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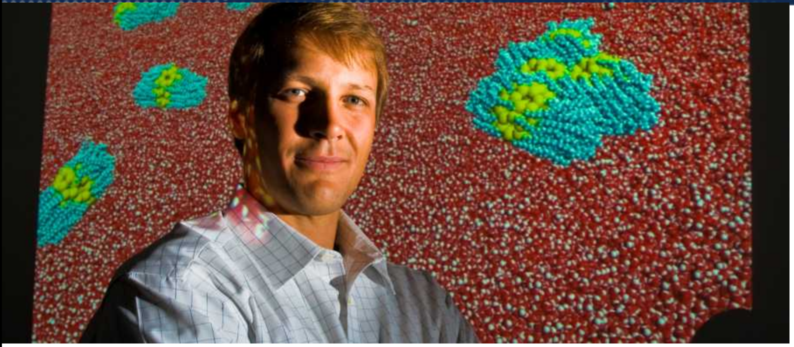

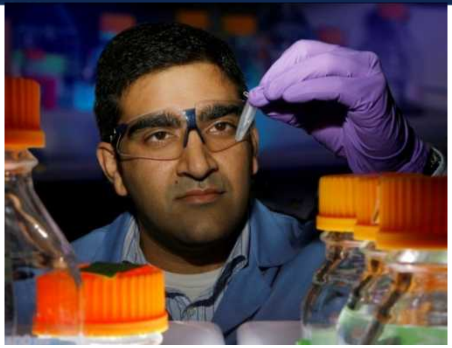

Sandia's Research Challenges: Overview and a Few Highlights

Jerry Simmons, Laboratory Fellow

February 20, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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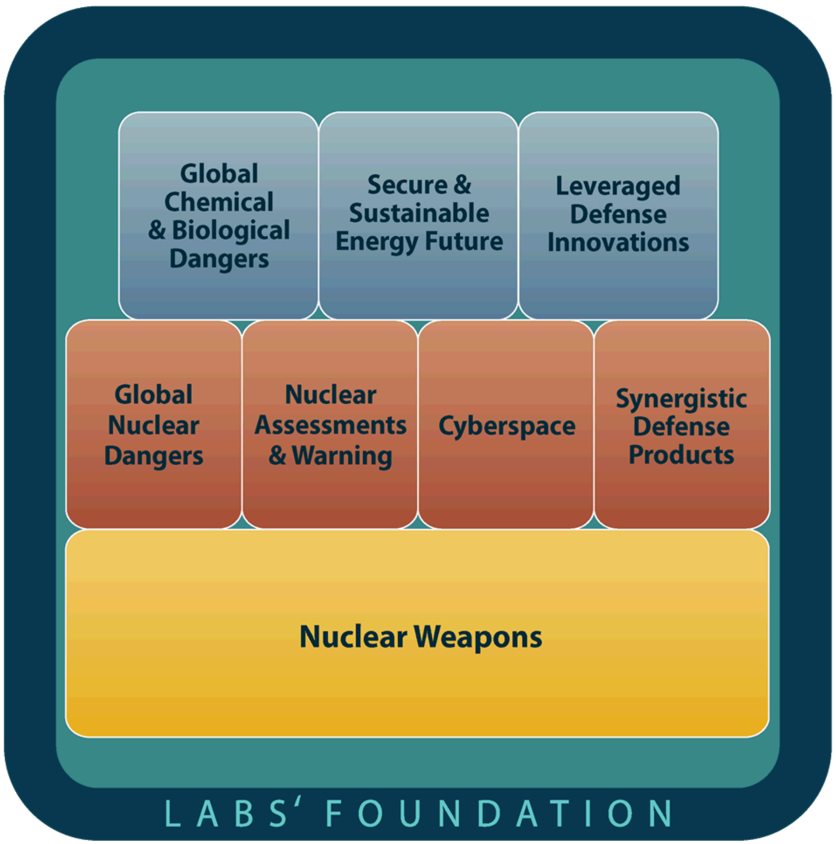
Outline

- Two Sandia Constructs: *Mission Areas* and *Research Foundations*
- Laboratory Directed R&D (LDRD) program
- *Research Challenges*: a new construct to better tie things together
- Descriptions of 3 selected *Research Challenges*
  - *Science and Engineering of Quantum Information Systems*
  - *Detection at the Limit*
  - *Power on Demand*

Sandia's Mission Areas



....depend on our foundation

Sandia's *Research Foundations* play a differentiating role in our mission delivery

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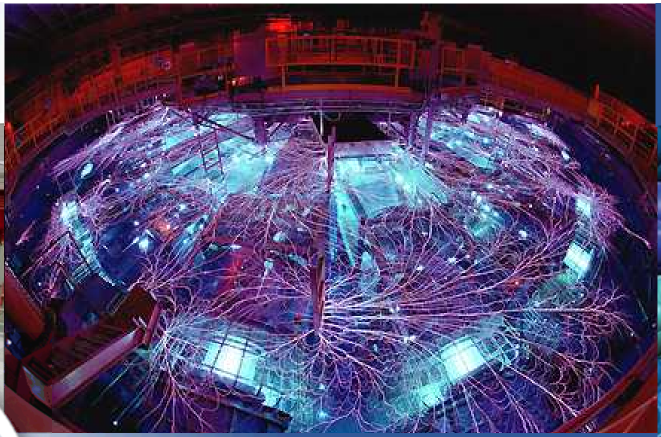
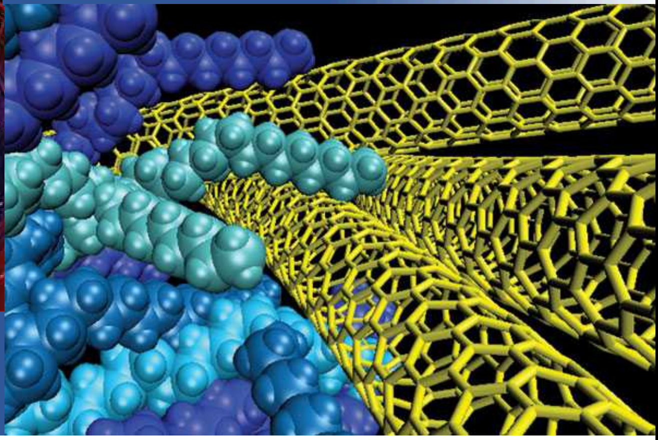
Computing & Information Sciences

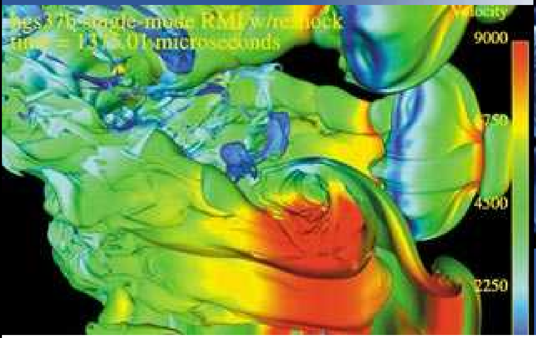


Radiation Effects & High Energy Density Science

Materials Sciences

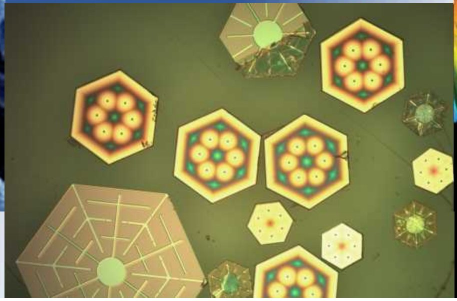


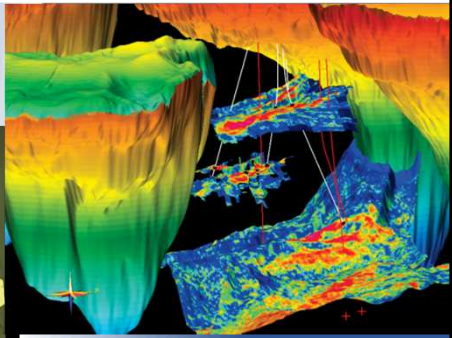
Engineering Sciences



Bioscience

Nanodevices & Microsystems





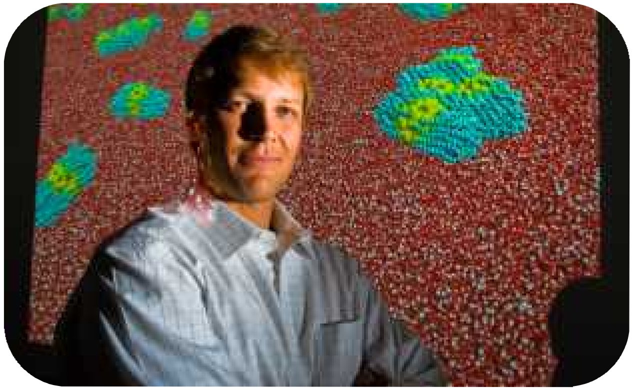
Geoscience

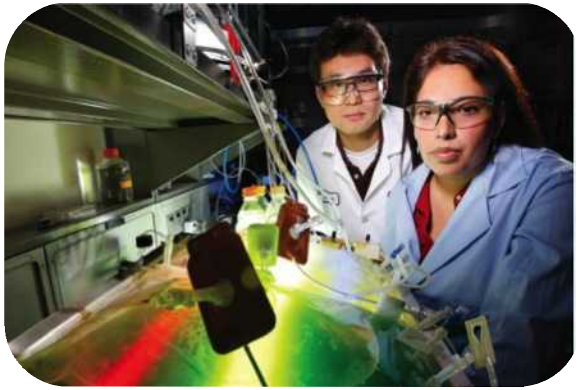
Sandia's Laboratory Directed R&D Program

- An internal R&D program; run by a competitive proposal process
- Authorized by Congress; funded by 6% tax on direct programs
- Sandia's sole source of discretionary R&D funds

Threefold purpose:

- Enables our national security mission, now and in the future
- Advances the frontiers of science and engineering
- Helps attract and retain a world-class research community





LDRD Portfolio Overview

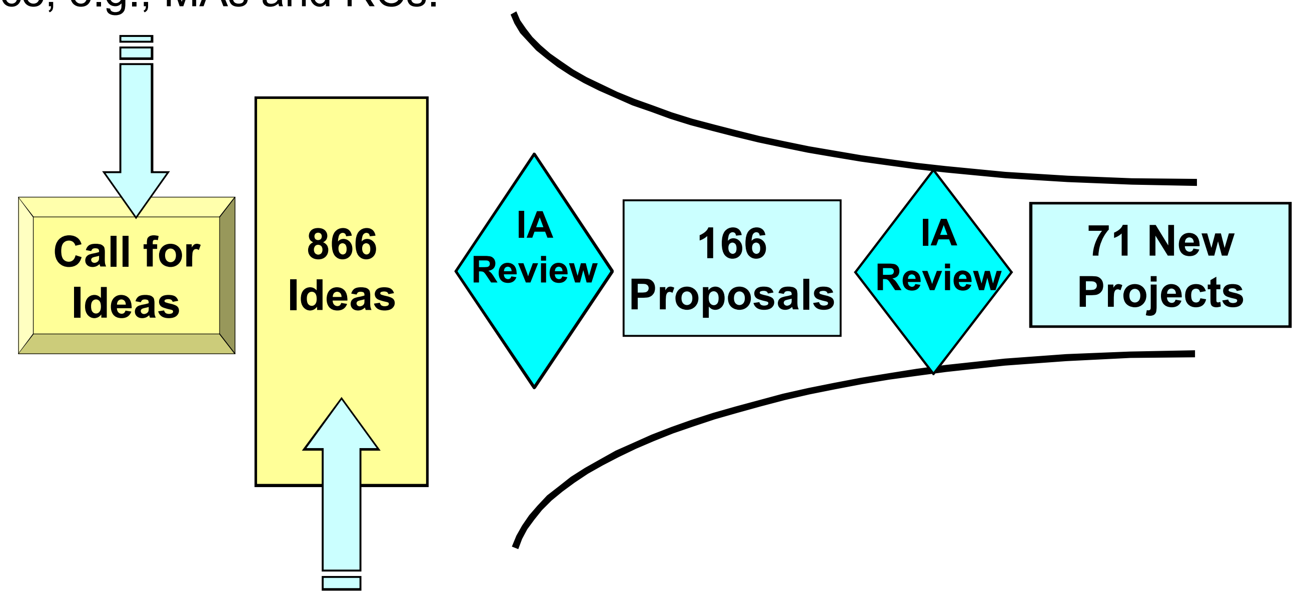
FY15 $146M

- **Research Foundations** – provide foundational support for all national security missions
- **Mission Foundations** – seeks to create innovative technologies in direct support of NNSA, DOE, and WFO missions
- **Corporate Investments**
  - Strategic Partnerships
  - Early Career
  - Exploratory Express
  - Reserves and Program Management

Both Mission and Research use LDRD as a tool to implement strategy

Laboratory-Directed
Investment Area Calls incorporate strategic guidance, e.g., MAs and RCs.

FY 2015 data

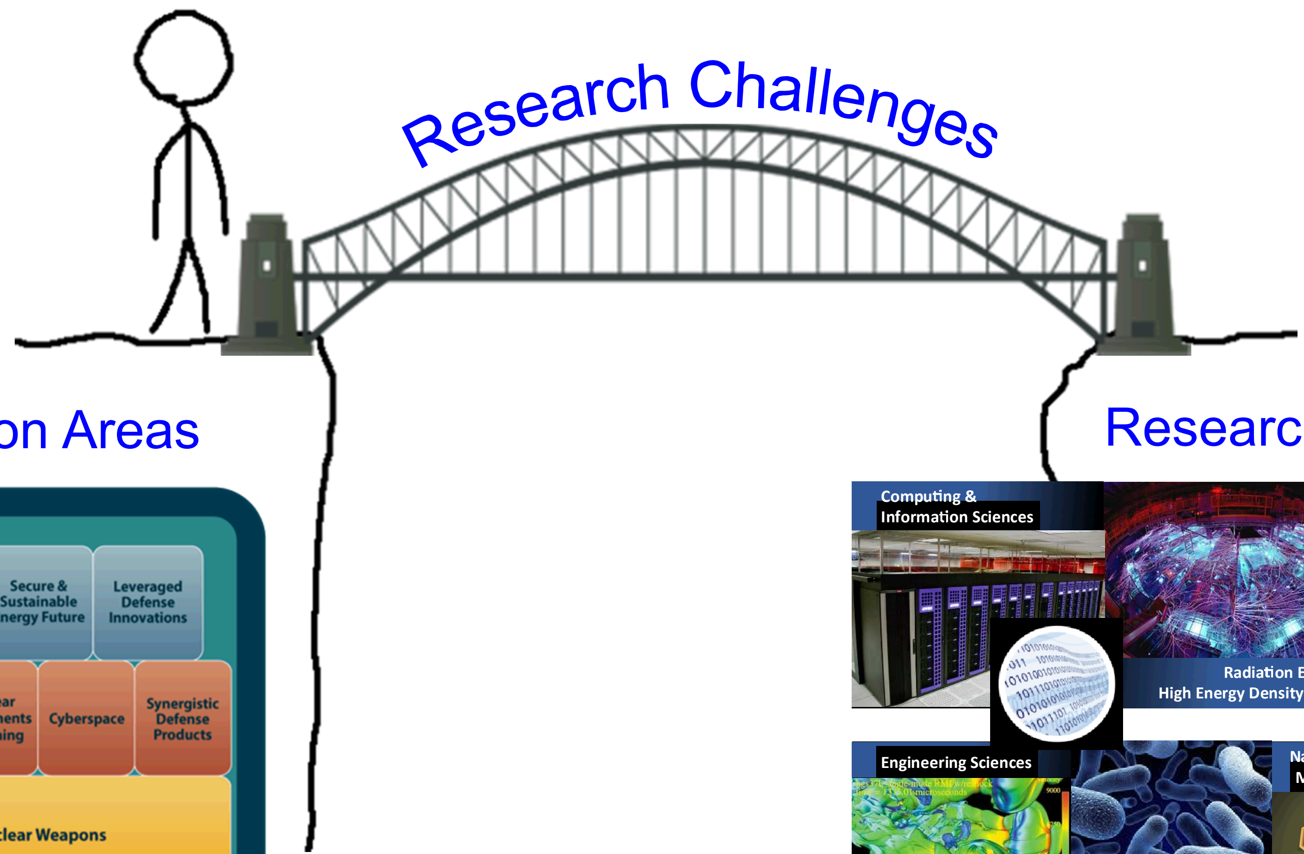


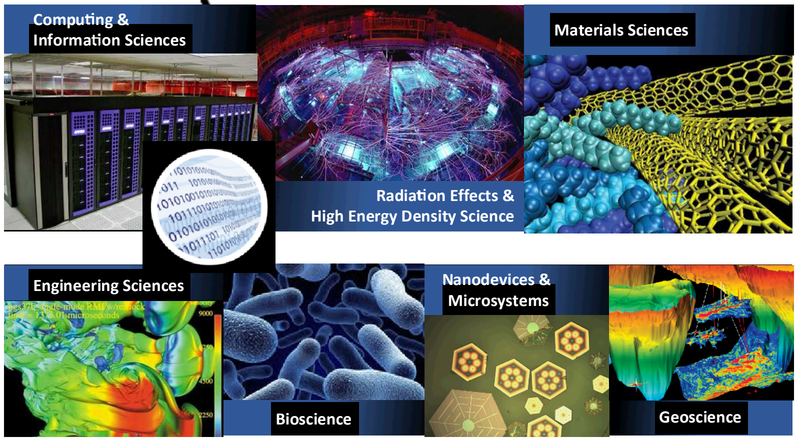
The Investement Area teams review and select ideas and proposals that will best achieve strategic intent.

