Microsystems
Science, Technology & Components

SAND2008-5890P

Sandia National Laboratories Capabilities Briefing in Support of Rochester Institute of Technology Detector Center of Excellence

September 5th, 2008

Thor D. Osborn

Contact: (505) 845-8786

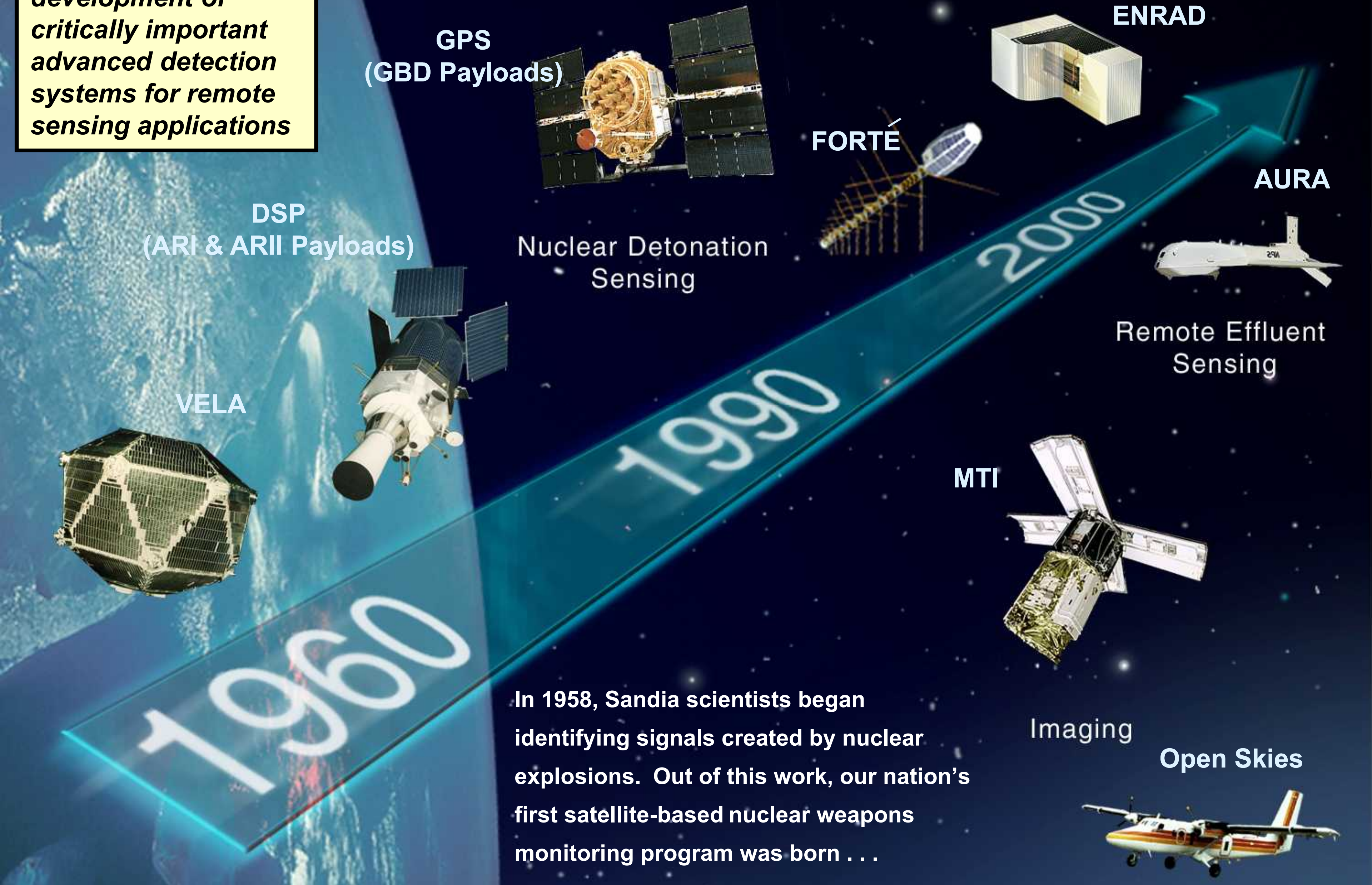
Sandia National Laboratories

Objectives

- Introduction to Sandia National Laboratories technologies and capabilities relevant to focal plane arrays and detectors
- Establish foundation for subsequent conversations regarding the potential role(s) of SNL in connection with the RIT DCE

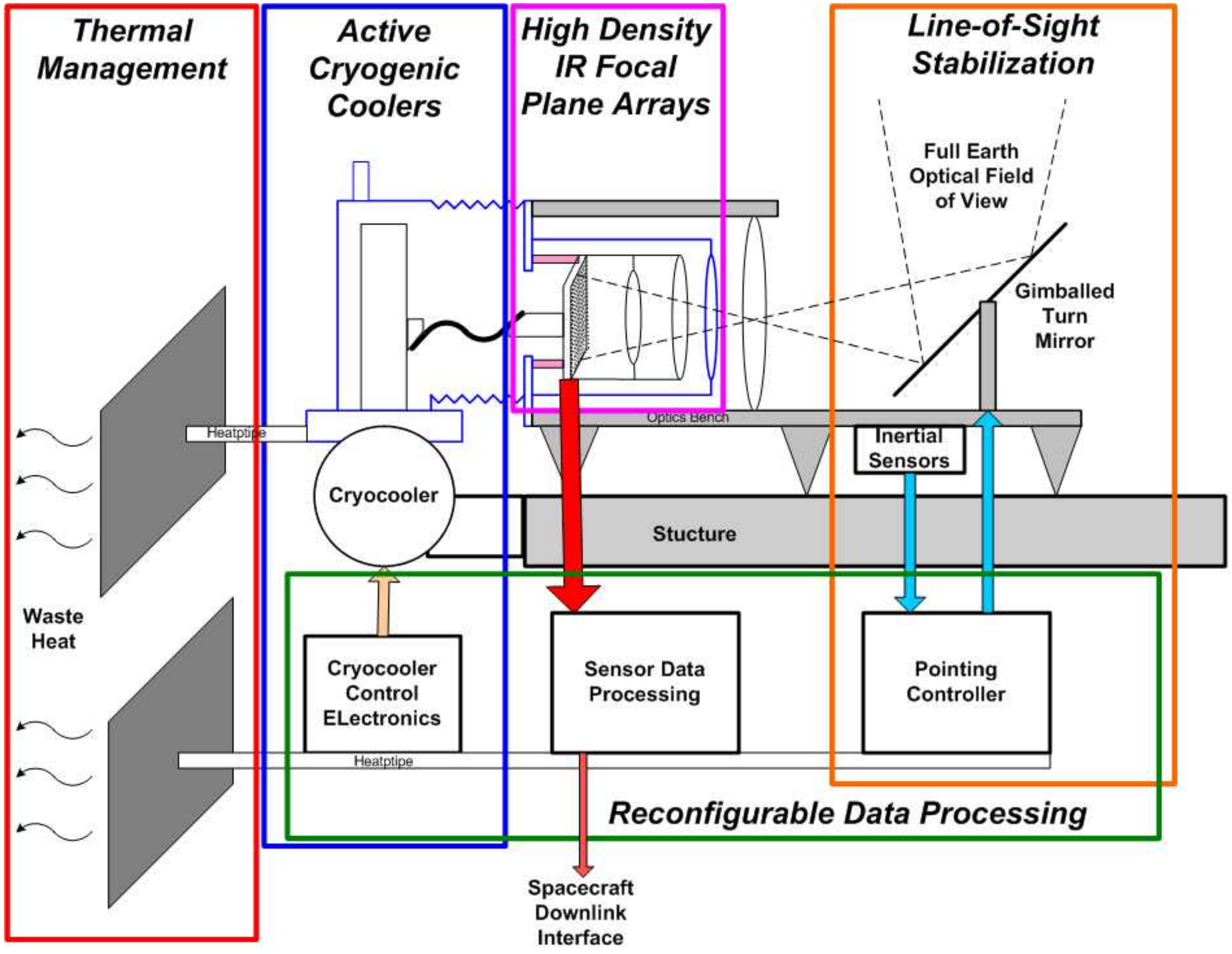
DOE Remote Sensing R&D

Sandia has a long history in the development of critically important advanced detection systems for remote sensing applications



In 1958, Sandia scientists began identifying signals created by nuclear explosions. Out of this work, our nation's first satellite-based nuclear weapons monitoring program was born . . .

