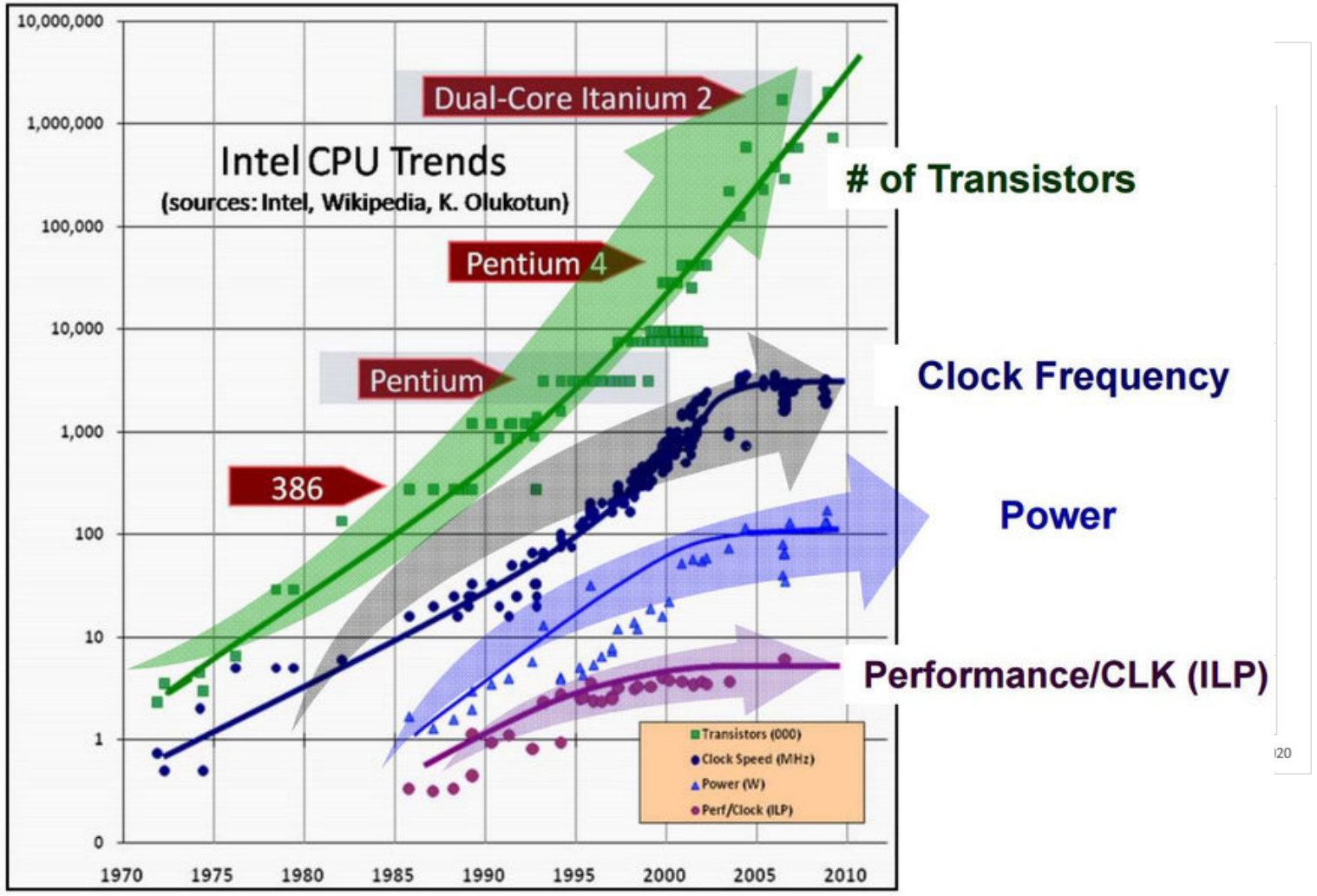
Nanotechnology and Electronics Converging Initiatives: NNI + NQI = ?

Celia Merzbacher, Associate Director

Quantum Economic Development Consortium (QED-C)

Quadrennial Review of the NNI
National Academies of Science, Engineering and Medicine
July 30, 2019

Moore's Law = scaling → nanotechnology



Managed by SRI International [2]

