Metrology and Benchmarking for Energy Efficiency Scaling of Microelectronics

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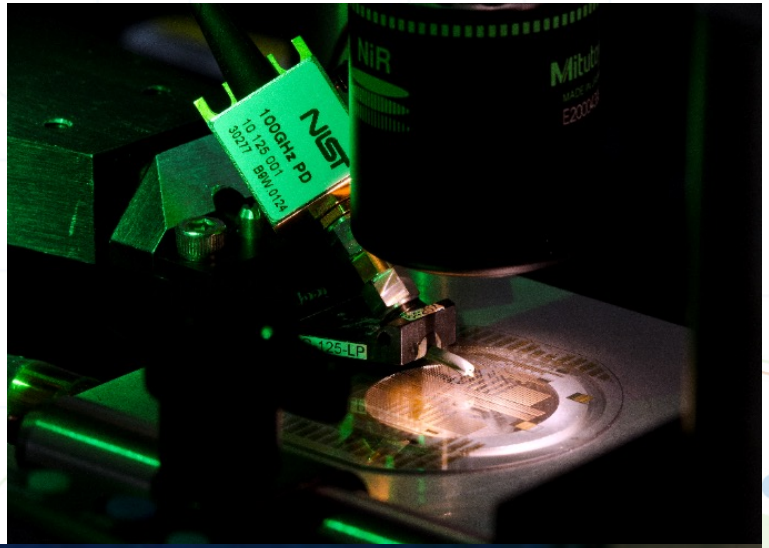
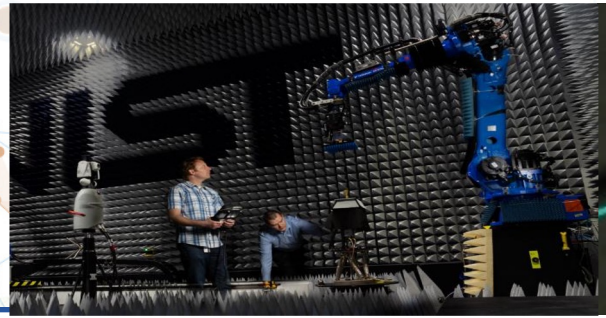
NIST COMMUNICATIONS TECHNOLOGY LABORATORY

Metrology for Microelectronics

- Definitions – What is Metrology?
- Role of Metrology in CHIPS at NIST
- Role of Metrology in EES2
- Opportunities and Impacts of Metrology for Microelectronics and Energy Efficiency





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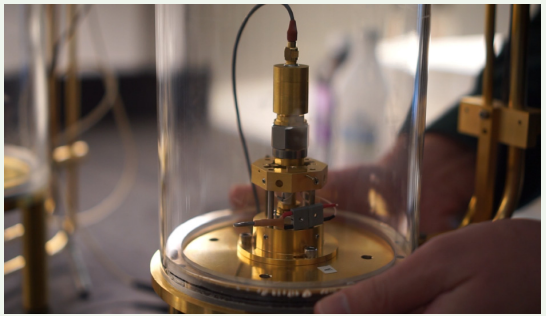
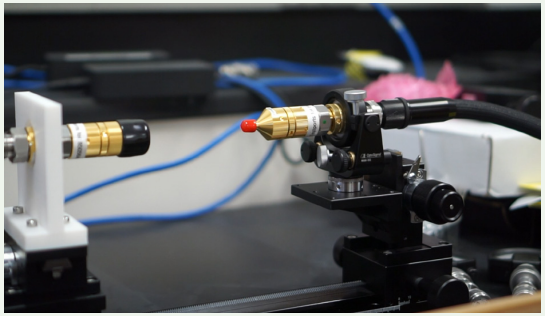
What is Metrology?

Metrology is the science of measurement and its application. NIST's work in metrology focuses on advancing measurement science to enhance economic security and improve quality of life.

A key component of NIST's metrology work is metrological traceability, which requires the establishment of an unbroken chain of calibrations to specified reference measurement standards: typically national or international standards, in particular realizations of the measurement units of the International System of Units (SI).

