USD(R&E)

Basic Research in Microelectronics

Department of Defense Basic Research Office

SLIDES ONLY

NO SCRIPT PROVIDED

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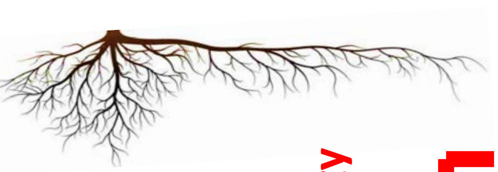
Outline

1. Basic Research Overview
2. Basic Research Investments in Microelectronics
3. The Future of Basic Research in Microelectronics
4. Basic Research and the Microelectronic Workforce

DoD Definition of Basic Research

DoD policy states that basic research is the *"systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts…"*

DoD's Research, Development, Test, and Evaluation (RDT&E) Structure



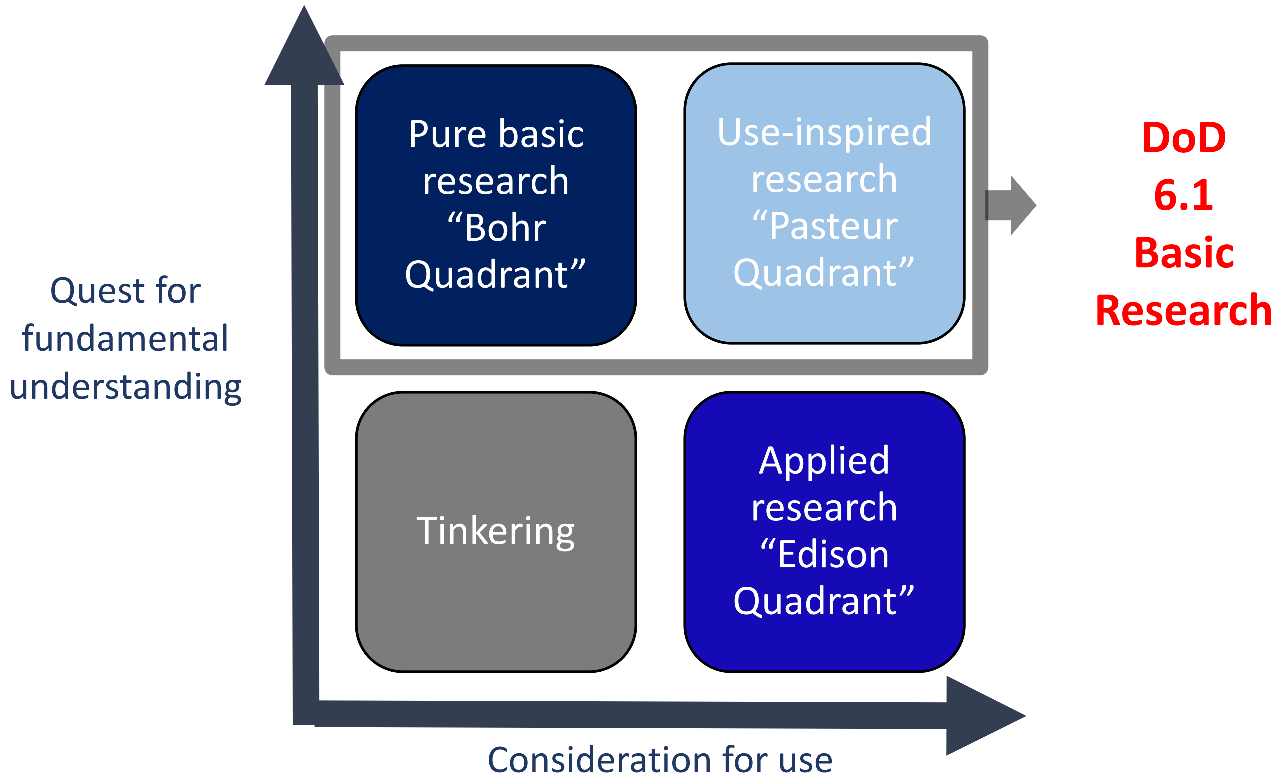
- 6.7 Operational Systems Development
- 6.6 RDT&E Management Support
- 6.5 System Development and Demonstration
- 6.4 Advanced Component Development Prototypes

Science and Technology Budget

- 6.3 Advanced Technology Development
- 6.2 Applied Research
- 6.1 Basic Research

The entire RDT(&E) budget ranges from 6.1 to 6.7. The S&T budget is 6.1-6.3.

