5G/6G Roadmap Creation and Packaging Challenges

(10:45 – 12:45)

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Introduction

NIST Advanced Manufacturing Technology Roadmap Program

- Funding to address high-priority research challenges to grow advanced manufacturing in the United States

MICROELECTRONICS | SUPPLY CHAIN RESILIENCE | FUTURE INDUSTRIES | REVITALIZING TRADITIONAL INDUSTRIES

iNEMI International Electronics Manufacturing Initiative

5G/6G mmWave Materials and Electrical Test Technology Roadmap

May 2022 – September 2023

Project Scope:

- Characterization
- Materials development
- Electrical test
- Manufacturing scale-up
- Workforce development

Goal:

- 10 Year Roadmap
- Gap assessments

Roadmap Partners

3DGS	Florida International University	Nantero
3M	Georgia Institute of Technology	NIST
AMD	IBM	Nokia
Applied Materials	iNEMI	Panasonic Industry
Arizona State University	Intel	Penn State University
Binghamton University	ITRI	Qorvo
Dell	Keysight Technologies	QWED
Dow	liloTree	TechSearch International
DuPont	Massachusetts Institute of Technology	University of Illinois Chicago
	Mosaic Microsystems	Zestron America

Principal Investigator: Urmi Ray

https://www.inemi.org/article_content.asp?article=275#

5G/6G mmWave Materials and Electrical Test Technology Roadmap (5G/6G MAESTRO)

10:45 – MAESTRO Roadmap: Dielectric Characterization

Michael J Hill
Principal Engineer, Intel

11:15 – MAESTRO Roadmap: Electrical Test

Professor Hongbin Yu
Arizona State University

11:45 – MASH & CHIPS Implementation Strategy

Professor Daniel Lopez
Penn State

12:15 - Dielectric reference material development

Lucas Enright
National Institute of Standards and Technology

5G/6G mmWave Materials and Electrical Test Technology Roadmap
5G/6G MAESTRO

Low Loss Dielectric Materials Characterization Roadmap

Michael J. Hill
Intel Corporation

Lucas Enright
NIST

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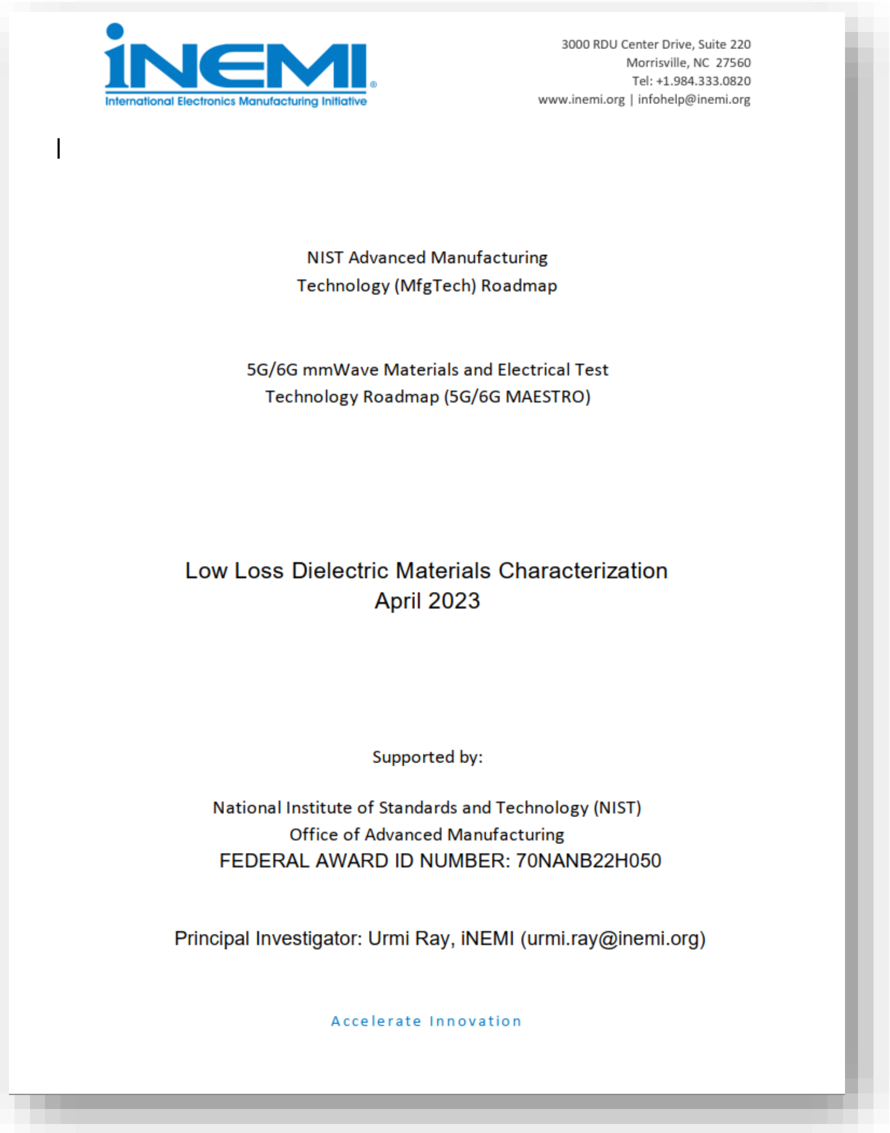
Agenda

