DoD Advanced Electronics COI

NDIA S&ET Conference

Dr. Gerald M. Borsuk, Chair

13 April 2016

Overview

1) **COI Portfolio Overview**
   - Challenge & Vision
   - Description and taxonomies – Internationally recognized, Context with other COIs
   - COI Membership
   - Overall COI investment profile
2) **Roadmap**
   - COI Technical objectives to meet pervasive and enduring operational/mission needs
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     - Quad
     - Level 1 Roadmap
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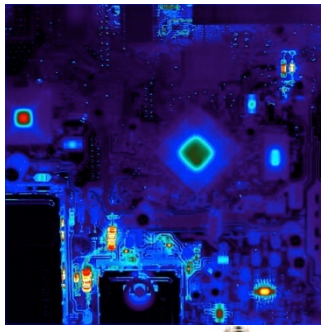
   - Prototyping opportunities
   - New Directions
3) **Recommendations to Address Capability Gaps and Technical Opportunities**
4) **Collaboration**
5) **Summary**

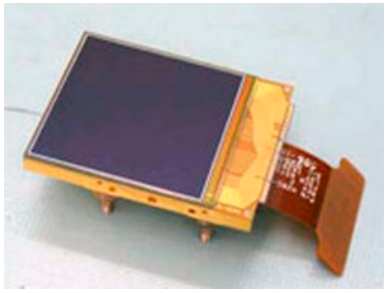
Challenge & Vision

- **Challenge**
  - ***Highly capable electronics are critical but ubiquitous.***
  - ***Ensure DoD has affordable access to leading edge high performance electronics to avoid technology surprise.***

- **Vision**
  - ***Create and exploit S&T advances for leap-ahead capabilities ensuring military superiority in:***
    - **EM Spectrum Warfare from DC to light;**
    - **Advanced signal processing components; and**
    - **Trusted electronic components**

AE COI Portfolio Overview

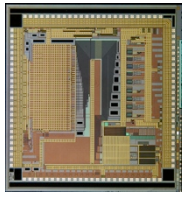




Capabilities:
C4 ISR Cyber EW
Weapons

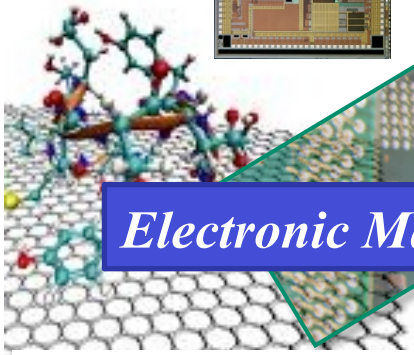
Electronics Integration

EO/IR Components



RF Components

Micro/Nano Electronics



Electronic Materials

Fundamental Research

Trust and Supply Chain Security

Radiation Hardness

Industry

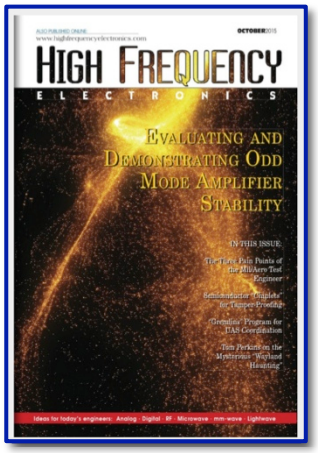
Internationally Recognized S&Es and World Class Facilities

ARL Specialty Electronic Materials & Sensors Cleanroom

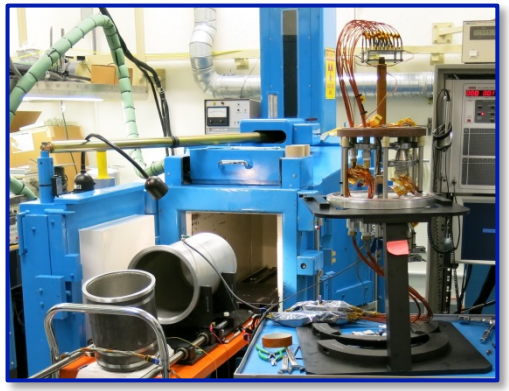
DMEA Ultra-High Resolution X-Ray Analysis/Imaging Tool

Navy SiC Epitaxial Growth System

Air Force Device Research Facility Lithography Bay



Oct 2015 – Cover Story, Mr J. Penn, Army



Drs J. Siddiqui, K. Geoghegan & Mr T. Shepherd Inventors – DMEA Synergistic Rad Testing Techniques

Ka-band amplifier demo of 12 kW peak output power

Drs D. Abe, S. Cooke, B. Levush, & J. Pasour

Bulk (3D) fully dense nanocrystalline materials with unprecedented improved performance

Drs B. Feygelson & J. Wollmershauser

Asst. Sec. of the Navy RD&A Dr. Delores M. Etter Top Scientists and Engineers of the Year Award

Dr J. Hendrickson AFRL Early Career Award Recipient

Advanced Electronics Linkage to other COIs

- *Cost, Size, Weight and Power Consumption Reductions*
- *Trusted and Sustainable Supply Chain – Trustworthy, Cyber-Hard, Tamper-Proof Electronics*
- *Obsolete and Counterfeit Parts*

Electronic Warfare COI	*Sensors and Processing COI*	*C4I COI*	*Cyber COI*	*Autonomy COI*	*Space COI*