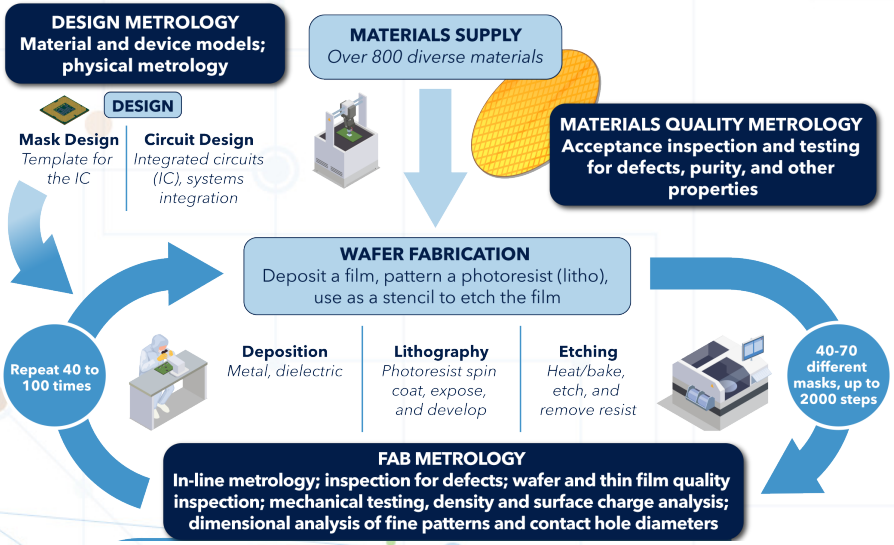
https://www.nist.gov/metrology

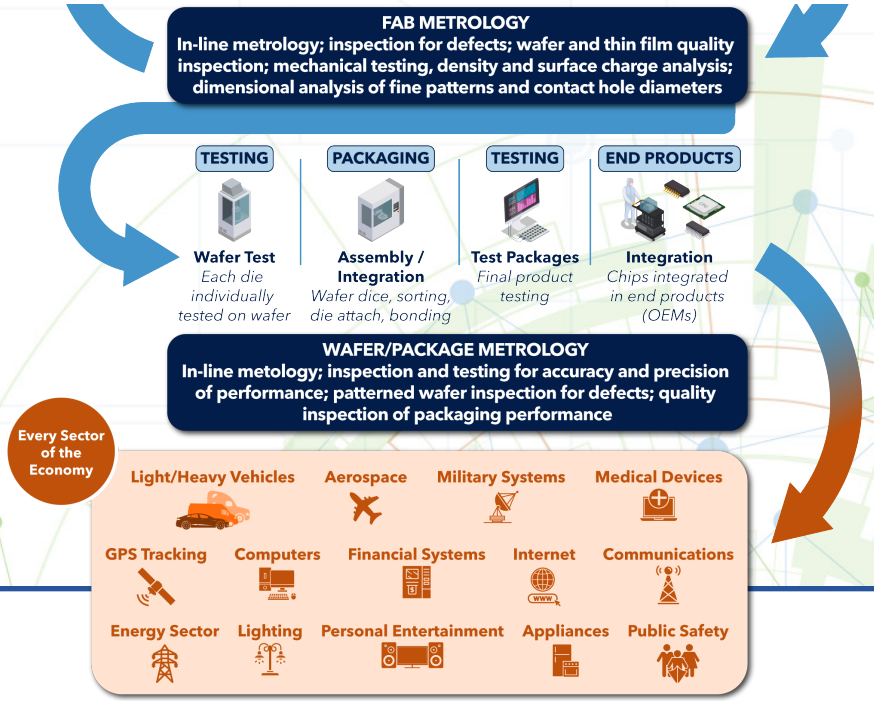




NIST maintains the U.S. National Standards for RF quantities, including power, scattering parameters, thermal noise, antenna gain, and the Josephson Volt. Calibrated electrical measurements, traceable to the SI, are critical for all aspects of microelectronics from the characterization of components and design of circuits through production test.