Employee-Suggested
Staff generate creative, high-risk, high-value ideas.

A new construct seeks to increase integration between Mission and Research

Research Challenges are a bridge between MA's and RF's





Sandia's Research Challenges will drive Research-Mission Integration

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Research Challenge attributes:

- Advances the frontiers of science and engineering
- Surmounts a critical path technical obstacle for a mission challenge
- Endures for 10 years or more
- Integrates across multiple dimensions
- Requires partnerships

Current Research Challenges:

- Beyond Moore Computing
- Data Science
- Cyber Resiliency
- Trusted Systems & Communications
- First to High-Yield Fusion
- ***Detection at the Limit***
- Engineering of Materials Reliability
- Resiliency in Complex Systems
- ***Science & Engineering of Quantum Information Systems***
- Revolutionary Approaches to the Stockpile
- ***Power on Demand***
- **EN**gineering **A**biotic/**B**iotic **L**iving **S**ystems

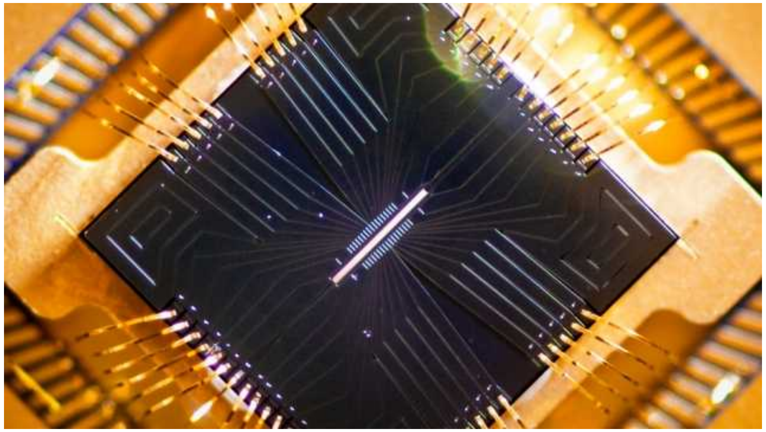
A Major Mechanism for implementing *Research Challenges* is through *Grand Challenge LDRD's*

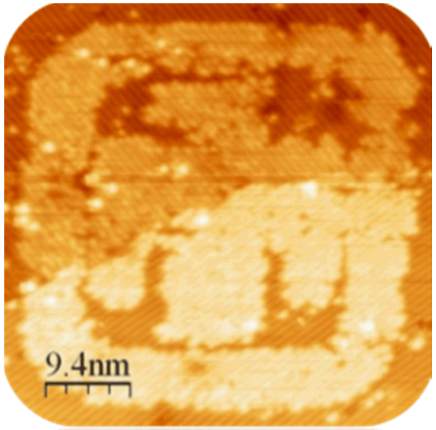
FY15 $146M

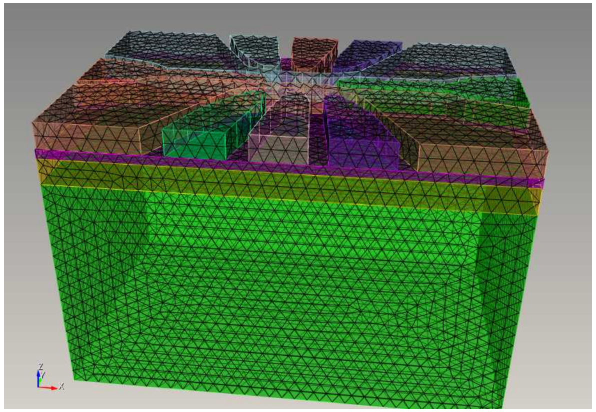
Aligned Investments in Research Challenges

- **Research Foundations** – provide foundational support for all national security missions
- **Mission Foundations** – seeks to create innovative technologies in direct support of NNSA, DOE, and WFO missions
- **Corporate Investments**
  - Strategic Partnerships
  - Early Career
  - Exploratory Express
  - Reserves and Program Management
- **Grand Challenges** – bold, high risk ideas with the potential for significant national impact
  - Large projects, typically $2-5M/year
  - Multidisciplinary teams
  - Focused on Research Challenge roadmaps

First Research Challenge







Science and Engineering of Quantum Information Systems (SEQIS)

Motivations for Quantum Information Science

Improve upon classical limits using quantum properties of matter

- Quantum computing
  - Rapid factoring for decryption
  - Accelerated search of large databases
  - More efficient for simulation of quantum systems
    - For understanding/predicting physical properties (e.g., materials, Ising/Potts spin glasses)
- Quantum Communications
  - Eavesdropping is detectable
  - Physically secure data transfer

- Quantum Sensing
  - Single electron transistors (SETs)
  - Clock synchronization
  - SQUIDs

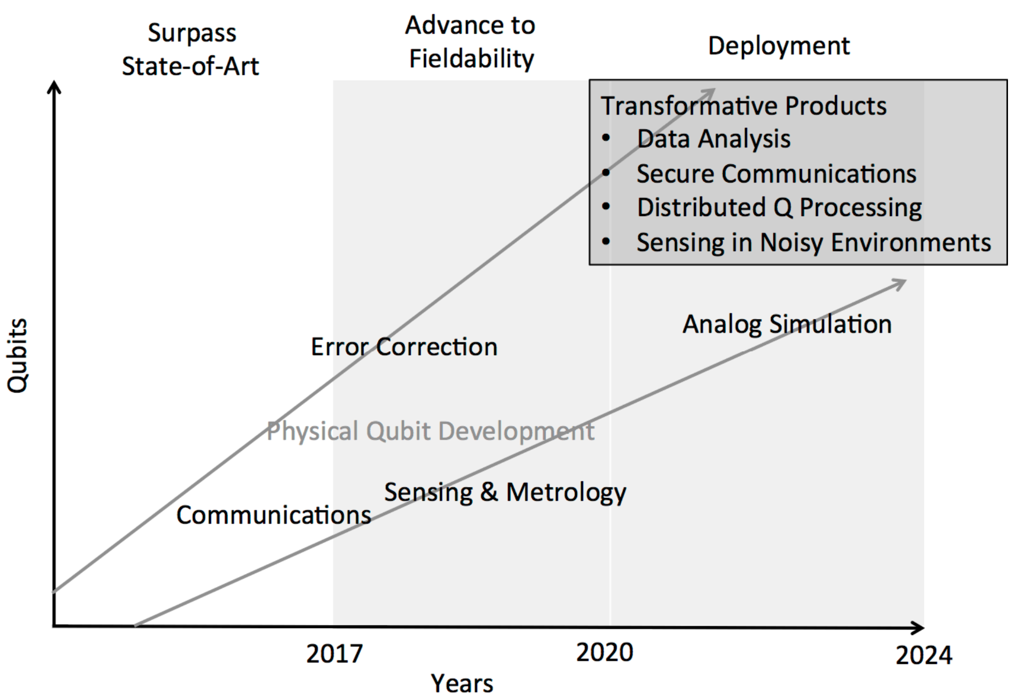
QIP will impact all these applications.
Near-term impacts are in communications and sensing.

Vision of the SEQIS Research Challenge

***S**cience and **E**ngineering of **Q**uantum **I**nformation **S**ystems*

- SEQIS seeks to advance the S&T of:
  - ***Entanglement-enhanced sensors*** that surpass SOA in multiple areas, including imaging, navigation, gravimetry
  - ***Entanglement-enhanced information storage/processing devices*** that surpass SOA classical computing technologies
  - ***Long distance, secure communications protocols*** that leverage quantum information-disturbance relationships

SEQIS Technology Roadmap



Three Grand Challenge LDRDs to date

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QIST Quantum Information S&T

AQUARIUS™ Adiabatic quantum architectures in ultracold systems

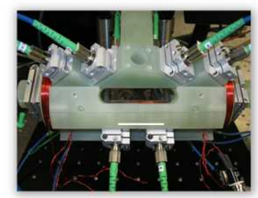
SECANT QKD

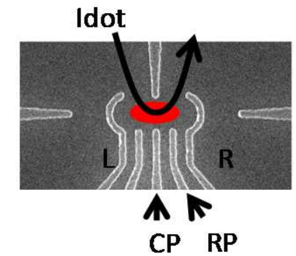
FY08 – FY10
Si-based qubits

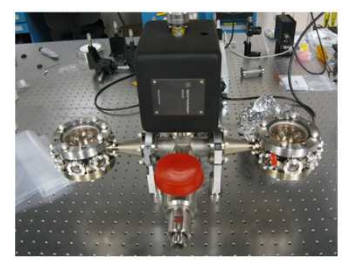
FY11 – FY13
Architectures

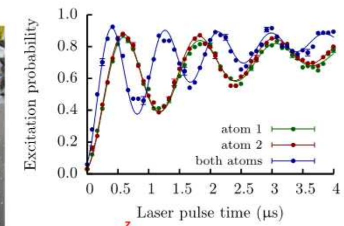
FY14 – FY16
Comms/QKD

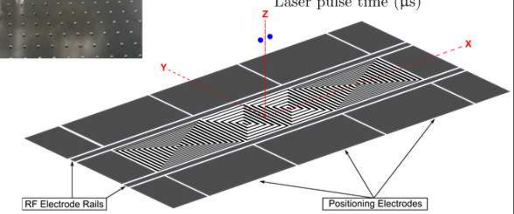
- Broad and deep portfolio, spanning many facets of QIS:
  - **Qubits:** physical qubit development, logical qubit design, entanglement, noise modeling
  - **Quantum engineering:** architectures, robust quantum gates, on-chip microwave control of ion traps, tomography
  - **Algorithms/applications:** demonstration of few-qubit apps, algorithm design
  - **Simulation:** design toolkits, error correction threshold simulators
  - **Sensing:** matter-wave sensors, atom interferometry
  - **Communications:** QKD, single photon source development, single photon detectors







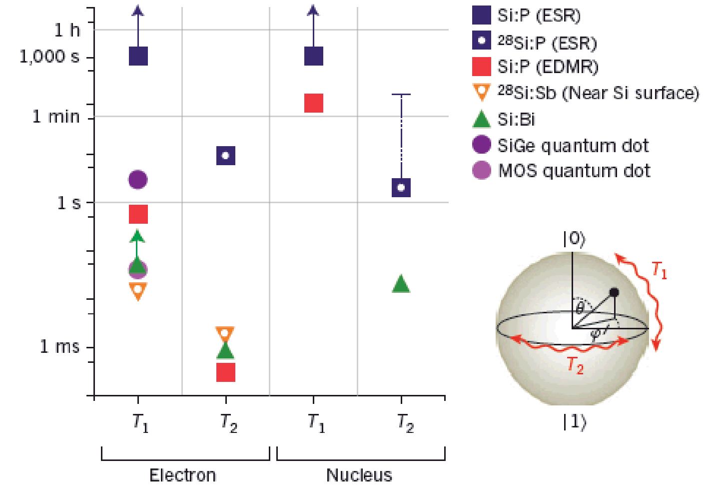




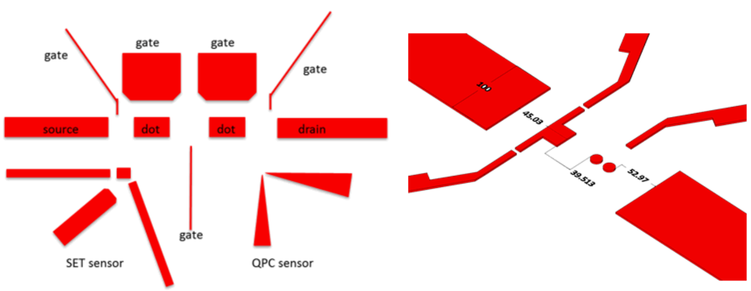
Silicon-based Qubits

Why silicon-based qubits?

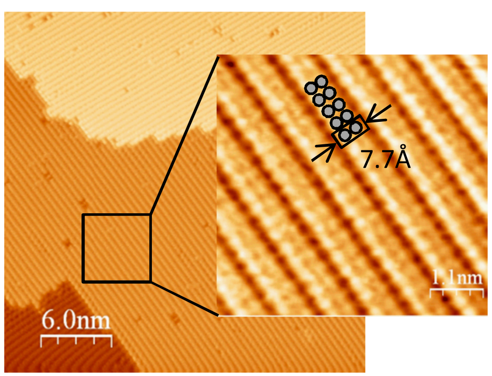
- Long demonstrated spin qubit T_1 and T_2 times
  - Key to high fidelity, controllable, usable qubits
- Large, mature Si microelectronics manufacturing base
  - Leverage manufacturing techniques and technologies
- Ultimate limit in device scaling
  - Atomic precision fabrication provides miniaturization limit on qubit size
  - Design and fab at the sub-nanometer scale



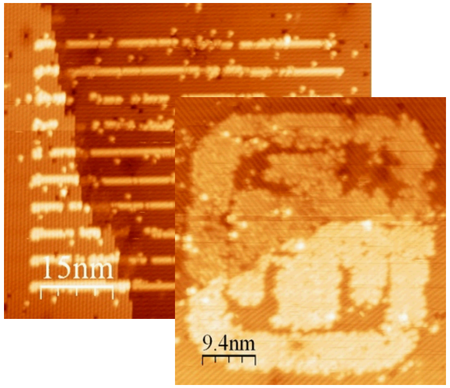
Various spin lifetimes in Si; from Morton et al, Nature, V479, (17 Nov 11), 345.



Early designs of atomic scale charge qubits, Sandia (AQUARIUS, 2012)



STM images of Si(100) surface, Sandia (AQUARIUS, 2011)



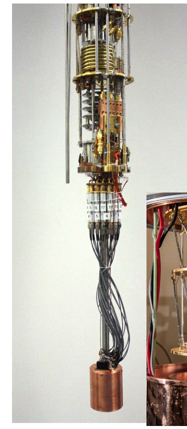
Sandia nanologo and lithographically etched lines, Sandia (AQUARIUS, 2011)

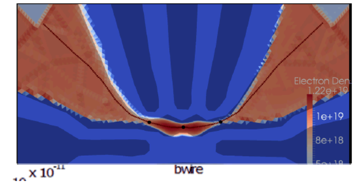
Silicon Qubit Program

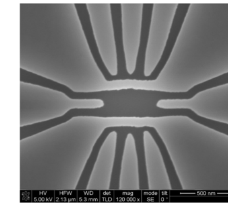
- Two primary device thrusts:
  - Double quantum dots (both spin and charge-based qubits)
  - Donors in silicon

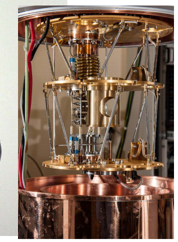
- Under development for over six years
  - Genesis – QIST GC LDRD
  - Adiabatic qubits explored under AQUARIUS
    - ➢ Developed charge qubit (prov. patent)
    - ➢ Preliminary work on donors in silicon
    - ➢ Key result – Pauli blockade on double quantum dots
  - Single and two qubit devices designed, fabbed, tested
    - ➢ Multiple generations of devices

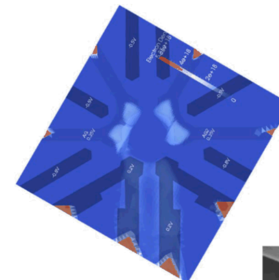
- Design-fab-test-evaluate cycle
  - Design – multiple tools (e.g., QCAD)
  - Fab – MESA Fab, CINT (STM-based atomic precision fab, EBL), ion beam lab (nano-implanter)
  - Test – cryogenic test facilities in CINT
  - Key result – first spin readout of Sb donor