Deep Experience in Complex FPA-Enabled Systems



Sandia has maintained substantial ($100M+ /yr) ongoing efforts for many years in the development of challenging experimental and operational imaging and non-imaging FPA-enabled detection systems. While the specifics of these systems are customer-confidential, the insights garnered from these programs would enhance the impact of the RIT DCE.

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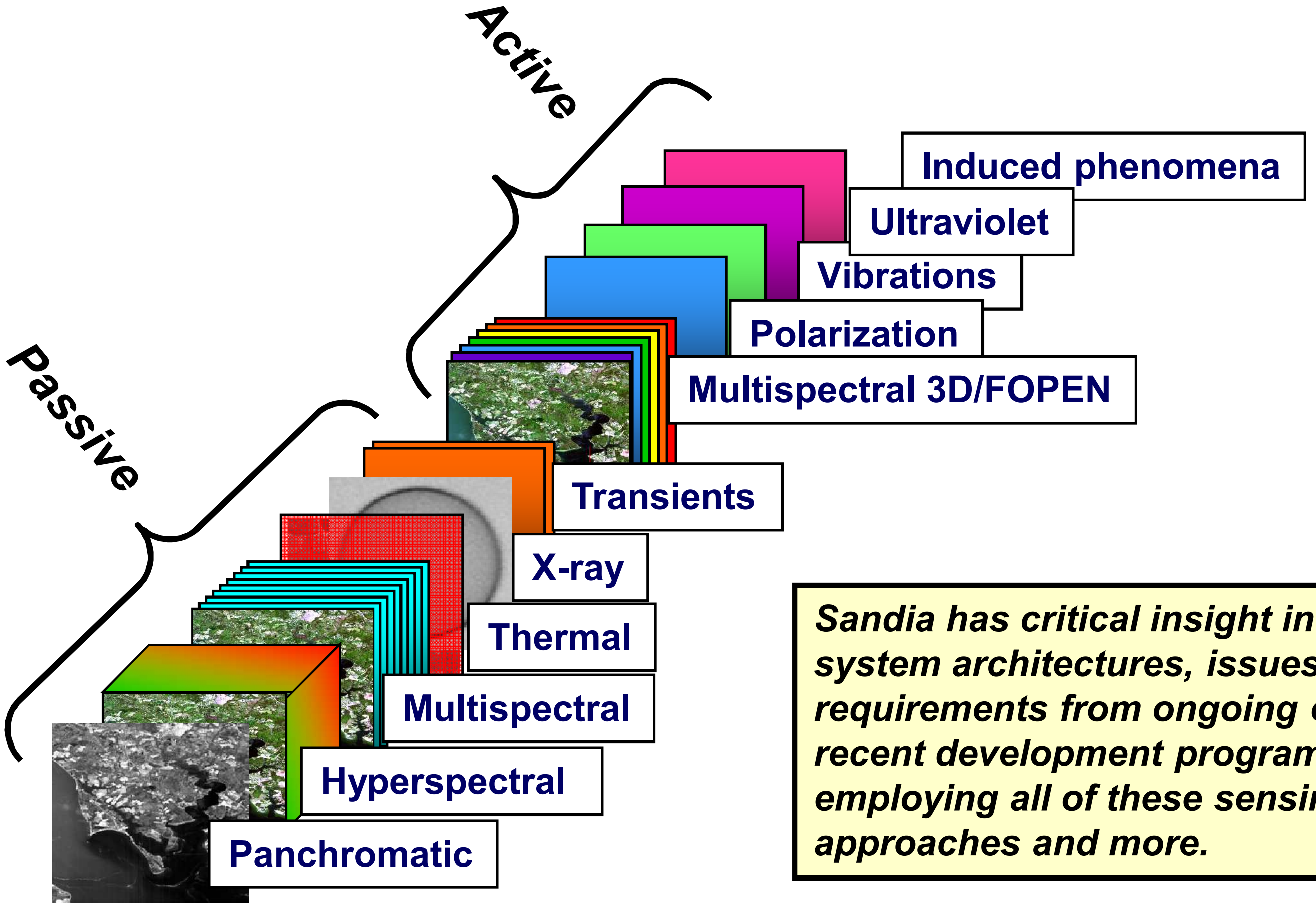
Sandia Has Expertise in a Broad Range of Detector Modalities



Active

Induced phenomena

Ultraviolet

Vibrations

Polarization

Multispectral 3D/FOPEN

Passive

Transients

X-ray

Thermal

Multispectral

Hyperspectral

Panchromatic

Sandia has critical insight into system architectures, issues, and requirements from ongoing or recent development programs employing all of these sensing approaches and more.

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Sandia Nine-Point Readiness Scale

Technology

TR1: Interesting science - basic research

TR2: Potentially useful science - applied research

TR3: Research result of direct customer value

TR4: Lab demonstration of concept

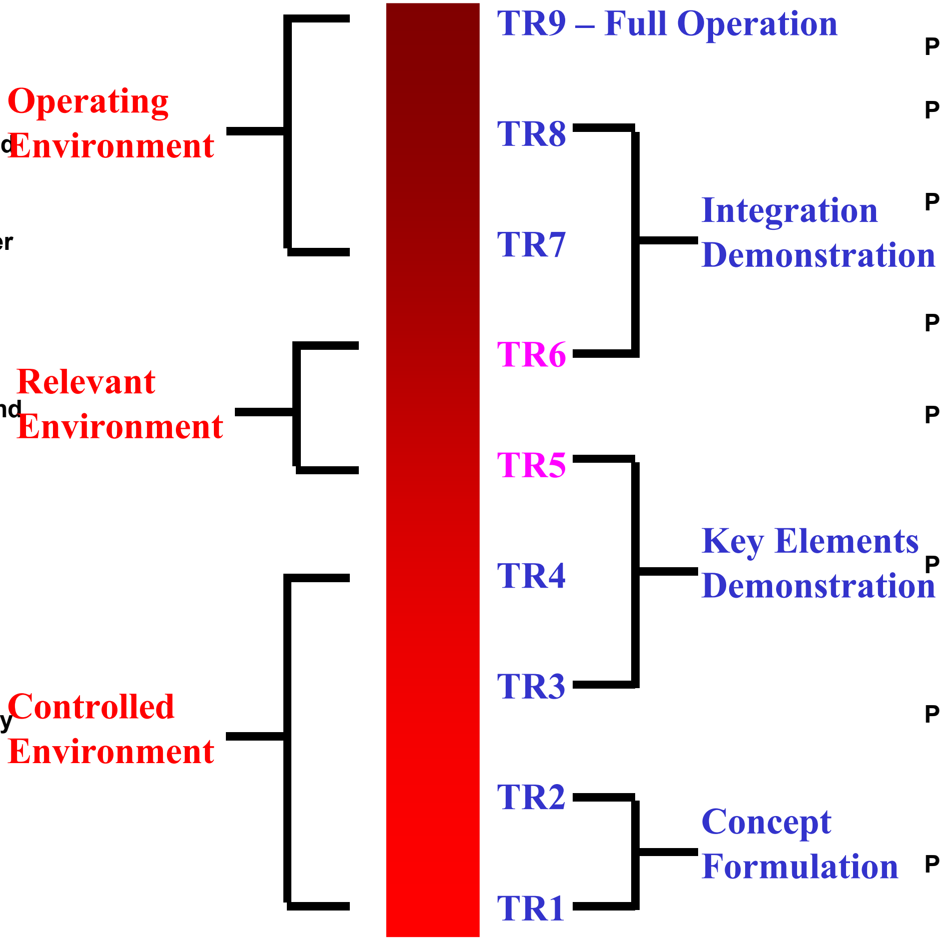
TR5: Processes & tools for one-of-a-kind process flow developed to realize new concept

