Sandia National Laboratories: Capabilities and LDRD Program Overview

Presented by:

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Sandia National Laboratories

Outline

- **Sandia ST&E Capabilities and Research Foundations**
- **LDRD Program Overview**
- **Grand Challenge LDRD Projects Overview**
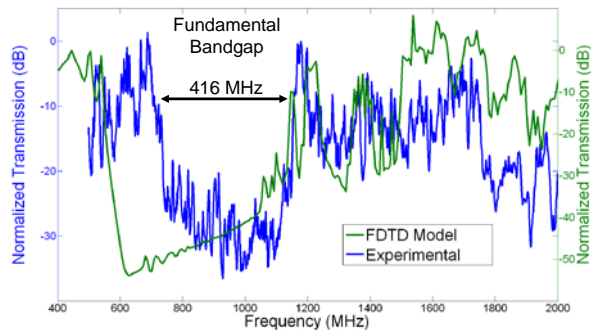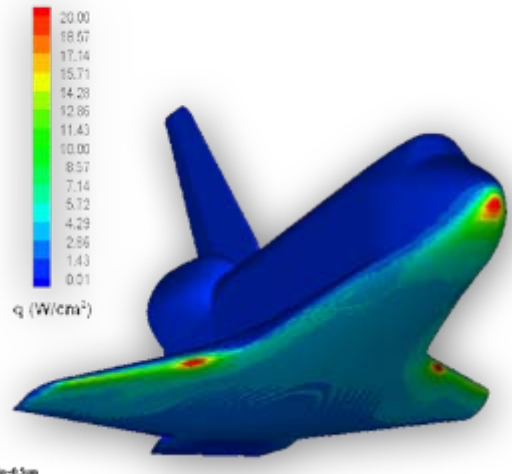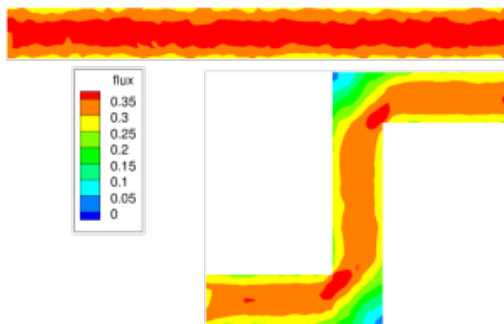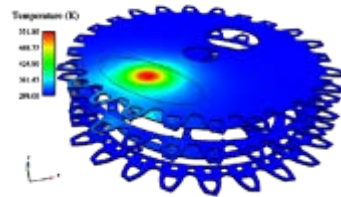- **Selective Examples of LDRD Impact on Lab Mission**

High-Performance Computing
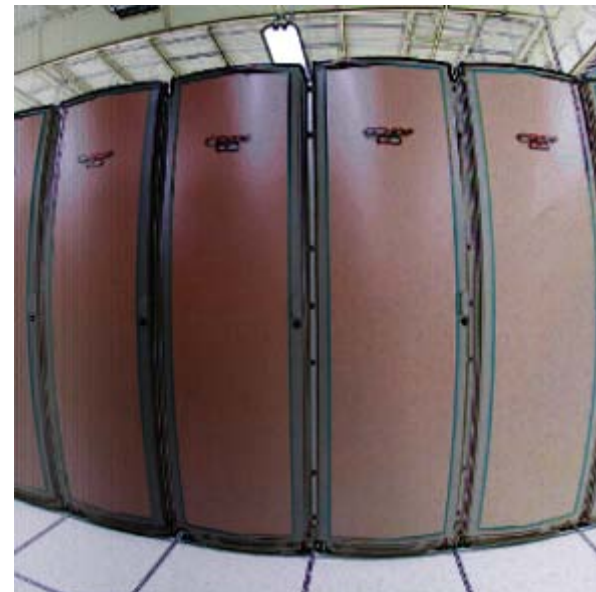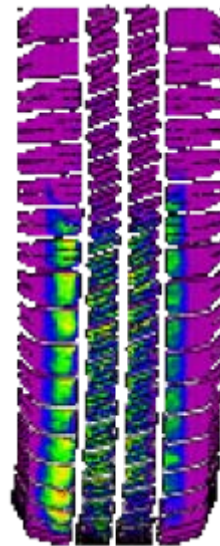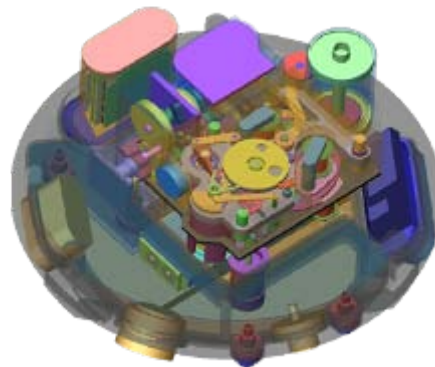
Microsystems and Nanotechnology

Extreme Environments

Environmental Testing

Acoustic bandgap

Diffuse phonon scattering

-Advanced simulation capabilities: quantum, EM, continuum mechanics…
- Advanced computing platforms