- *Wideband/spectrum Access*
- *Reconfigurable and Agile RF Systems*
- *Advanced Sources/Transmitters*
- *Advanced Detectors/Receivers*
- *Compact, Efficient Computation*

- *Assured Communications*
- *On-Board Processing*

- *Rad Hard Electronics and Microsystems*

Energy and Power COI

- *Power Electronics*

Advanced Electronics COI

- *Industrial Base and ManTech*
- *Advanced Materials and Computational Electronics*
- *Beyond Moore's Law*

Materials and Manufacturing Processing COI

BA1 and University Research (not in AE COI)

1b) COI Portfolio Overview - COI Membership

Executive Steering Group

Navy (NRL) - Dr. Gerald M. Borsuk, Chair
Dr. Baruch Levush, Working Group Chair
Mr. Chris Bozada, SME
Army (ARL) - Dr. Phil Perconti
Air Force (AFRL) – Ms. Ruth Moser
DMEA - Mr. Ted Glum
DARPA - Mr. Ellison Urban

Working Group Members

Army - Dr. Romeo DelRosario, Dr. Paul Amirtharaj, and Dr. James Wilson
Navy - Dr. Paul Maki and Dr. Baruch Levush (Chair)
Air Force - Dr. Steve Hary, Ms. Cathy Deardorf, and Mr. Jesse Fanning
DMEA - Mr. Douglas Casanova, Mr. Daniel Marrujo, and Mr. David Pentrack
DTRA - Dr. Bruce Wilson and Mr. John Franco

MITRE Support – Dr. Shamik Das

Technical objectives to meet pervasive and enduring operational/mission needs

The Advanced Electronics COI bridges fundamental research and commercial investments to militarily-critical hardware capability gaps

- Watch and leverage international and commercial technology base (fast follower with investment focus on military-unique needs or opportunities)
- Understand and mitigate globalization trends and technology availability (Avoid technology surprise)
- Enable full use of electromagnetic spectrum in highly contested environments; and counter other's ability to do the same (deliver technology surprise and cost imposition)
- Increased assured communications and on-board processing (basis for autonomy and swarms)
- Extreme reductions of size, weight, power consumption and cost (basis for expendable and attritable)
- Enable open system architectures (provide modularity for low cost upgrades)
- Increased capability to operate in harsh environments, supply chain risk management, and sustainment (includes tamper-proofing technologies)

Some Key Technology Opportunities

- Trustworthy Electronics
- Wide Bandgap Semiconductors
- Reconfigurable, Frequency-Agile Devices and Circuits
- Vacuum Electronics at mm-wave
- 3D Integration
- Integrated Photonic Circuits
- Neuromorphic Electronics
- IC's Beyond Moore's Law
- Quantum Information & Sensing Technologies

AE COI Taxonomy

Taxonomy Thrusts:

Microelectronics & Nanoelectronics,

EO/IR Components,

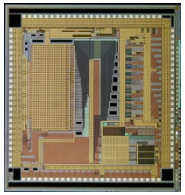
RF Components,

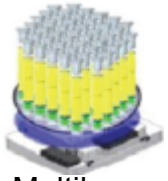
Electronics Integration, and

Electronic Materials

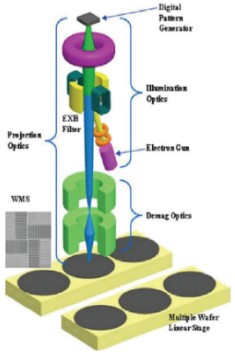
Microelectronics/Nanoelectronics Overview

Circuit Realization At Faster Timescales (CRAFT)



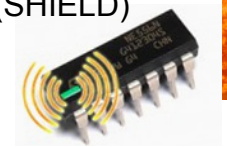


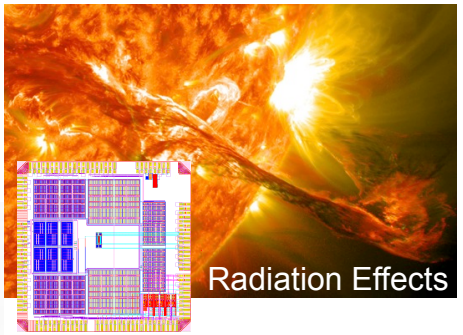
Multibeam



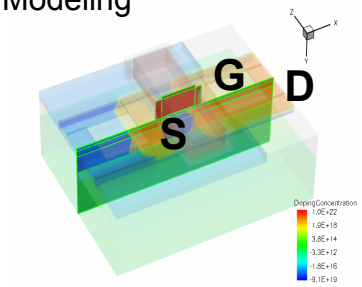
Nanowriter

Supply Chain Hardware Integrity for Electronics Defense (SHIELD)

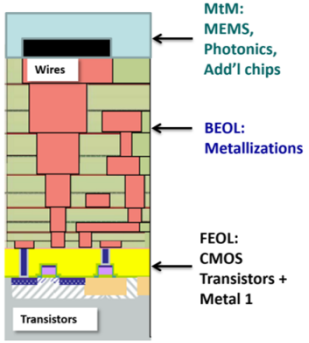


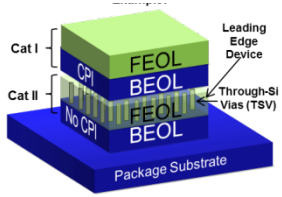


Rad-Hard by Design Modeling

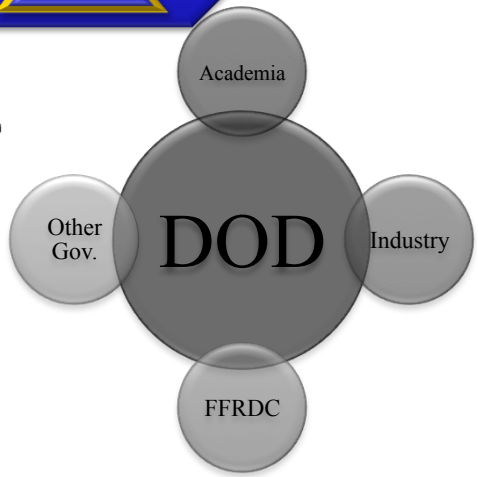


Split-Fabrication Untrusted Foundry Front End of Line (FEOL) with Trusted Foundry Back End of Line (BEOL)