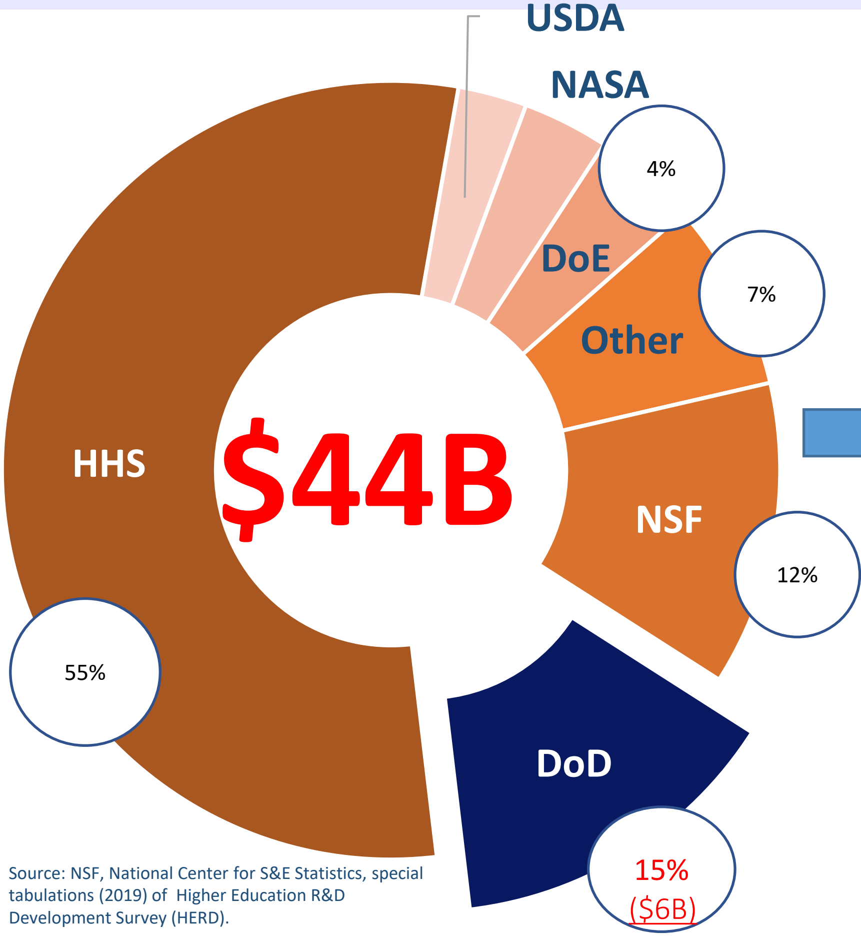
Why DoD Funds Basic Research



Donald Stokes: 'Pasteur's Quadrant'

Federal Academic R&D Expenditures across the USG

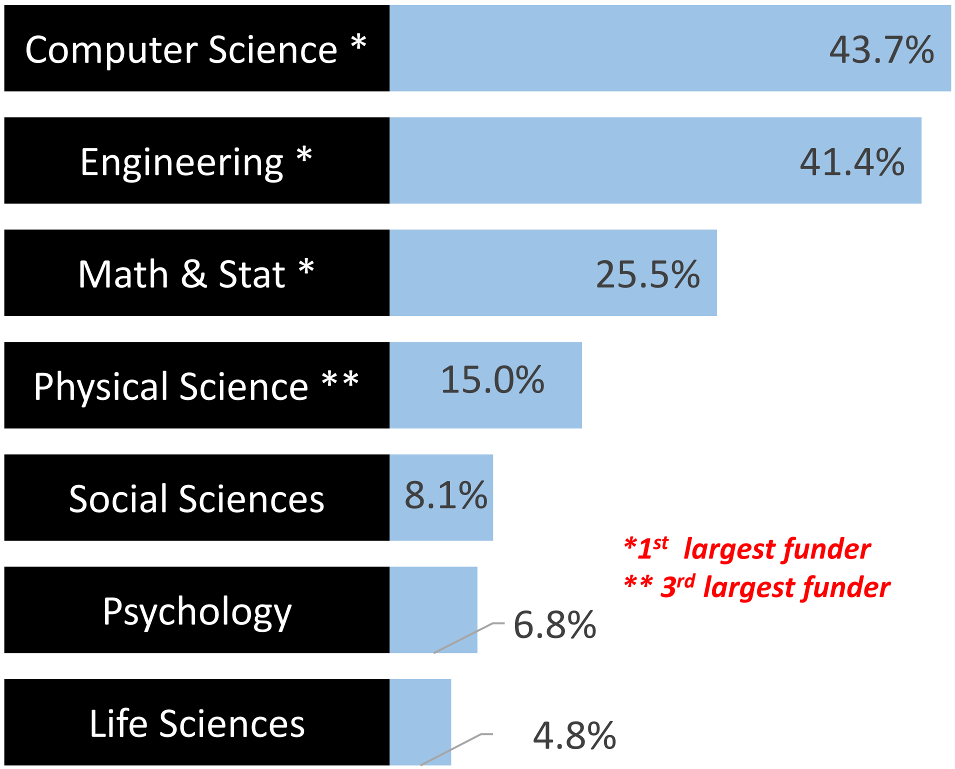
Academic R&D Expenditures by Federal Agency (2019)



Source: NSF, National Center for S&E Statistics, special tabulations (2019) of Higher Education R&D Development Survey (HERD).