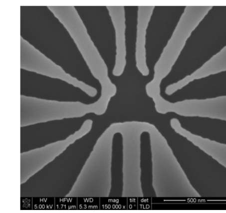


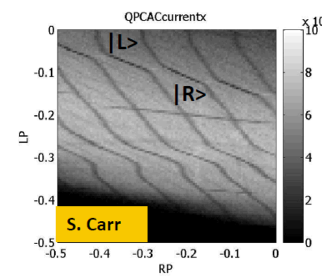


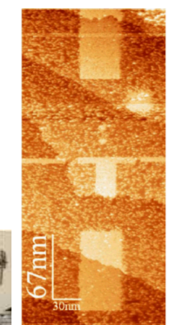


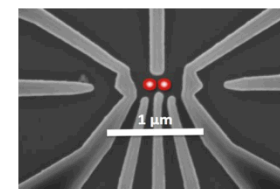


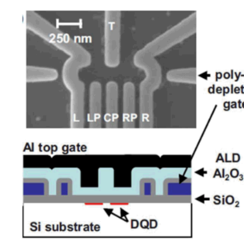


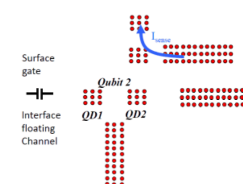




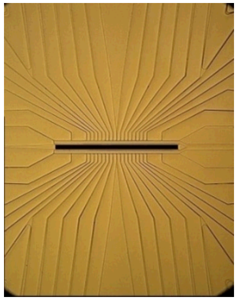


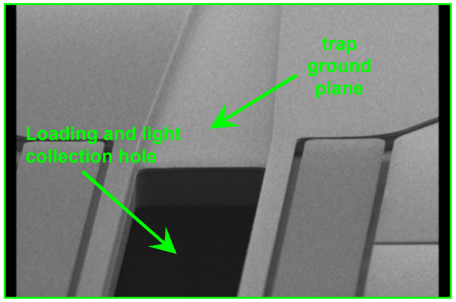






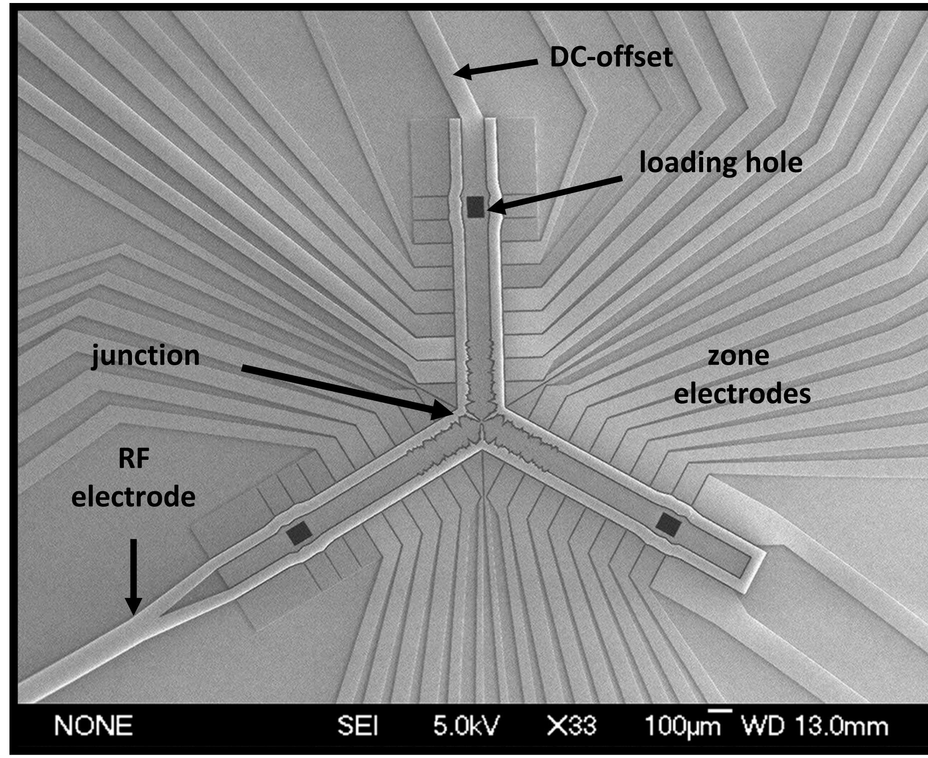
Ion Trap Qubit Program



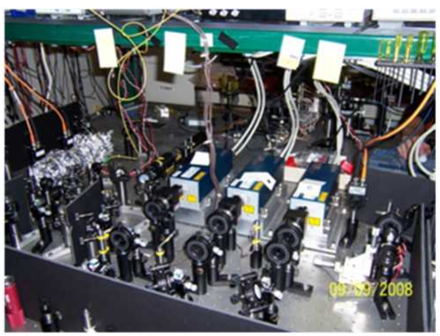


Sandia linear surface micro-trap

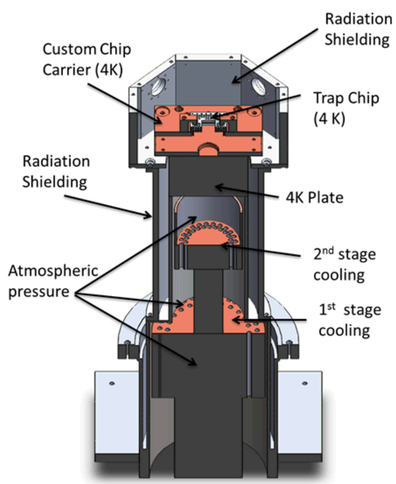
- **Loading hole**
- **Under-cut insulator**
- **10^6 round trips shuttling demonstrated**



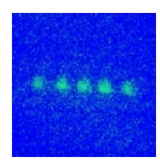
Sandia Y-junction surface micro-trap
Dynamic shuttling of Ca^+ through junction demonstrated



Experimental setup (Sandia, 2008)

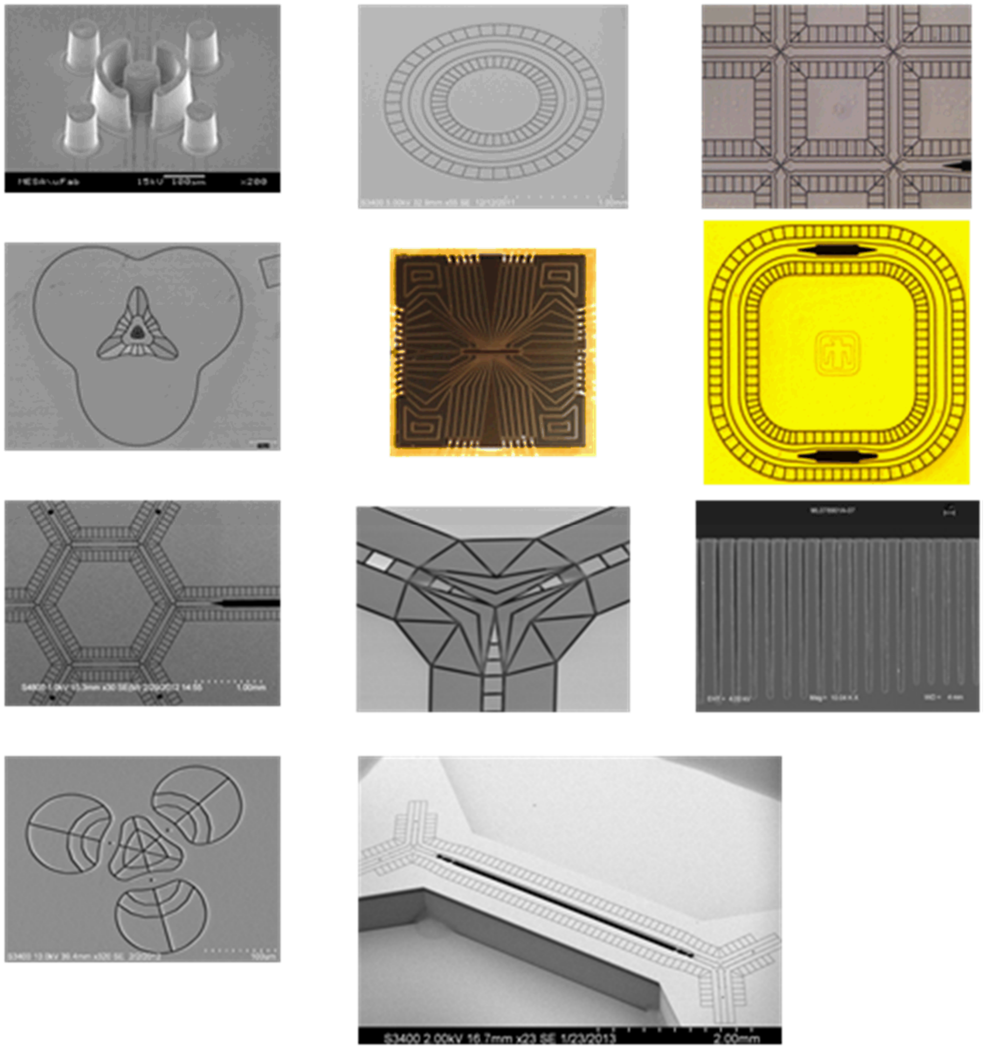


New cryogenic ion trap chamber (2014)



Linear crystal of $^{40}Ca^+$ ions
In Sandia surface micro-trap

The Ion Trap Foundry



- *Performing 2-qubit gates on surface traps with Yb ($\mathcal{F} > 97\%$)*
- Multiple designs delivered to multiple customers
  - 12 institutions, 5 countries
  - 8 institutions have successfully trapped using SNL designs
- Traps used with Ca, Yb, Mg
- Sponsored trap fabrication program - MQCO
- Examining key device issues through:
  - Integrated diffractive optical elements (eliminate bulk optics)
  - Microwave on-chip control of ions (decrease laser/optics requirements)
  - Multiple metal layers (routing of control signals, increased design flexibility)

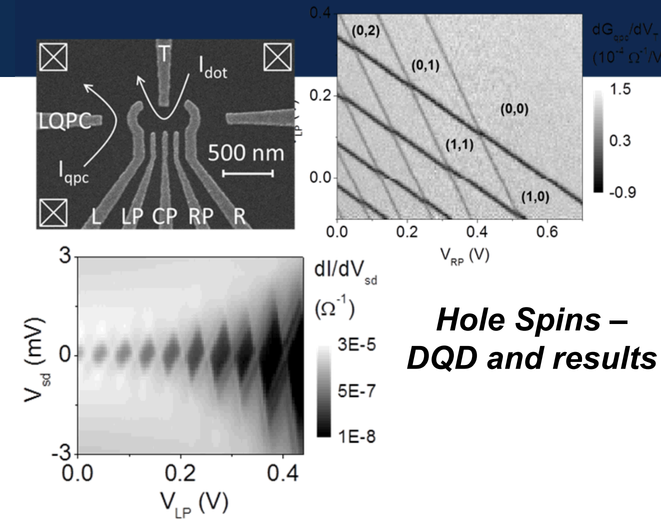
Additional Qubit Expertise

- **Hole Spins in GaAs**
  - Goals: develop single hole transistor devices in GaAs, investigate hole spin physics, eventual qubit evaluations
  - Observing regular Coulomb blockade, diamonds, few hole occupation

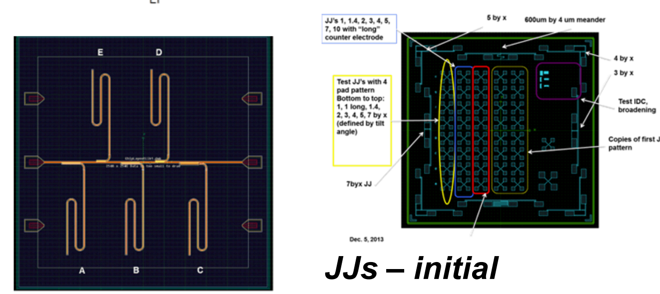
- **Josephson Junctions**
  - Goals: isolate transmon qubits, develop scaling techniques, enable single/multiple high fidelity gates
  - In initial device fabrication stage

- **Fractional Quantum Hall Effect – Majorana Fermions**
  - Goals: examine physics of FQHE states; determine bulk and edge transport properties, quasiparticle charge, possible non-abelian properties

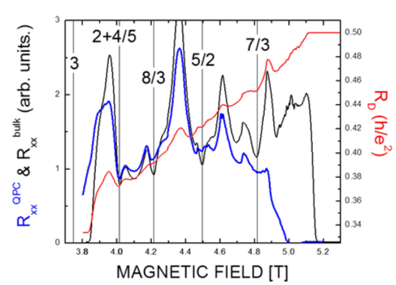
- **Neutral Atoms**
  - Goals: further demonstrate entanglement of neutrals; develop new entangle gate techniques, develop optimal control algorithms for improved bell-state generation
  - Applications in quantum computing and sensing



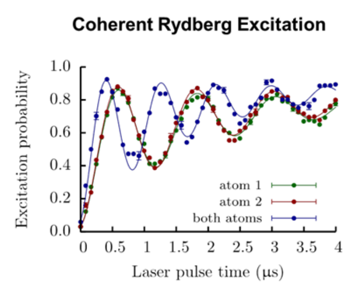
Hole Spins – DQD and results



JJs – initial layouts

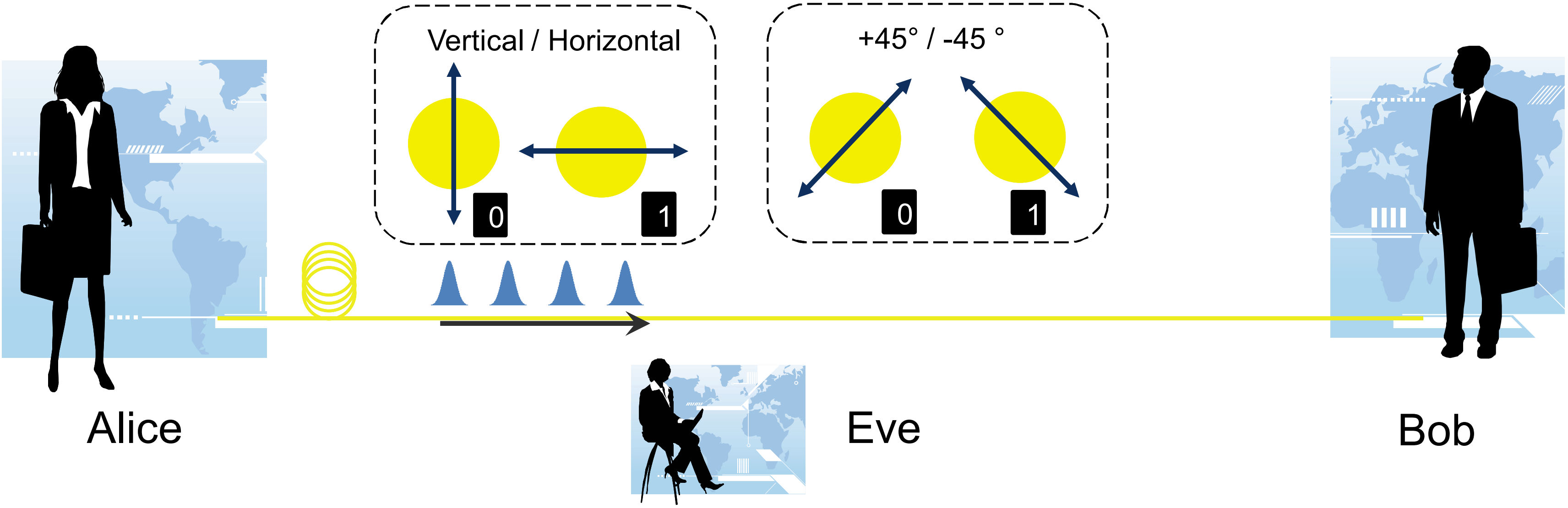


Experimental results - FQHE

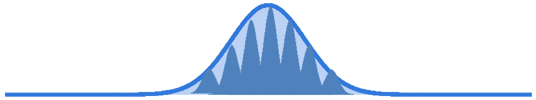


Experimental results – neutral atoms

Quantum Key Distribution (QKD)



Continuous Variable



Discrete Variable

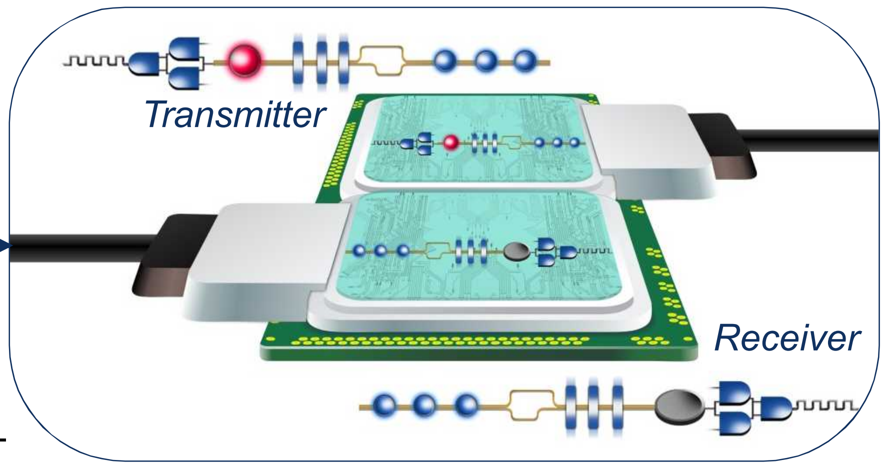
SECANT QKD Grand Challenge LDRD

Goals

1. Construct chip-scale, handheld **quantum transceivers** that can implement DV, CV, free-space, and fiber based QKD.
2. Demonstrate hybrid QKD network with chip-scale transceiver nodes.

Potential Impact

1. Quantum-based key generation for hybrid networks of mobile trusted nodes without central hub.
2. Toolbox for other applications in photonic QIP.



Challenges

1. Develop robust CMOS compatible room temp single-photon detectors.
2. Develop integrated quantum sources.
3. Low-loss quantum signal processing.
4. Combine all components onto one integrated chip.

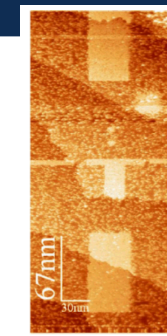
Capabilities

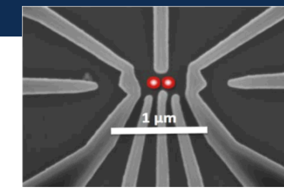
1. World class teams in integrated photonics, quantum theory, and systems.
2. MESA/CINT microfabrication facilities.