TR6: Process flows have been converted to sustainable technology, reliability structures identified, and assembly and test infrastructure demonstrated

TR7: Process flows stabilized, reliability models developed, and product reliability demonstrated - qualification is product specific

TR8: Process flow is frozen, qualification is based on technology, not product specific

TR9: Proven technology used before in similar environments



TR1	TR2	TR3	TR4	TR5	TR6	TR7	TR8	TR9

Product

PA1: Interesting science – basic research

PA2: Potentially useful science – applied research – use in strategic planning

PA3: Research result that has compelling & direct customer value – customers should be informed of potential

PA4: One-of-a-kind device demonstrating proof-of-principle in lab environment

PA5: Research prototype demonstrating packaging concept & functionality in lab environment – hand built, no reliability.

PA6: Engineering prototype (alpha) demonstrating package design & functionality in simulated field environment - rugged & repeatable

PA7: Flight/field prototype (beta) demonstrating final product design using stable technologies – reliable & manufacturable

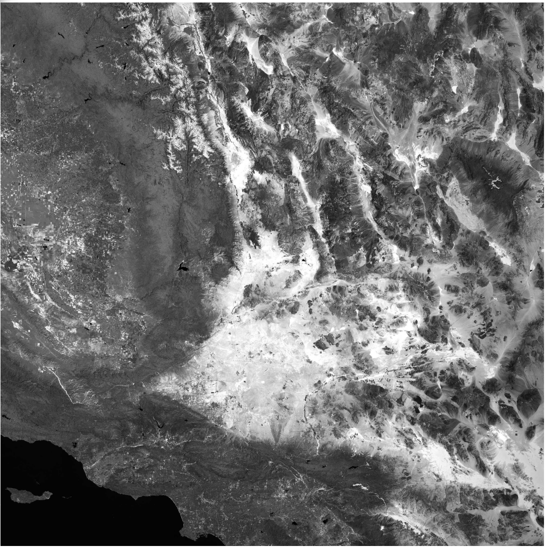
PA8: WR/Hi-Rel production unit with qualification, acceptance testing, & certifications in-place – cost wrung out

PA9: Qualified product used before in other systems having similar environments.

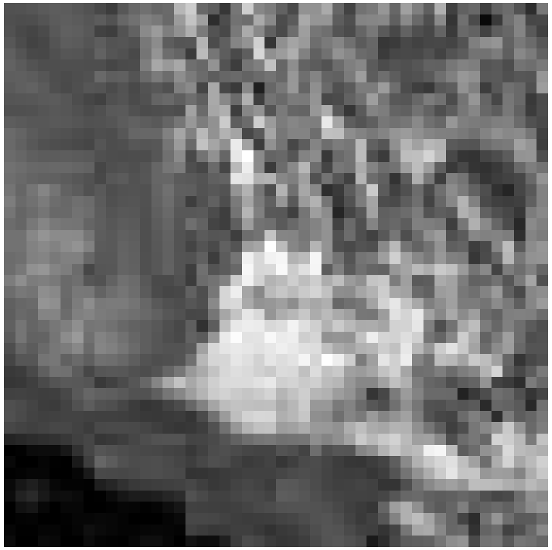
Sandia's missions span the gamut from scientific advancement to hardened high-reliability deliverables: technology maturation is a core competency.

SNL Capability: Modeling CET & Sensor Radiance

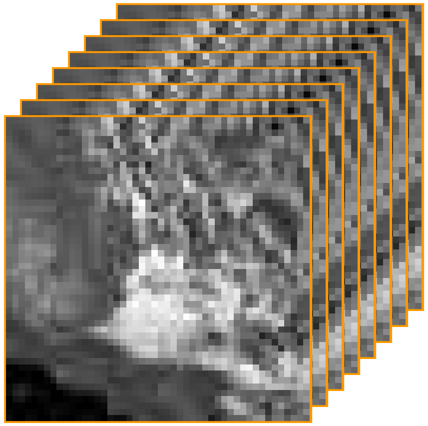
TR5



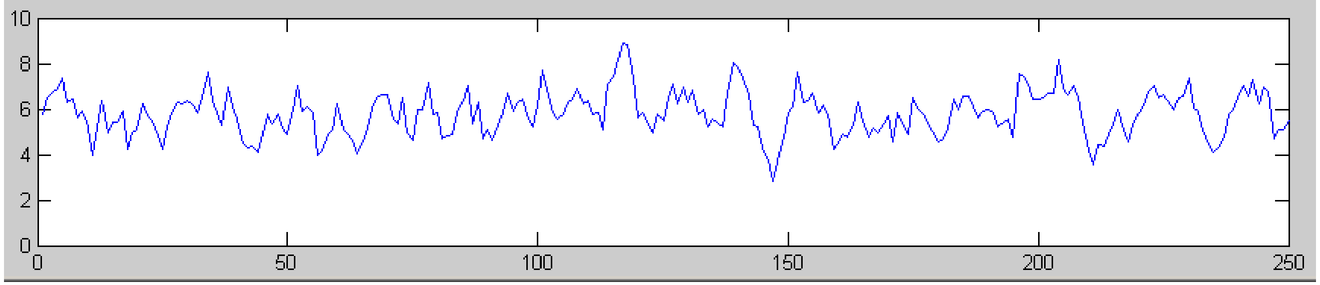
Generate an over-sampled synthetic scene that represents viewing and lighting geometries



Blur the scene with optical, slew and jitter effects



Down-sample Scene to generate a time series of frames



Results in per-pixel temporal radiance variations (background clutter)

Sandia scene modeling capabilities provide essential understanding of the challenges placed on sensor systems by real-world background fluctuations early in the system design phase.