Where can Metrology help in Microelectronics?





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NIST and Advanced Microelectronics

NIST has a long history and broad portfolio of targeted investments in microelectronics spanning the following areas:

- Materials and chemistry
- Devices and interconnects
- Circuit design and computer automated design tools
- Fabrication/Manufacturing
- Packaging and test
- Computing architectures
- Software, modeling, simulation
- Beyond digital CMOS technologies
- RF electronics

Metrology Program

VISION: CHIPS R&D Metrology catalyzes innovation with emphasis on measurements that are accurate, precise, and fit-for-purpose for the production of microelectronic materials, devices, circuits, and systems.

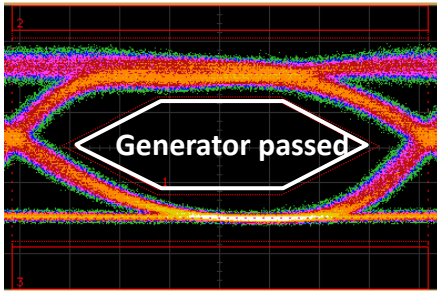
MISSION: Measure, innovate, lead to enhance a vibrant U.S. ecosystem for semiconductor manufacturing and to promote U.S. innovation and industrial competitiveness.

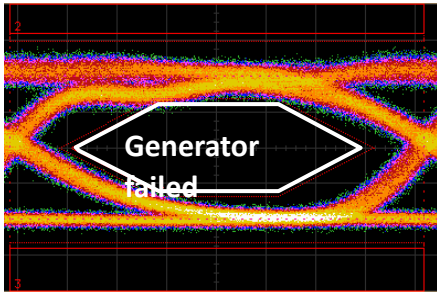
GOALS:

1. Expanding measurement solutions for the semiconductor ecosystem.
2. Increase the number of solvers by harnessing the diversity of people and ideas, inside and outside of NIST.
3. Expand education and workforce development opportunities that inspire excitement about manufacturing careers and expand career pathways.

Metrology Importance

Reduce Cost



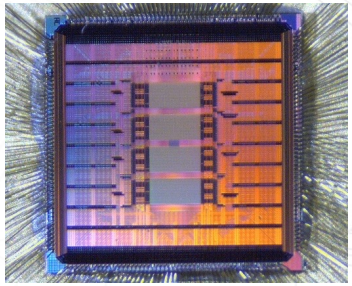


Same transceiver measured on two different oscilloscopes

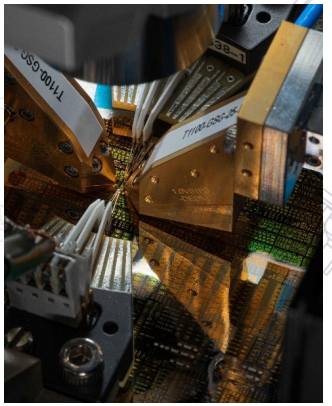
10 Gb/s Ethernet Transceivers
False rejects cost: $200M/yr

