Materials Research Overview

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Materials Research

Fundamental research for scientific discovery and innovation to provide superior materials and devices needed for lasting strategic land power dominance

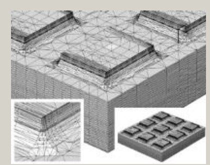
Manufacturing Science
- Advanced & Additive Manufacturing
- Polymer Coatings
- Corrosion & Fatigue
- Energy Coupled-to-Matter

Biological and Bio-inspired
- Materials from Biology
- Technology from Biological Systems
- Characterization and Sensors

Structural
- Advanced Platform
- Integrated Structural & Energy

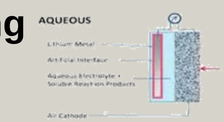
Photonics
- Imaging Sensors & Optics
- Chemical Specific Sensing
- Sensor Protection
- UV Optoelectronic
- High Energy & Tactical Laser
- Quantum Information Science

Electronics
- Nano & 2D
- MEMS
- Flexible & Conformable
- Energy Efficient
- RF Active & Passive



High Strain Rate & Ballistics
- Lightweight & Specialty Metals
- Ceramics & Transparent
- Fabrics & Wearables
- Energy Absorbing
- Composites & Hybrid
- Penetrator & Warhead
- Advanced Mechanics of Materials

Energy & Power
- Energy Storage
- Power Generation & Energy Harvesting
- Fuel Cell
- Thermal Science



Initial ARL West Materials Research focus:
Energy efficient electronics and semiconductor modeling

Materials Research: decrease the Size, Weight, Power & Cost of Army technology; reduce logistics burden and enhance survivability, lethality & mobility

Materials for Soldier and Platform Power Systems – Power generation and storage technologies that simultaneously reduce hazards, the logistics tail, and the burden on the Soldier while increasing mission time and effectiveness

Energy-Efficient Electronics and Photonics – Novel materials to reduce the power demand of future Soldier systems

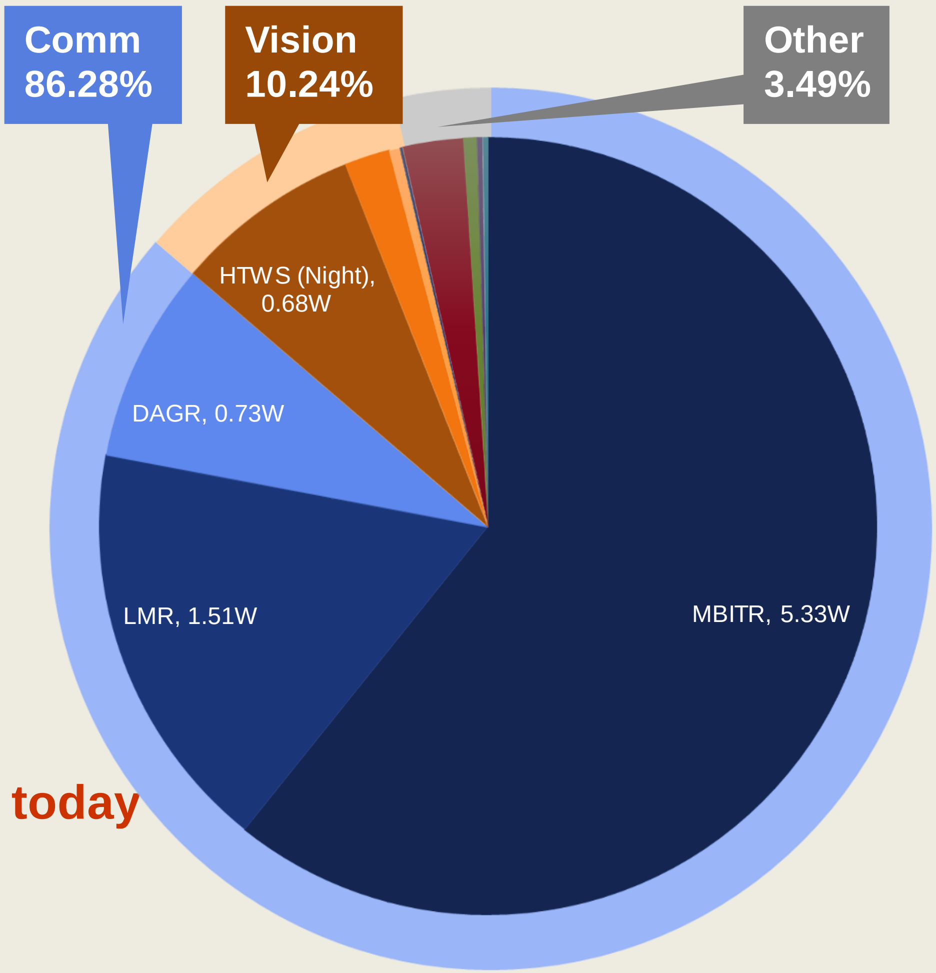
Agile Expedient Manufacturing – Rapid, adaptable production of consumable parts through development of new synthesis and processing capabilities