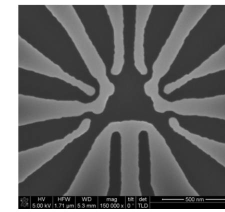
3 yr program, 11 months in...
(FY 2014 – FY 2016)

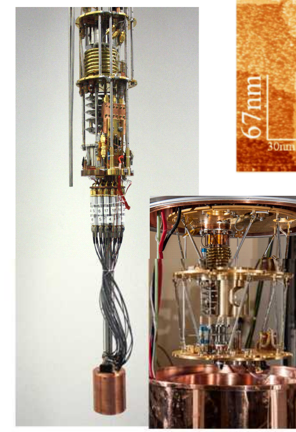
Summary

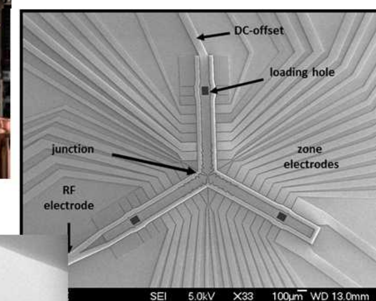
- Quantum information sciences: a multidisciplinary, integrated activity spanning Sandia
- Expertise in key technologies:
  - Fundamental science and engineering of quantum systems
  - Qubits: Si quantum dots/donors, ions
  - Architectures: circuit, adiabatic
  - Algorithms/apps: demonstrations, analysis, development
  - Systems engineering
- Leverages unique facilities: microelectronics fabrication, atomic-precision fabrication, HPC
- Extensive external collaborations
- Technical capabilities, workforce, and facilities that cover device physics, classical electronics, architecture, algorithms, fab and test
- ***The technical challenges are vast – solving them is our focus***

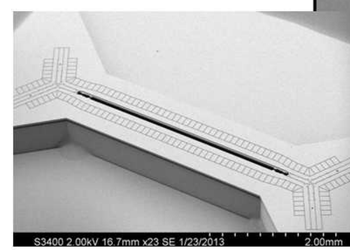


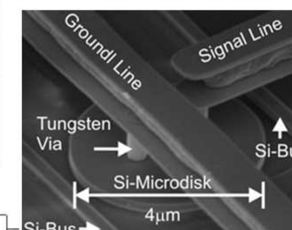


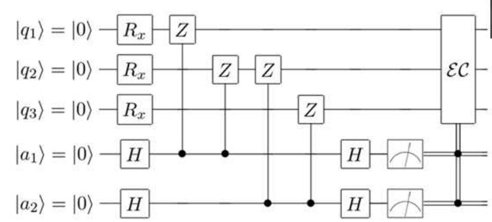


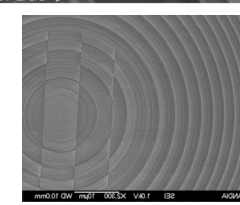


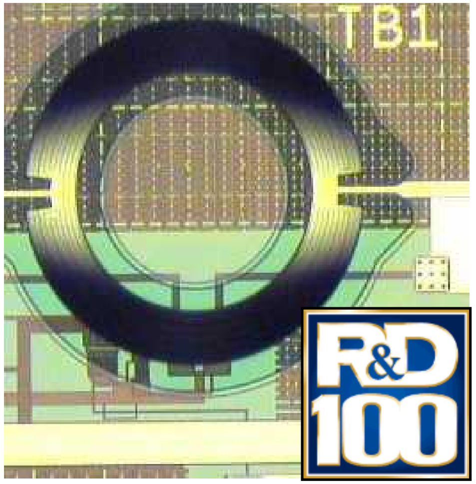


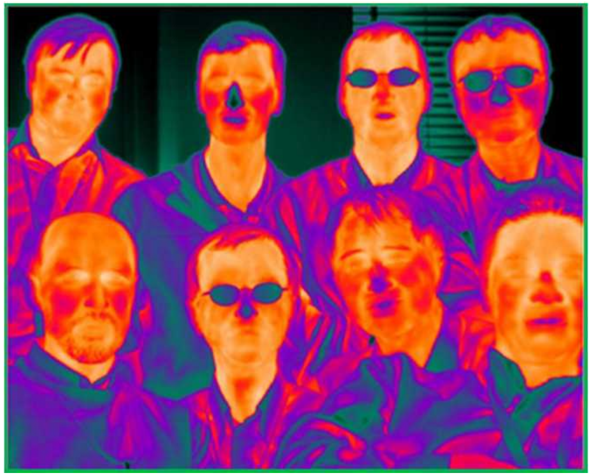








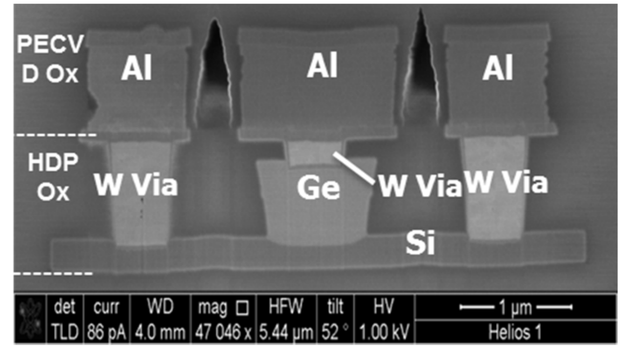




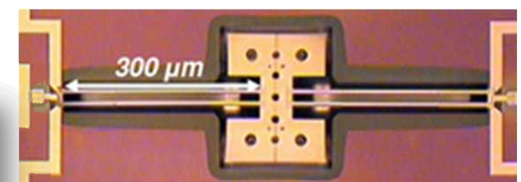
Detection at the Limit (DATL)

Detection Challenge

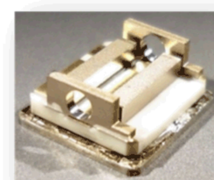
- Need to improve **both remote and proximate** electromagnetic, chemical, and particle sensing capabilities.
  - Detection performed in-situ or from significant stand-off ranges, up to and including from satellites.
- The ultimate in sensitivity is the ability to **detect the minimum unit of information** -- whether it is a photon, an RF emanation, a molecule, or a single nuclear particle.
- The need to field systems that meet performance requirements including size, weight and power (SWaP).



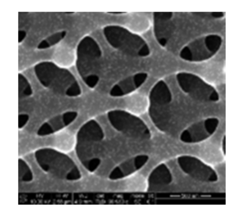
Integrated waveguide Ge on Si photodetector demonstrated best in class performance



Inertial Sensors



Tiny trapped ion clock

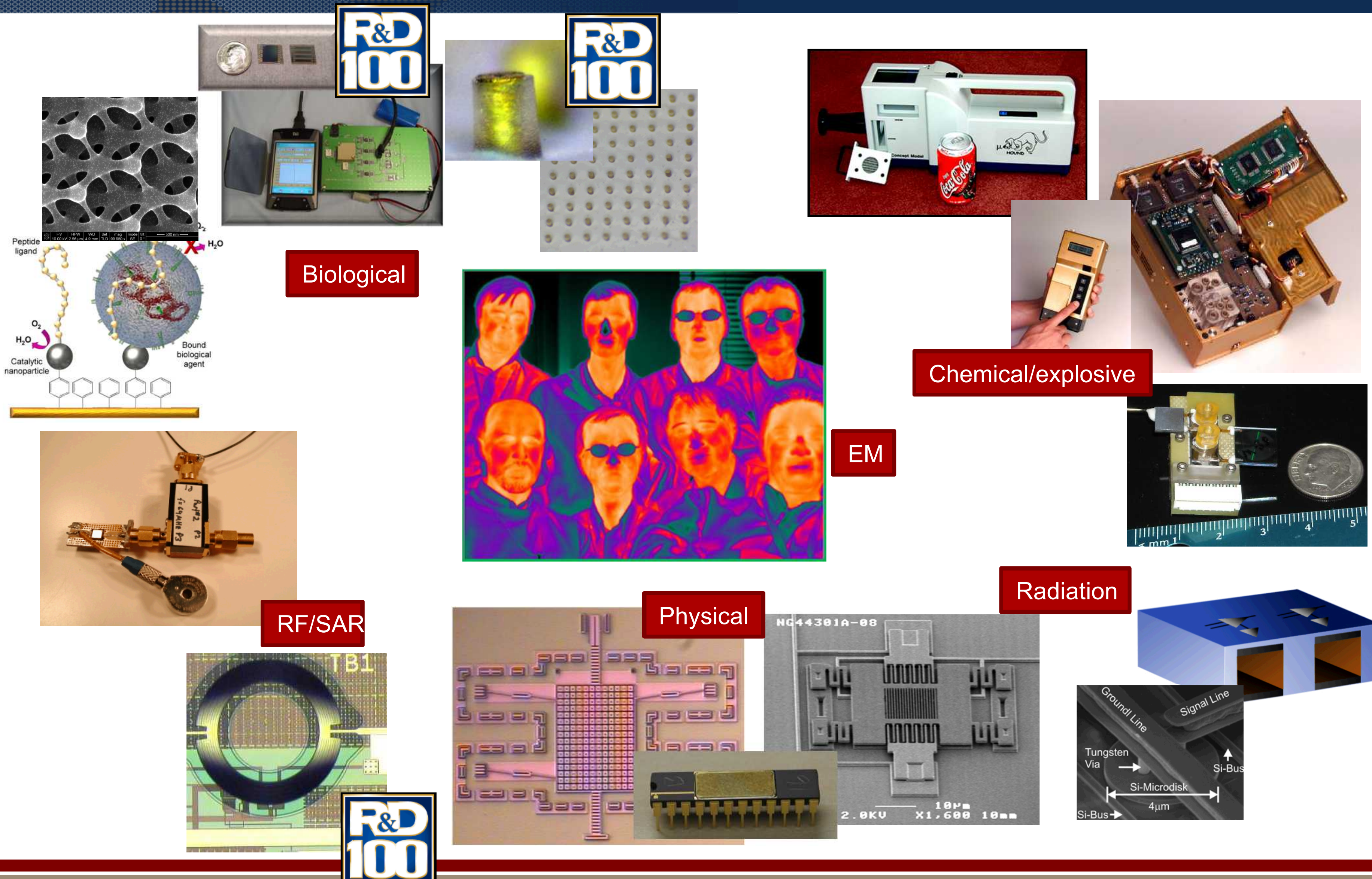


Nanostructured detectors

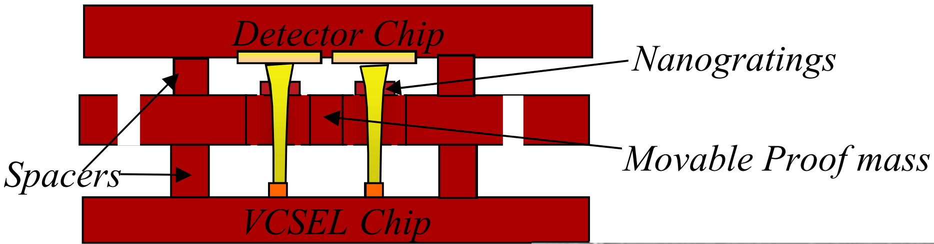
Sensitivity, selectivity, small size, low weight, low power are enhanced through microscale and nanoscale features

Sandia National Laboratories

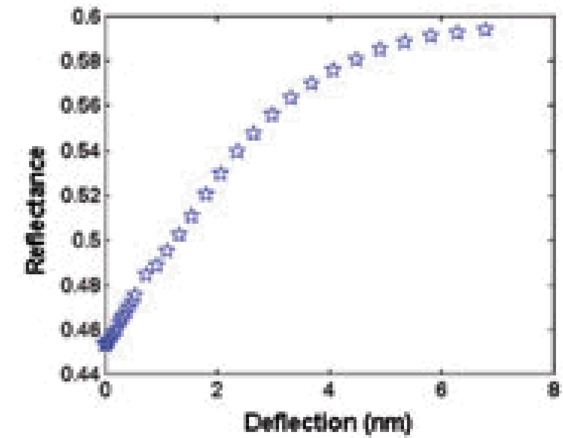
Representative Remote and Proximate Sensor Capabilities



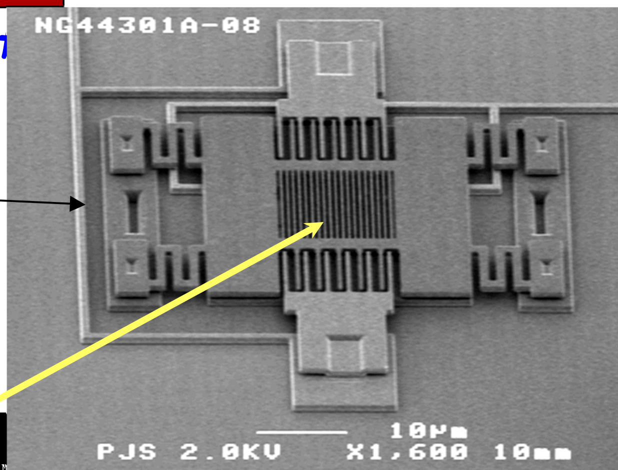
Example: Integrating MEMS with optoelectronics to achieve nano-G accelerometers

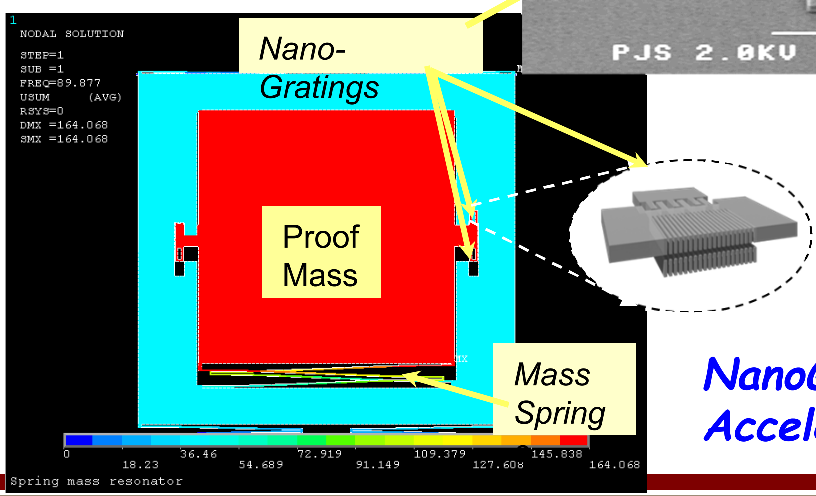


Accelerometer concept



Dual layer nanograting test device





NanoG ($10^{-8} m/s^2$) Accelerometer

- Displacement sensitivity **12 fm/√Hz**
- Record Mass Resonant Frequency for a MEMS device **~ 40 Hz**
- Record Thermal noise floor **~10nG/√Hz**

Applications include:

1) Non-GPS Navigation,
2) Treaty monitoring,
3) Seismic Sensing,
4) Sensors for Oil wells

Down-selected to MWIR/NIR optical sensing

- Sub-team Planning in 5 Thrust Areas:
  - Electromagnetic Sensing (Team Lead: Reno Sanchez)
  - RF/SAR (Team Lead: Marce Armendariz)
  - Chem/Bio Sensing (Team Lead: Susan Brozik)
  - Physical Sensing (Team Lead: Hy Tran)
  - Nuclear Sensing (Team Lead: Laura Biedermann)

- Decided to focus on one area for the time being: *Electromagnetic Sensors for Remote Sensing Applications*

Nano-antenna-coupled Infrared FPA DATL RC LDRD

Goal:

- FPA SWaP improvement for space
- Relax low temperature requirement
- Enhance detector function & performance
  - Integrated pixel-by-pixel polarization and spectral filtering capability
  - Eliminate angular sensitivity
  - Built-in EMI protection

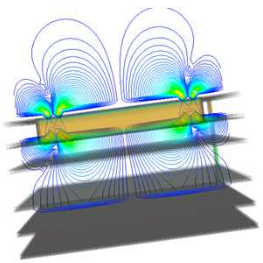
Approach:

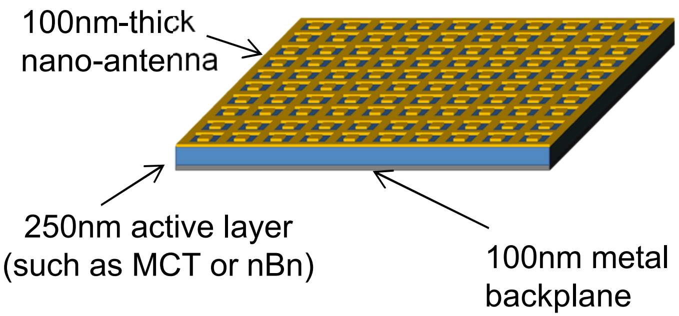
- Integration of nano-antenna directly onto FPA
- Utilization of alternative active layer architecture

Program Milestones and Deliverables:

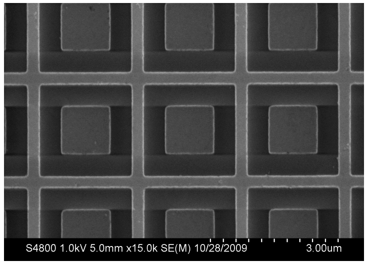
- Deliver small prototype arrays of nano-antenna integrated with a detector material
- Characterize individual components at first FY
- Deliver a demo of a nano-antenna-coupled FPA

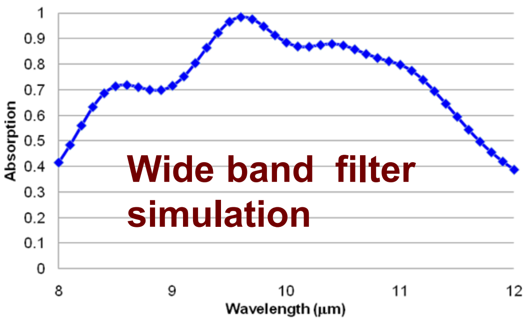
One FPA pixel with integrated nanoantenna