Measurements to test 6G technologies do not exist

Catalyze Innovation



NIST/Google Open Source Chip designs

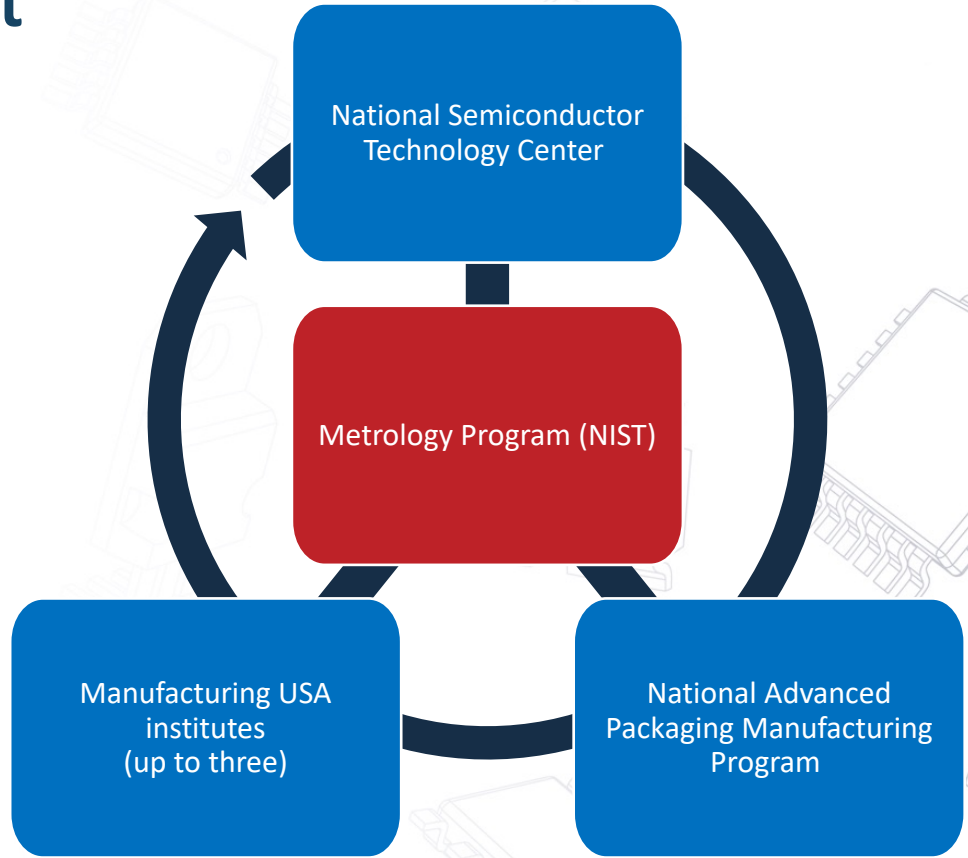


NIST/DARPA On-chip Calibration Kits

Measurement designs so that industry and academia can evaluate their technology

Maximize Speed and Impact

- Metrology is **foundational** and **fundamental** for all R&D programming
- Metrology **tools are delivered** to other CHIPS R&D programs;
- High impact research areas **sourced from industry**
- Metrology technologies should reach **commercial scale**



Industry Input is Key

- Measurement science for new materials and packaging
- Physical metrology for next-generation microelectronics
- Computation and data
- Virtualization and automation
- Reference materials and data, and calibrations
- Standards for processes, cybersecurity, and test methods

https://nvlpubs.nist.gov/nistpubs/CHIPS/NIST.CHIPS.1000.pdf

Strategic Opportunities

Extensive feedback from stakeholders across industry, academia, and government

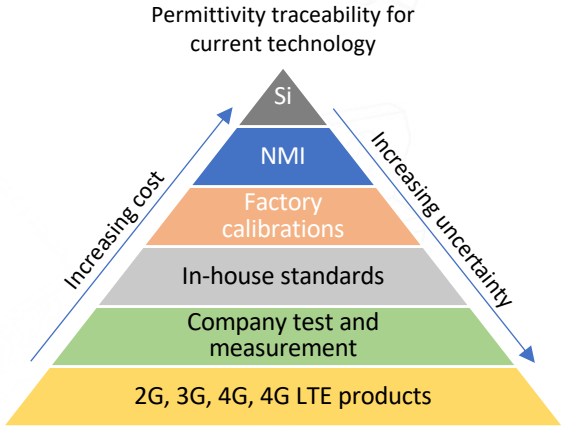
- Metrology for materials purity, properties, and provenance
- Advanced metrology for future microelectronics manufacturing
- Enabling metrology for integrating components in advanced packaging
- Modeling/ simulating semiconductor materials, designs, and components
- Modeling/ simulating semiconductor manufacturing processes
- Standardizing new materials, processes and equipment for microelectronics
- Metrology to enhance security and provenance of micro-electronic based components and products