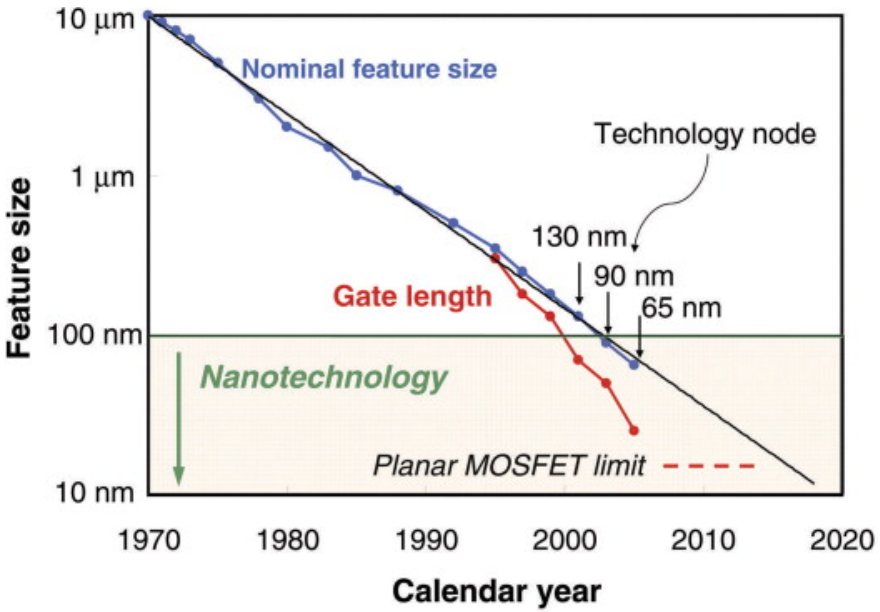
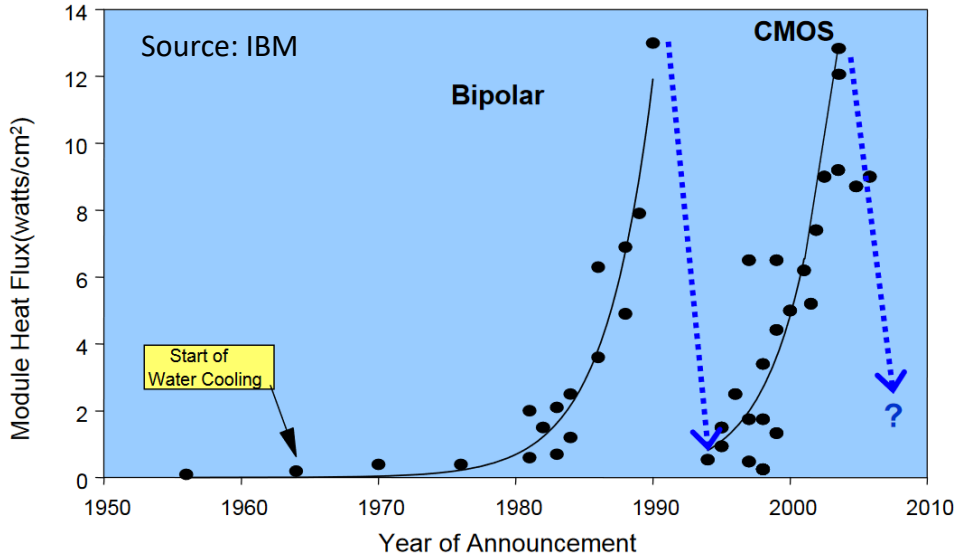


Fig. 1. Logic technology node and transistor gate length versus calendar year. Note mainstream Si technology is nanotechnology. (Published at the International Electron Devices Meeting.)

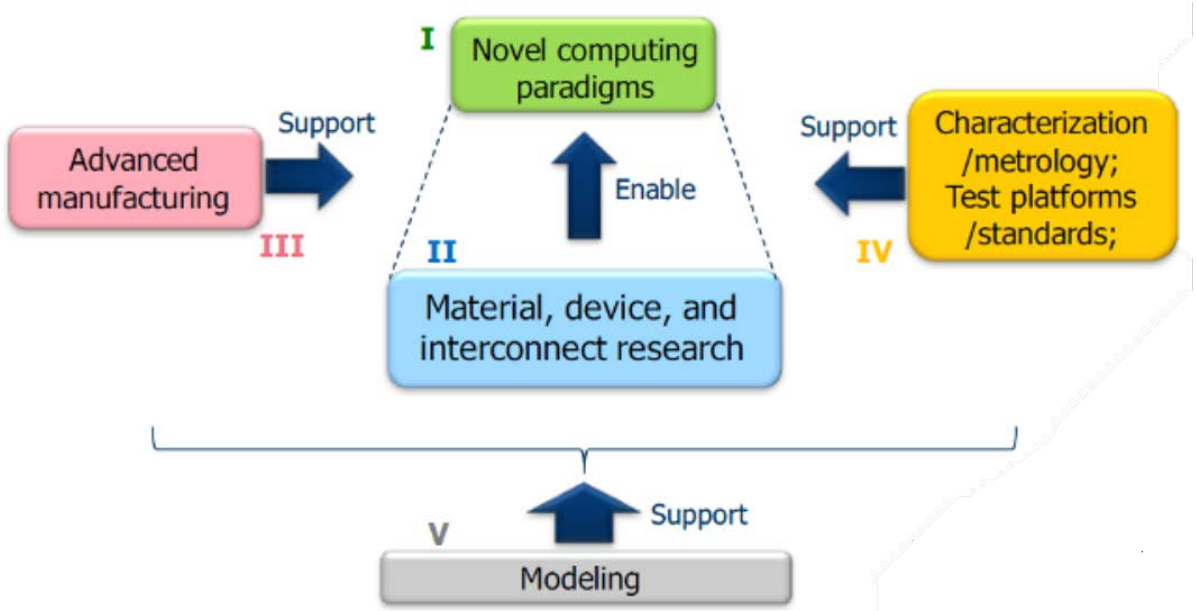
Source: Thompson and Parthasarathy, June 2006, *Materials Today*

Nanoelectronics part of NNI since the start

- 2005: Nanoelectronics Research Initiative (NRI) launched by industry (as a subsidiary of SRC) in partnership with NSF and NIST
  - NSF program: Nanoelectronics for 2020 and Beyond
  - Mission to demonstrate a device capable of replacing the CMOS transistor