3-Dimensional Integrated Circuit to Enhance Trust



Aggregate solutions of quantitative technologies ensure integrity of ME lifecycle

Microelectronics/Nanoelectronics

Objectives

Create, explore and exploit commercial and emerging concepts, devices, components, and techniques for:

- Beyond silicon and Moore's Law concepts for digital, high frequency and electro-optic devices
- Leading-edge, trusted silicon integrated circuits
- More digital and cognitive apertures

Program Overview

- Advanced application specific integrated circuits
- Trustworthy electronics
- Rad Hard electronics

Key Technical Challenges

- Expensive and long design cycles
- Availability of trusted, high-quality, affordable foundries and packaging houses for SOTA and SOTP technologies
- Ability to model and simulate under operational conditions over time - Computational Electronics
- Exploiting advances in electronic materials and device models

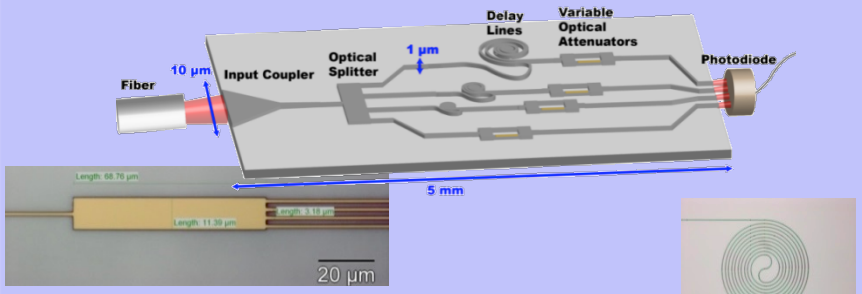
Operational Opportunities

- Absolute trust/verification of critical electronics
- Wide availability of trusted commercial electronics for military critical applications
- Advanced, efficient on-board computation, signal processing and assured communication

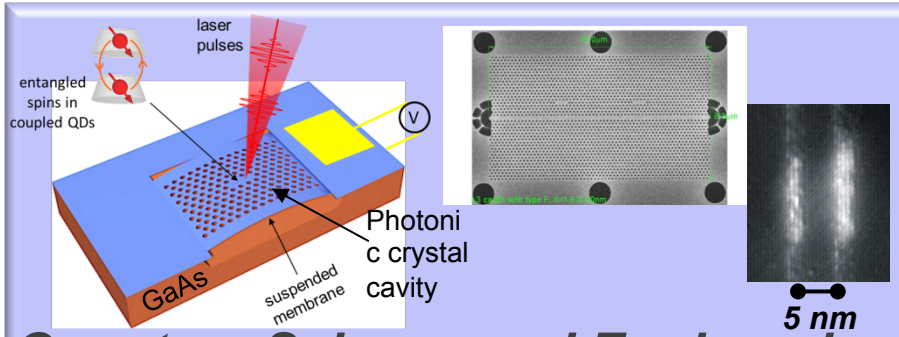
Microelectronics/Nanoelectronics Level 1 Roadmap

	Near-term					Mid-term	Far-term Operational Opportunities
	FY 16	FY 17	FY 18	FY 19	FY 20		
Advanced Application Specific Integrated Circuits *Establish robust, cross-organization R&D, P&Q and CAPEX programs to improve the success of maturation and transition of R&D to the user community.*	Split-Fabrication Multi E-Beam Direct Write Establish alternative SiGe BiCMOS secure process Circuit Realization at Faster Time Scales						Develop alternative fabrication sources for low volume secure manufacturing and support the maturation and transition of R&D to the user community.
Trustworthy Electronics *S&T to develop foundations of trust, rapid and low-cost verification tools, trade space analysis – cost, risk, benefit of trusted, access to advanced electronics and counterfeit detection*	S&T to inform and implement policy Supply Chain Hardware Integrity for Electronics Defense Alternative Manufacturing for Trust Trusted Foundry Transition Advanced Verification/Validation Tools Trust by Design						Access to most advanced technologies to meet mission and security requirements
Rad-Hard Electronics *Assess radiation hardness of critical electronics technology and harden/ mitigate to meet future space electronics needs*	Access to 45/32 nm Partially Depleted Silicon on Insulator Rad Hard by Design of 16/14 nm GaN Microwave Power Amplifier Space Qual Radiation Effects Modeling – Atoms to Parts						Advanced space payloads