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Microsystems
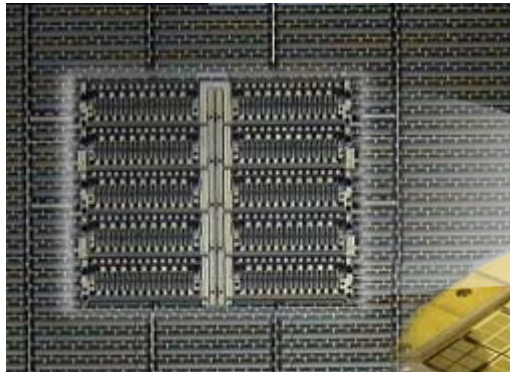
- Specialized microsystems for weapon systems
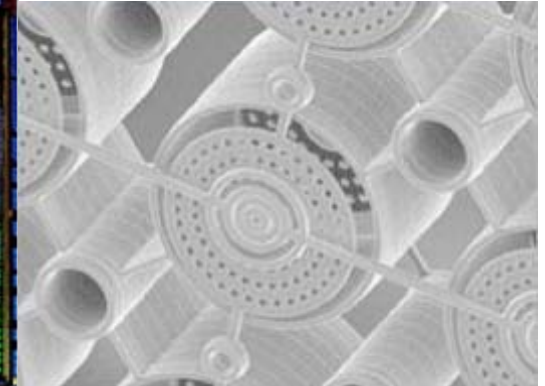- Rad hard microelectronics and qualified COTS components

MEMS louvers manufactured at Sandia

Application-specific integrated circuit

Ion traps for quantum computing

Johns Hopkins/APL thermal regulator

Microgears

Outside view of the Microsystems Engineering for Strategic Applications (MESA) and clean room at MESA

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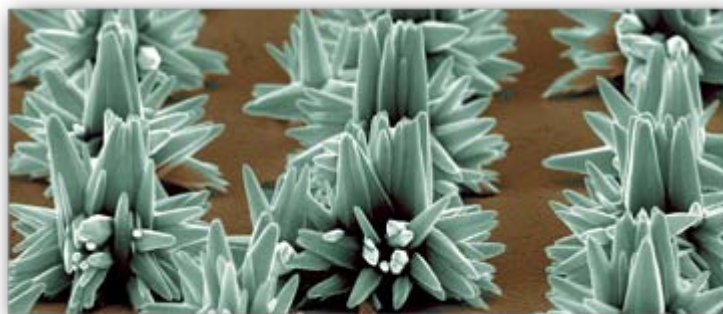
Nanotechnology

Complex functional nanomaterials

Center for Integrated Nanotechnologies (CINT)

Nano-bio-micro interface
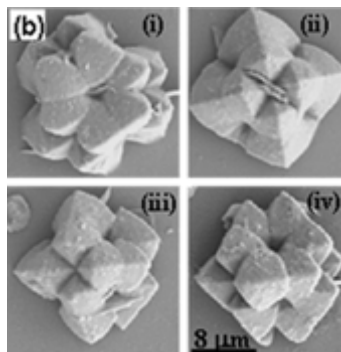
Microfluidic chip

Nanomaterials—ZnO

- Nano/biomaterials and nanosynthesis
- Microscale platforms for nanoscience research

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Extreme Environments

Saturn
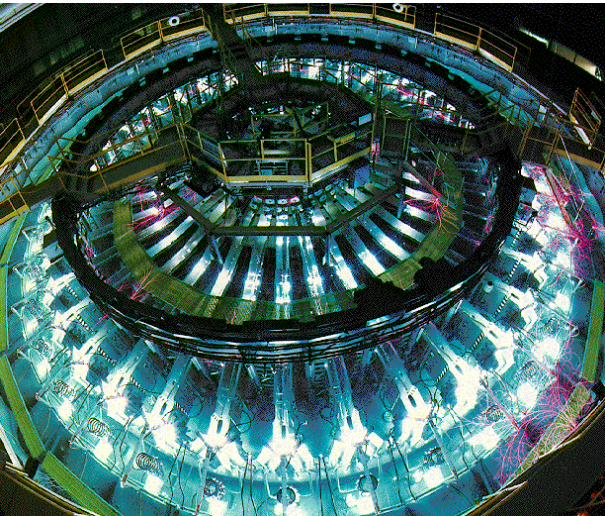
Light Initiated High Explosives Facility (LIHE)

ZR pulse forming line

- Qualification of weapons systems and components for hostile environments
- Fundamental understanding of HEDP
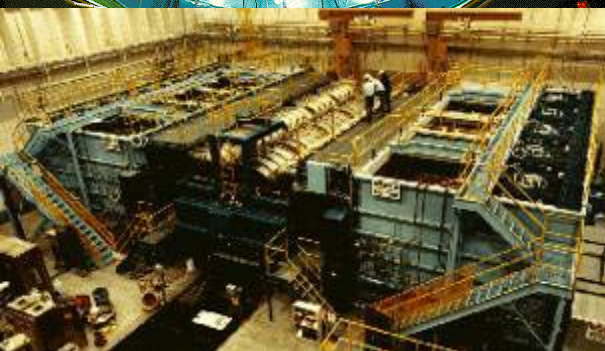
Hermes III

Annular Core Research Reactor (ACRR)

Large-Scale Environmental Testing

Thermal Test Complex
(TTC)