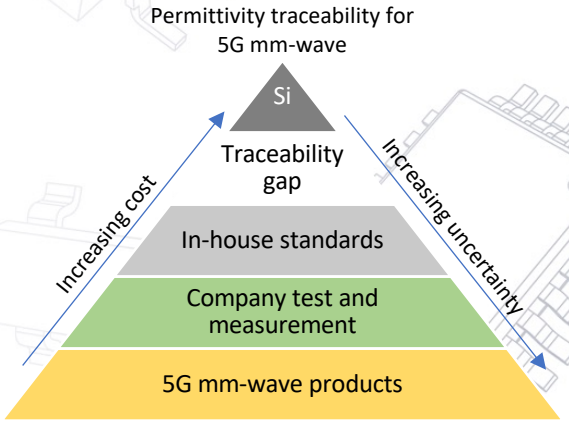
https://nvlpubs.nist.gov/nistpubs/CHIPS/NIST.CHIPS.1000.pdf

Example: SRMs for 5G materials

International Manufacturing Initiative (iNEMI)
"The lack of traceable reference material for mmWaves is a very serious problem. This lack makes verification of measurement methods and laboratory techniques impossible in an industry setting." - *5G Materials Characterization Project Report I*

Semiconductor Research Corporation
"Dielectric characterization up to 500 GHz and beyond. Scope includes anisotropic and inhomogeneous materials … High-frequency and high-temperature dielectric characterization of low-loss materials (encapsulants, mold compounds, substrates, etc.)." - *Research Needs: Packaging*





'5G' extends beyond wireless applications, including wired applications with needs for material characterization to 100+ GHz

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iNEMI International Electronics Manufacturing Initiative

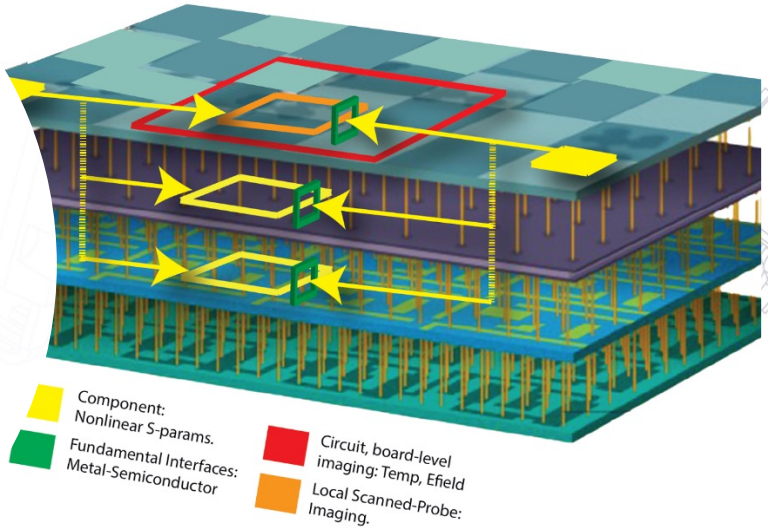
Example: Metrology for Increasing Circuit Complexity

Why?

- Increased integration density & functionality
- Add new materials & functionality
- Reduce power, cost, & latency

What's needed?

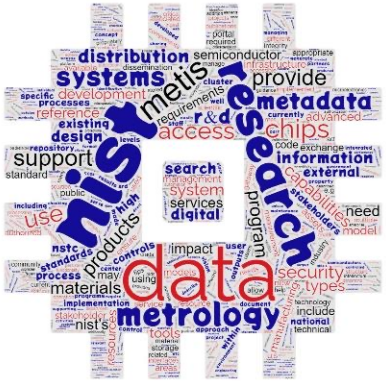
- Evaluate chips, interfaces, and materials buried in multilayer stacks
- New models to evaluated dynamic 3D systems
- Electromagnetic, thermal, & mechanical properties of constituent materials
- Broadband/dynamic material properties