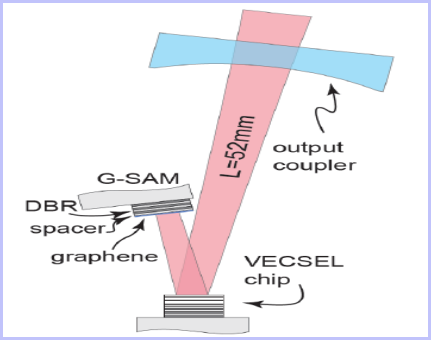
EO/IR Components Overview

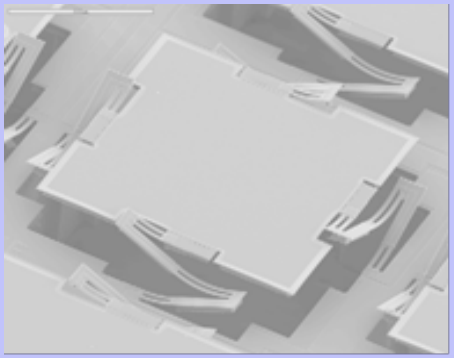


Integrated Photonics



Quantum Science and Engineering





Detectors, Sources and Beam Control

Exploit the ultraviolet through long-wave infrared spectrum through novel concept breakthroughs to improve performance; reduce cost, size, weight and power; increase reliability; and to provide multi-functionality

EO/IR Components Quad

Objectives

Create and explore new concepts, components and techniques for:

- Advanced sources, detectors and optical components for the generation, transmission and detection of ultraviolet through long-wave infrared electromagnetic radiation
- Photonic devices and circuits
- Quantum components for sensing, information and computation
- Advanced read-out integrated circuits (ROICs)

Program Overview

- Integrated Photonics Systems/Circuits
- Quantum Science and Engineering
- Detectors, Sources and Beam Control with Advanced Digital Read-out Integrated circuits (ROICs)

Many interactions/links with the EW and Sensors COIs

Key Technical Challenges

- Ability to model and simulate devices and circuits under operational conditions over time - Computational electronics
- Exploiting advances in electronic materials
- Heterogeneous device integration, fabrication, reliability and robustness

Operational Opportunities

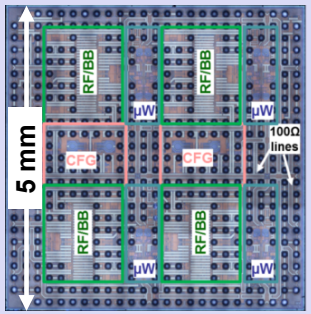
- Improved sensing and signal processing for ISR, tracking and targeting, electronic warfare, information technology and communication systems
- Advanced infrared countermeasures
- Directed energy

EO/IR Components Level 1 Roadmap

	Near-term					Mid-term	Far-term Operational Opportunities
	FY 16	FY 17	FY 18	FY 19	FY 20		
Integrated Photonic Systems/ Circuits *Explore and develop the integration of light and electrons to meet the most challenging performance, size, cost and reliability applications*	AIM Photonics (Manufacturing Innovative Institute)						Capable and self-sustaining US industrial base to produce the most advanced microsystems for military critical weapons
	Tools and Techniques for design and co-simulation						
	S&T for testing and characterization						
	Direct On-chip Digital Optical Synthesis						
	Service Unique IPC Demos						
Quantum Science and Engineering (ARAP) *Collaborative research for scalable quantum network technologies to accelerate critical building blocks for quantum networks*	SiC-based memory						Unprecedented A2/AD capabilities for: ultrasecure comm networks, tunnel detection, PNT, imaging decision-making, and new material simulations
	Ion-Based Memory						
	Compact Atomic Sensor						
	Chip Scale Solid-state Sensor				Q-Network 2-node Demo		
Detectors, Sources and Beam Control *Explore and develop enabling technologies in support of applications driven by EO/IR Electronic Warfare and Reconnaissance, Surveillance, and Targeting*	Laser UV Sources for Tactical Efficient Raman						Low-cost, high-performance, high operating temperature sensors, communications and electronic warfare systems
	Mid-wave to long-wave Infrared laser sources						
	Pixel Network for Dynamic Visualization						
	MWIR/LWIR Multi-color Detectors						
	Advanced Read-out Integrated Circuits and Hybridization						
	Beam Control and Beam Steering						

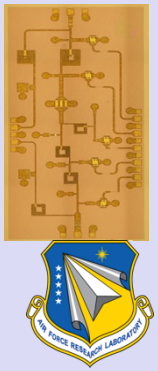
RF Components Overview

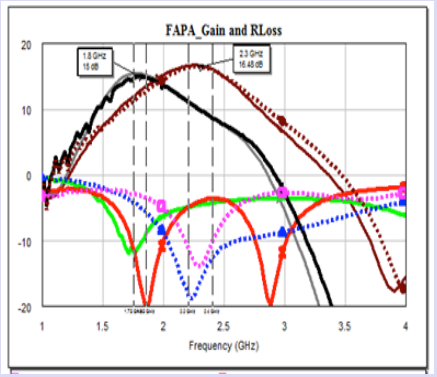
Reconfigurable Adaptive RF Electronics (RARE)