Artist's rendering of flame
facility at TTC
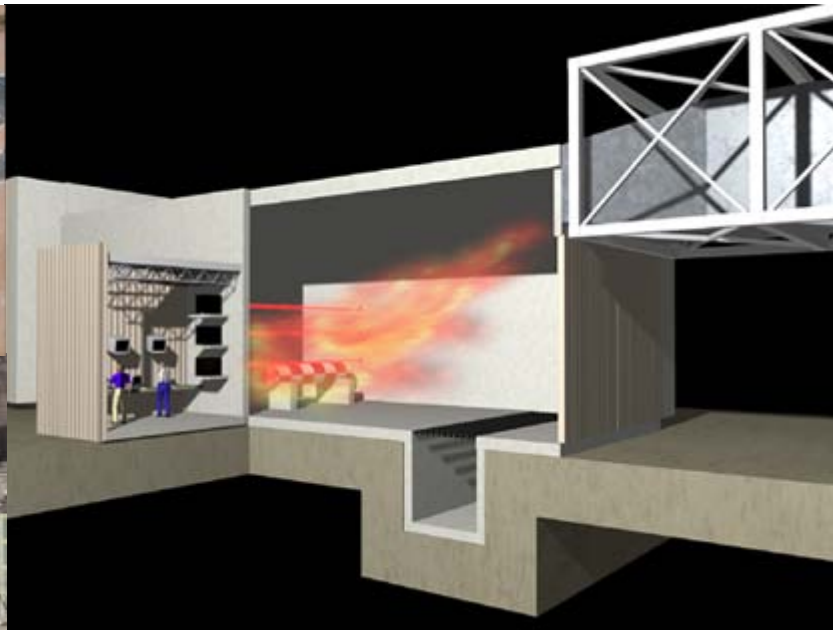
B83 drop test

Drop tower
facility

Destruction of
hazardous
materials

- Qualification of weapon
systems and components in
normal and abnormal
environments
- Validation of computational
capabilities

Explosives test

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Strategic Capabilities
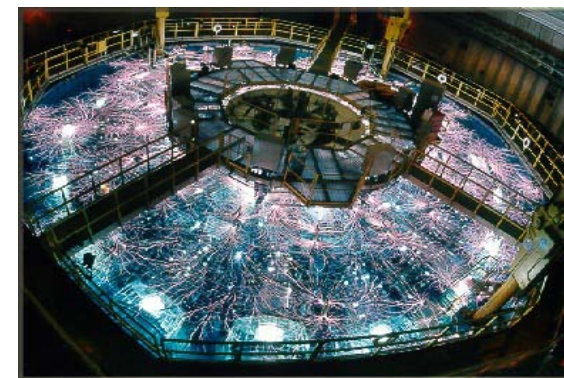
High Performance Computing, Simulation,Testing

Nanotechnologies and Microsystems

Extreme Environments
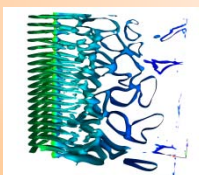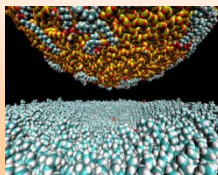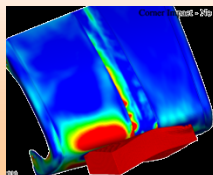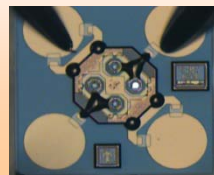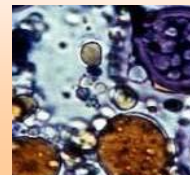
Computer Science	Materials	Engineering Sciences	Micro Devices	Bioscience	Pulsed Power

Research Foundations

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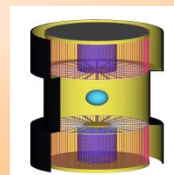
Outline

- **Sandia ST&E Capabilities and Research Foundations**
- **LDRD Program Overview**
- **Grand Challenge LDRD Projects Overview**
- **Selective Examples of LDRD Impact on Lab Mission**

Sandia National Laboratories

- **The Laboratory Directed Research and Development (LDRD) Program was <u>authorized</u> by Congress*, with oversight by DOE/NNSA, and strategic guidance by Lab Directors**

- **LDRD is the Labs' sole source of discretionary R&D funds for staff-generated, innovative ST&E****

*National Defense Authorization Act for FY 1991 (P.L. 101-510, Section 3132)

**** Energy Research and Development Administration Authorization Act for FY 1977 (P.L. 95-39, Section 303) provides specific authority for DOE to use a portion of the National Labs' operating budgets to fund employee-suggested projects up to the pilot stage of development**

Sandia National Laboratories

- ## <u>DOE Order 413.2B Objectives</u>

  - **Maintain the scientific and technical vitality of the laboratories**

  - **Enhance the laboratories' ability to address future DOE/NNSA missions**

  - **Foster creativity and stimulate exploration of forefront S&T**

  - **Serve as a proving ground for new concepts in R&D**

  - **Support high-risk, potentially high-value R&D**

- ## <u>Sandia Objectives</u>

  - **Be at the forefront of science and engineering**

  - **Enable SNL's national security missions**

LDRD invests in four major areas that support our DOE and WFO missions.