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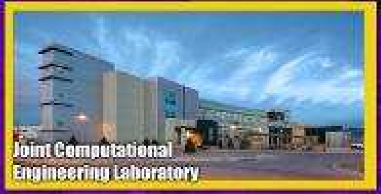
MESA Provides Top Facilities & Equipment for Microsystems Design, Fabrication, & Test

- **Trusted Digital, Analog, Mixed Signal & RF Integrated Circuits Design & Fabrication**
- **Micromachining**
- **RAD Effects and Assurance**
- **Failure Analysis,**
- **Reliability Physics**
- **Test & Validation**
- **3-D Integration**

- **Compound Semiconductor Epitaxial Growth**
- **Photonics, Optoelectronics**
- **MEMS, VCSELs**
- **Specialized Sensors**
- **Materials Science**
- **Nanotechnology, Chem/Bio**
- **Mixed-Technology Integration & Processing**



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

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MESA serves a unique role for the U.S. Government

- MESA is a $462M FFRDC-based development and production facility for any microsystem component technology that cannot, or should not be obtained commercially.
- Our operational environment is particularly suited to rapidly advance research concepts from TRL 1 to TRL 6.
- Microsystems represent much more than digital ICs and MEMS
  - This capability also includes analog/mixed-signal/RF ICs, design into Trusted Foundry, qualified COTS, failure analysis/reliability physics, IC/MEM/microfluidic/optoelectronics advanced packaging, specialized sensors, micro/nano, mod/sim, and a complete IIII-V materials growth and device design/fabrication capability that yields world-class optoelectronics and high-frequency devices.
- *MESA offers its partners technological differentiation in a wide variety of advanced component technologies.*

Trusted Microsystems for National Security

Trusted Systems for National Security Customers

Nuclear Weapons

Non Proliferation Payloads

MicroChemLab-based Sensor system

Intelligence Customers

Trusted COTS and Custom Electronic Components

- Assure performance, quality and reliability meet system requirements
- Custom Magnetics, Capacitors, RF, Optical, Interconnects, Transducers, Clocks, connectors & cables

Trusted R&D

- Chip Scale Atomic Clock
- Ion Traps for Quantum Computing
- Nano-G Accelerometers
- Acoustic Bandgap Science
- Advanced Sensors for Chem/Bio Detection

Trusted Fabrication

Custom, low-volume, high-reliability

- Silicon custom & rad-hard process technologies for digital, analog, mixed signal and micromachining
- DOE/NNSA War Reserve Supplier
- Trusted Foundry accreditation in process

- III-V semiconductor Epitaxial Growth and processing
- Photonics, Optoelectronics
- MEMS, VCSELs, Specialized Sensors

Trusted Design

- Secure design facility with disciplined and trusted design flow and methodologies
- Trusted Structured ASIC
- Design for fabrication at Sandia or at Trusted Foundries:
  IBM, Honeywell & National

Trusted BEOL

- Advanced Packaging
- 3-D Integration
- Test & Validation
- Failure Analysis & Reliability Physics
- Rad Effects & Assurance
- Anti-Tamper

As part of the DOE NNSA Nuclear Weapons Complex Transformation:
"SNL will be the Center of Excellence for Non-Nuclear Design and Engineering ... "

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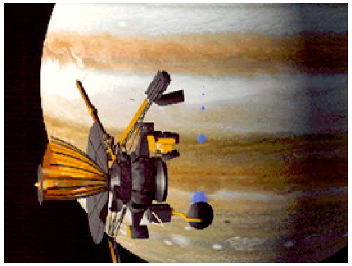
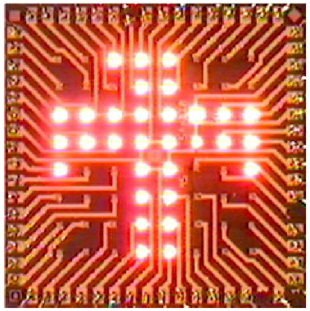
Sandia Has a Long History in Microelectronics & Microsystems

Laminar Flow Clean Room

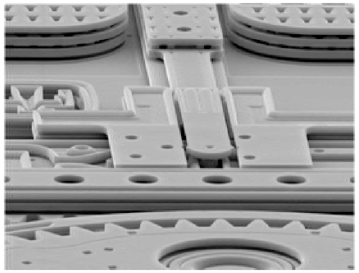
Design/Build Galileo ICs



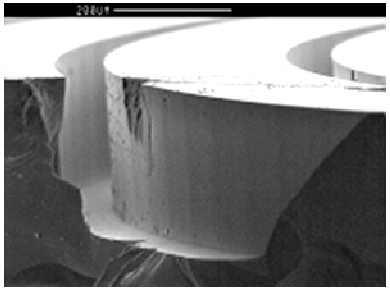
High Efficiency VCSEL

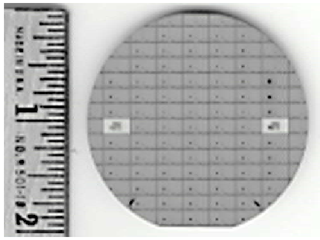


5-Level Surface Micromachining

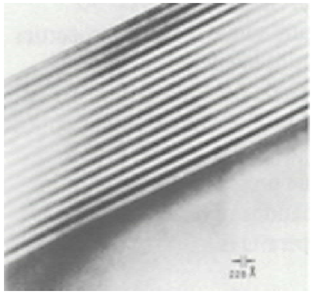


Chem Lab on a Chip

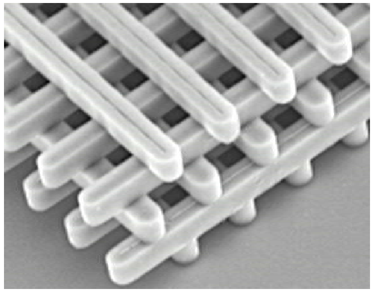




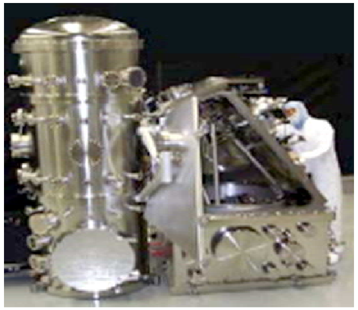
Radiation Hardened CMOS



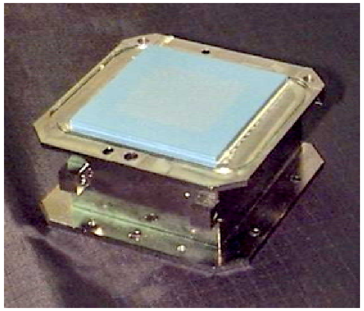
Strained-layer Superlattices



Photonic Lattice



Extreme Ultra Violet Lithography



3-D Microsystems Integration

1960s **2000s**

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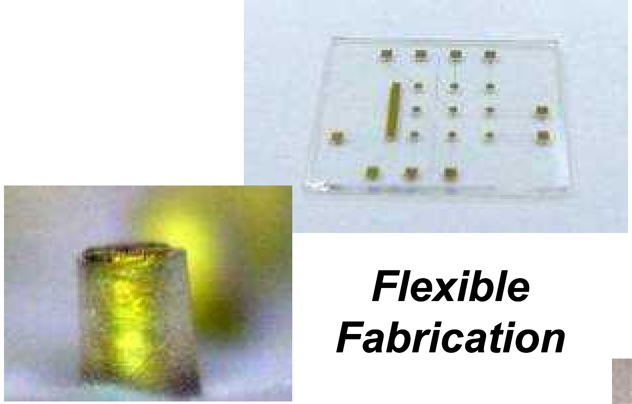
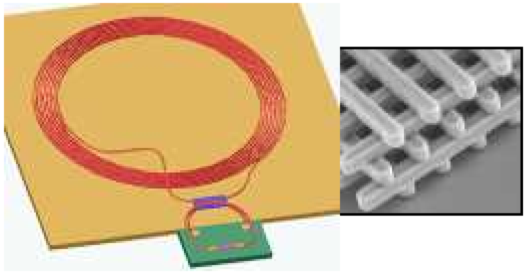
MESA Supports Multiple Enabling Technologies