Quantum Sciences – Materials to exploit quantum phenomena to enable exponential increases in capabilities for command, control, communications, intelligence, surveillance, & reconnaissance

Energy-Coupled-to-Matter for Responsive Materials – Application of high energy fields during materials processing to beneficially alter the resulting material

Lightweight Materials for Army Platforms – Lightweight materials that are stronger than their conventional counterparts to reduce the logistics tail while providing better performance

The Soldier Power Problem



7 types, 70 batteries, 16 pounds

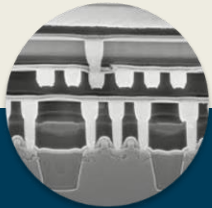
9.16 watts average for 72 hour mission today

Weight is constrained but additional warfighting capabilities are in demand

Efficiency must improve

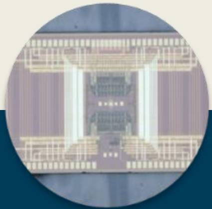
Energy Efficiency Program Overview

Reduce the battery load on the Soldier by addressing the demand side of the electronics that will underpin the Soldier’s future communications, computing, and sensing gear.



Improved materials and devices

- III-V + CMOS
- 2D materials (MoS2)
- Phase change (GeTe)



Circuits and systems

- All CMOS Front End
- Ultra-Low-Power FPGA
- RF Data Converters
- GeTe RF switches

Heterogeneous integration of efficient devices

- InP on Si
- FPGA-FLEX-ASICs Stack
- GaN on Si

Waveforms and signal processing

- Embedded Processing
- Digital Waveforms
- Waveform parsing to accelerator chiplets

Program goals require improvements across the board

ULP-FPGA Impact

Problem: It now takes more energy to move data than to generate it.

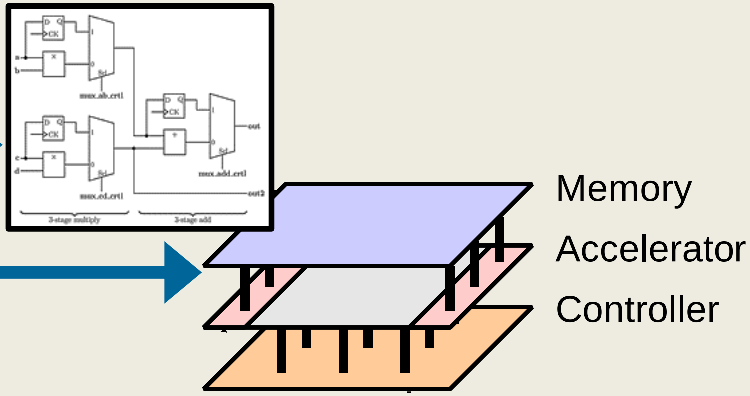
Approach: Increase efficiency by stacking accelerators, FPGAs, & memory.