- **Science, Technology and Engineering (ST&E)**
  - anticipating future ST&E needs and capabilities, with critical support to all mission needs

- **Mission Technologies (MT)**
  - directly supporting NNSA, DOE, and WFO missions and their S&T needs

- **Grand Challenges (GC)**
  - bold, high-risk ideas with enormous potential impact to national security

- **Corporate Investments (CI)**
  - collaborations with academia, support of high risk, leading edge R&D, and early career R&D

FY10 LDRD Budget $166M

Legend: MT, STE, GC, CI, Reserves, PM

The Science, Technology and Engineering Foundations Program Area seeks to anticipate and provide for the future ST&E needs of the Laboratory, fostering our science base as a means to further developing the critical existing and future ST&E capabilities that the SMUs need to support our national security missions. The ST&E Foundations Investment Areas are:

Enable Predictive Simulation (EPS) – Building the knowledge base and the capabilities necessary for predictive simulation of complex problems.

Nanoscience to Microsystems (NTM) – Understanding and manipulating matter across atomistic to micro scales in order to exploit unique properties and create complex systems.

New Directions (ND) – Cultivating interdisciplinary ST&E that requires expertise not in our traditional areas of strength, but that has promise for addressing future national security needs.

Science of Extreme Environments (SEE) – Creating new knowledge that enables revolutionary advances in the areas of energy, pulsed power and electromagnetics, high energy density physics and radiation sciences for National Security needs.

Computer Science   Materials   Engineering Sciences   Micro Devices   Bioscience   Pulsed Power

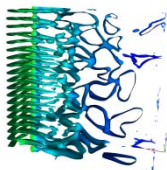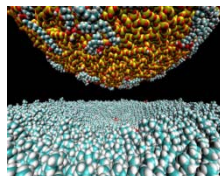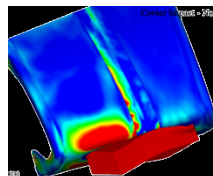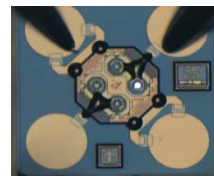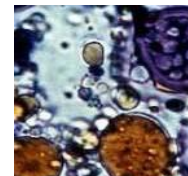Sandia National Laboratories

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FY10 LDRD Budget $166M

- MT
- STE
- GC
- CI
- Reserves
- PM

Sandia National Laboratories

Defense Systems & Assessments

- Space mission and remote sensing
- Information and Intelligence Technologies
- Integrated Domain Awareness and Precision Response

Energy, Climate and Infrastructure Security

- Energy Security
- Understand/mitigate climate change impacts
- Protection of Critical Installations
- Fuel and Water Systems
- Systems Modeling

Nuclear Weapons

- Surety Systems
- Arming, Fusing & Firing
- Gas Transfer Systems
- Neutron generators
- Warhead engineering and integration

International, Homeland & Nuclear Security

- Nuclear assets, materials, emergency response
- Nonproliferation
- Counter terrorism and arms control
- WMD Countermeasures
- Systems Modeling

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"Bold, high-risk ideas with the potential for significant national impact."

- Address tough national security problems

- Extensive cross-disciplinary content <u>and</u> cross-laboratory participation

- Oversight by an External Advisory Board
  - 5-15 members from gov't, industry, and/or academia

- Typically >$3M/year and >10 FTEs, 15% of LDRD funds

- Expectation of developing a new line of business that clearly addresses future NNSA/DOE/WFO needs
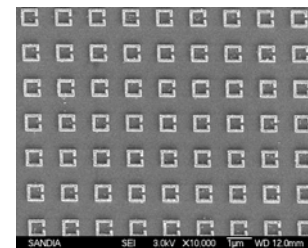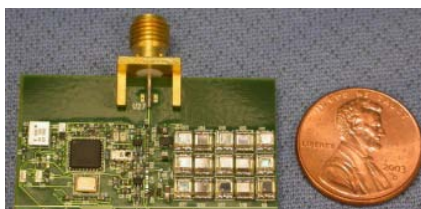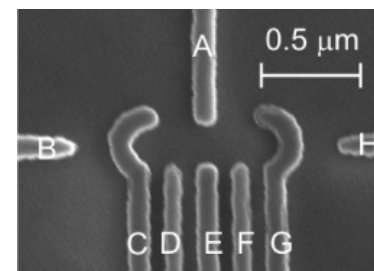
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Network Discovery, Characterization and Prediction

Quantum Information Science and Technology

Reimagining Liquid Transportation Fuels: Sunshine to Petrol

Metamaterials Science and Technology

Featureless Tagging, Tracking, and Locating

Rapid threat organism recognition (RapTOR)

Adiabatic Quantum Architectures In Ultracold Systems (AQuArIUS)