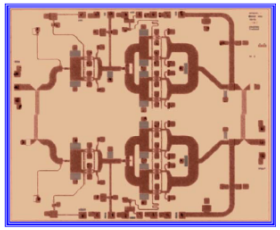
MATRICs V1 Chip

First Ever RF-FPGA

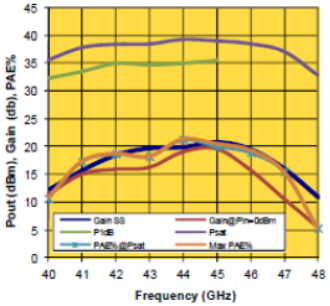


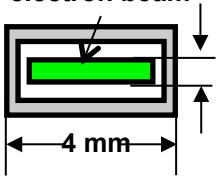


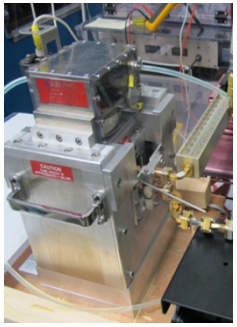
L/S dual band Power Amp

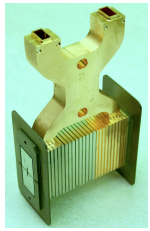


0.2um GaN HEMT







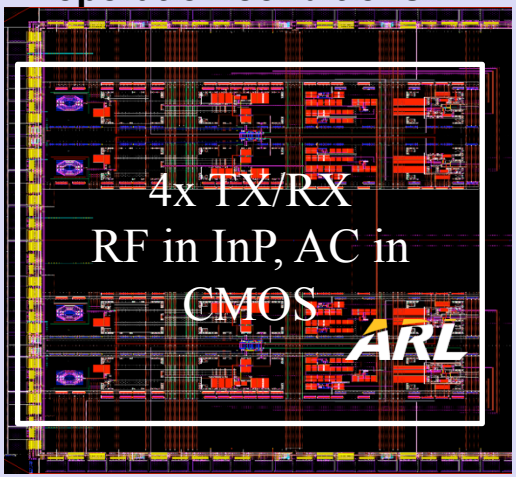


Vacuum Electronic Devices

Ka-band Sheet Beam TWT
~ 11 kW peak RF power at 35 GHz
Power × Bandwidth ~ 6000 W x 5 GHz

Performance beyond Commercial Capability

- Higher Power/Efficiency for Sensing/Countermeasures
- Broad instantaneous bandwidth
- Reliability in extreme operation conditions



Heterogeneous integration for triple band coverage

Enable blue force systems to dominate the RF spectrum by providing unprecedented agility, efficiency, power and spectral coverage across diverse platforms and military operating conditions.

RF Components

Objectives

Create and Explore New Concepts, Components and Techniques for:

- Lightweight, miniature, efficient and affordable wide-bandwidth, high-linearity wide bandgap semiconductor devices/ vacuum power electronics that cover frequencies from ~ 1 MHz to ~10 THz
- Extremely low power devices for mixed signal integrated circuits
- Advanced control components (filters, switches, etc.)
- Advanced computational electromagnetic techniques and methods
- Technologies that are reconfigurable and adaptive – both active and passive

Program Overview

- Device/Component Performance
- Reconfigurable, Adaptive RF Electronics
  - Adaptive RF Technologies
  - Reconfigurable Electronics for Multifunction RF
  - Next Gen Fires
  - Switchless Tunable Filters
- mmW Electronics
  - Vacuum Electronic Devices
  - Solid State Power Amplifier Combining

Key Technical Challenges

- Limited technologies for wideband reconfigurability
- Meeting extreme military operational requirements
- Efficiency, thermal management and performance shortfalls
- Design tools, models and new architectures for bandwidth, efficiency and linearity goals
- High instantaneous spur-free dynamic range
- Bulky, costly and power hungry components

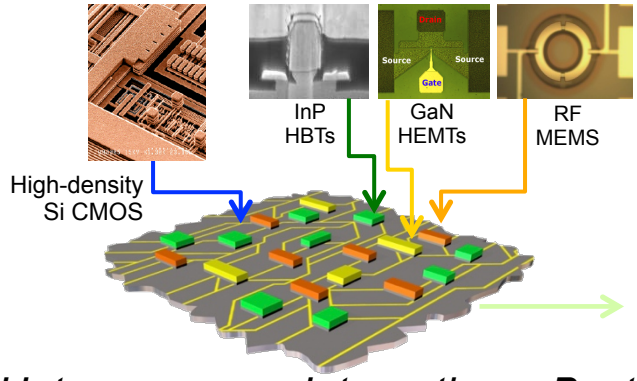
Operational Opportunities

- Next generation cognitive and adaptive sensors and countermeasures
- Improved device reliability and robustness
- Advanced electromagnetic sensor, communication, electronic warfare, imaging and directed energy (high power microwave) systems
- Simultaneous Transmit and Receive