Top Field Areas *funded by DoD (out of entire $44 B budget)*

Major funder of basic research in math, physics, and engineering

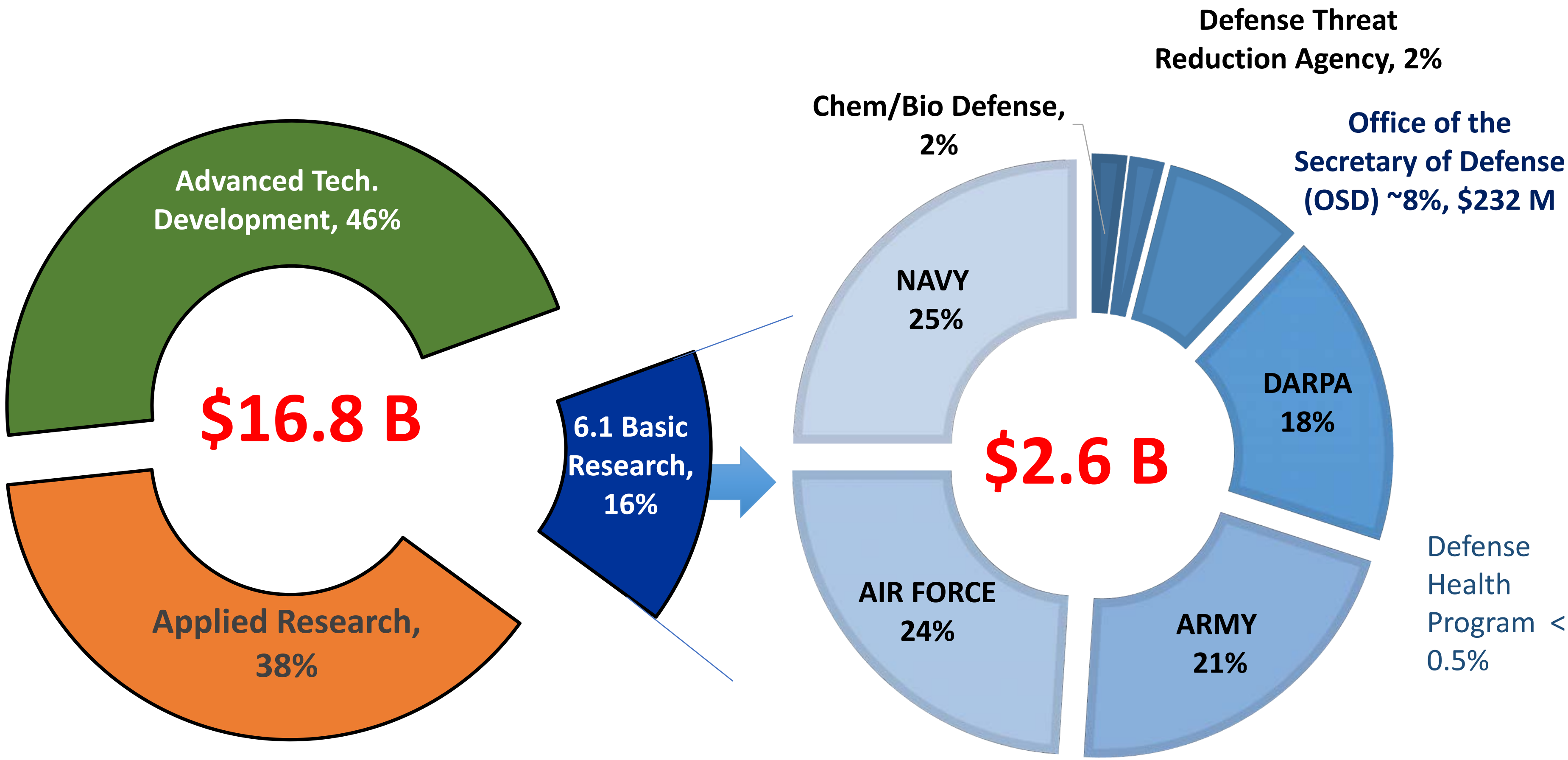


In 2019, DoD had the second largest Academic R&D Expenditures and prioritized funding areas like math and physical sciences.