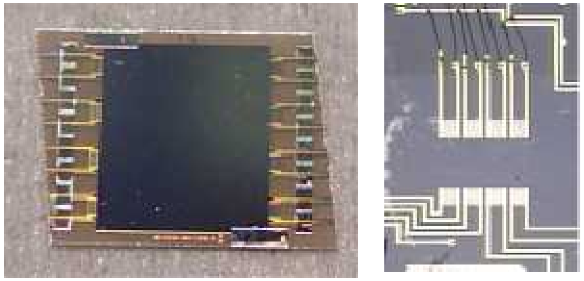
Flexible Fabrication



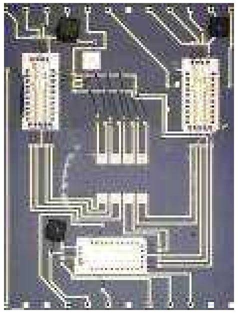
Photonics

Si CMOS

Piezoelectrics

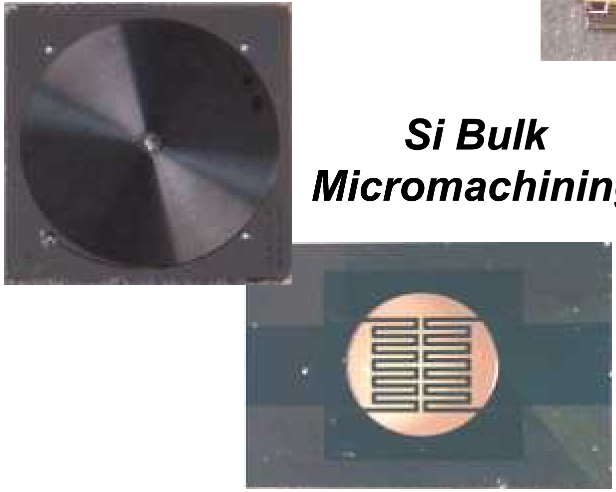


Compound Semiconductor

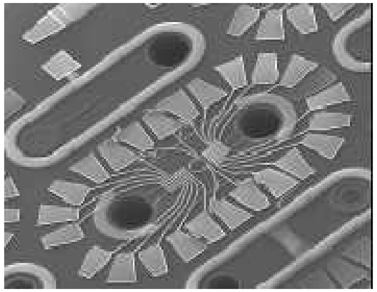


Advanced Packaging

Si Bulk Micromachining



Si Surface Micromachining



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Sandia's Innovation Corridor Combines Multiple Disciplines to Create Microsystem Solutions

Center for Integrated Nanotechnologies

Sandia Science & Technology Park

Integrated Materials Research Laboratory

MESA Microfabrication Facilities and MicroLab

Weapons Integration Facility

Red Storm

Joint Computational Engineering Laboratory

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Premier µSystem Integration & Packaging Laboratory Enables System-Level Solutions

System-level integration involves development of many individual technologies

- 3D integration through wafer-to-wafer & die-to-wafer stacking
- Wafer level thinning (<100 µm thick)
- Bonding (surface activated, fusion, metal to metal)
- High density interconnects
- Second level packaging
- Advanced thermal solutions
- Reliability testing

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μPackaging Facility enables Heterogeneous Microsystem Integration

Automated precision Die Placement and Attach (± 1 μm)

Precision Epoxy and Underfill Dispense (~ 0.1 microliter)

Automated Precision Flip Chip Attach

Flip Chip Rework

Solder Reflow

Real Time X-Ray System

Surface Acoustic Microscopy

Laser Profilometer

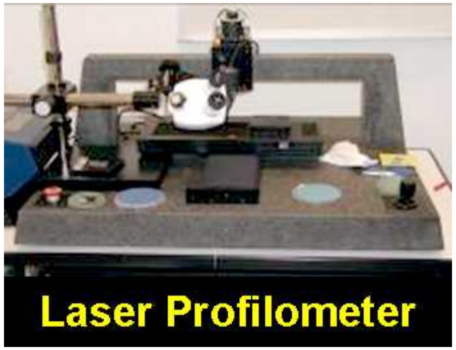
Curing Ovens

Plasma Cleaner

Flip Chip

Real Time X-ray

Underfill/epoxy dispense



Laser Profilometer

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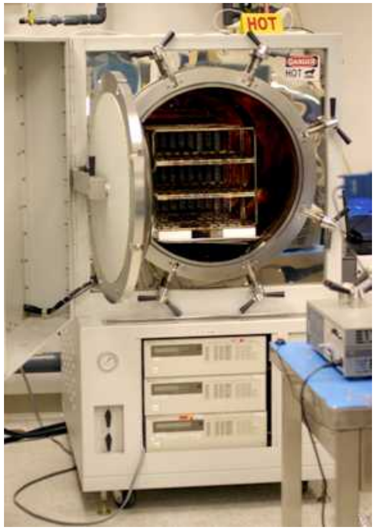
Essential Testing Equipment Assures Reliability of Developed Products

HALT

Temperature Cycling



HAST

Sandia's testing equipment includes: Highly Accelerated Life Test, Highly Accelerated Stress Test, Temperature Cycling, thermal shock, mechanical shock, mechanical vibration, and acceleration

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Integrated Circuit Test

- Credence EXA3000 Digital Tester

- Teradyne Catalyst Mixed Signal Tester

MEMS Technologies at Sandia

Pushing the technology envelope for national security applications

R&D for Advanced MEMS

- Mechanisms
- Pressure Sensors
- Inertial Sensors
- Fluidic Components
- Electrical Switches
- RF Switches
- RF Filters
- Mirrors
- Planar Light Wave Circuits
- Solar Cells
- Radiation Detectors

Prototype Development and Limited Production

Core Fabrication Processes

- SUMMiT V™, Baseline plus
  - Silicon Nitride
  - DRIE
  - SOI
  - SFET
- Molded Tungsten
- Aluminum Nitride

Core Technologies

- Design, Layout and Analysis
- Device Testing/Characterization
- Reliability Science and Testing
- Failure Analysis

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Working With Us

Our niche is national security, complementary to industry

Differentiated by
- Unique, challenging performance
- Prototyping and small volume production of high-value devices
- National security sensitive applications

Fabrication Services
- Shared wafer, SUMMiT V™
- Dedicated wafer
- Process development

Reliability, Failure Analysis

Product Development
- Consultation
- Complete turnkey solution



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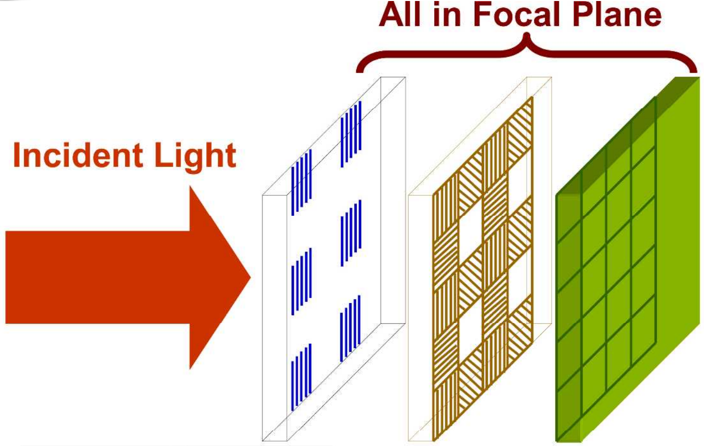
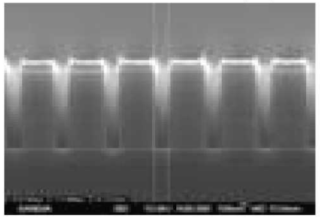
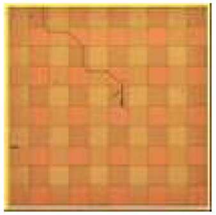
SNL Technology: Surface Micro-Optics Processed On FPAs