- Roadmap document
- Ideal endpoint
- Common methods & their limitations
- Key challenges
- Summary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NIST Advanced Manufacturing
Technology (MfgTech) Roadmap

5G/6G mmWave Materials and Electrical Test
Technology Roadmap (5G/6G MAESTRO)

Low Loss Dielectric Materials Characterization
April 2023

Supported by:

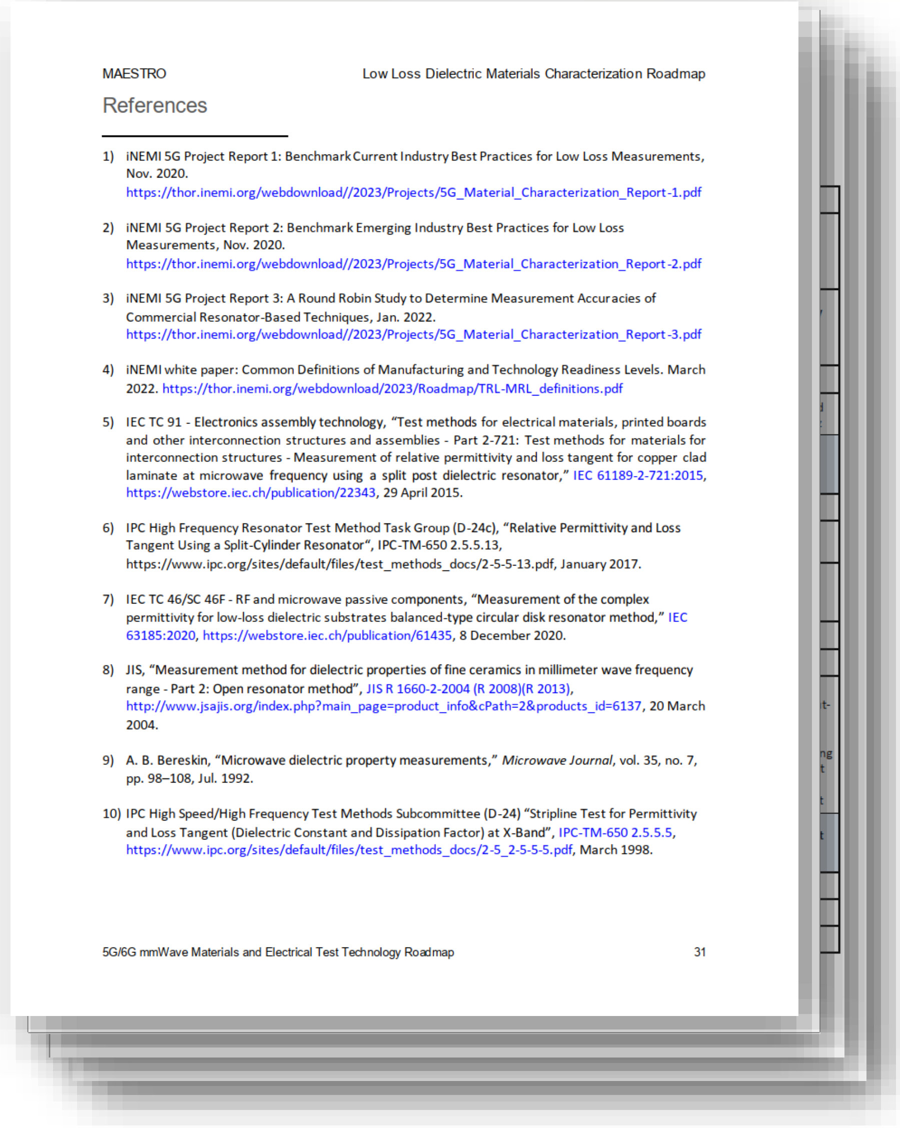
National Institute of Standards and Technology (NIST)
Office of Advanced Manufacturing
FEDERAL AWARD ID NUMBER: 70NANB22H050

Principal Investigator: Urmi Ray, iNEMI (urmi.ray@inemi.org)