The Secure Scalable Microgrid

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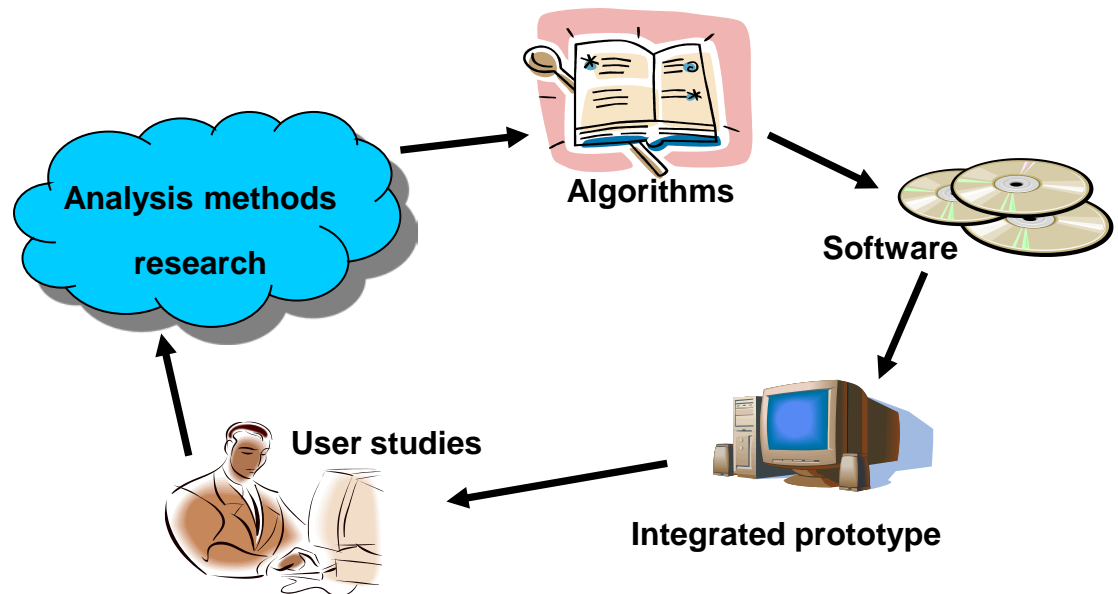
Informatics capabilities to confidently detect attacks and defend data

Challenges

- "Big Data"
- Predictive detection analysis.
- Uncertainty analysis.

Analysis methods research

Algorithms

Software

Integrated prototype

User studies

Detecting & defending threats to our nation's information networks

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Building the foundation for Quantum Computing with Si Quantum Dots
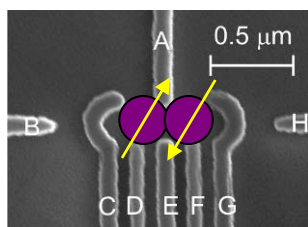
Physical Qubit & Native Gate Set

Challenges

- QD and circuit fabrication for logical Qbit
- Low temperature Electronics
- Theory
- Modeling & error correction algorithms

Logical Qubit

Leading the way to High-Performance Quantum Computing through Si nanoelectronics & modeling

Recycling CO_2 into Fuel

$$\text{Sunlight} + CO_2 + H_2O \rightarrow \text{Fuel} + O_2$$
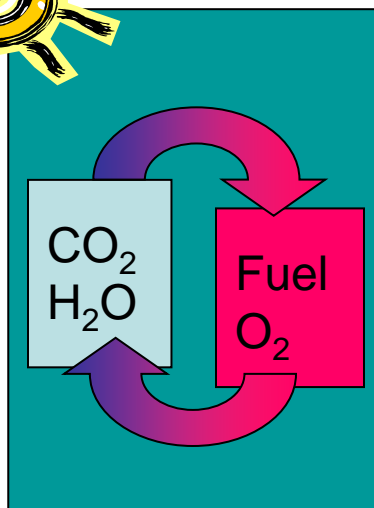
Challenges

- **5% sunlight to methanol efficiency**
- **Physical/chemical stability (<5% loss) over 1000 cycles**
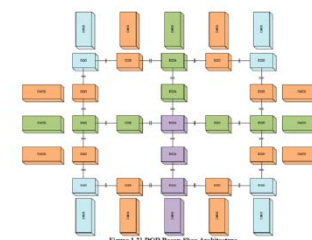- **Material: mixed metal oxide**
- **Reactor design and simulation**
  - **quantitative knowledge and models of reactions and transport processes**

Concentrating solar system that supplies heat for reactor to turn carbon dioxide and water into fuel

Creating a sustainable, carbon neutral fuel supply

New family of materials with new uses for national security

Metamaterials & Plasmonics

Challenges

- **Low loss materials for the IR**
- **Multi-element design and simulation**
- **3D fabrication**
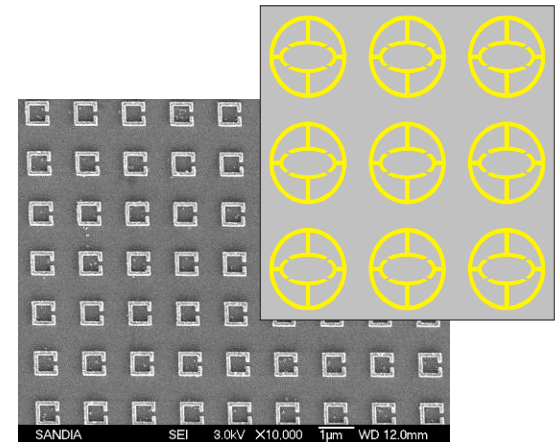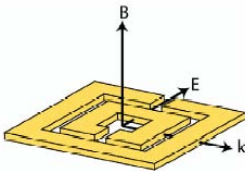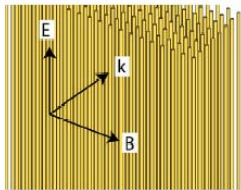
- *Enable game-changing applications: cloaks, low-SWaP optics, etc.*
- *Highly differentiated capabilities for future RF and IR systems deliveries*

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Low-detection tag with precise geolocation

Challenges

- **On-demand global-reach**

- **Order of magnitude improvement in power, size, and waveform and antenna sophistication over state-of-the-art**