TR5



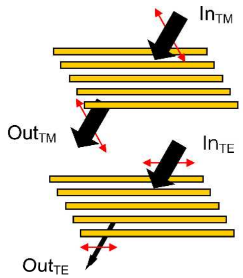


Microwaveplate Array

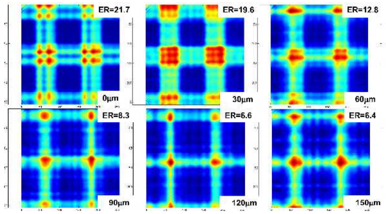


Micropolarizer Array

"Snapshot Polarimetry"

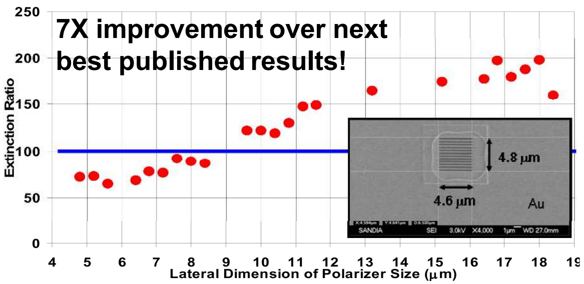


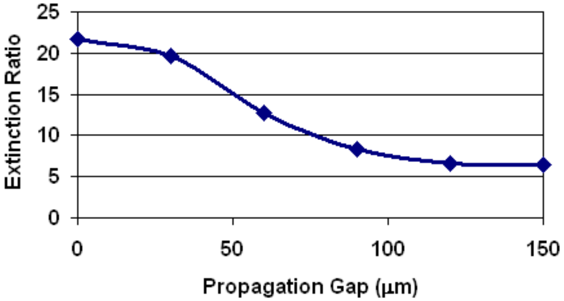
$$\text{Extinction Ratio} = \frac{TM_{TRANSMITTED}}{TE_{TRANSMITTED}}$$



- **Demonstrated for Polarimetric Imaging**
- **Enables improved materials classification and object identification in remote sensing applications**
- **Macro-scale sequential polarimetric imaging ineffective for dynamic scenes**
- **Sandia leads this field**

Measured Extinction Ratio @ λ= 3.39 µm





Must be intimately integrated with the FPA at the micro scale to preserve capability

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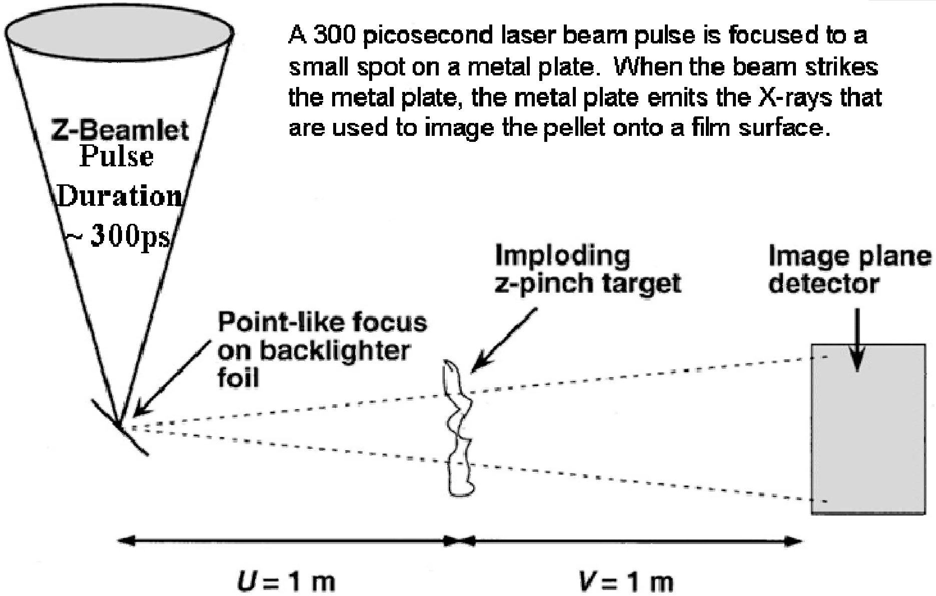
X-Ray Detector Array

TR3

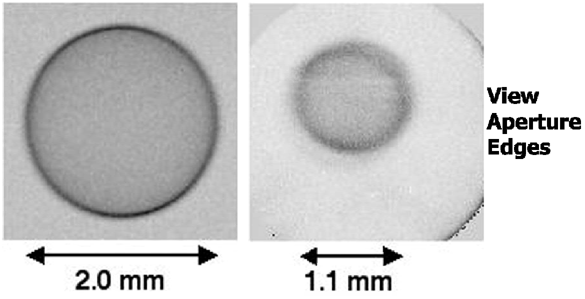
The Z-Machine at SNL is an important national resource for studying the physics of nuclear fusion reactions. Assessment of the implosion of D-T pellets by X-ray radiograph is a key data collection task. Presently this is done with film and cannot capture a singular implosion event, necessitating multiplication of experiments.



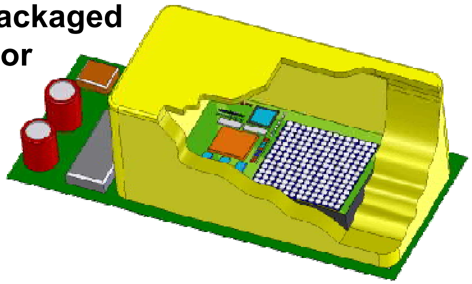
A 300 picosecond laser beam pulse is focused to a small spot on a metal plate. When the beam strikes the metal plate, the metal plate emits the X-rays that are used to image the pellet onto a film surface.

Sandia's X-ray detector array will enable the capture of time sequences from implosion events, increasing Z-Machine throughput by about 20% /yr (~$5M value) while improving data quality.