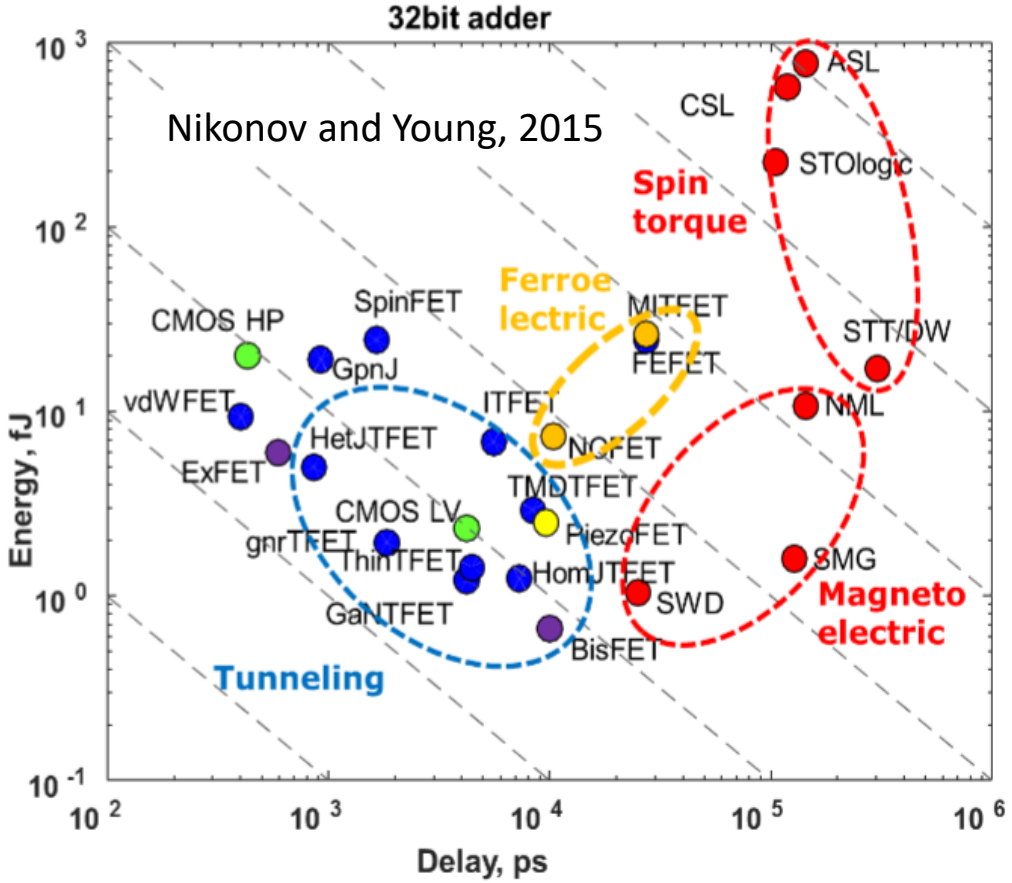


- 2015: NRI transitioned to nCORE
  - Still partnering with NSF and NIST
  - Mission to develop key technologies to enable novel computing and storage paradigms

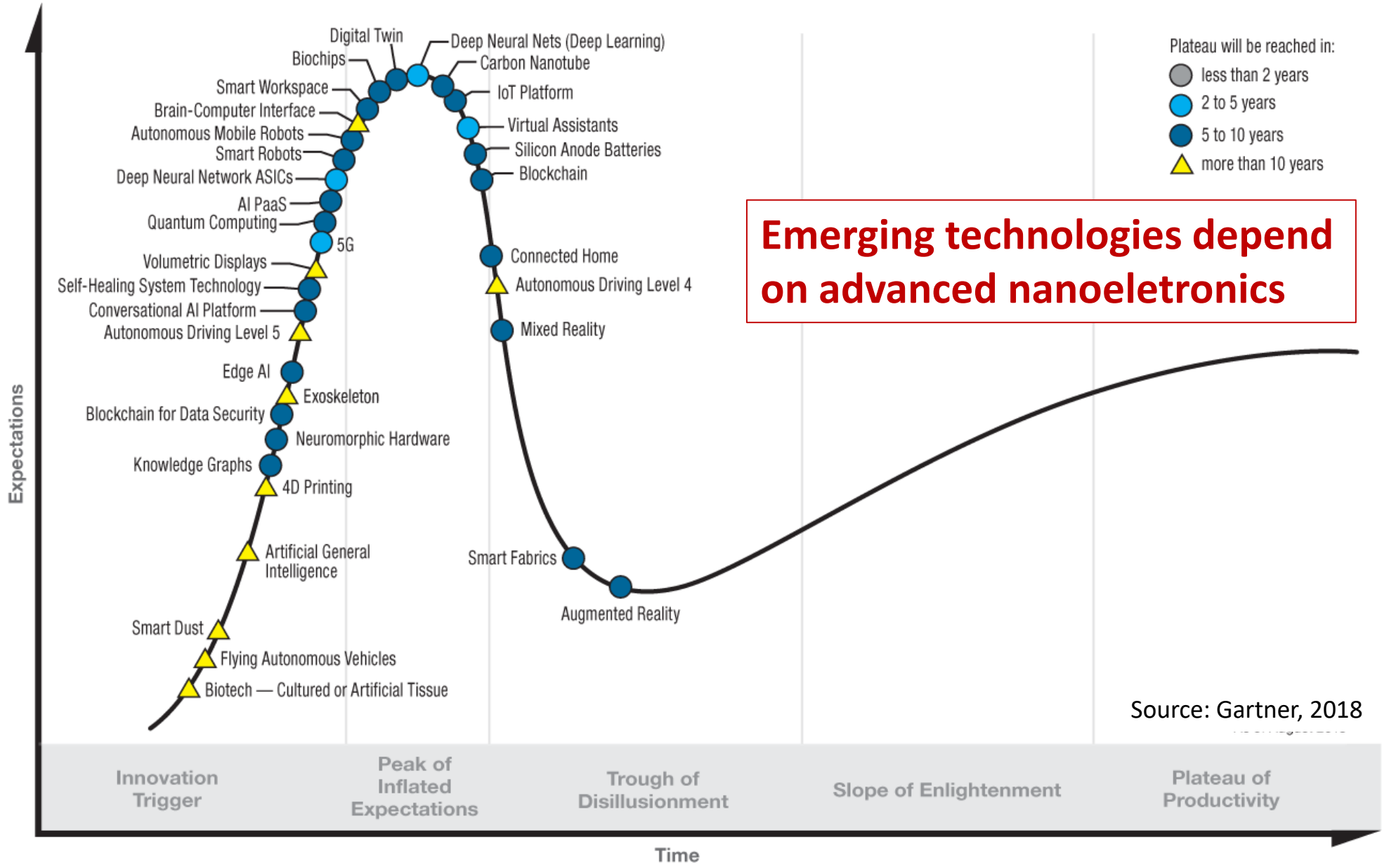


NRI partnership model as an exemplar

- Industry and government leverage their investment
- Government gains insight on industry needs
- University researchers get exposure to & build relations with industry
- Students get enhanced educational experience
- Industry-relevant benchmarks developed to guide research direction
- Results are transferred efficiently to U.S. companies