Fabricated rectangular nano-antenna arrays





Graphene Detectors: *Bilayer* Graphene Tunability

nature Vol 459|11 June 2009|doi:10.1038/nature08105

LETTERS

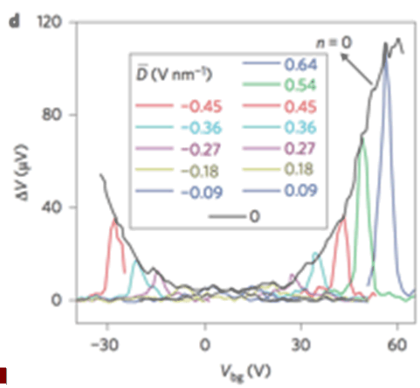
Direct observation of a widely tunable bandgap in bilayer graphene

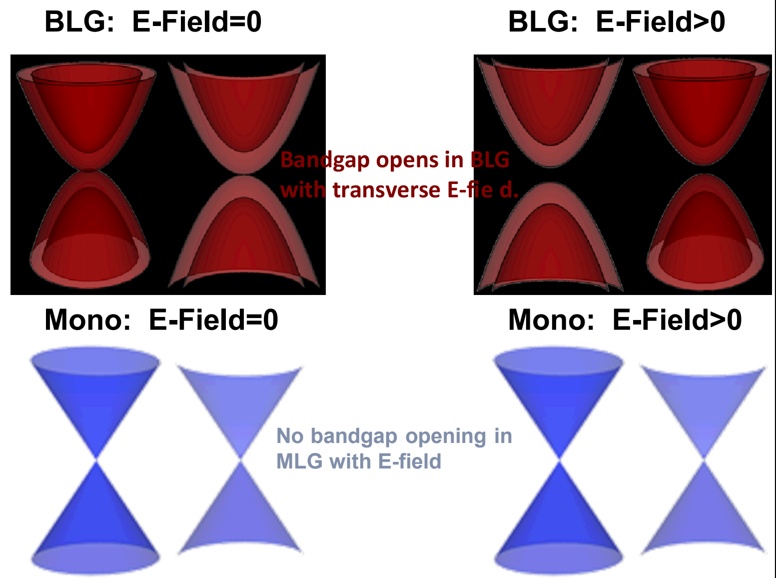
Yuanbo Zhang[1]*, Tsung-Ta Tang[1]*†, Caglar Girit[1], Zhao Hao[2,4], Michael C. Martin[2], Alex Zettl[1,3], Michael F. Crommie[1,3], Y. Ron Shen[1,3] & Feng Wang[1,3]

ARTICLES
PUBLISHED ONLINE: 3 JUNE 2012 | DOI: 10.1038/NNANO.2012.88
nature nanotechnology

Dual-gated bilayer graphene hot-electron bolometer

Jun Yan[1,2], M-H. Kim[1,2], J. A. Elle[2,3], A. B. Sushkov[1,2], G. S. Jenkins[1,2], H. M. Milchberg[2,3], M. S. Fuhrer[1,2]* and H. D. Drew[1,2]





Problems:

1. Scalability
2. Low absorption
3. Multiphysics problem

DATL RC LDRD Stretch Goals

Infrared Rectennas

Heat into power: solar cell enhancer or power for unattended sensor

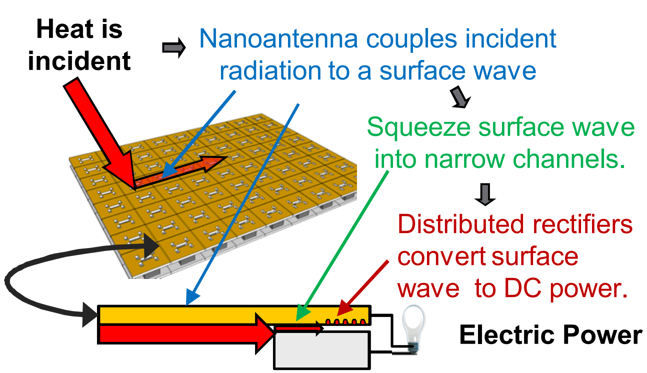
III-V MWIR Detectors

Improved IR detection: lower noise floor and less crosstalk

Graphene Detectors

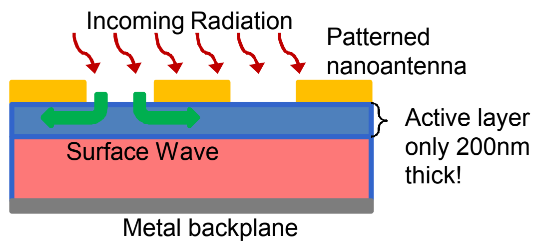
Real-time voltage-tunable IR detection

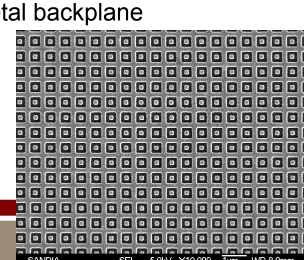
The nanoantenna creates a surface wave that travels to a rectifying tunnel diode. Previous IR rectifiers had 0.1% efficiency: Project Stretch Goal of **30X** improvement **RESULT: 30X Improvement**

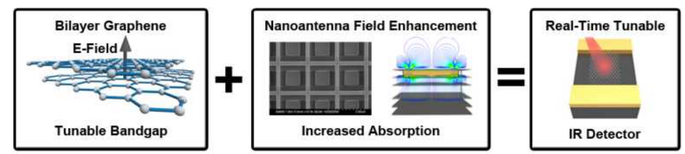


The nanoantenna allows us to use over an order of magnitude thinner active layer and thus reduce crosstalk, dark current: Project Stretch Goal of **10X**.

RESULT: 4.5X



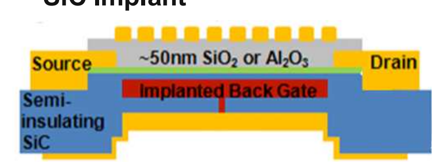




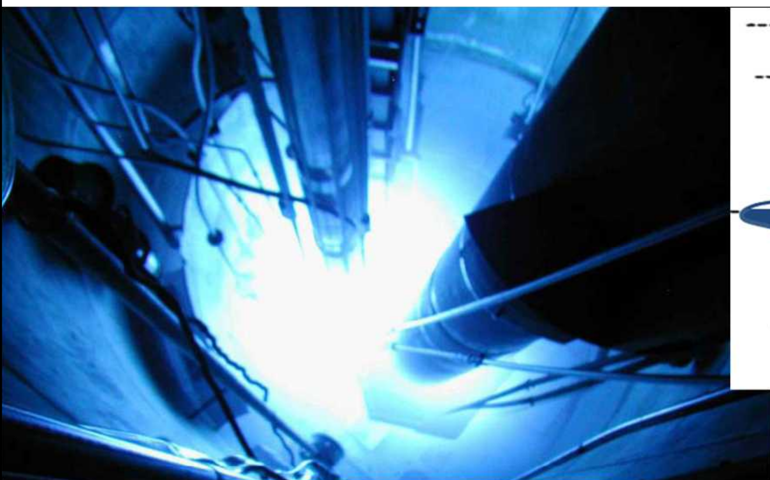
The 2 atomic layers of bilayer graphene only absorb 4.6% of an incident plane wave. We can concentrate the light with the nano-antenna greater efficiency: Project Stretch Goal 10x.

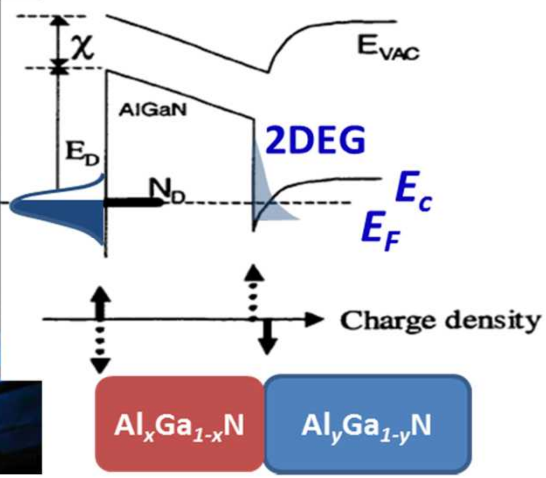
RESULT: 10X Improvement

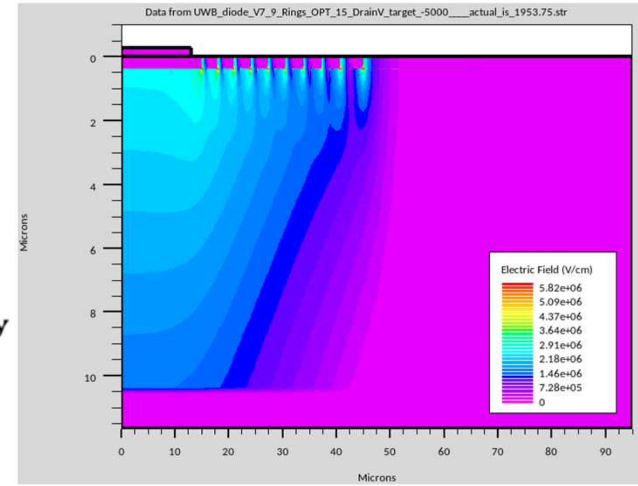
SiC Implant



Third Research Challenge





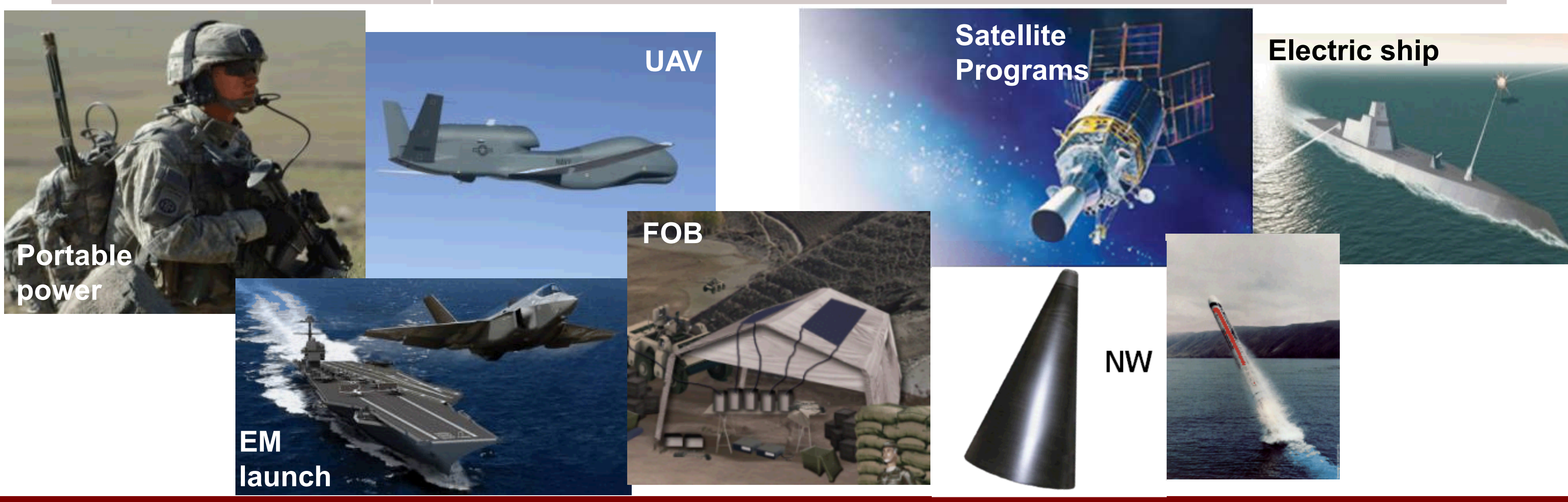


Power on Demand

Mission Needs: National Security

Mission Area	Examples of Specific Areas of Interest and Impact
Synergistic Defense Products AND Leveraged Defense Innovations	• **Aeronautical applications** (SWaP requirements) • **Electromagnetic aircraft catapults** for navy carriers • Extended operation of **UAVs and robotics** • Operational lifetime of **remote sensors** • Recharging and rejuvenation of **satellites** • Enhanced **warfighter capabilities** • Electrical power for **FOBs**
Nuclear Weapons	• High-efficiency **power translators** • Replacements for **high-voltage standoff** components • Components enabling more efficient **rad-hard** subsystems • Embedded evaluation for **stockpile surveillance** and life assessment
Nuclear Assessments & Warning	• Compact, reliable, radiation-hard power conversion for **satellite systems**

SWaP issues are paramount for all of these applications

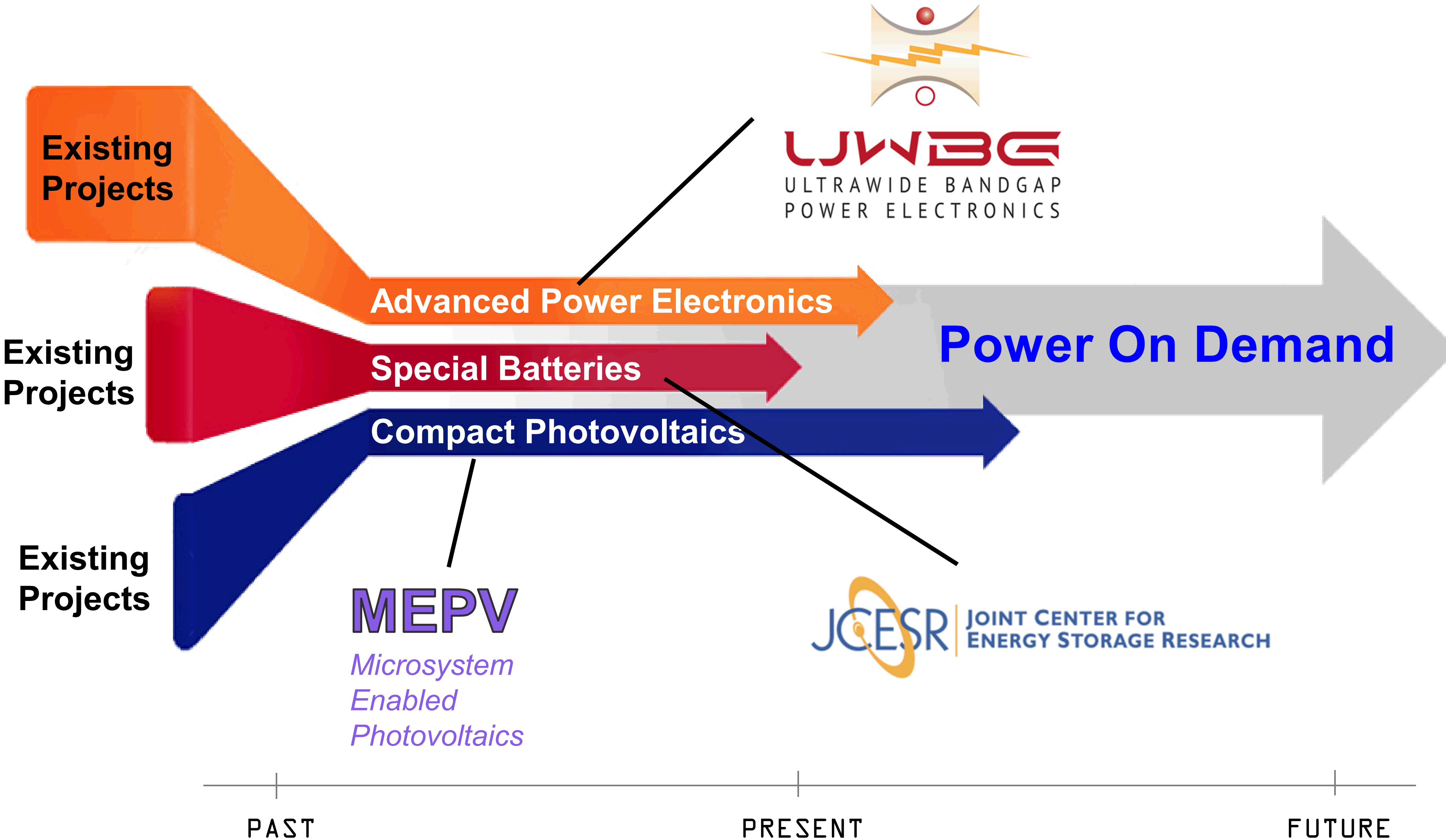


Power on Demand Vision: "A power plant in your palm"

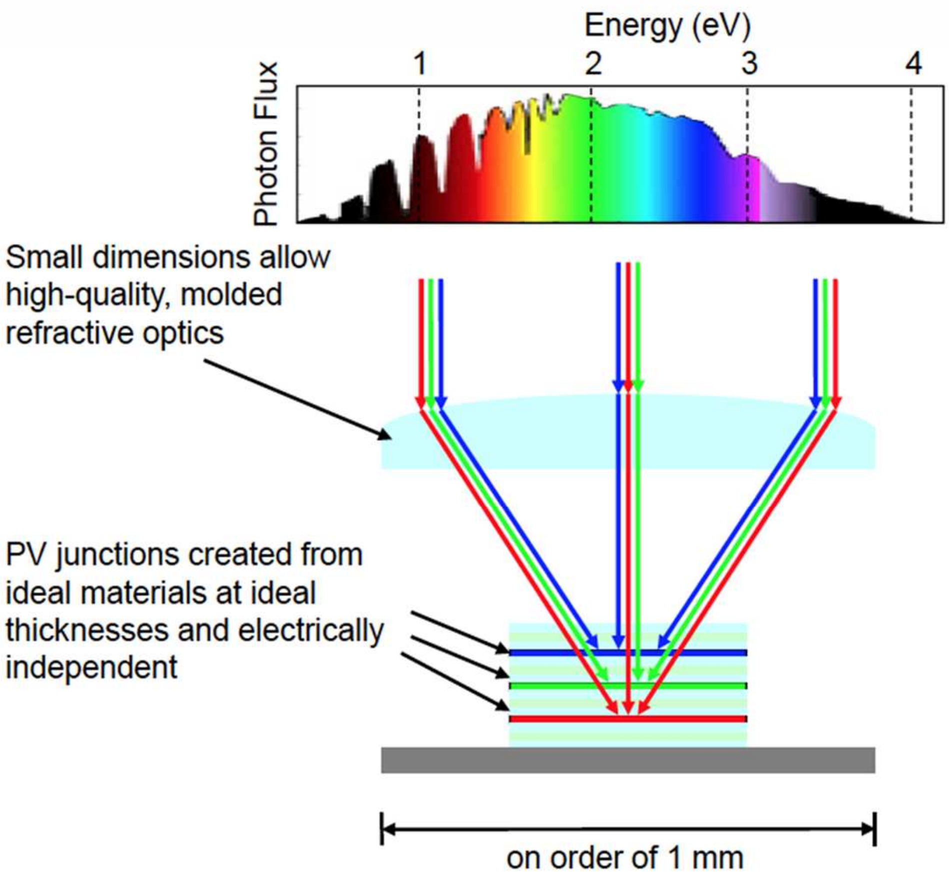
- **Power on Demand (PoD):** Develop highly controllable and agile power systems with the smallest size, lightest weight, and highest reliability, for harsh environments.