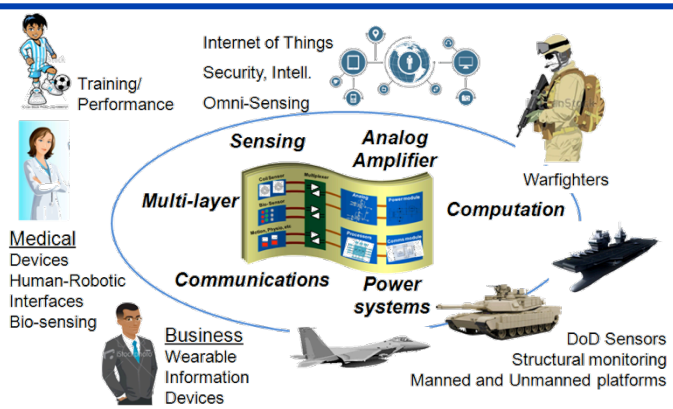
RF Components Level 1 Roadmap

	Near-term					Mid-term	Far-term Operational Opportunities
	FY 16	FY 17	FY 18	FY 19	FY 20		
Device/Component Performance - *High Power RF sensing/ countermeasures* - *High efficiency* - *High linearity* - *Broadband*	High-power Amplifier using Vacuum electronics for Overmatch Capability Energy Efficient Electronics Ga-polar N-polar GaN High-Electron Mobility Transistor Devices for Simultaneous Transmit and Receive						Beyond Si performance enabling DoD systems to dominate the RF spectrum in traditional RF uWave bands and provide operational advantage in emerging mmW bands
Reconfigurable/Adaptable - *Active Supercomponents* - *Tunable filters* - *Low loss/high isolation switches*	Adaptive RF Technology Reconfigurable Electronics for Multifunction Agile RF Next Gen Fires						Cognitive adaptive capabilities to support next generation sensing, EW, communications and cyber in highly dynamic, spectrally-dense and contested environments
mmWave - *Single chip T/R Module* - *Integrated filters/passives* - *High power vacuum devices*	Vacuum Electronic Devices mmW modules Solid State Power Combining at mmW W-Band Satcom Components						LPI Sensing and Communications. Countermeasure capability against emerging mmW threat systems.

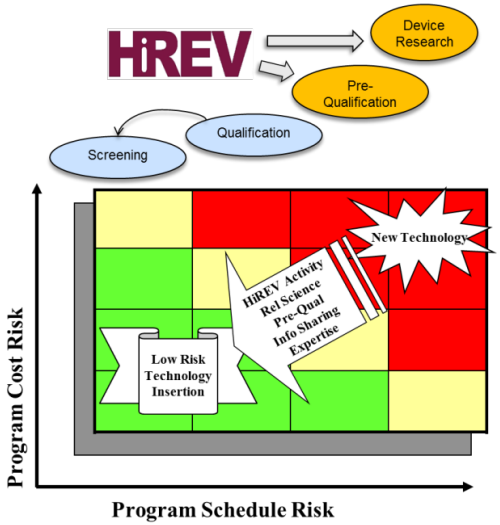
Electronics Integration Overview



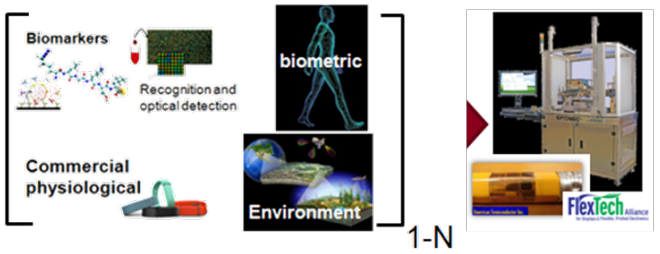
Heterogeneous Integration – Best Junction for the Function



NextFlex – Flexible Electronics Manufacturing Innovative Institute



Tools and Techniques for Rapid and Affordable Reliability Assessment



Multi-Aspect Sensor and Power demonstrator

ARL Unique in the World; 2/3D Packaging capabilities

$$P = \left[U^{*}_{1-N} A.P\right] = \left[\begin{bmatrix} \text{bio-marker} & \text{biometric} \\ \text{physiological} & \text{environment} \end{bmatrix}_{1-N} \times [\text{Platform}]_{1-X}\right] > \sum_{1}^{N} (\text{soldiers})$$

Information Science, Noisy, Fuzzy Data

Continuous Multi-faceted Soldier Characterization for Adaptive Technologies

Electronics Integration

Objectives

Create and explore new concepts, components and techniques for:

- Extreme miniaturization - higher functionality per unit volume
- Lower cost especially for limited production/ volume needs
- High reliability in extreme conditions

Program Overview

- Heterogeneous Integration
- Reliability and Protection
- Flexible Hybrid Electronics/Additive Manufacturing for Electronics
  - Next Flex (Manufacturing Innovative Institute) for Flexible Electronics

Key Technical Challenges

- Heterogeneous integration with intimate integration of digital control and reconfiguration
- Device design, fabrication, reliability and robustness
- Computational electronics or modeling and simulation

Operational Opportunities

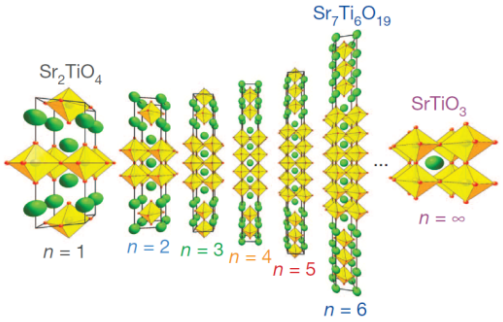
- Operation in harsh environments with superior thermal management for military systems
- Higher performance for size, weight and power constrained platforms
- Higher power density and efficiency at high voltages