4,096 point Fast Fourier Transform computation example:

	Tech. node	Power	Efficiency (GFLOPs/W)	Comparison	
				Power	Eff.
1x **ULP-FPGA**[2]	65 nm	0.3 W	28.9	**1x**	**1x**
14x **Virtex-5**[1] **(Convey HC-1)**	65 nm	392 W	0.4	**1307x**	**72x**
3x **Virtex-6**[1] **(Pico M-503)**	45 nm	37 W	1.4	**123x**	**21x**

Improvements from:

- **Dedicated flexible accelerators**
- **Tight memory integration with application specific memory controller**



1. K. S. P. Pereira, "Characterization of FPGA-based high performance computers," Master's thesis, Virginia Polytechnic Institute and State University, 2011.
2. P. Gadfort, A. Dasu, et. al. "A Power Efficient Reconfigurable System-in-Stack: 3D Integration of Accelerators, FPGAs, and DRAM," IEEE SOCC 2014.

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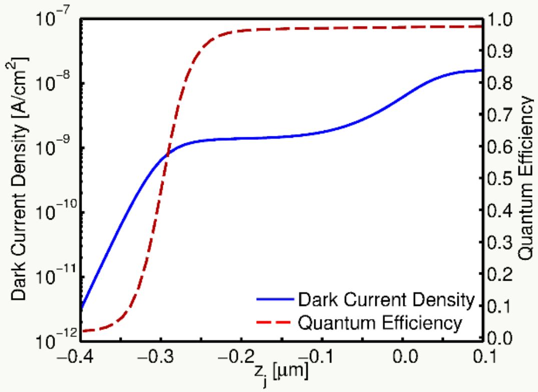
Open Campus Center for Semiconductor Materials Modeling

ARL

A virtual center to bring together government, academia, and industry from across the country to push semiconductor research forward to benefit all partners



Example

Numerically modeled the dark current density and quantum efficiency of a single P^+-on-n HgCdTe pixel versus junction depth z.

Schuster *et al*, Proc. SPIE 9609 (2015)

Schuster *et al*, Appl. Phys. Lett., 118 (2015)

- **Start with HgCdTe: modeling, growth, and characterization from materials to devices to focal-plane arrays**
- **Expand into other IR materials**
- **Broaden scope to other material systems**
- **Share Computational Resources**
  - Pooling of computational tools and resources, (i.e. DoD HPC)
  - Streamlined access to DoD HPC – hours free to ARL collaborators
  - Modeling software: VASP (DFT) for Material Modeling, ANSYS, etc.
- **Establishing virtual center with presence at ARL West**

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From Atoms to MTF:
Multi-Scale IR Detector Development Started

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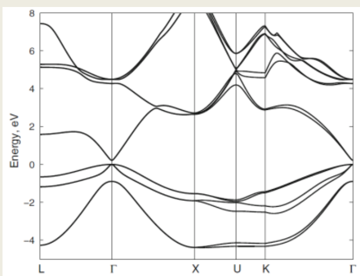
Models can be used stand-alone or to bridge scales.
Parameters extracted at each level become inputs for next level.

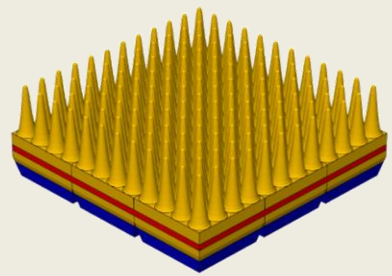
Material Modeling | **Device Modeling** | **System Modeling**

Increasing length scale from atoms-to-systems

1 – 50 Å | **1 – 500 nm** | **100 nm – 10 μm** | **5 – 50 μm** | **1 – 1000 mm**

Feedback to earlier levels for validation





Material Characteristics:
- Properties
- Carrier Recombination
- Transport Phenomena

Device/Array Performance:
- Geometrical effects
- J(V), SR, QE, MTF
- Crosstalk
- Array MTF

System Performance:
- Sensitivity
- Dynamic Range
- Resolution (MTF from detector/lenses, etc.)

The Center will develop new and leverage existing models at every scale.
Validate performance through growth, processing, and characterization

Leveraging the combined capabilities of government, academia, and industry in a collaborative fashion will accelerate semiconductor research to the benefit of all partners

Summary

ARL Materials Campaign is pursuing fundamental research for scientific discovery and innovation to provide superior materials and devices needed for lasting strategic land power dominance

To that end, ARL seeks collaboration with West Coast partners to expand research efforts in:

- **Embedded signal processing**
- **Energy-efficient electronics**
- **Multiscale modeling of semiconductor materials and devices**