- **Electrical Energy** is the focus
- **Power on Demand** will develop **innovative technologies** for differentiating performance in power systems for:
  - **National security applications**
  - **Civilian energy sector**

The Power on Demand RC Seeks Order-of-Magnitude Improvements in Electrical Power System SWaP



Microsystem-Enabled PV Cells for High Solar Conversion Efficiency



Material	Bandgap
InGaN	*2.5*
InGaP	*1.85*
GaAs	*1.4*
Si	*1.1*
InGaAsP	0.9
InGaAs	0.6

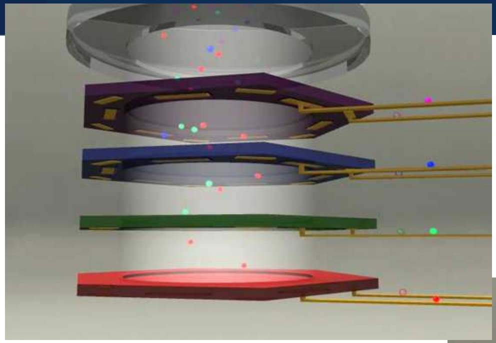

Triple junction Si/GaAs/InGaP cell

MEPV Vision

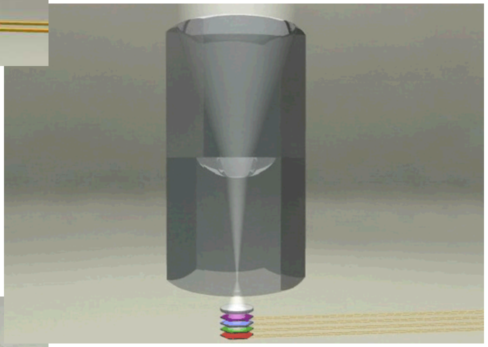
Explore fundamental scale effects within photovoltaic cells, modules, and systems for enhanced performance, reduced costs, and new functionality

Goals:

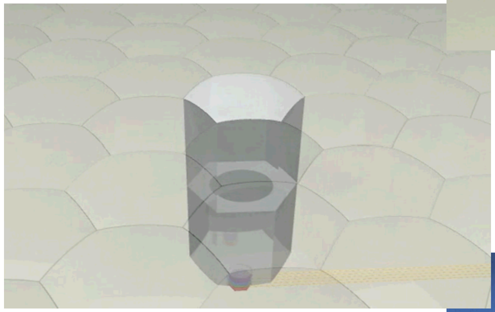
- 40% efficient PV system with the potential for $0.10/kWh levelized cost of energy (LCOE)
- Highly functional, highly flexible PV modules
- Establish Sandia leadership in this R&D area



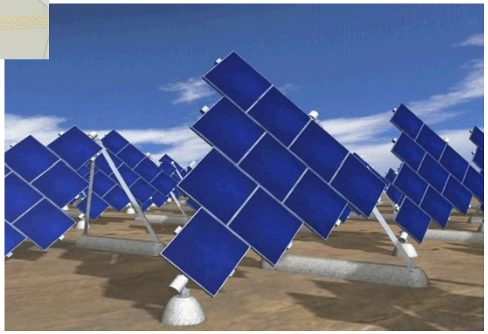
Micro-PV Cells



Micro-optics



High Performance Modules



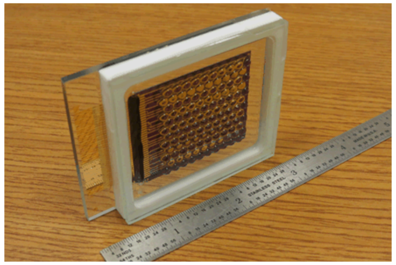
Low-cost, uniquely functional Solar PV Systems

MEPV Micro-Concentrator for Utility-Scale Power Systems

MEPV technology is receiving interest from industry and DOE
- ***2012 R&D100 Award***
- ***49 patents filed***
- ***DOE ARPA-E (New $25M MOSAIC Program)***

Micro-Concentrator

Reduced balance of system costs through micro-concentrator design. Rigorous cost models suggest MEPV Technology can provide < $0.5/Watt module cost



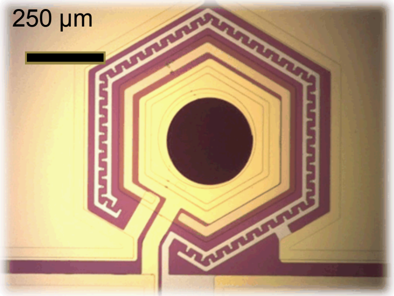
200x concentration, 1cm thick Hybrid micro-concentrator

Silicon III/V Cell Integration

Demonstrated release and bond of active III-V materials on silicon with a double junction cell on active silicon (efficiency ~30% 200-sun)

Hybrid PV Cell Architecture

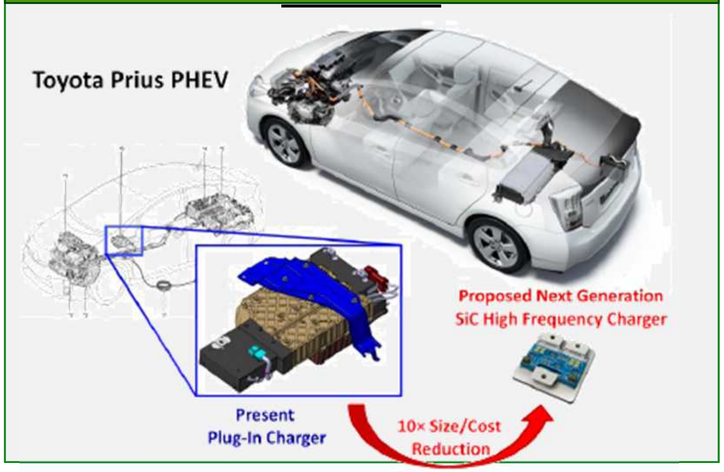
Improved performance in all climates. Hybrid design allows capture of both direct normal and diffuse light



Wafer bonded GaInP/GaAs:Si 30% efficient solar cell

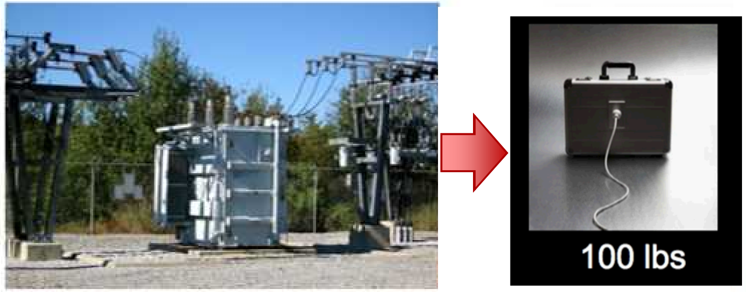
WBG Power Electronics: SWaP reductions for electrical energy applications

Automotive



SiC is 10% the volume and weight of Si for equivalent capability (10 kV, 100 A)

Power Grid



8000 lbs, 60 Hz Distribution Transformer

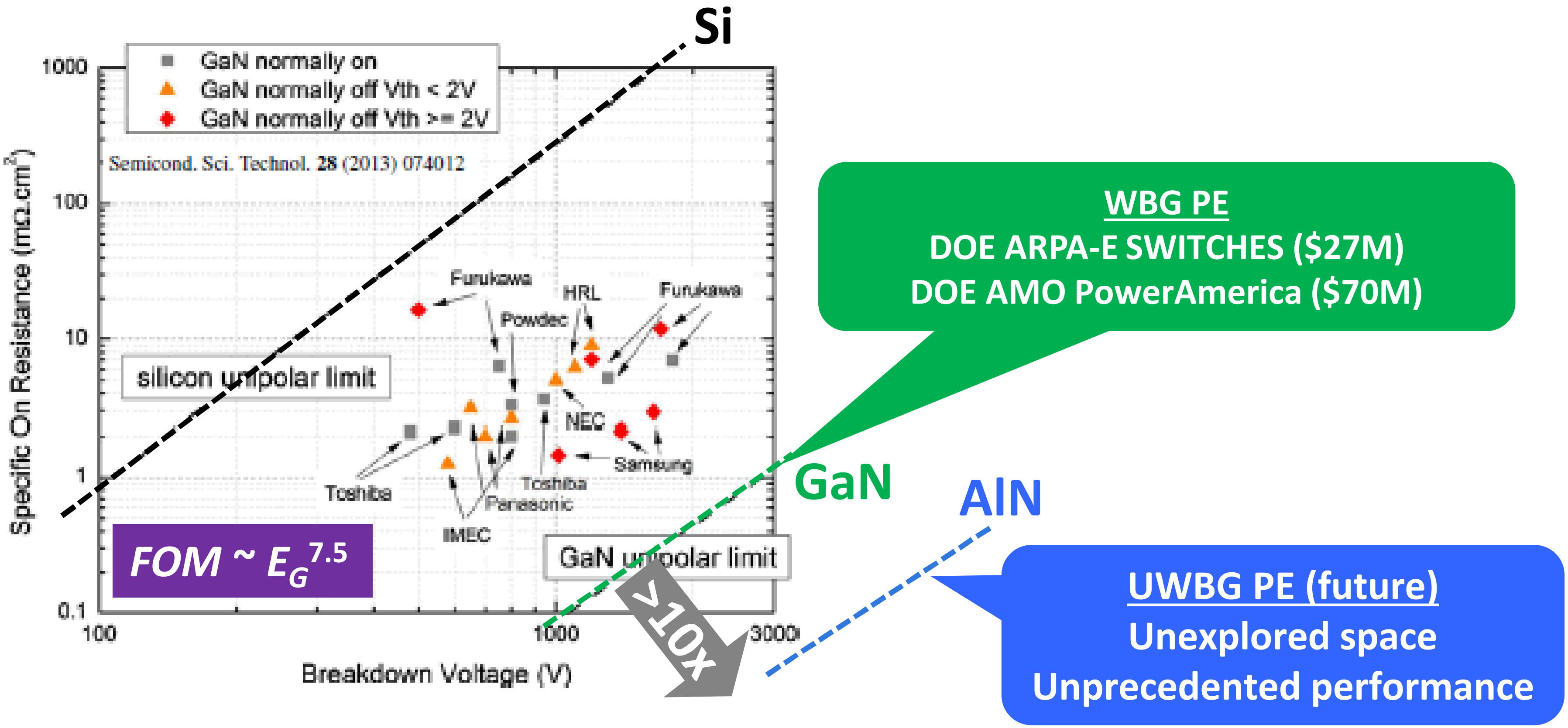
Silicon Carbide IGBT;
15 kV, 100 A;
50 kHz from Cree Inc.

Potentially 100 lbs Transformer

80% of grid power expected to flow through PE by 2030

Ultra-WBGs will offer an *additional* 10× SWaP improvement compared to SiC and GaN, as well as Ultra-High-Voltage (potentially 100's of kV)

Comparative Landscape – A Different View

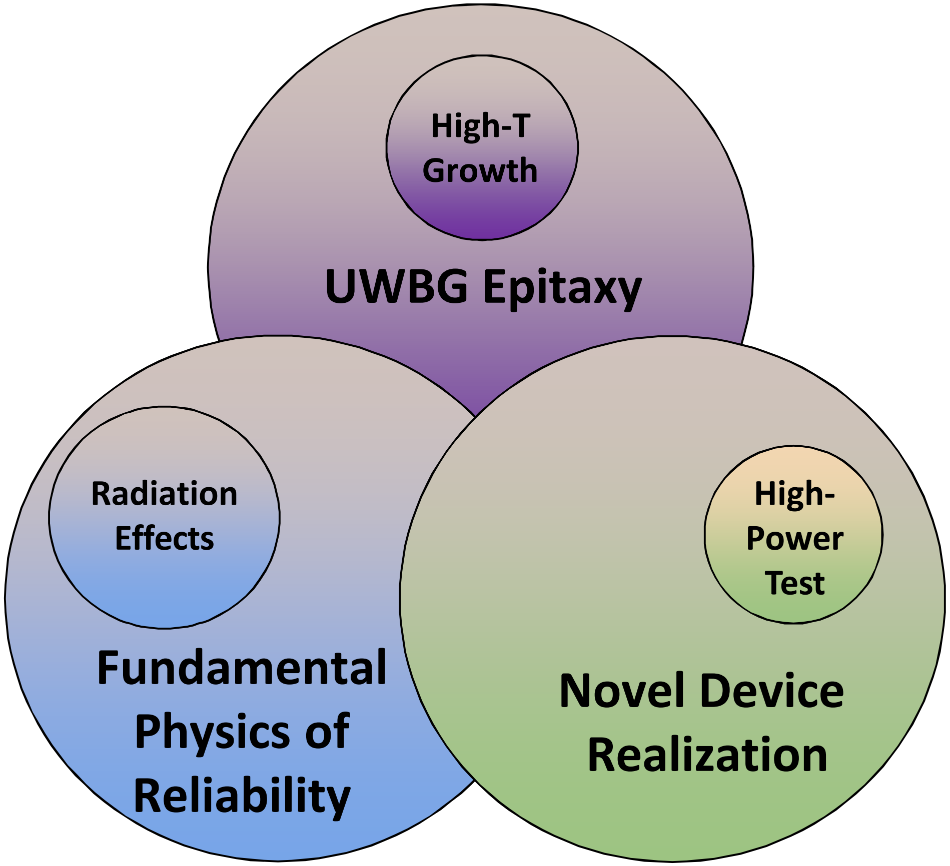


Truly transformative potential: Unique opportunity to make a foundational contribution to a strategically important field

Grand Challenge LDRD: Ultra-WBG Power Electronics

Extend WBG capability to create new class of UWBG radiation-hard power electronics, which offers orders-of-magnitude improvement in Size, Weight, and Power (SWaP), enabling national security missions

~$5M per year for three years, starting October 1, roughly evenly distributed among the three areas



Challenging UWBG Materials Synthesis

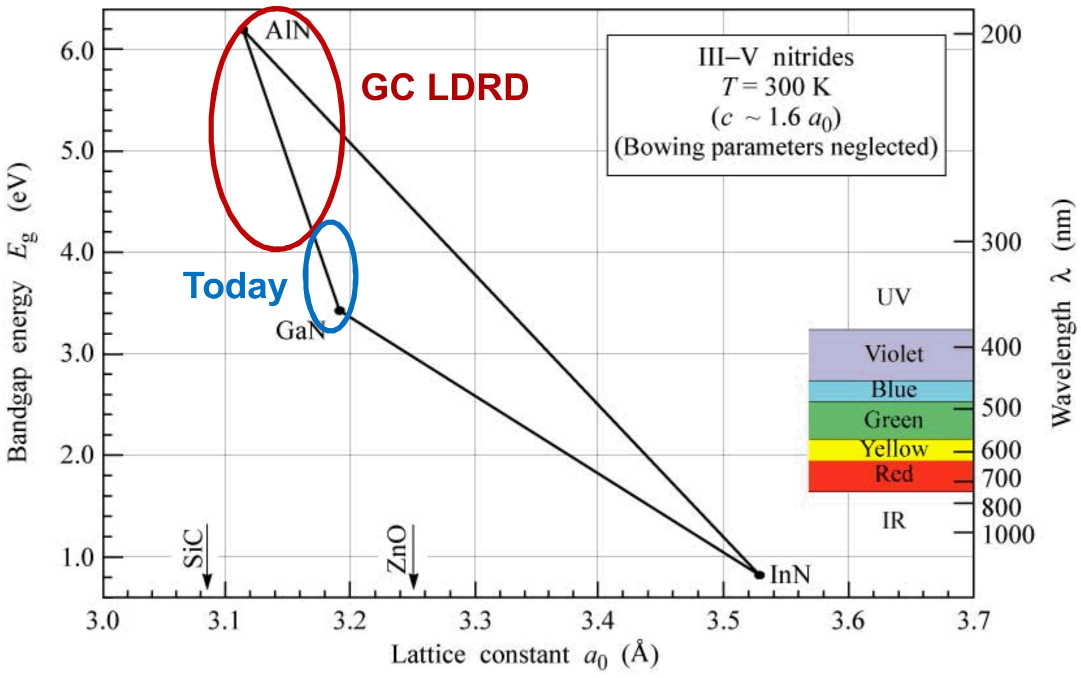
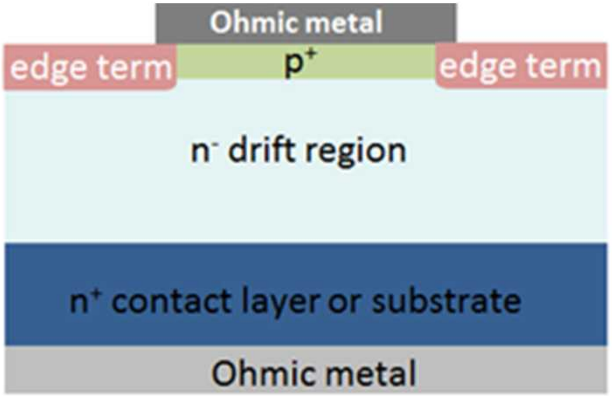


Fig. 12.12. Bandgap energy versus lattice constant of III–V nitride semiconductors at room temperature.