Electronics Integration Level 1 Roadmap

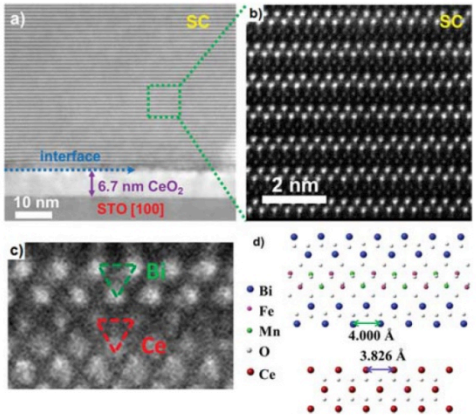
	Near-term					Mid-term	Far-term Operational Opportunities
	FY 16	FY 17	FY 18	FY 19	FY 20		
Heterogeneous Integration *Explore, Develop and Exploit monolithic and highly integrated system in a micropackage integrating the best electronic and optical elements into a single component*	Intrachip Enhanced Cooling Diverse and Heterogeneous Integration Common Heterogeneous Integration and IP Reuse Strategies Integration of 3D Printing and Additive Techniques Service Specific Applications Demonstration						Unprecedented security, miniaturization, performance and reliability for electronics for weapons, ISR, EW and C4I
Reliability and Protection *Understand and develop the S&T to accurately predict electronic lifetime based on the governing physics and chemistry of degradation/failure for a given application and environment. Provide the means to protect function and prevent reverse engineering*	High Reliability Electronics Virtual Center GaN Amplifier Assessment for Space Application Advanced CMOS 16/14 nm Assessment for Military Application Physics and Chemistry-based Degradation Model Development Heterogeneous Integration/Flexible Hybrid Electronics Evaluation Tamper Event Monitoring Secure Processing						Government-led capability to assess and evaluate new technologies and legacy/ obsolete sustainment issues to accelerate the insertion of new breakthroughs and to provide affordable techniques to protect US military critical technologies
Flexible Hybrid Electronics/ Additive Manufacturing *Exploit, develop and demonstrate: materials scale-up, thinned device processing, device/sensor integrated printing and packaging and design*	Service Specific Applications Demonstration Next Flex						Industrial base to provide human performance enhancement technologies; conformal-soldier-borne sensors and ruggedized-individual soldier information systems

Electronic Materials Overview

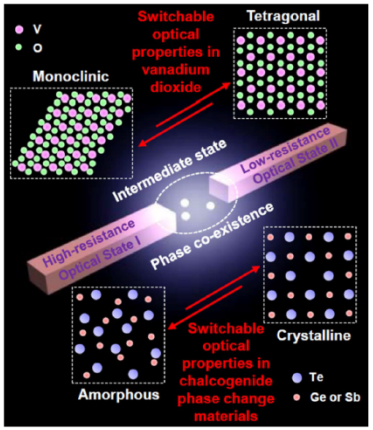
Complex Oxide Heterostructure Electronics



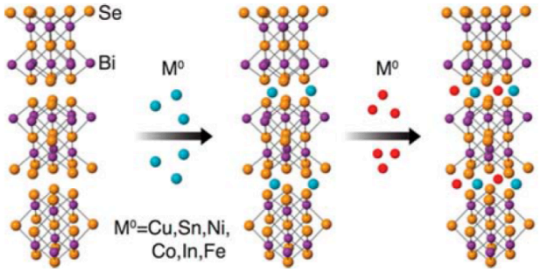
Multiferroic Self-assembled $Be_3Fe_2Mn_2O_x$ supercell



Phase-Change Materials

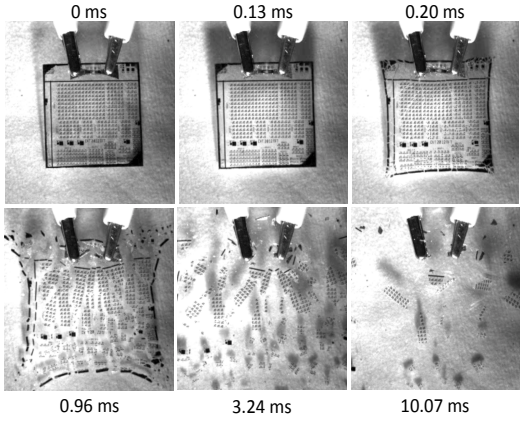


Advanced 2D Materials: Intercalated Bi_2Se_3



Enabling Future Breakthrough Capabilities

Vanishing Programmable Resources



Electronics Materials

Objectives

Create and Explore New Materials:

- With tailored responses: metamaterials, multi-ferroics, oxides and phase-change materials
- For infrared focal plane arrays, quantum optics, mmW RF photonics
- For novel low power, high-speed devices for heterogeneous integration with silicon
- For leading edge trusted silicon integrated circuits
- For high current high density cathodes

Program Overview

- Significant Leverage with BA1/University Research – including DARPA STARnet Program
- Significant cross-COI efforts with Materials and Manufacturing Processes COI
- Vanishing Programmable Resources

Key Technical Challenges

- Lack of high quality growth techniques and characterization methods
- Immature bottom-up and top-down assembly techniques for nanoelectronic materials
- Ability to model and simulate materials under operational conditions over time - Computational Electronics

Operational Opportunities

- Advanced sensing and imaging
- Generation after next electronic warfare
- Military ready information technology
- Assured and protected communication

Electronics Materials Level 1 Roadmap

	Near-term					Mid-term	Far-term Operational Opportunities
	FY 16	FY 17	FY 18	FY 19	FY 20		
Next Generation Materials for Advanced Electronics *Develop, exploit and mature novel materials for next generation devices and highly integrated microsystems*	Vanishing Programmable Resources Complex Oxide Heterostructure Electronics Phase-Change Materials Advanced 2D Materials Multiferroic Self-Assembled Supercell Basic Research (BA1 Funded) (Not binned to COI)						Breakthrough performance for generation after next DoD systems