Accelerate Innovation

The Roadmap Document

- Many details – 32 pages
- Detailed overview of primary methods
- Specific details about the key challenge areas
- Discussion of potential known & unknown solutions
- Technical readiness vs time estimates
- References
- Focus: Low loss substrate materials


MAESTRO Low Loss Dielectric Materials Characterization Roadmap

References

1) iNEMI 5G Project Report 1: Benchmark Current Industry Best Practices for Low Loss Measurements, Nov. 2020. https://thor.inemi.org/webdownload//2023/Projects/5G_Material_Characterization_Report-1.pdf

2) iNEMI 5G Project Report 2: Benchmark Emerging Industry Best Practices for Low Loss Measurements, Nov. 2020. https://thor.inemi.org/webdownload//2023/Projects/5G_Material_Characterization_Report-2.pdf

3) iNEMI 5G Project Report 3: A Round Robin Study to Determine Measurement Accuracies of Commercial Resonator-Based Techniques, Jan. 2022. https://thor.inemi.org/webdownload//2023/Projects/5G_Material_Characterization_Report-3.pdf

4) iNEMI white paper: Common Definitions of Manufacturing and Technology Readiness Levels. March 2022. https://thor.inemi.org/webdownload/2023/Roadmap/TRL-MRL_definitions.pdf

5) IEC TC 91 - Electronics assembly technology, "Test methods for electrical materials, printed boards and other interconnection structures and assemblies - Part 2-721: Test methods for materials for interconnection structures - Measurement of relative permittivity and loss tangent for copper clad laminate at microwave frequency using a split post dielectric resonator," IEC 61189-2-721:2015, https://webstore.iec.ch/publication/22343, 29 April 2015.

6) IPC High Frequency Resonator Test Method Task Group (D-24c), "Relative Permittivity and Loss Tangent Using a Split-Cylinder Resonator", IPC-TM-650 2.5.5.13, https://www.ipc.org/sites/default/files/test_methods_docs/2-5-5-13.pdf, January 2017.

7) IEC TC 46/SC 46F - RF and microwave passive components, "Measurement of the complex permittivity for low-loss dielectric substrates balanced-type circular disk resonator method," IEC 63185:2020, https://webstore.iec.ch/publication/61435, 8 December 2020.

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9) A. B. Bereskin, "Microwave dielectric property measurements," *Microwave Journal*, vol. 35, no. 7, pp. 98–108, Jul. 1992.

10) IPC High Speed/High Frequency Test Methods Subcommittee (D-24) "Stripline Test for Permittivity and Loss Tangent (Dielectric Constant and Dissipation Factor) at X-Band", IPC-TM-650 2.5.5.5, https://www.ipc.org/sites/default/files/test_methods_docs/2-5_2-5-5-5.pdf, March 1998.

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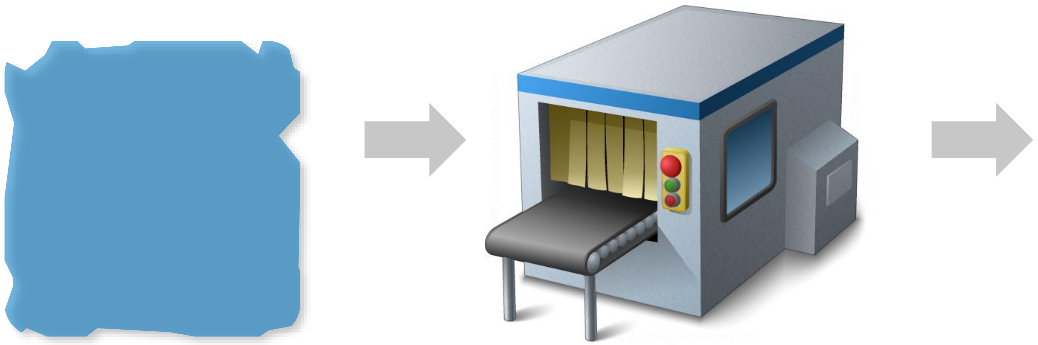
Key Contributors:

NIST National Institute of Standards and Technology, intel, iNEMI International Electronics Manufacturing Initiative, KEYSIGHT TECHNOLOGIES, 3M, DUPONT, AIMED, NOKIA, ITRI Industrial Technology Research Institute

Team Members:

AMD, Applied Materials, Binghamton University, Dell, Dow, Dupont Ectron Corporation, Florida International University, Georgia Tech, IBM, liloTree, Mosaic Microstystems, Nantero, Penn State University, Qorvo, TechSearch International, 3DGS and others

Ideal Future End Point – Permittivity Measurements



Non-Ideal Sample

$$[\varepsilon_r\ \delta]\hat{x}$$
$$\varepsilon_r\ \delta$$
$$[\varepsilon_r\ \delta]\hat{z}$$