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

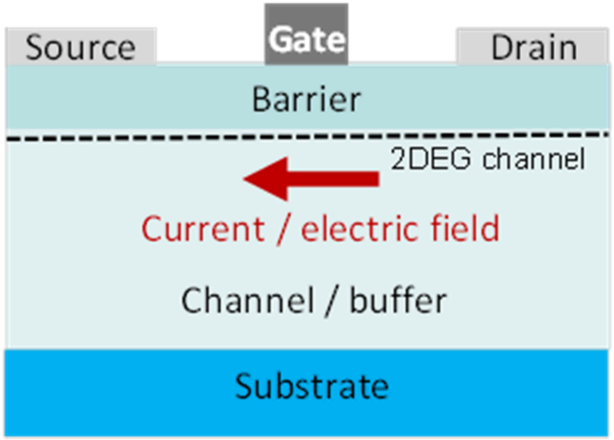
- New high temperature (>1500C) growth chamber with chemically reacting flow modeling
- *AlGaN challenges include:*
  - Dislocations < 1×10^{7} cm^{-2}
  - Doping (n- and p-type)
  - Point defects and compensation
- Epitaxial design for polarization engineering
- Surface physics

Two Target Classes of Power Devices



Vertical device (15 kV)

- **Current flow and voltage drop perpendicular to surface**
- **Architecture is better-suited to high voltage devices**
- **But requires native substrates and low doping**



Lateral device (5 kV)

- **Current flow and voltage drop parallel to surface**
- **Availability of heterostructures is an advantage**
- **Electric field management is challenging**

Sandia and Purdue were Partners in the $210M WAMII Proposal

- **Did not win the competition, but we built good relationships with numerous institutions nationwide**
- **32 Partner Institutions**
- **$145M in matching funds**
- **133 letters of support**

BACKUPS

FY15 Grand Challenge Portfolio

Project	PI/PM	Project Status (as of FY15)	Mission Area Impact	Research Challenge Priority
HAANA-Hardware Acceleration of Adaptive Neural Algorithms	Conrad James, 1714/Kevin Dixon, 5621	New Start	Multi-mission (Cyber, SDP)	BMC (Cyber, Trust)
Revolutionary SWaP – UWBG materials	Bob Kaplar, 1768/Rick Schneider 1120	New Start	Multi-mission (NW, SSEF, LDI)	POD (Rev. Approach Stockpile)
PANTHER – Pattern Analytics	Kristina Czuchlewski, 5316/Bill Hart, 1464	3rd Year	Multi-mission (SDP, GND, NAW, LDI)	Data Science
SECANT – Quantum Key Distribution	Ryan Camacho, 1131/Dan Barton, 1121	2nd Year	Cyber	SEQIS (Trust)
Hostile Environments	Mike Cuneo, 1650/Pat Griffen, 1340	2nd Year	NW	Fusion (Rev. Approach Stockpile)

SEQIS Mission

- Understand and master quantum systems
  - … to manipulate information with greater sensitivity, speed, and security than is possible with classical technologies
  - … with the ultimate goal of developing and prototyping functioning quantum devices and algorithms that run on them that realize transformative advances in information sensing, processing and communications
  - … to address the needs of Sandia's US Government customers.
- Aims
  - Create an ecosystem around existing and future quantum research projects
  - Identify and incubate important technologies
  - Technologies that steward quantum superpositions, entanglement, and coherent operations.

Possible Applications of Q. Computers

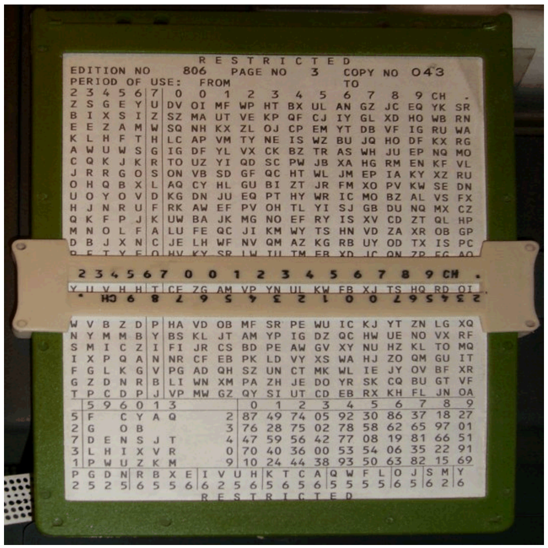
Sandia National Laboratories

- Solution of basics physics problems including:
  - Lattice Quantum Electro/Chromo-Dynamics (QED/QCD)
  - Simulations of Condensed Matter Hamiltonians – High T_c Superconductivity
- Optimization of commercially important problems:
  - Electronic Circuit layout
  - Airline Schedules (efficiency here – even at a fraction of a penny per mile can drive out competitors)
- Accelerated search of large databases (numerous possibilities)
- Simulation of important physical systems:
  - Biological applications: e.g. protein folding & pharmaceutical binding
  - Potential design of new commercial materials with unimagined properties
- Other undreamt of applications – remember:
  - In 1960 nobody believed the laser would be used for eye surgery, welding, …
  - In 1950 nobody guessed the transistor would lead to the information revolution, little own the integrated circuit and personal PC!!!

Protecting Cyberspace through Cryptography

The one-time pad is the gold standard:

One-Time Pad



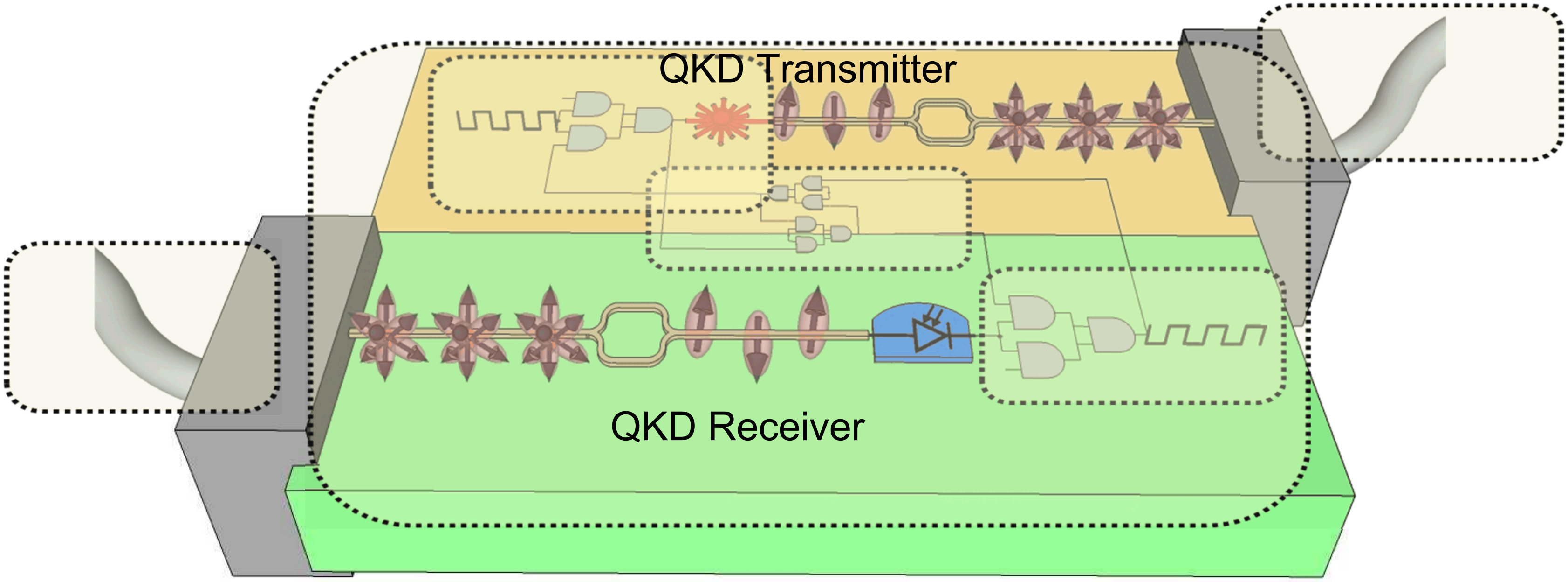
The one-time pad is unbreakable *iff*:

- The key is as long as the encrypted message
- The key is truly random
- The key is never re-used
- The key is kept secret

		H		E		L		L		O	message
	7	(H)	4	(E)	11	(L)	11	(L)	14	(O)	message
+	23	(X)	12	(M)	2	(C)	10	(K)	11	(L)	key
=	30		16		13		21		25		message + key
=	4	(E)	16	(Q)	13	(N)	21	(V)	25	(Z)	message + key (mod 26)
		E		Q		N		V		Z	→ ciphertext

In practice, nearly all modern cryptosystems use alternate encryption methods owing to the difficulty of securely sharing secret keys.

The Vision

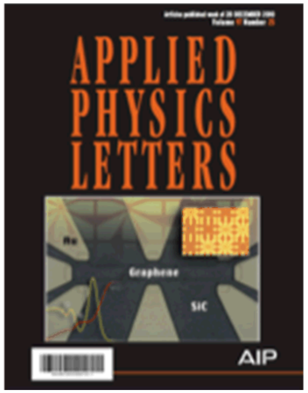


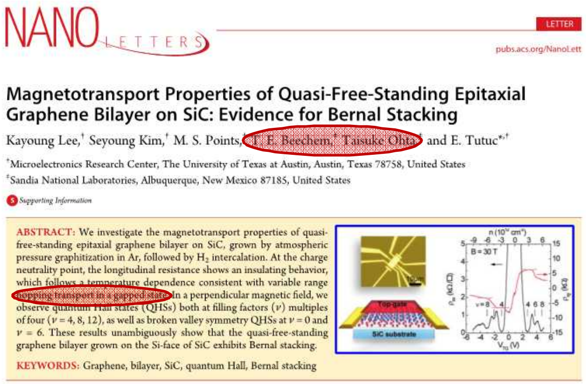
Five Program Thrusts:

1. Network QKD: Security proofs not yet available, systems higher TRL, integration
2. Chipscale Integration / Single Photon Detectors: Dark counts, packaging, protocols
3. Quantum Transmission Link: Different technologies, adaptive setup
4. Continuous Variable Sources: Loss, controller synthesis, on-chip nonlinearities
5. Single Photon Sources: very challenging, lowest TLR, deterministic placement

Approach: Combination of Technologies

Scalability: Wafer-Scale BLG





NANO LETTERS — LETTER

pubs.acs.org/NanoLett

Magnetotransport Properties of Quasi-Free-Standing Epitaxial Graphene Bilayer on SiC: Evidence for Bernal Stacking

Kayoung Lee,[†] Seyoung Kim,[†] M. S. Points,[‡] T. E. Beechem,[‡] Taisuke Ohta,[‡] and E. Tutuc*[,†]

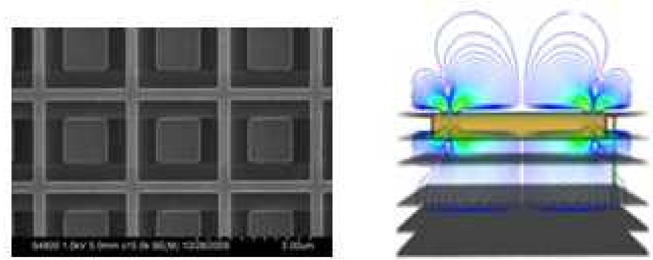
[†]Microelectronics Research Center, The University of Texas at Austin, Austin, Texas 78758, United States
[‡]Sandia National Laboratories, Albuquerque, New Mexico 87185, United States

Supporting Information

ABSTRACT: We investigate the magnetotransport properties of quasi-free-standing epitaxial graphene bilayer on SiC, grown by atmospheric pressure graphitization in Ar, followed by H_2 intercalation. At the charge neutrality point, the longitudinal resistance shows an insulating behavior, which follows a temperature dependence consistent with variable range hopping transport in a gapped state. In a perpendicular magnetic field, we observe quantum Hall states (QHSs) both at filling factors (ν) multiples of four ($\nu = 4, 8, 12$), as well as broken valley symmetry QHSs at $\nu = 0$ and $\nu = 6$. These results unambiguously show that the quasi-free-standing graphene bilayer grown on the Si-face of SiC exhibits Bernal stacking.

KEYWORDS: Graphene, bilayer, SiC, quantum Hall, Bernal stacking

Low Absorption: Nanoantennas



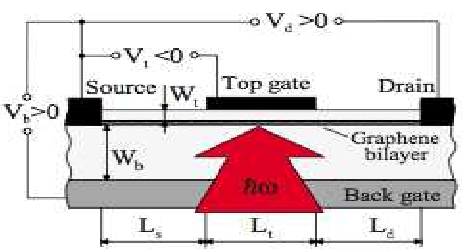
Nanoantenna-Enabled Midwave Infrared Focal Plane Arrays

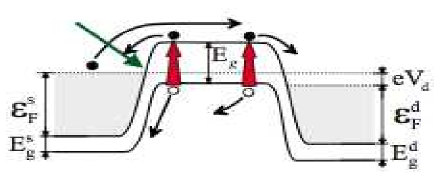
David W. Peters*, Charles M. Reinke, Paul S. Davids, John F. Klem, Darin Leonhardt, Joel R. Wendt, Jin K. Kim, Sally Samora

Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM, USA 87185-1082

Proc. of SPIE Vol. 8353 83533B-1

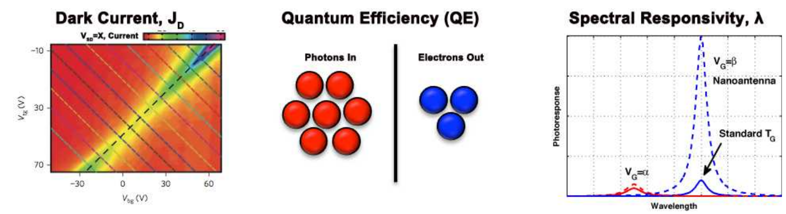
Phenomenon: PhotoFET

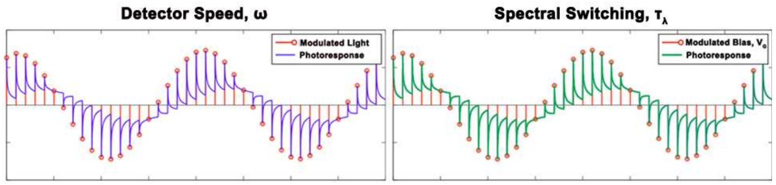




Ryzhii et al. PRB (79) 245311, 2009

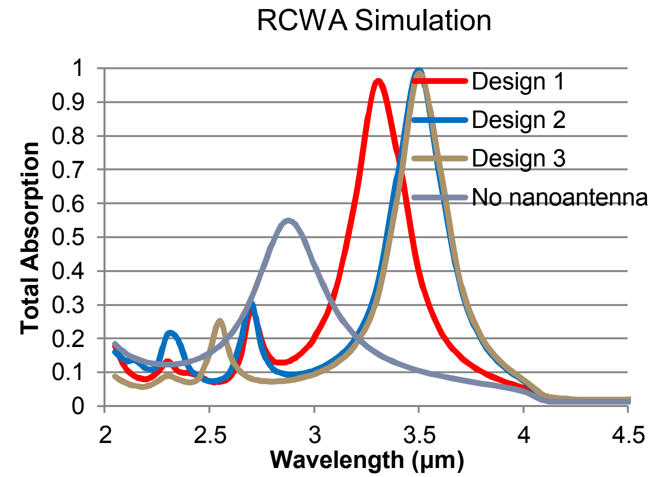
Next Steps: Technology Maturation

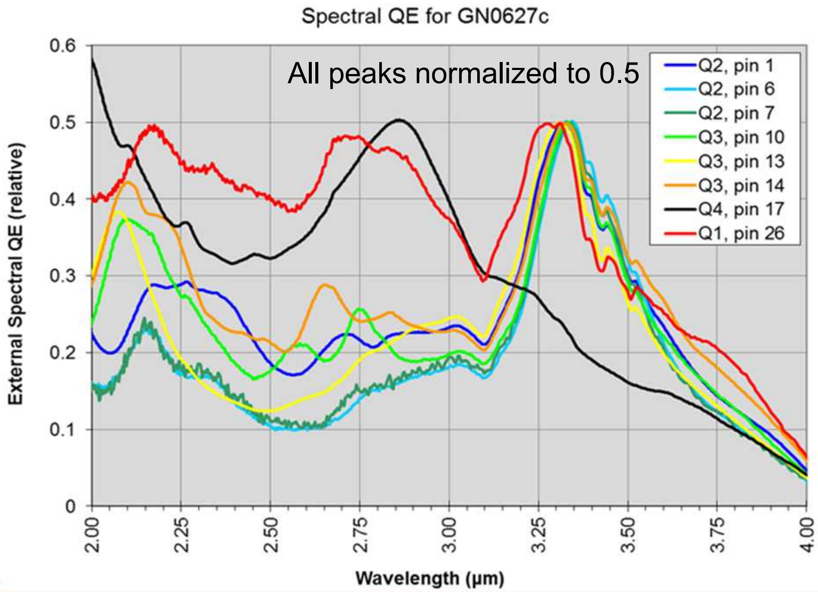


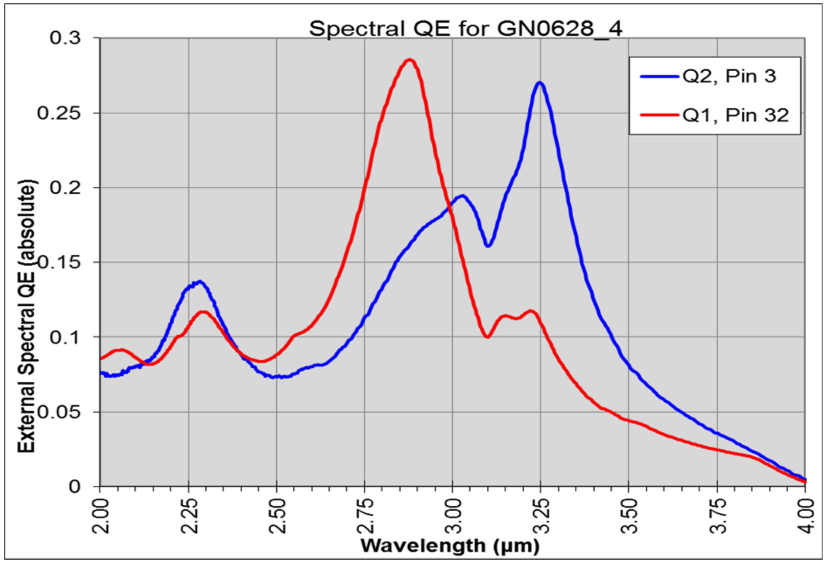


Nanoantenna-Enhanced InAsSb Detector Results

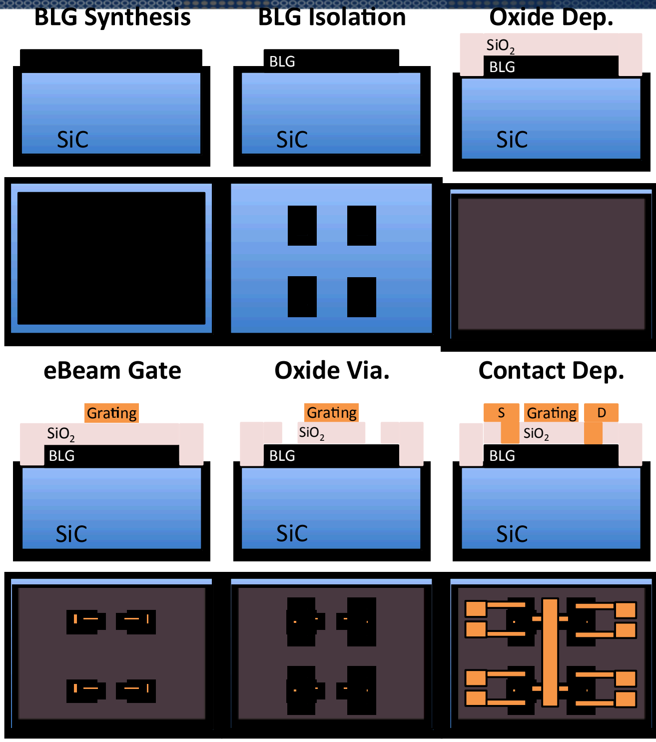
- Epitaxial growth of two designs for integration with NA for test/ evaluation.
- Successful fabrication of detectors with integration of NAs using a flip-chip bonding process and selective substrate removal.
- Room for optimization in modeling and in characterization procedures.

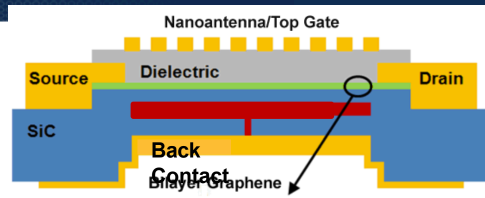


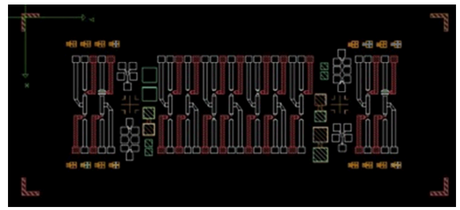


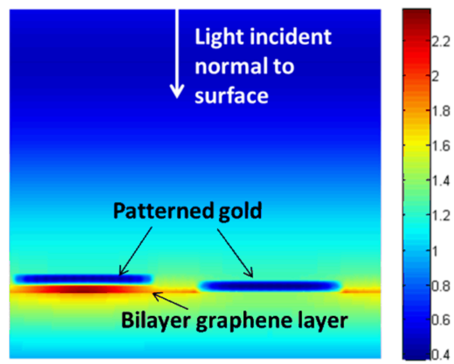


Graphene Detector: Early Fab and Results

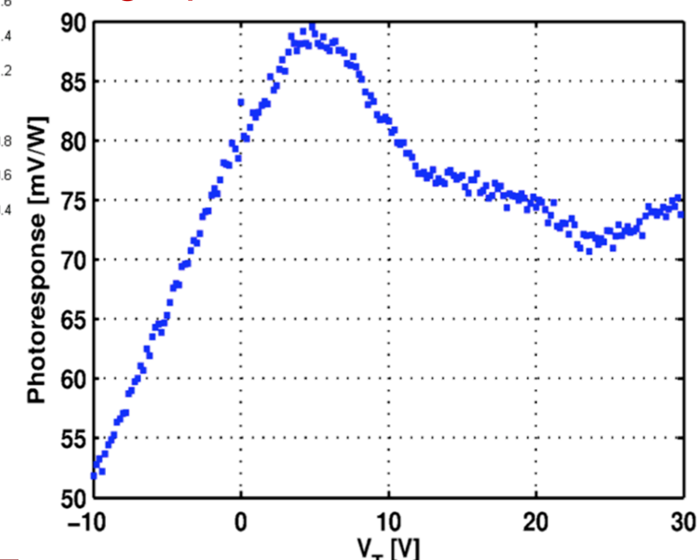








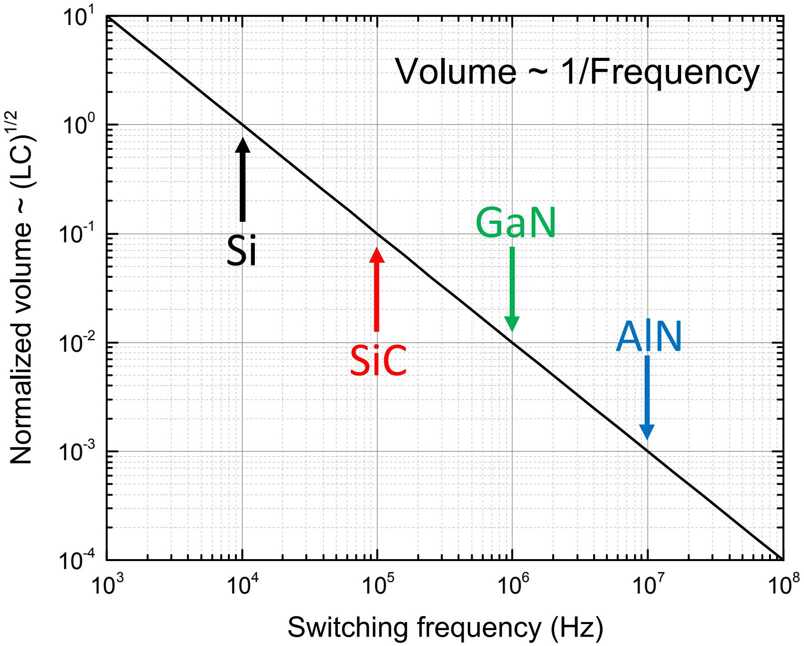
- Scalable fabrication using "standard" techniques
- Multiple operational devices on a chip
- Opens path towards arrays
- Developed an improved understanding of the graphene/SiC interface



Devices show bias dependent tunability with a signal enhanced by nanoantennas.

Dramatic Reduction in Power Converter Volume with Increasing Bandgap

SiC is 10% the volume and weight of Si for equivalent capability (10 kV, 100 A)

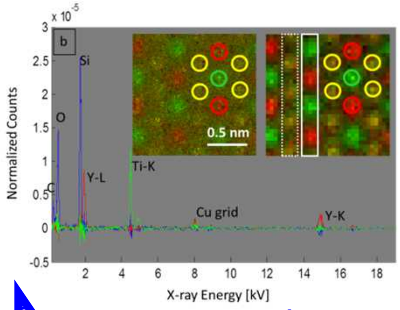


UWBG PE may result in *another* order-of-magnitude SWaP improvement compared to WBG PE

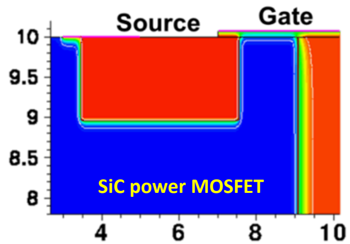
SNL has extensive R&D capabilities in WBGs – materials, devices, and systems

- **60+ years as DOE/NNSA mission lead in electronics**
- **35+ years of compound semiconductor research**
- **20+ years of wide band gap materials & device R&D**
- **Facilities:** ~30,000 ft^2 clean room (MESA facility); Solid-State Lighting EFRC; microgrid testbed (DETL facility); ASIC design & fab; extensive reliability testing and failure analysis

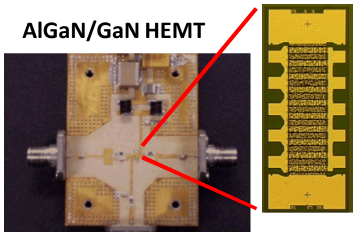
Atomic scale → ***Grid scale***



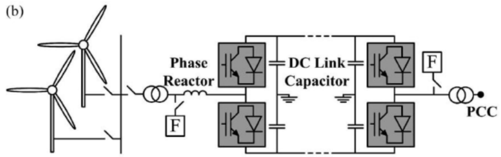
Atomic-resolution characterization



Material and device simulation

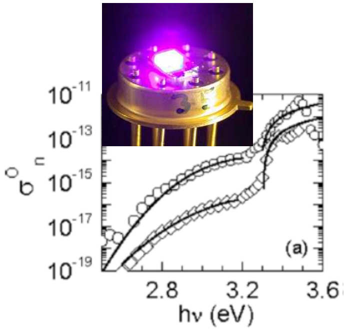


Device fabrication (MESA fab)

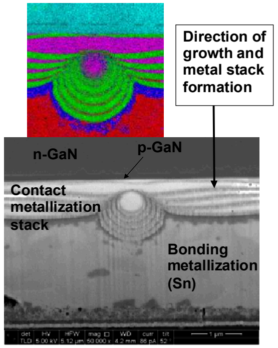


Power circuits and systems

Epitaxial growth



Defect spectroscopy

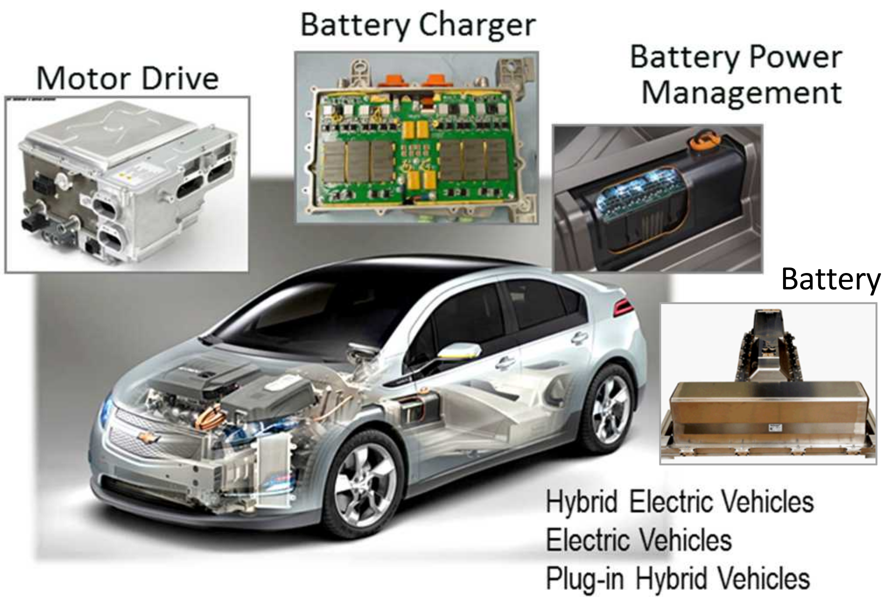


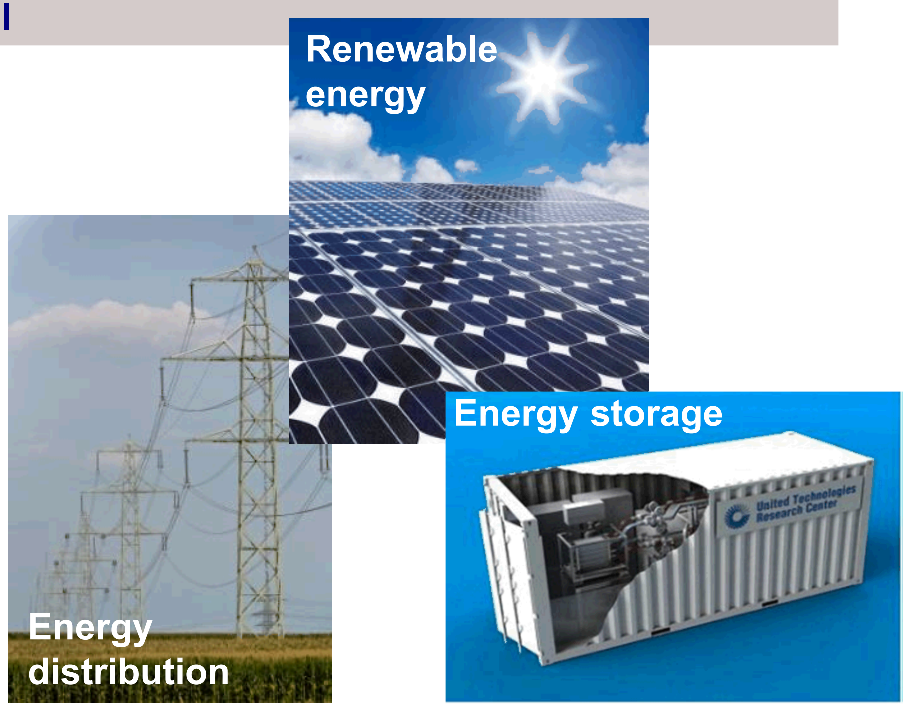
Reliability physics

Grid-level power networks (DETL)

Mission Needs: Civilian Energy

Mission Area	Examples of Specific Areas of Interest and Impact
Secure and Sustainable Energy Future (Energy and Climate)	• **Next-generation grid** (efficiency & intelligence; long & short term storage) • **Transportation sector** (vehicle electrification) • **Solar PV, PV Inverters and Wind Inverters** (clean electricity; key enabling technology for increasing grid renewable generation) • **Building and Industrial efficiency** (variable speed electrical motors for HVAC, elevators, industry) • **Small power supplies and appliances** – computers, solid-state lighting power drivers, appliances • **Electric rail, aeronautical**

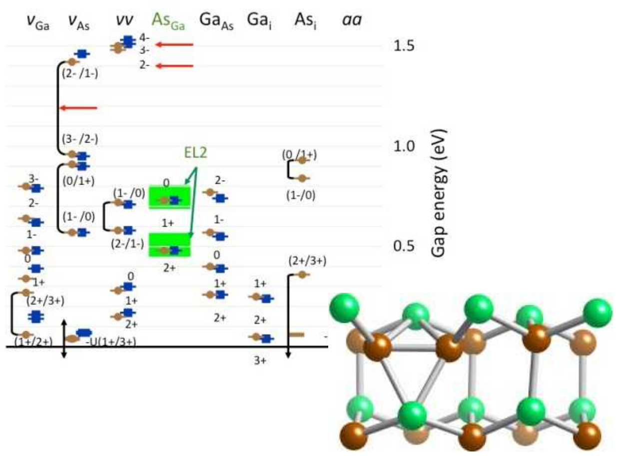




Defect and Radiation Physics: Technical / Science Challenges

Foundation for III-N radiation effects

- Understand physics of radiation-induced defects in $Al_xGa_{1-x}N$ alloys relevant to UWBG PE
- Establish foundation for physics-based atomistic models of UWBG response to radiation



Fundamental materials properties impacting device physics

- Understand two-dimensional electron gas (2DEG) formation in AlGaN heterostructures
- Thermal conductivity of constituent GaN and AlGaN thin films and heterostructures