Funding across the DoD Basic Research Enterprise

DoD S&T Budget (6.1-6.3)

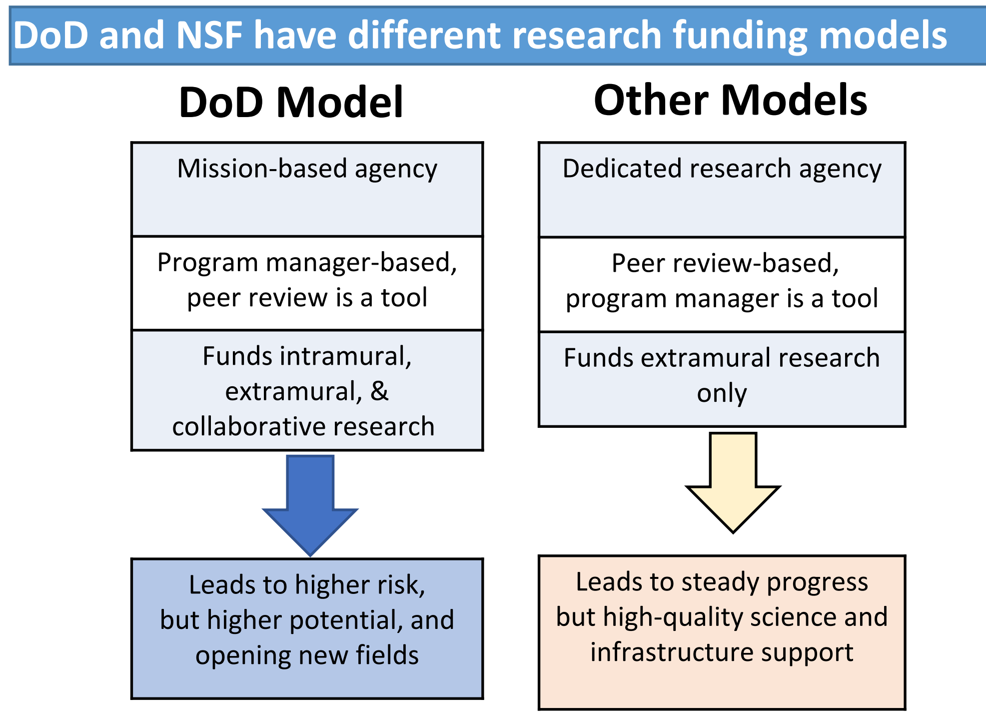
DoD Basic Research Budget (6.1)



DoD's S&T Budget (6.1-6.3) is $16.8 B. Basic Research (6.1) primarily funds extramural programs (over two-thirds). Some Applied Research (6.2) funds are also allocated for academia through programs like UARCS.

DoD's Program Manager-Centered Funding Mechanism to Academia Fuels the S&T Ecosystem

- The DoD model is unique because our funding basic research relies on program managers who have insight into DoD future needs and a vision of the scientific community.
- This model results in some incredibly important investments
  - Program managers see beyond academic trends identifying future needs, sustaining fields, and leading to early investments in successful researchers
  - Program managers can have incredible long-lasting impact



DoD Basic Research Sets the Stage for Future DoD Research Priorities

FY12 Basic Research Priorities have low alignment with FY12 priorities & high alignment with FY22 priorities

- Engineered Materials
- Synthetic Biology
- Quantum Information and Control
- Human Motivation and Behavior
- Cognitive Neuroscience
- Nanoscience and Engineering

FY12 S&T Priorities (Low alignment)

- Data to decisions
- Engineered resilient systems
- Cyber science and technology
- Electronic warfare/electronic protection
- Counter weapons of mass destruction
- **Autonomy**
- Human systems

FY22 S&T Priorities (High alignment)

- **Biotechnology**
- **Quantum Science**
- **Future Generation Wireless Technology**
- **Advanced Materials**
- **Trusted AI and Autonomy**
- Integrated Network Systems-of-Systems
- Microelectronics
- Space Technology
- **Renewable Energy Generation and Storage**
- Advanced Computing and Software
- **Human-Machine Interfaces**
- Directed Energy
- Hypersonics
- Integrated Sensing and Cyber

DoD Basic Research Sets the Stage for Future DoD Research Priorities

2009 Priorities: Data to Decisions, Engineered Resilient Systems, Cyber S&T, Electronic Warfare /Electronic Protection, Counter WMDs, Autonomy, & Human