Radiographs of D-T Pellet Before and During Implosion



Solid model of packaged SNL X-ray detector array



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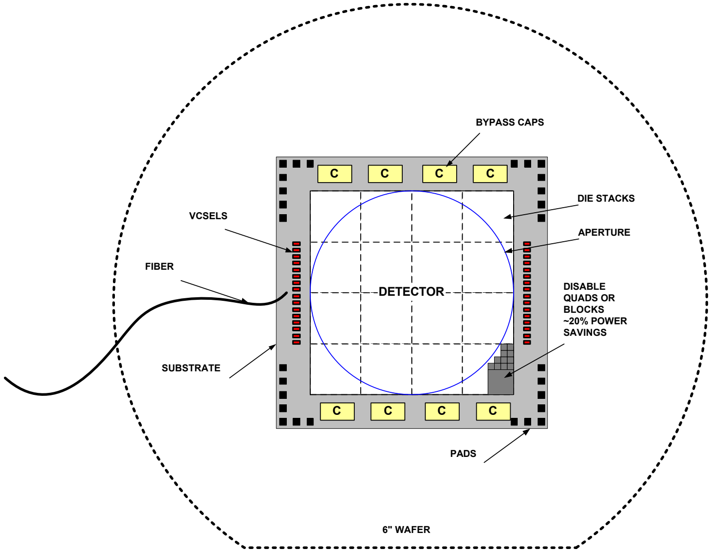
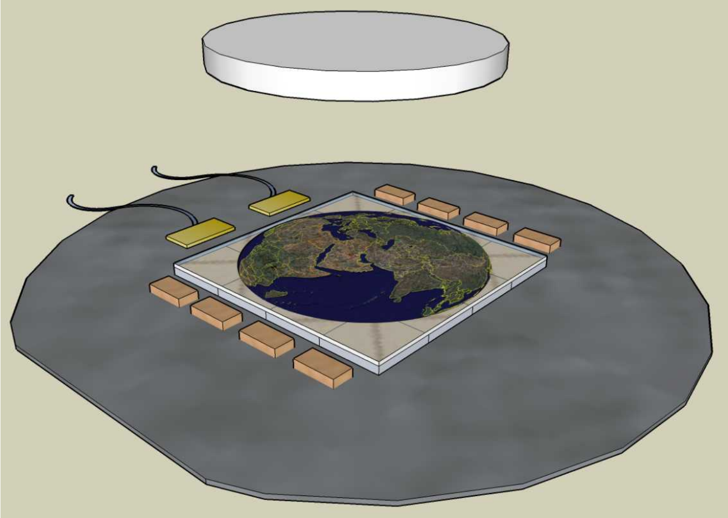
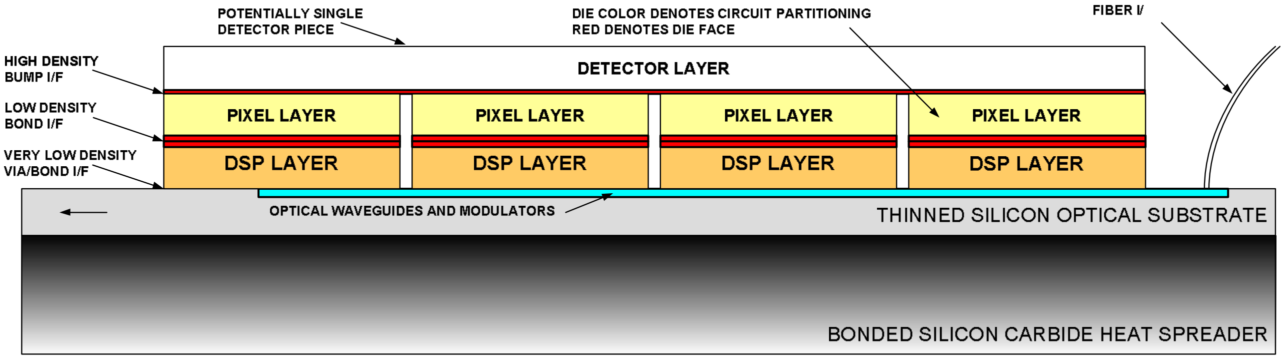
Heterogeneous Mosaic Packaging for Very Large Arrays

TR3







Very Large FPAs With

- ***Acceptable Rolled Throughput Yield***
- ***Enhanced Functionality***
- ***Multiple Process Technologies***
- ***Fewer Process Compromises***

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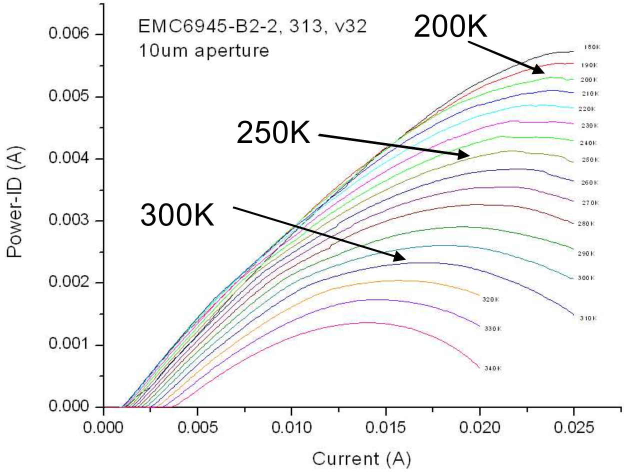
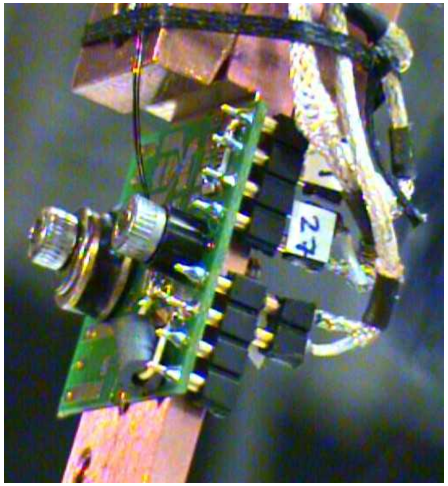
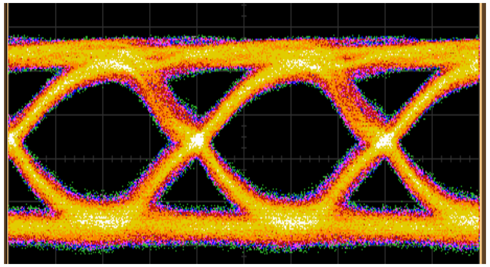
SNL Optical Interconnect Cold VCSEL Development

TR3

200K-optimized VCSEL L-I curves







VCSEL in cryostat assembly for demo of 2.5Gb/s operation at 200K

Optical data transmission is advantageous for ultra high density or high frame rate IR FPAs due to thermal considerations and electronic data bus congestion issues. SNL compound semiconductor research and development facilities and leadership in VCSEL technology enable optimization of these technologies for demanding operating conditions.

Low-power MUX and driver IC development collaboration with Prof. Mark Horowitz at Stanford

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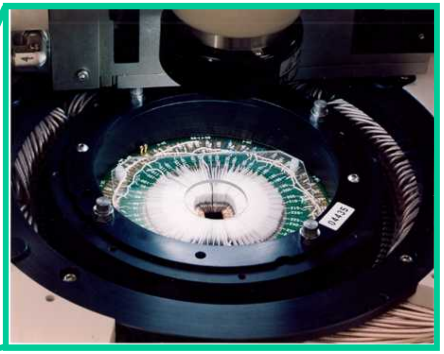
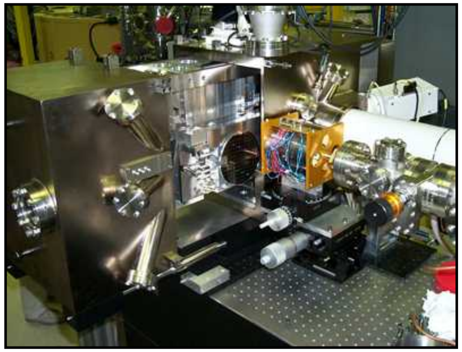
Sandia Rad-Hard Characterization Capabilities

10-keV X ray sources for wafer-level total-dose testing

256-channel capacity with integrated IC tester



Focused ion microbeam used for code validation



Radiation effects modeling on the Teraflop computer

Technology Development

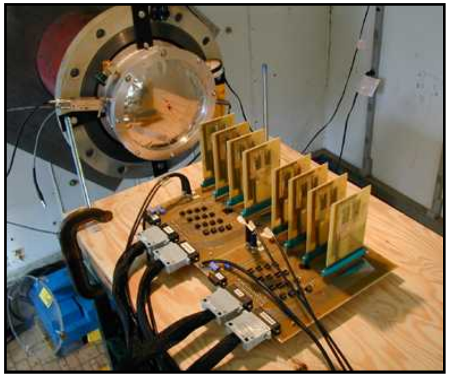
Modeling & Simulation

Basic Physics of Radiation Effects

Scientific Studies

Qualification & Hardness Assurance

Electron paramagnetic resonance for defect studies



Neutron testing at LANL for SEE in terrestrial systems

Heavy ion testing at BNL for SEE in spaceborne systems

Co-60 and Cs-137 cells for IC qualification

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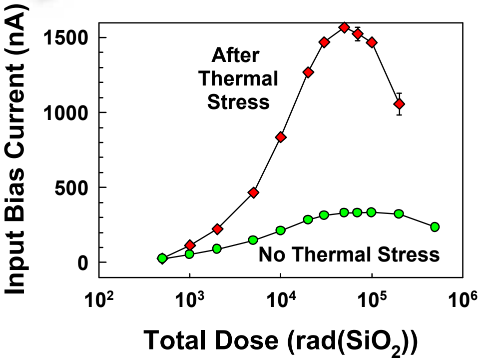
Sandia Rad-Hard Expertise Has Many Beneficiaries