Why we care if nanoelectronics succeed



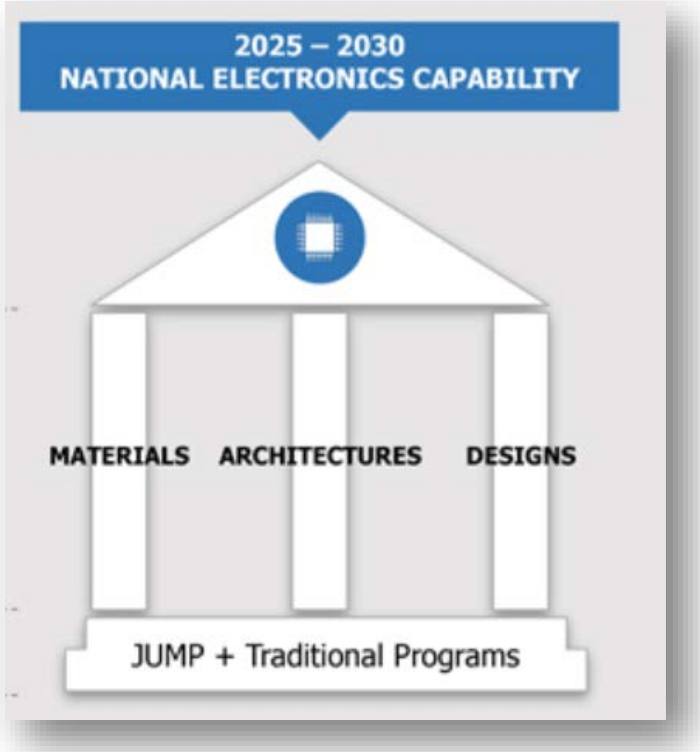
Emerging technologies depend on advanced nanoeletronics

Source: Gartner, 2018

What can be done to ensure US leadership?