Aligned to '09 Priority Areas

- Removing the Botnet Threat
- Machine Intelligence and Adaptive Classification for Autonomous Systems
- Highly Decentralized Autonomous Systems for Force Protection and Damage Control
- Computational Intelligence for Decentralized Teams of Autonomous Agents
- Multi-Scale Fusion of Information for Uncertainty Quantification and Management in Large-Scale Simulations
- Learning Decision Architectures for Intelligent Cooperative Control of Autonomous System

NOT Aligned Priority Areas

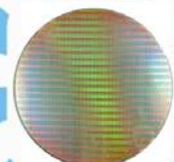
- Ultracold Molecules
- Synthesis, Analysis, and Prognosis of Hybrid-Material Flight Structures
- Integrated Quantum Circuits
- Grounding Language Understanding in Cognitive Architecture

2019 priorities informed by 2009 work: Cyber, Autonomy/AI, Quantum Science, Hypersonics

Discovering new fields and areas of inquiry requires creativity that cannot be managed using traditional acquisition strategies

Basic Research Lays the Foundation for Semiconductor Development

Microprocessors: From 1981 to 1989, DoD and DARPA supported research at Stanford University that would lead to major innovations in microprocessor manufacturing. Government support for basic research made it possible to overcome critical obstacles to producing microchips with millions and even billions of transistors. Without this research, products like the Intel Pentium, AMD Athlon, or Micron 2 Gbitmemory chip would not exist.



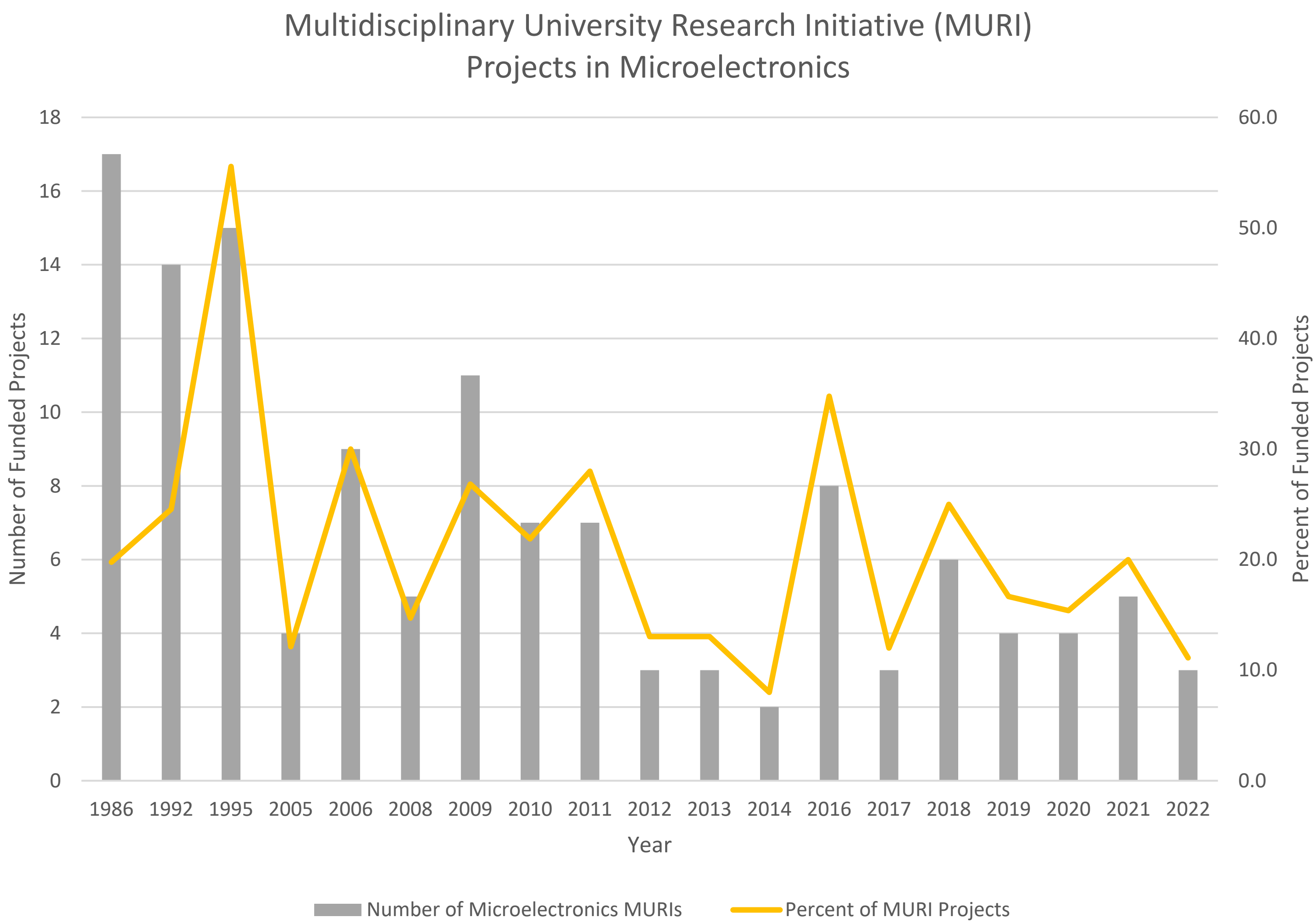
LEDs: From 1981 to 1987, the Office of Naval Research (ONR) and National Science Foundation (NSF) provided funds for basic research at North Carolina State University that led to the development of technology for the growth of single crystals of SiC and GaN. Single crystals of SiC and GaN are key components of ultra-bright, the solid state light sources that have made possible full color displays on modern cell phones and other devices, as well as a new generation of traffic lights.

