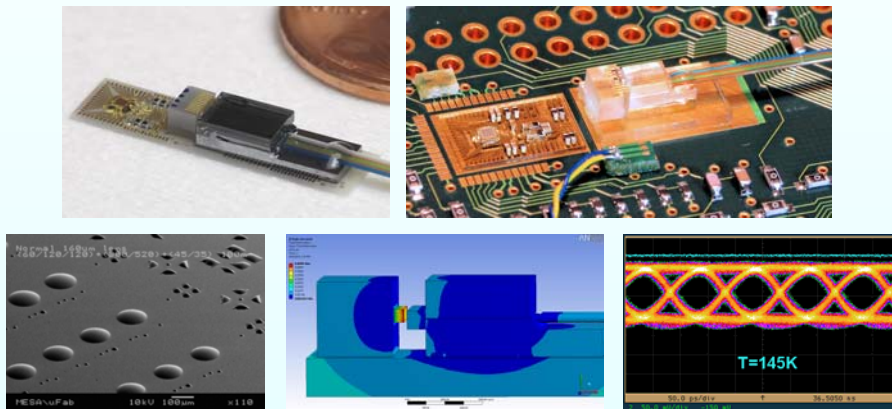
- wafer-level bonding for multi-junction solar cells
- InGaAsP/InP and InGaP/GaAs devices on silicon
- dielectric interfaces with III-V substrate removal
- integration with collection optics

## High Performance Computing



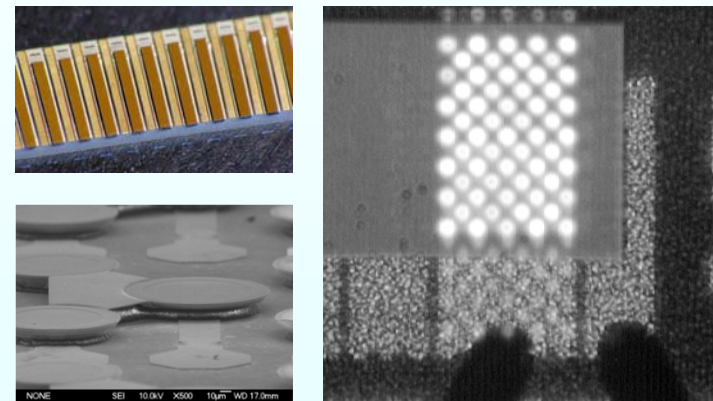
- silicon photonics on high-speed silicon ASIC
- independent optimization of electronics & photonics

## 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

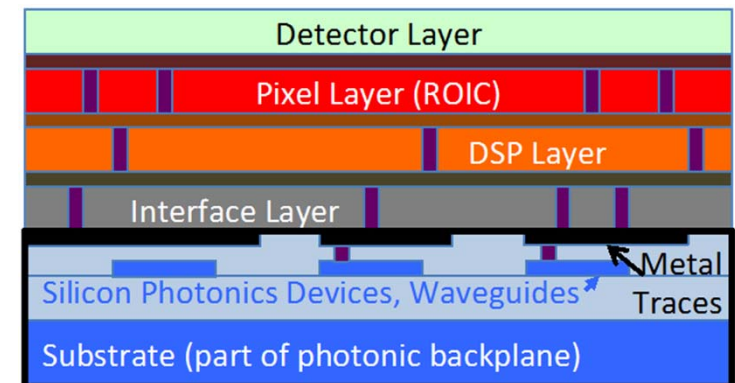
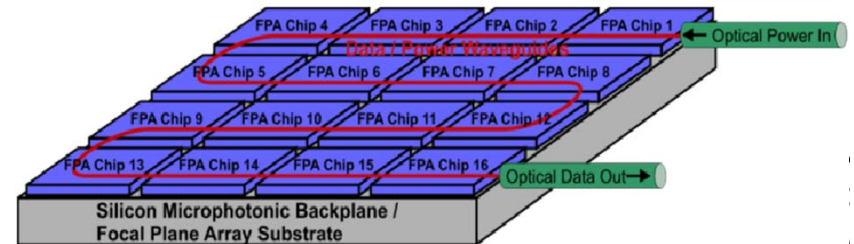


# \$220M+ Integrated Photonics Institute for Manufacturing Innovation

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

## Potential Roles for Sandia:

- 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

## PROJECT AREAS

### Integrated photonic manufacturing processes for:

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.