Metrology Research Infrastructure

- Support metrology R&D
- Reduce technical risk for emerging technologies

WORLD-CLASS FACILITIES



- Ensure CHIPS R&D is available & useful for stakeholders
- Accelerating data ecosystem by leveraging existing resources

METIS

Metrology Exchange to Innovate In Semiconductors

Metrology for Energy Efficiency Scaling of Microelectronics

EES2 ENERGY EFFICIENCY SCALING

- Algorithms /Software
- Heterogenous Integration and Advanced Packaging
- Circuits and Architectures
- Materials and Devices

+

- Metrology and Benchmarking
- Power and Control Electronics
- Manufacturing Energy Efficiency and Sustainability

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Metrology and Benchmarking

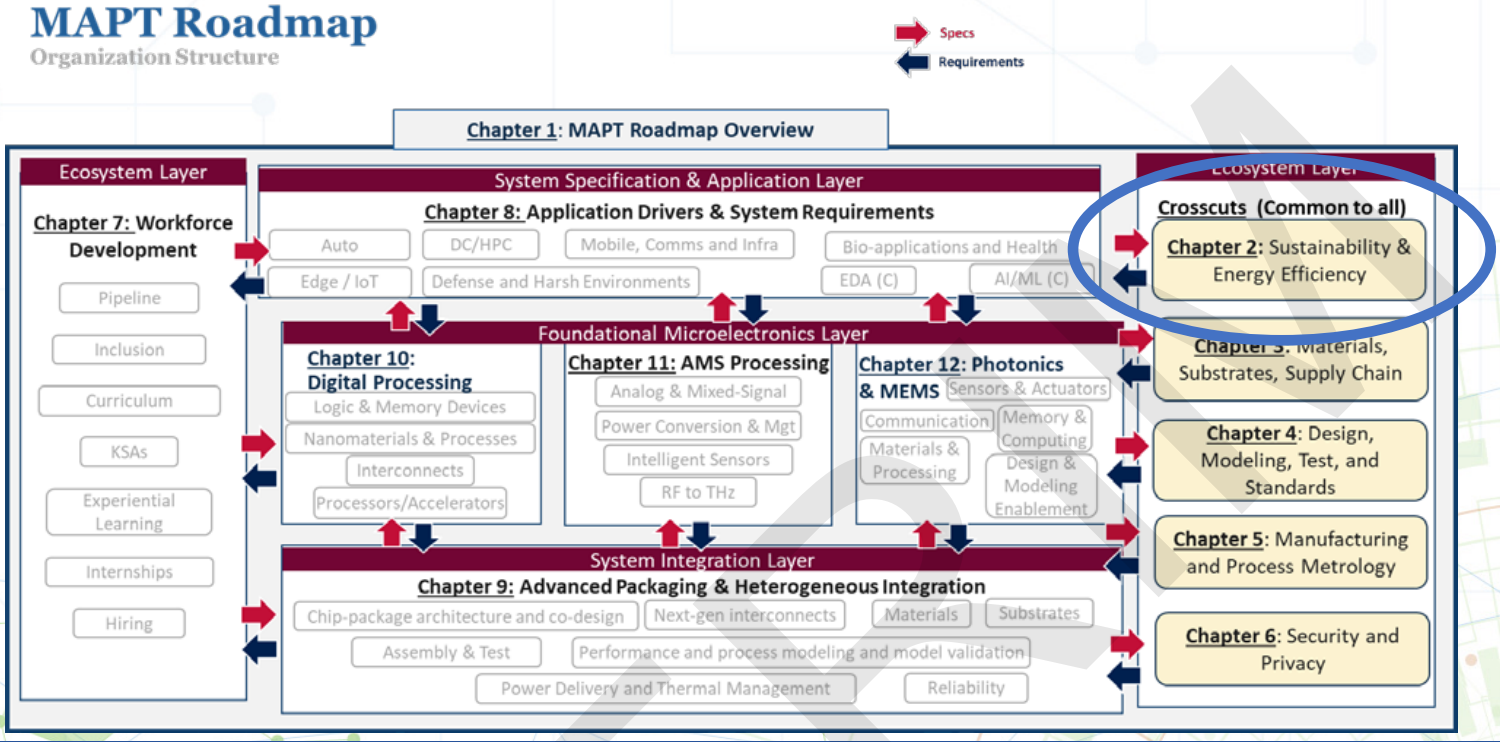
EES2 – Metrology and Benchmarking Solution Pathways