FLASH Memory: From research conducted at U.C. Berkeley 1984 to 1990 that was supported by funding from DARPA and the Air Force Office of Scientific Research. This research generated an understanding of the physics of hot-electron injection in thin insulator films, without which we could not have today's digital cameras, pocket memory sticks, iPods, or numerous other devices.

Flat Panel Displays: From 1981 to 1990, research by professors from Cornell, M.I.T., CalTech, and Columbia, supported by funding from DARPA, NSF, and the Department of Energy, advanced the laser crystallization of amorphous silicon necessary for producing the flat panel displays used in today's televisions and computers.

Produced by the Semiconductor Industry Association and the Association of American Universities, 2011

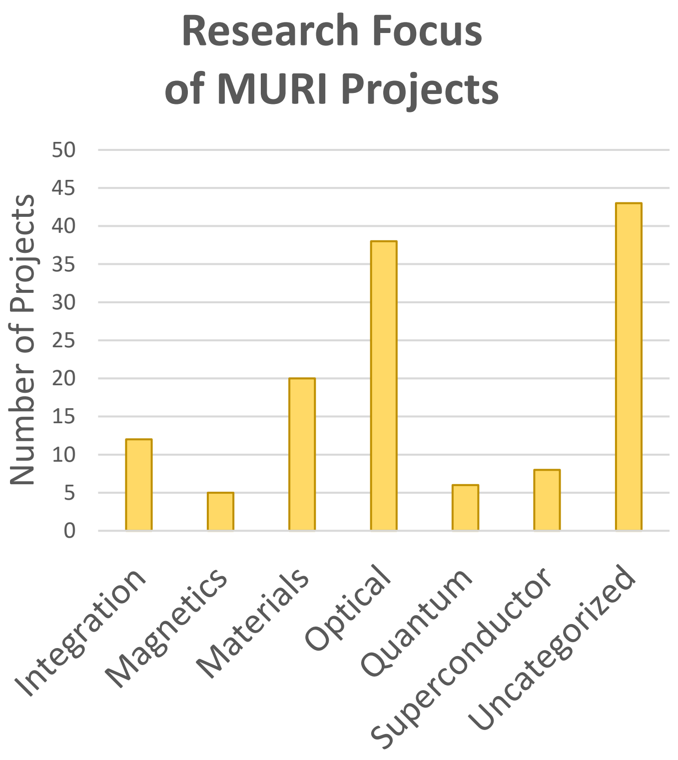
On Average 20% of MURI Projects are in Microelectronics



MURI Projects in Microelectronics

Research focus trends:

- Superconductors were a research focus area in the 1990s
- Optical computing and communication (on-chip, nano-photonics) were the focus of early investments (2000-2010)
  - Nano-photonics is more developed today, but we are still not to the point of having all-optical computing
  - Communication is better, with sources on-chip coupled to fibers
  - Likely, the all-around computing approach requires a lot more integration than just coupling a fiber to a chip and follow-on engineering research that is lacking
- Material studies are a persistent focus area but the materials themselves vary over time
- Fewer studies focus on integration (multiple modalities on one chip) but it becomes more of a focus area in the late 2010s, likely indicating that integration is gradually recognized as a critical issue