DARPA Electronics Resurgence Initiative launched in Sept 2017

Investing $1.5 billion over 5 years

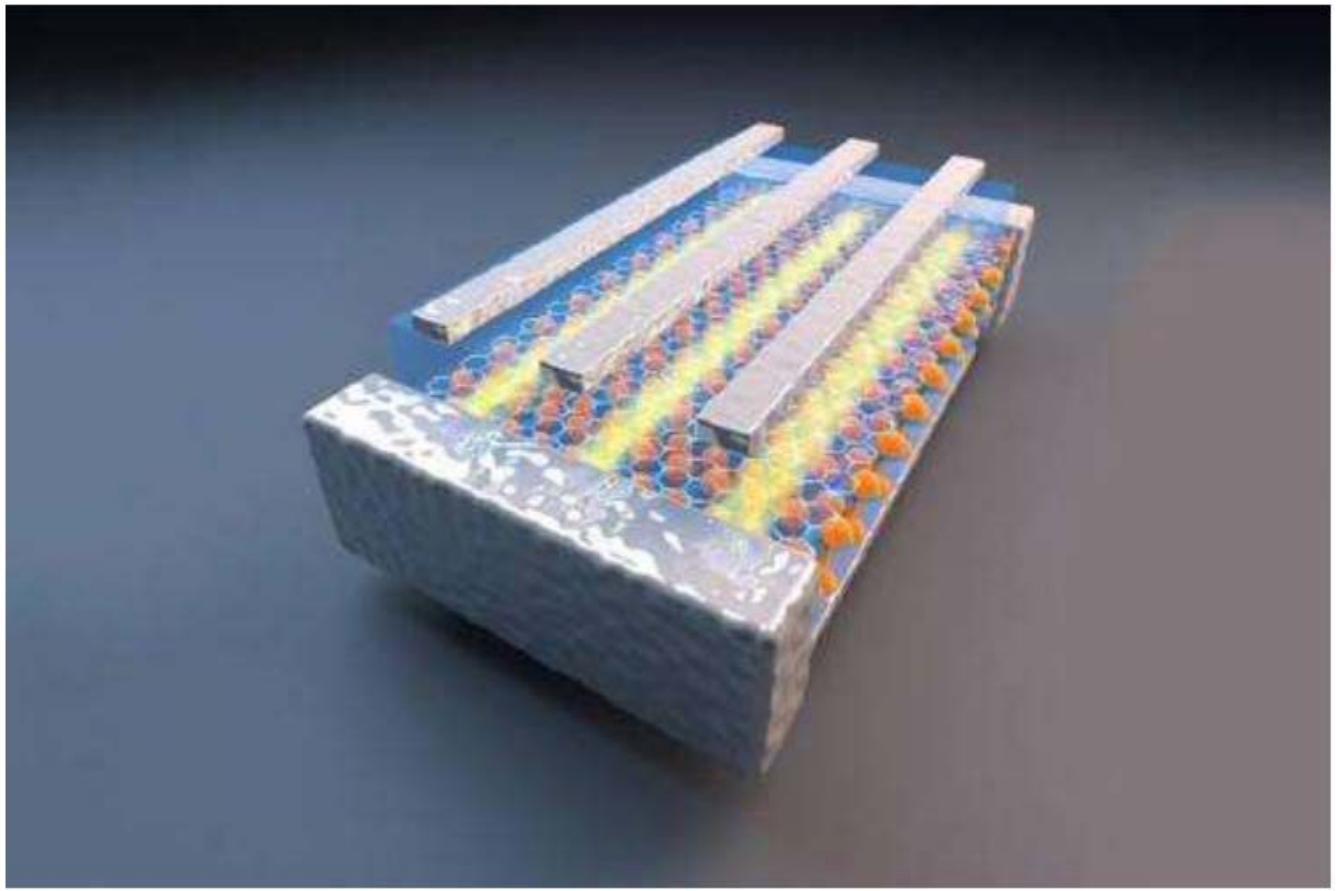


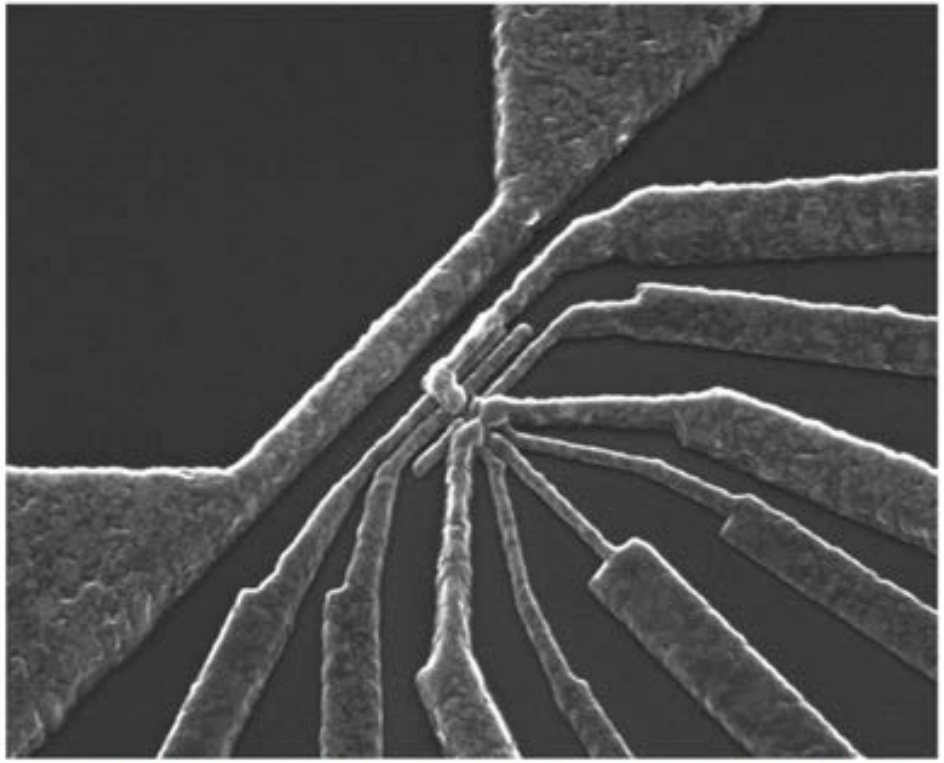
Nanoelectronics and the NNI

- The NNI focus on nanoelectronics led to significant investments and willingness to work collaboratively
- How does the NNI support nanoelectronics (research)?
- What more can the NNI do to advance nanoelectronics?
- What would happen to nanoelectronics (research) if the NNI ended?
- Will “quantum electronics” research replace nanoelectronics?