WFO/DTRA



Discovery of thermal stress effects leads to improved hardness assurance tests

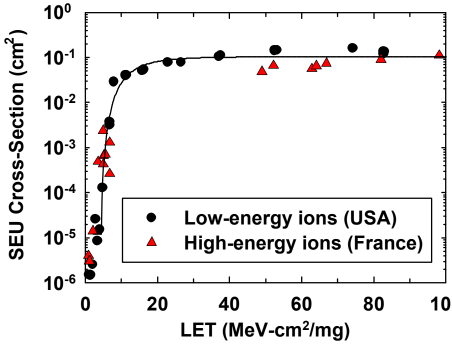
Nuclear Nonproliferation

Sandia satellite systems use a mix of radiation-hardened and commercial technology

WFO/NASA-JPL

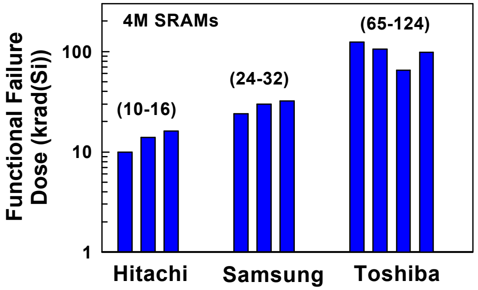
Sandia rad-hard technology enables Galileo mission success

International Interactions



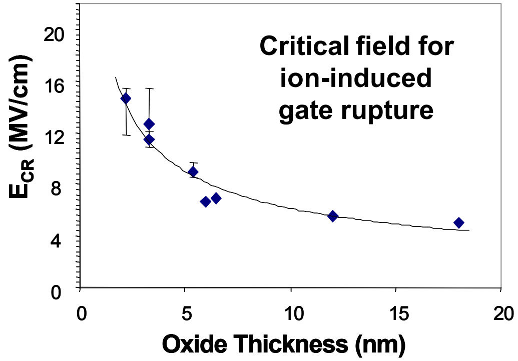
Lack of ion energy effects validates current SEU test methods & facilities

CRADA/Lockheed Martin



Addressing limitations of COTS technologies

University Interactions



Evaluating failure mechanisms in next-generation technologies

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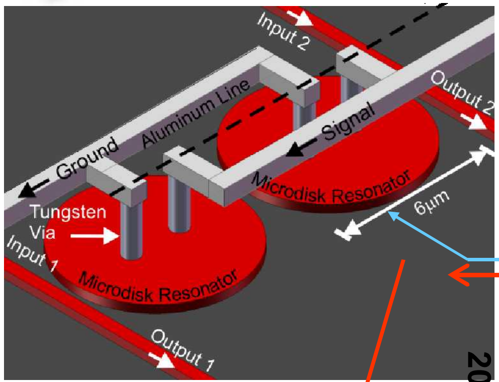
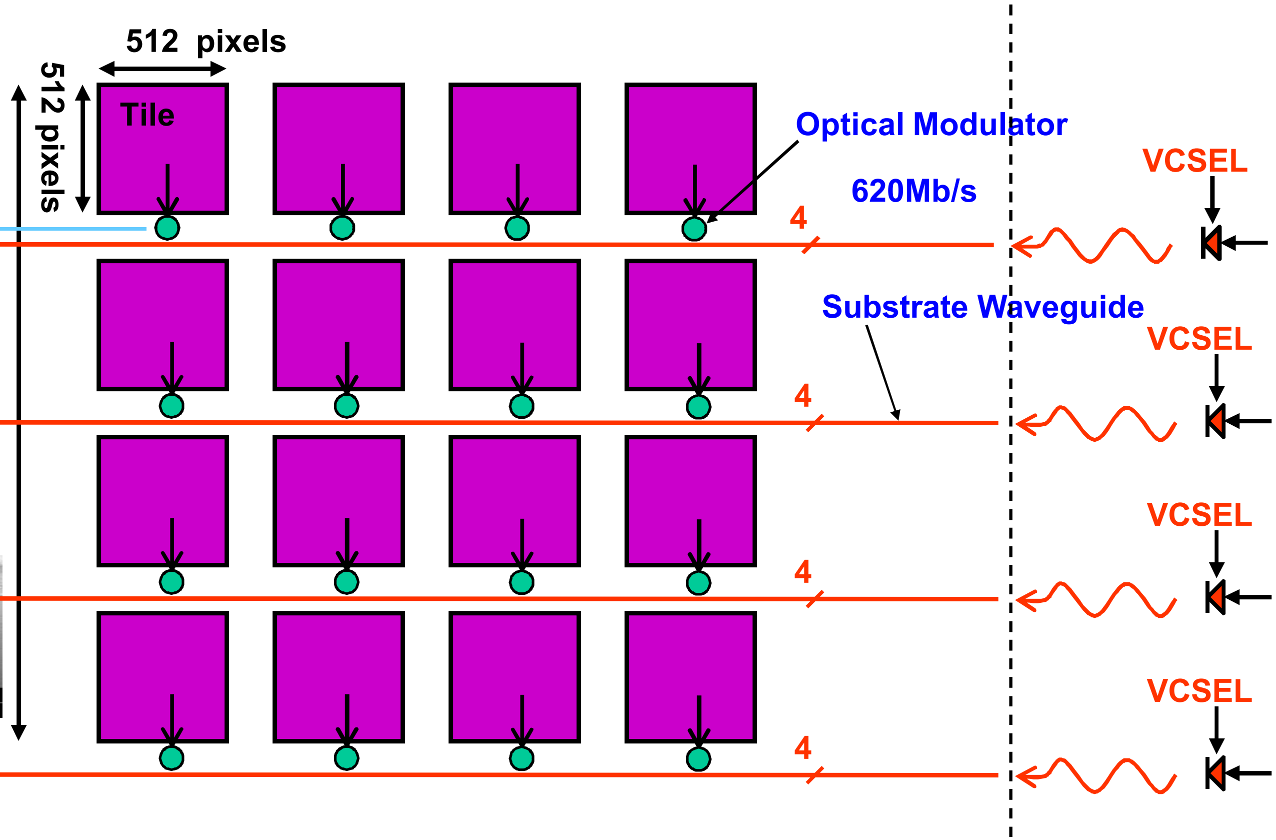
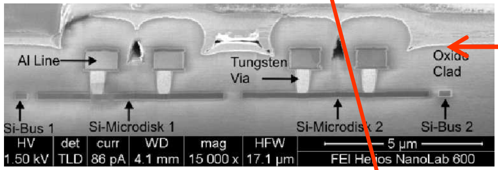
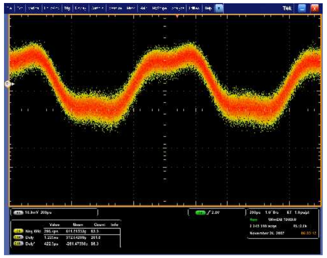
Optical Interconnect Photonic Substrate Alternative

TR3









1GBS Modulation

Sandia Si process compatible planar waveguide technology enables optical acquisition of data from dense focal plane arrays with dramatic reduction of in situ thermal dissipation – advantageous for cryogenically cooled IR sensors.

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Additional Technologies

- Laser threat detectors and detection systems
- Multispectral detector technology
- Gamma ray detector technology and systems
- Thermal Micro-Photonic detector technology
  - Similar to bolometric detectors but with potential for superior performance based on fundamental physics