- **RF microresonator-based tag**

- **Featureless signal generation and detection algorithms**
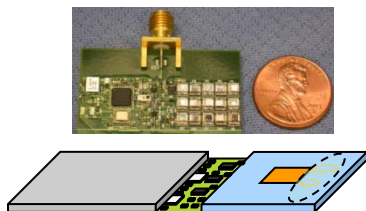
Featureless

Waveform
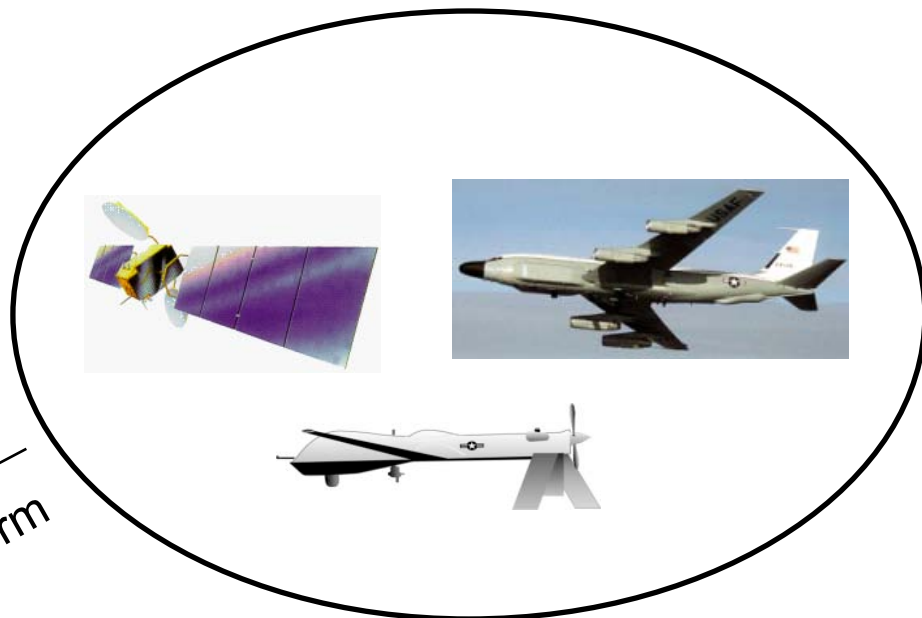
Impact: chip-size spectrum analyzer & advanced sensor command/control

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- **Rapid threat organism recognition (RapTOR)**
  - **create a new, rapid, and powerful approach for identifying unknown pathogens, thus preventing or containing outbreaks in their earliest stages.**

Approach:
- ultrahigh-throughput sequencing of DNA
- subtractive and suppressive modes to improve pathogen SNR by 10^4
- microfluidic platforms to concentrate and enhance underlying reactions
- detailed bioinformatics and unique computer architecture for identification.
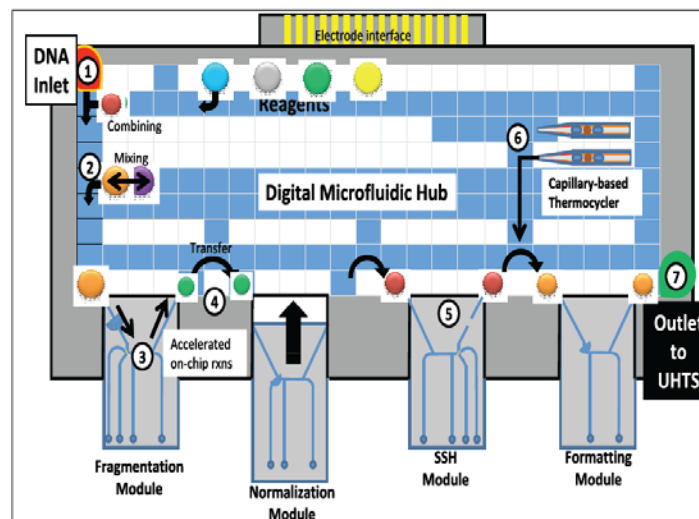
New models, theories, and tools to analyze the unconstrained behavior of microgrids and coupled microgrids to optimize their design.
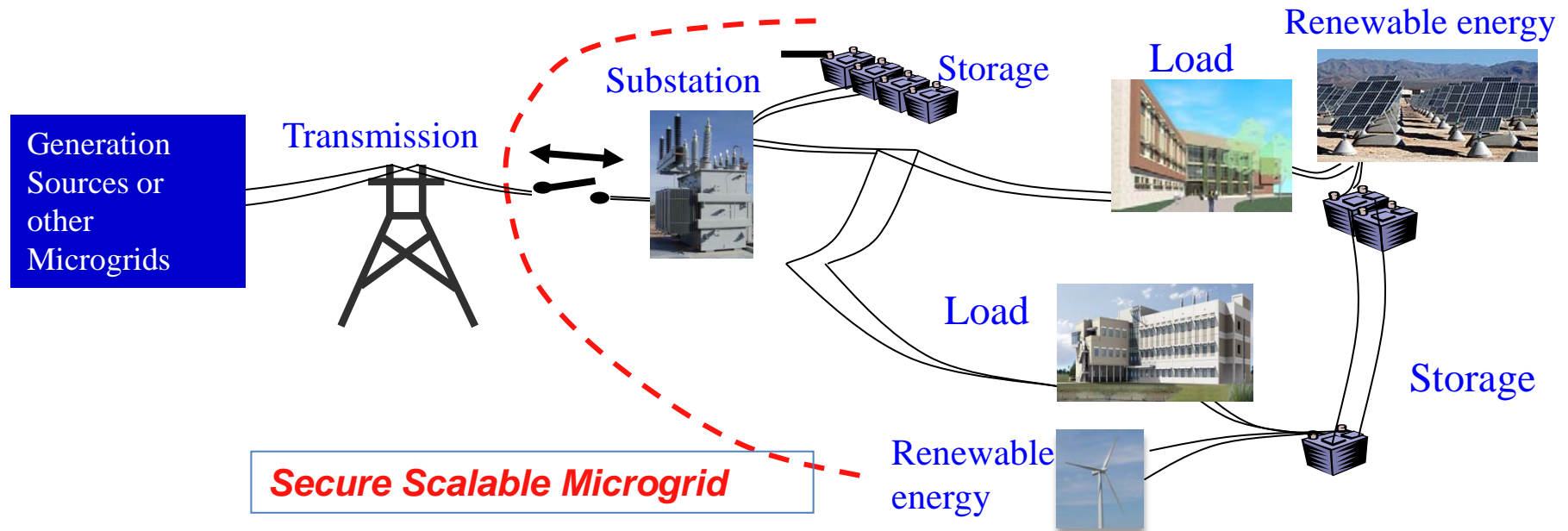
- **Scalable, non-linear models of key components in a microgrid.**
- **Nonlinear control theory involving new formulations for microgrid analysis and a unifying theory linking energy and information flow.**
- **High level agent based controls that work cooperatively to achieve common goals.**