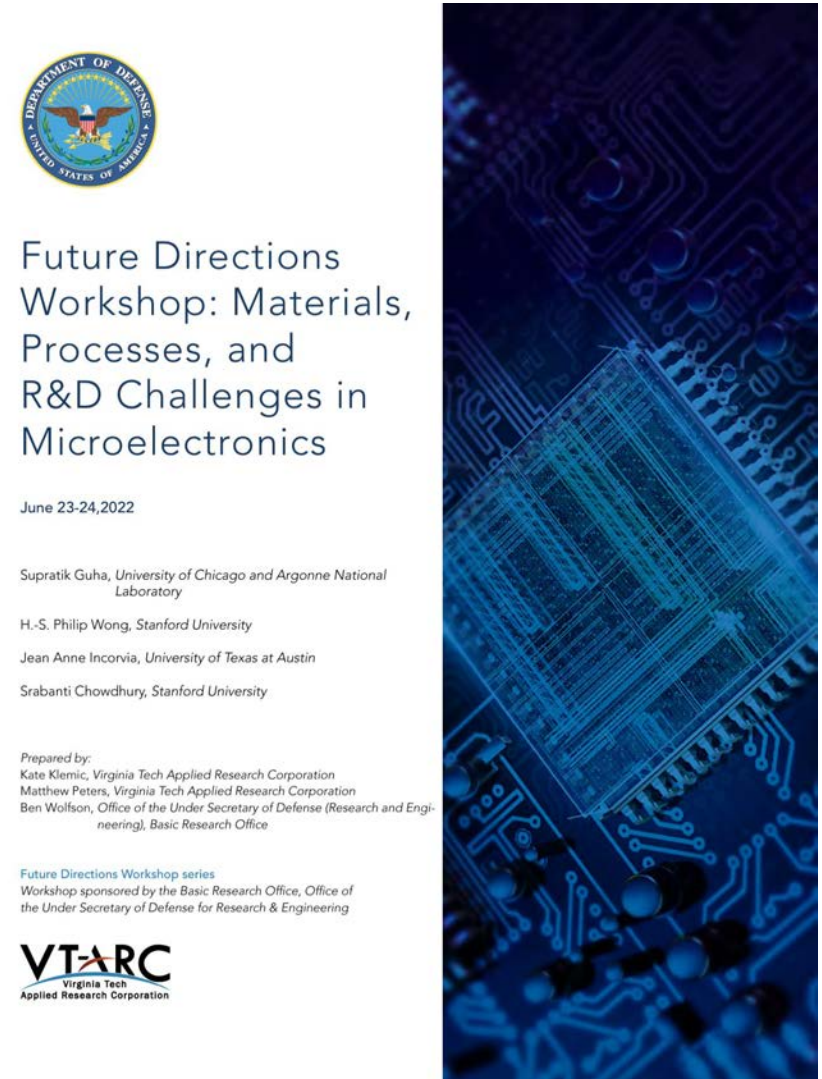


Future Directions Workshop – Materials, Processes, and R&D Challenges in Microelectronics

The Basic Research Office runs Future Directions Workshops (FDW) with leaders of a field to create a roadmap of basic research advances necessary to move the field forward

The FDW report on Materials, Processes and R&D Challenges in Microelectronics is available at:

https://basicresearch.defense.gov/Programs/Future-Directions-Workshops/



Future Directions Workshop: Materials, Processes, and R&D Challenges in Microelectronics