New 2-D quantum materials for nanoelectronics

by David L. Chandler, Massachusetts Institute of Technology



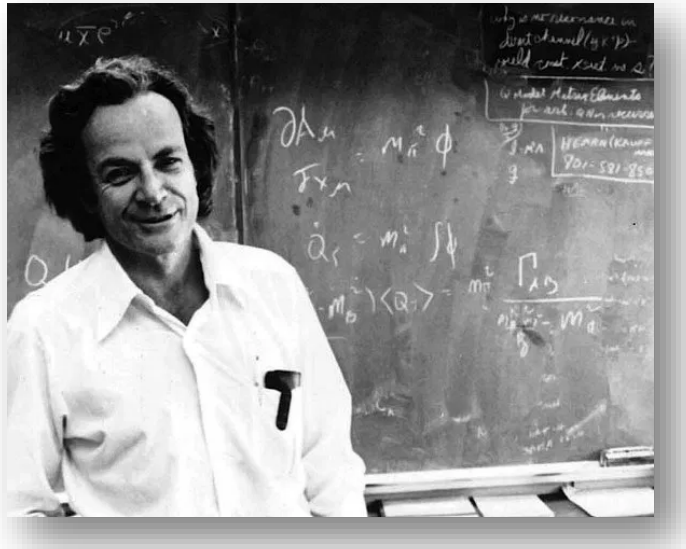


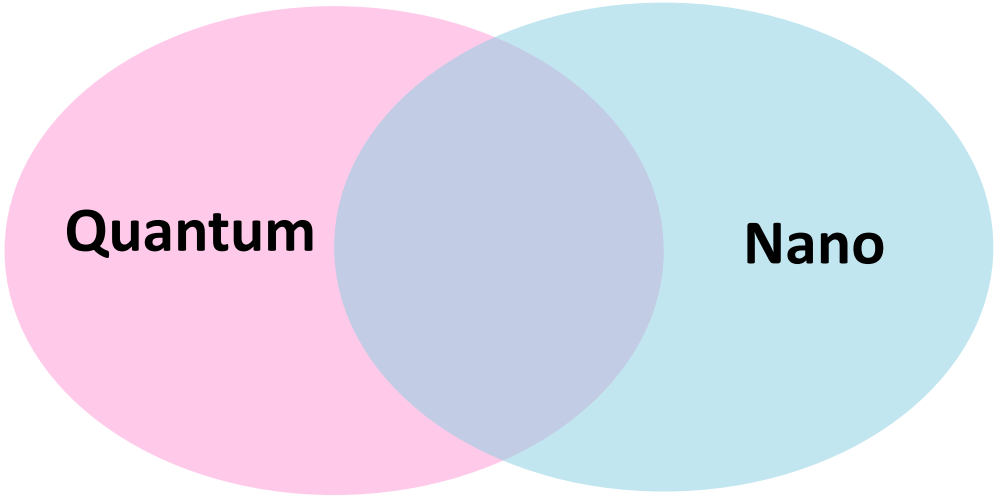
Very small quantum dots constructed in Si/SiO2 devices. Courtesy A. Dzurak, University of New South Wales.

Managed by SRI International [8]

What is quantum technology?

- Based on “non-classical” phenomena that occur at small length scales
  - Quantized states
  - Tunneling
  - Particle-wave duality
  - Probability/uncertainty
  - Superposition
  - Entanglement



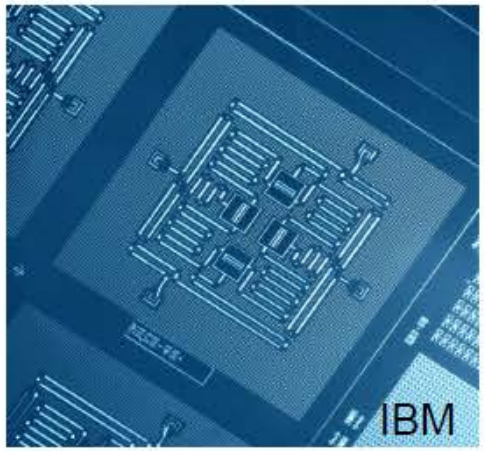


Potential quantum applications

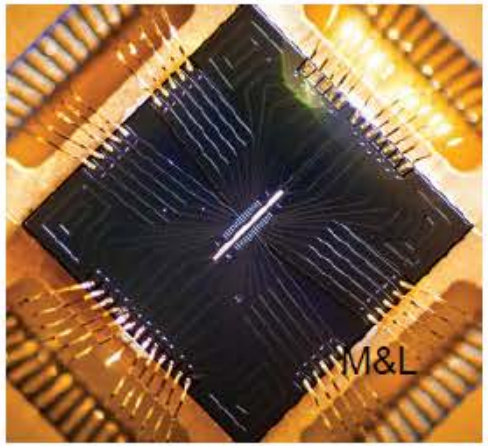
- Exquisitely sensitive sensors/measurement technologies
- Truly secure communication networks
- Computers that can solve currently intractable problems

✓***All part of "quantum information science" (QIS)***

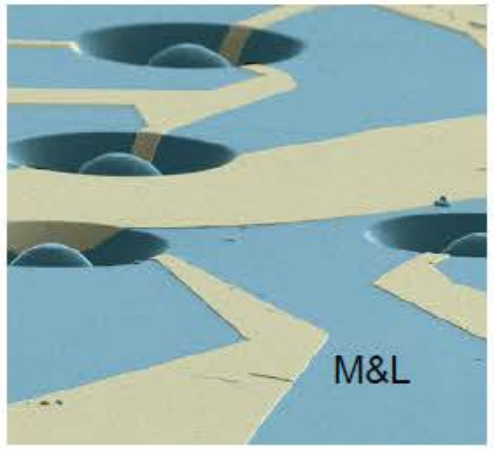
Quantum computing: It starts with the qubit



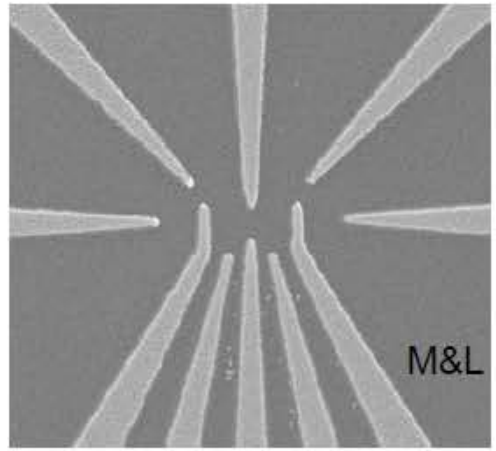
Superconducting Qubits



Trapped Ions



Engineered Defects



Quantum Dots or Spins

Sources: IBM and Morton and Lo, IEEE Spectrum, Aug 2014

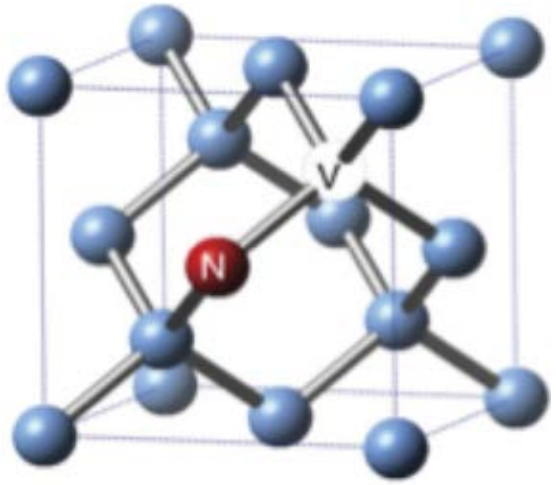
Nanoscale manufacturing for quantum devices

Fabrication of high-quality Josephson junctions for quantum computation using a self-aligned process

Wei Chen, Vijay Patel, J.E. Lukens

Quantum computers are believed to have the potential to perform certain tasks much better than conventional computers. Recently, very promising results have been demonstrated with superconducting devices based on Josephson junctions. The quality of the Josephson junctions plays an important role in determining the coherence time of superconducting quantum bits, and hence the viability of superconducting quantum computers.