High-Efficiency Thin Single-Junction (c-Si) or Multi-Junction (III-V) Cells

IC Manufacturing Approaches

Low-Cost Module Materials

Integrated Electronics

Micro to mm-scale Tracking and Micro-optics for Low-Profile Concentrator System

Massive Parallel Self-Assembly

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Energy (eV)
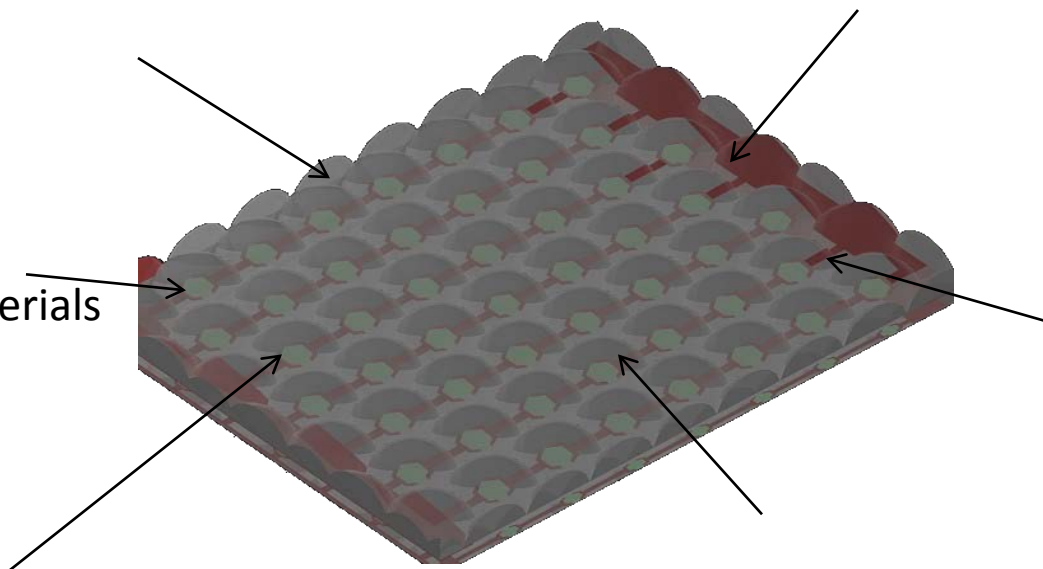
Small dimensions allow high-quality, molded refractive optics

PV junctions created from ideal materials at ideal thicknesses and electrically independent

on order of 1 mm

Material	Bandgap
InGaN	2.3
InGaP	1.9
GaAs	1.4
Si	1.1
InGaAsP	0.95
InGaAs	0.6

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Challenge: Develop rad-hard integrated-circuit technology able to meet STS of strategic systems.

LDRD Origin:
- **1996** - MDL ASIC cell library, 352609000 ($300k)
- **1997-99** - Time-Resolved Ion-Beam Induced Charge-Collection Imaging, 3506330000 ($1025k)
- **2000-02** - Radiation-Induced Prompt Photocurrents in Microelectronics, 10719 ($757k)
- **2001-03 –** Radiation Aging of COTS Stockpile Electronics, 26523 ($735k)
- **2004** - Low-Power Ultra-Fast Current Transient Measuring Device, 67071 ($90 k)
- **2007** – ViArray Antifuse Film, 93520 ($124K)

ST&E Evolution:
- First mega-rad hardened, scalable shallow-trench integrated circuit (1997)
- Only rad-hard technologies able to support W76-1 Stockpile Life Extension (2005).
- Low-cost, fast-turn ViArray baselined for B61 LEP (2009).