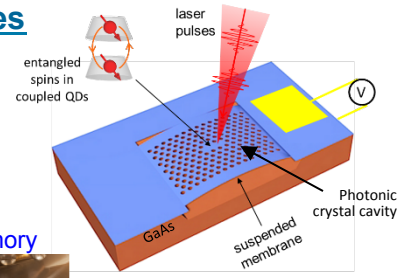
ARAP Quantum Science and Engineering Program

Objectives

- Develop cohesive tri-service capabilities needed to define quantum applica-tions and shape their future for DoD
- Accelerate critical technologies for quantum networks and sensors that enable early prototyping opportunities

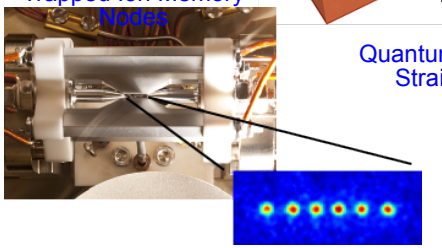
Potential Prototyping Opportunities

3d printed mockup of next gen vacuum cell for dual atom accelerometer and gyroscope prototype



Quantum Dot Based Strain Sensor

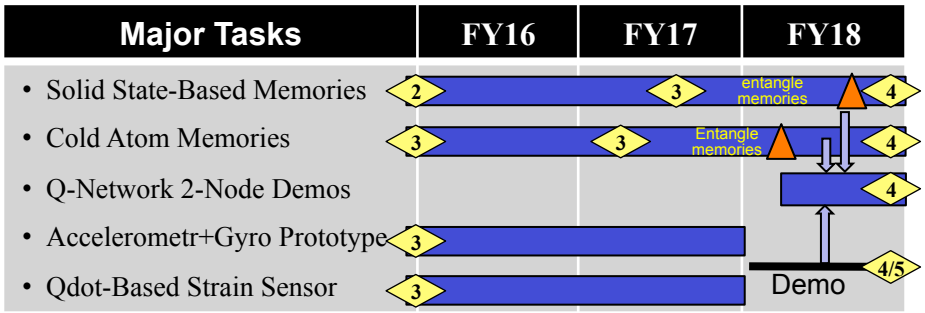
Trapped Ion Memory Nodes



Approach

- Develop solid state and cold atom quantum memory nodes
- Develop sources, detectors and integrated photonics needed to make practical, scalable networks
- Entangle two similar memory nodes at each service lab
- Miniaturize atom-based accelerometer and gyro for near-term prototype and follow-on flight test

Schedule



Legend: Key event # TRL

Changing Directions

- Trustworthy Electronics – National review, assessment and planning resulting in a highly coordinated response and division of labor
  - OSD Seedling on establishing joint cloud based integrated circuit capability
  - Tri-service R&D planning for Joint Federated Assurance Center (JFAC) Hardware

- Prior Tri-Service studies on advanced electronics for EW led to joint portfolio decisions:
  - Navy emphasizing mm-Wave for EW (joint with EW COI)
  - AF starting a Reconfigurable and Agile RF Front End initiative (joint with EW COI)
  - Joint development and leadership of the Integrated Photonic Circuit Institute (also joint with MMP COI)

Technical Opportunities

Lead

– Trustworthy Electronics – Increased emphasis and refinement of joint activity through continued funding to address S&T

– Next Generation Wide Bandgap Semiconductors – Capture untapped theoretical power, efficiency, frequency, bandwidth and linearity gains

– Reconfigurable, Frequency Agile Devices and Circuits – tunable multifunctional devices, phase change materials, and tunable metamaterial-based circuits

Leverage (Fast Follower)

– Commercial 3D Integrated Circuit Technologies – for critical military applications

– Neuroelectric Devices – devices that perform electronic functions and biomimetics for autonomous systems

Watch

– Beyond Moore's Law – Understand commercial drivers and influence academic approaches in emerging material, devices and architectures

Collaboration & Out Reach Within DoD

- Annual meeting of AE COI SMEs/Leadership at GoMACTech (Government Microcircuit Application and Critical Technologies Conference)
- The evolution Tri-Service advanced components for electronic warfare studies into joint portfolio decisions:
  - Navy emphasizing mm-Wave for EW (joint with EW COI)
  - AF starting a Reconfigurable and Agile RF Front End initiative (joint with EW COI)
  - Joint development and leadership of the Integrated Photonic Circuit Institute (also joint with MMP COI)
- Successful Joint Quantum Sciences and Engineering ARAP initiative
- Successful joint COI Seedling - DOD-Wide Cloud-based Collaborative Silicon Microelectronics Design
- Successful Foreign Technology Comparative Testing on commercial GaN amplifiers
- Joint discussions and plans for the way-ahead on trusted and trustworthy electronics including obsolescence and supply chain issues

Collaboration & Out Reach External to DoD

- NDIA SE&T Conference Engagement
- Defense Innovation Market Place
- GOMACTech Annual Conference

Summary

The AE COI is a critical foundational element of DoD's S&T Enterprise leading the understanding, exploitation, and transition of breakthroughs in materials, devices, circuits and highly integrated microsystems for next generation electronic systems capabilities

- Critical linkages to other COIs – many unintended consequences when one COI has funding and emphasis changes
- Primary driver for Increased performance, miniaturization, multi-functionality and efficiency
- High potential to lower development, acquisition and life cycle costs
- DoD lead on the preservation and evaluation of the electronics supply chain and sustainment S&T in military relevant electronics technologies.