Microelectronic Engineering, June 2004



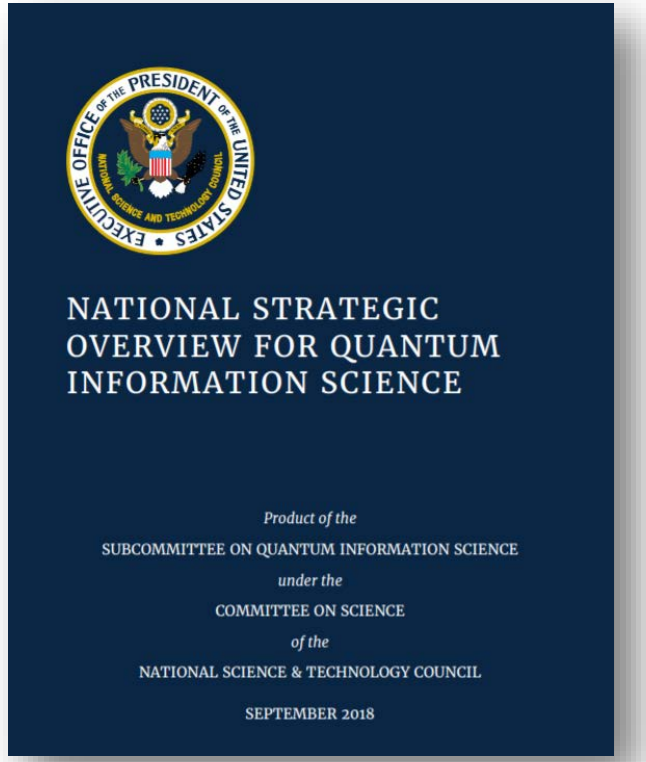
NV defect in diamond requires atomically precise manufacturing

Applications:

- Magnetic sensor
- Single-photon source
- Spin-based Qubit

Government is ramping up

- Recognition that quantum science advances create technological opportunities and challenges
  - NSF Big Ideas includes Quantum Leap (2016)
  - NIST request for post-quantum cryptographic algorithms (2016)
- National Strategic Overview for Quantum Information Science released (Sept 2018)
- National Quantum Initiative Act signed (Dec 2018)
  - Modeled on the NNI
  - Establishes interagency group and coordination office
  - Scheduled to sunset in 11 years
- NSF, DOE, NIST and DOD are investing in a broad portfolio of research
- NIST launches industry consortium



Quantum Economic Development Consortium (QED-C)

- An industry consortium with the mission to enable, accelerate, and strengthen the U.S. commercial quantum industry – with support of industry and government
- 60+ members from a broad cross-section of the quantum ecosystem
- QED-C purposes include:
  - Identify gaps that need to be filled to enable the robust U.S. quantum "ecosystem" that is necessary to realize the myriad benefits, including:
    - Enabling technologies
    - Standards and performance metrics
    - Workforce needs
  - Engage stakeholders to fill the gaps.
  - Provide a collective industry voice to guide R&D investment priorities, standards and regulation, and quantum workforce development

Nanotechnology for quantum

- Understanding and controlling materials at the nanoscales is essential to advancing quantum devices
- Nano characterization and fabrication tools and methods needed
- There is a shortage of graduates who are “quantum literate” and can do nanoengineering
- Nanomanufacturing of quantum materials, devices and systems that are commercially viable and scalable will need to be developed

Birth and Development of an Industry

First Transistor, 1947
Shockley, Bardeen, and Brattain

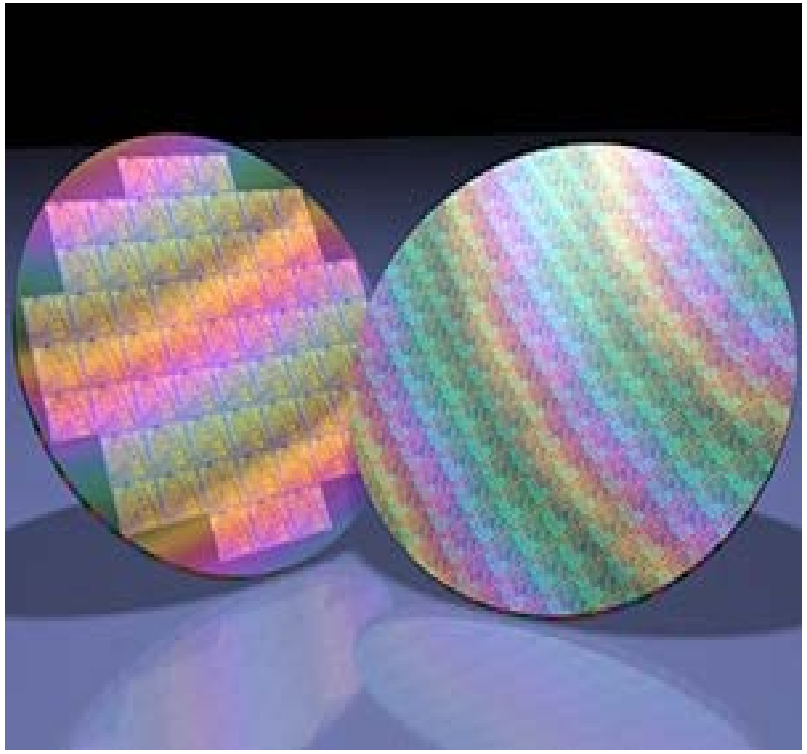
FROM LAB TO FAB

Supply Chain of Enabling Technologies

Wafer processing
- Wet cleans
- Photolithography
- Ion implantation
- Wet and dry etching
- Plasma ashing
- Thermal treatments
- Chemical vapor deposition (CVD)
- Physical vapor deposition (PVD)
- Molecular beam epitaxy (MBE)
- Electrochemical deposition (ECD)
- Chemical-mechanical planarization (CMP)
- Wafer testing
- Wafer backgrinding