- Multi-modal In-situ failure analysis of emerging electronic device and components
- System level models to evaluate the impact and efficacy of innovations that are achieved at the component or technology scale
- Access to samples for metrology development - Bridging the gap between idealized system metrology and actual system performance
- Leverage AI/ML for metrology - while there will not be a comprehensive one-size-fit-all solution, AI/ML can help metrology for a number of different industry challenges
- Development of enhanced metrology/characterization techniques to meet the needs of increasingly complex device designs/integration schemes.

EES2 – Metrology and Benchmarking Solution Pathways

- Benchmark AI/ML algorithms, data quality, and efficiency for metrology related projects and tasks
- Develop and offer training material/courses for metrology/characterization for industry and academia
- Generate representative measurements/data to generate models/simulations to enhance metrology/characterization
- Benchmark emerging devices

Microelectronics and Advanced Packaging Roadmap



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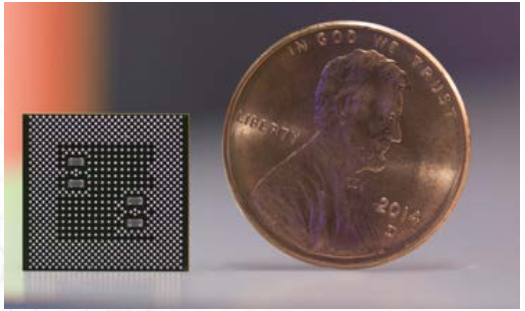
Metrology and Benchmarking

Impacts and Opportunities for Metrology

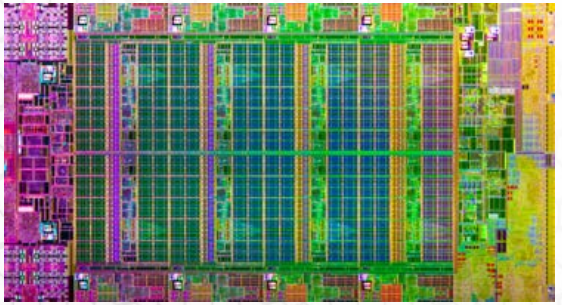
Example: Improved modeling capabilities can increase energy efficiency and reduce design costs

SIA presentation, ERI2.0, July 15, 2019

Advanced 5G chip = $250 million design costs



7nm advanced logic chip = $500 million design costs



Impacts and Opportunities for Metrology

- Algorithms /Software
- Heterogenous Integration and Advanced Packaging
- Circuits and Architectures
- Materials and Devices

- Metrology and Benchmarking
- Power and Control Electronics
- Manufacturing Energy Efficiency and Sustainability

EES2 ⟷ NIST Metrology Program

- Metrology for Materials Purity, Properties, and Provenance
- Advanced Metrology for Future Microelectronics Manufacturing
- Enabling Metrology for Integrating Components in Advanced Packaging
- Modeling and Simulating Semiconductor Materials, Designs, and Components
- Modeling and Simulating Semiconductor Manufacturing Processes
- Standardizing New Materials, Processes, and Equipment for Microelectronics
- Metrology to Enhance Security and Provenance of Microelectronic based Components and Products

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Metrology and Benchmarking

Exciting Opportunities Exist for New Collaboration Across the Emerging Microelectronics and Advanced Packaging Ecosystem

Education & Workforce Development

https://www.nist.gov/chips/workforce-development

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Metrology and Benchmarking