Mission Impact:
- Basis for every application-specific integrated circuit Sandia produces for the future stockpile and non-proliferation missions.
- Only strategically rad-hard technology available in the U.S.
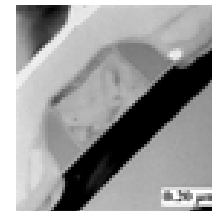
Silicon-on-Insulator BUSFET
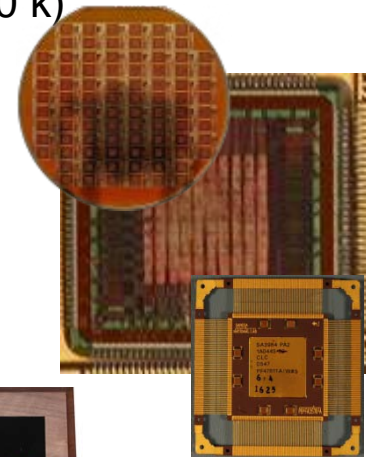
W76-1 AF&S Controller
(No bid from commercial suppliers)

Weapon Award of Excellence

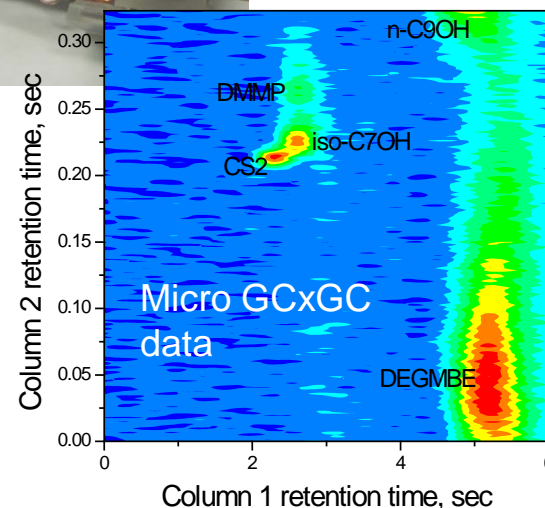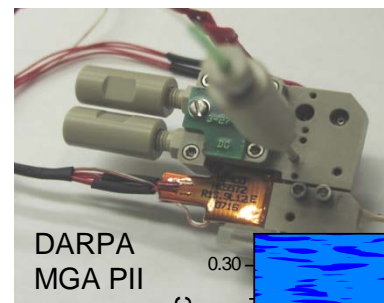http://www.sandia.gov/radar/index.html

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Challenge: Improved Chemical Agent Detection for Tactical Warfare and Civilian Applications

LDRD Origin:
- FY 1997-2000 — Autonomous Microchem Laboratory
- FY2002-2004 — Microsystems for Chemical Signature and Reagent Delivery
- FY 2003-2004 — Novel Micro-Preconcentrators

ST&E Evolution:
- MGA (DARPA)
- MGA (DTRA)
- CBNP (DOE)
- NA-22 (DOE)
- DoD-CMA
- DIA and other Intelligence Community

Micro SAW, PC, and GC

μChemLab™

DARPA MGA PII

Micro GCxGC data

Column 2 retention time, sec

Column 1 retention time, sec

n-C9OH
DMMP
iso-C7OH
CS2
DEGMBE

Mission Impact:
- Military intelligence, force protection, US chemical stockpile disposal
- Nonproliferation, civilian toxic industrial chemical incident response, environmental monitoring
- Spinoff companies: Defiant

http://www.sandia.gov/mstc/solutions/chemical-microsensors.html

MGA principal investigator: Dr. R.J. Simonson, rjsimon@sandia.gov

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Challenge: Manipulating, exploiting, and controlling quantum matter by micro-engineering and integrating the physical implementations and architectures of QIP systems.

LDRD Origin: 3 projects over 7 years
- Quantum computing (QC) accelerator I/O
- Engineer component building blocks for trapped-ion quantum computation
  - Solid state surface micro ion-traps
- Engineer/model silicon-based solid state quantum bits (qubits)

ST&E Evolution:
- Trap foundry—Intelligence Advanced Research Projects Activity (IARPA)
- Quantum Radar—Defense Advanced Projects Research Agency (DARPA)
- Quantum-enhanced sensing—DOE

Mission Impact:
- S&T leadership in quantum systems engineering for QIP community
- Creates a new conceptual platform with staggering impact on information processing.
- Ability to solve some of the "impossible" problems would enhance discovery and economic strength.
- Applications that rely on the "impossibility" of certain data protection problems are rendered obsolete.
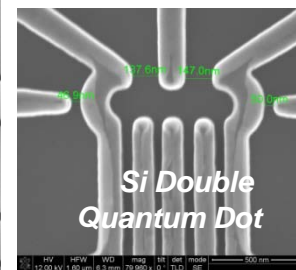
A Federal Vision for Quantum Information Science
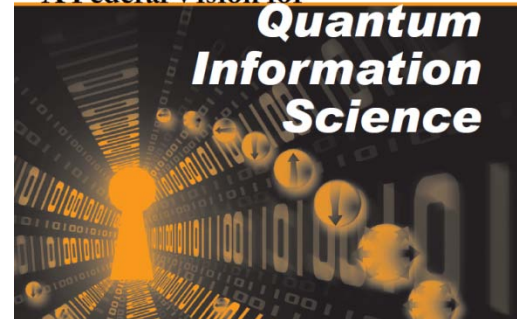
First Robust Micro Ion Trap Junction

Si Double Quantum Dot

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