June 23-24,2022

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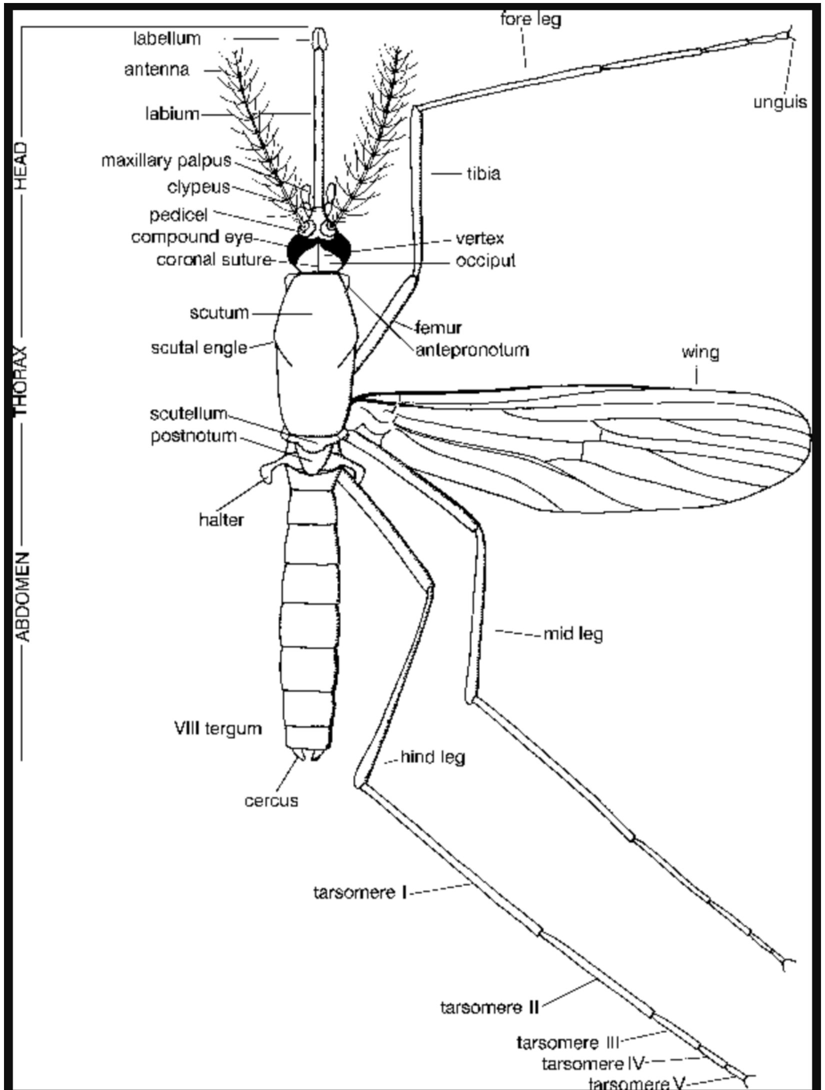
Future Directions Workshop series
Workshop sponsored by the Basic Research Office, Office of the Under Secretary of Defense for Research & Engineering

VT-ARC Virginia Tech Applied Research Corporation

Pushing the Field with Basic Research - Integration

- Biology is capable of integrating complex, varied modalities for organism function and behavior
- Mosquitos are on the scale of chips and are able to integrate finely controlled sensory, signaling, processing, and motor functions to elicit complex behaviors
- A future for microelectronics is to integrate different modalities onto one chip
- Requires rethinking current paradigms and new approaches – a strength of basic research



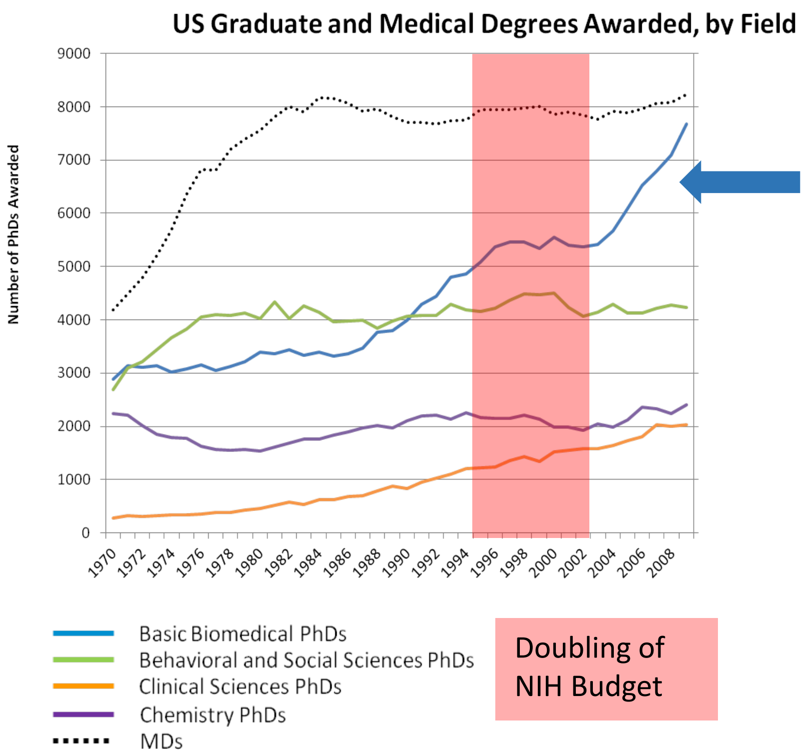
What Does Integration Mean ?

Integration changes over time

1) Multiple devices on one board
   - Several factories ➡ Several devices
   - Coarse system integration
2) Multiple components in one device
   - Several foundries ➡ Several components
   - Fine device integration (Si chip + photonic chip + memory..)
   - Non-Si integrated with Si
3) Multiple materials in one component
   - Design at atomic/molecular scale = hyper-fine integration
   - One Foundry? Self-Assembly?

Workforce is Tied to Investment in Academic Research

- Most graduate students and post-docs are supported off of research grants
- When research budgets grow, workforce grows



The number of Basic Biomedical PhD's grew immensely after the doubling of NIH's budget