Die preparation
- Wafer mounting
- Die cutting

IC packaging
- Die attachment
- IC bonding
- IC encapsulation
- IC testing

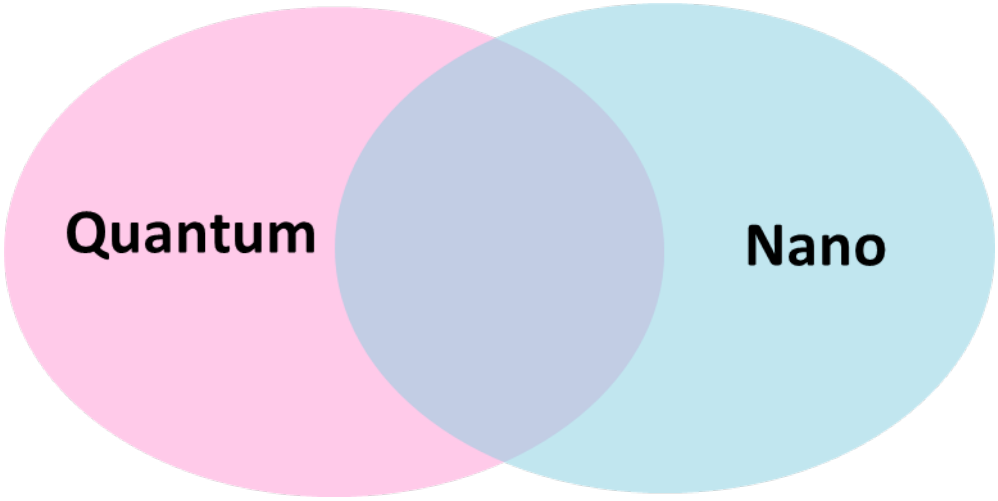


The NNI and NQI

- Does the NNI support QIS (research) not funded by the NQI?
- What more can the NNI do to advance QIS?
  - Make sure nano infrastructure supports QIS needs
  - Push the frontiers of nanoscale characterization and atomically precise fabrication
  - Integrate more quantum concepts into education (nano is still “cool”)

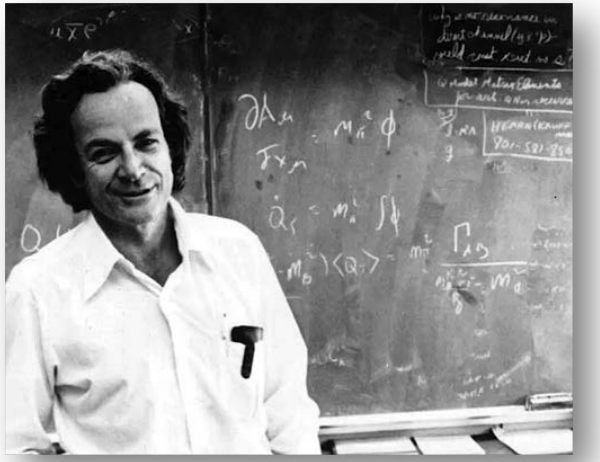
NNI + NQI = ?

- NNI < NQI not true
- NQI < NNI not true
- NNI ≠ NQI true



NNI 2.0?

- Consider a rebuild vs. a renovation
- Goals have served the NNI well – are they the right ones going forward?
- What are the Big Ideas for Nano?
- Is nano primarily enabling (of other priorities)?
- How should the NNI be organized to support national priorities?
- There is ***still*** plenty of room at the bottom



THANK YOU

Celia.Merzbacher@sri.com

QED-C LOI Signatories (as of 7/22/2019)

Corporate

- Advanced Research Systems (ARS)
- Amazon
- AO Sense
- ARM
- AT&T
- Atom Computing
- BAE Systems
- Boeing
- Boston Consulting Group
- Bra-Ket
- Citi
- ColdQuanta
- Corning
- D-Wave
- Entanglement Institute
- EZ Form Cable Corp.
- FieldLine
- FLIR
- GE Global Research
- General Dynamics Mission Systems
- Google
- Harris

Corporate

- Holzworth Industries
- Honeywell
- HPD
- Hyperion Research
- IBM
- Inside Quantum Technology
- Intel
- IonQ
- Janis Research
- Keysight
- KLA
- KMLabs
- Lake Shore Cryotronics
- Lockheed Martin
- Marki Microwave
- Microchip/Microsemi
- Montana Instruments
- NuCrypt
- Photodigm
- Photon Spot
- Psi Quantum
- QC Ware

Corporate

- QPRI
- Qrypt
- Quantum Circuits
- Quantum Xchange
- Qubitekk
- Raytheon
- Rigetti
- Riverside Research
- Rydberg Technologies
- SkyWater Technology Foundry
- Stable Laser Systems
- Strangeworks
- SRI International
- Toptica
- Twinleaf
- United Technologies Research Center
- Vescent Photonics
- Zapata Computing
- Zyvex Labs

Academic

- Caltech
- Colorado School of Mines
- George Mason University
- Georgia Institute of Tech.
- University of Colorado
- University of Maryland

Government

- DOD
- DOE
- NIST
- NSF

Other

- American Physical Society
- SEMI
- University Space Research Association