Across Frequency
Across Temperature

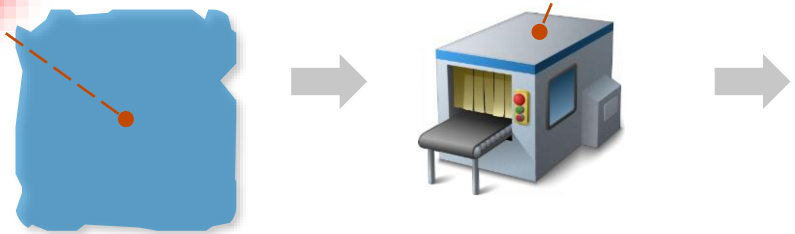
- Accurate
- Easy to use
- Wide sample geometries
- Insensitive to sample thickness & surface variations
- Fast / Compatible with humidity-soaked samples
- Turn-key

Today’s Common Tools – The Problems

Methods generally sensitive to non-ideal samples

Multiple tools, methods, vendors required

Different sample requirements, different tools



Non-Ideal Sample

$$\left.\begin{matrix}[\varepsilon_r\ \delta]\ \hat{x}\\ [\varepsilon_r\ \delta]\ \hat{y}\\ [\varepsilon_r\ \delta]\ \hat{z}\end{matrix}\right\}$$

Across Frequency
Across Temperature

No way to assess accuracy

- Accurate
- Easy to use
- Wide sample geometries
- Insensitive to sample thickness & surface variations
- Fast / Compatible with humidity-soaked samples
- Turn-key

Some difficult to use

Very specific geometries required by most tools

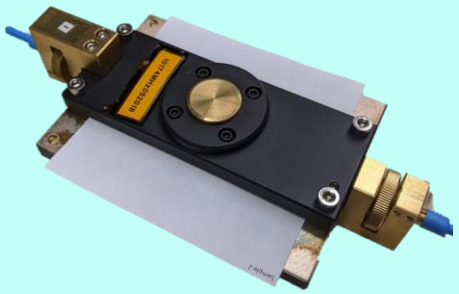
Highly sensitive to sample thickness & surface details

Many too slow

Few simple options

Average In Plane Methods

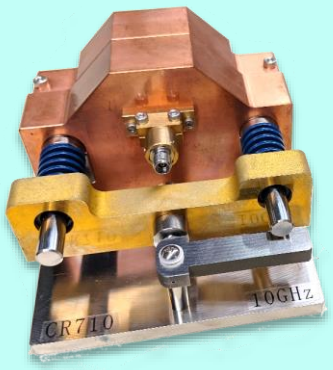
Split Post Dielectric Resonator



Features
- Simple to use
- Fast
- Thin & thick sample
- Environmental conditions

Limitations
- Limited to ~20GHz
- ~1:1 error with thickness error
- No detection of anisotropy

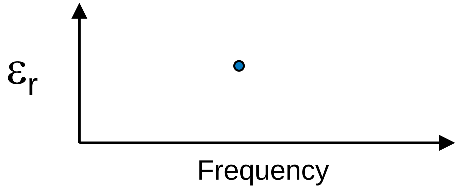
Split Cylinder Resonator



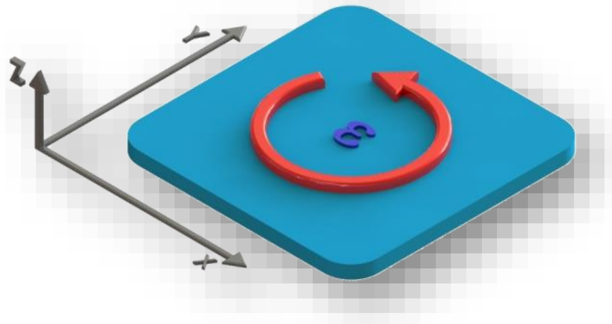
Features
- Simple to use
- Fast

Limitations
- Limited to ~80GHz
- Temperature sweeps difficult in industry*
- ~1:1 error with thickness error
- Requires thinner samples
- No detection of anisotropy

Single frequency per device



Provides average in-plane permittivity



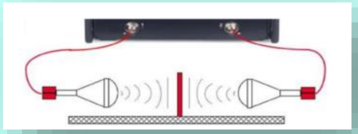
Linear In-Plane Methods

Fabry Perot Open Resonators

Features
- Span 20-200+GHz
- Ability to detect in plane anisotropy

Limitations
- Impractical for Temperature / Environmental
- ~1:1 error with thickness error*

Other



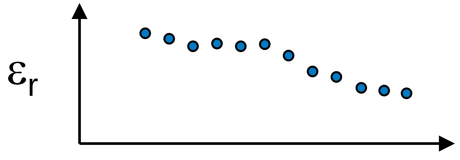
Free space methods

Rectangular cavity / Waveguides

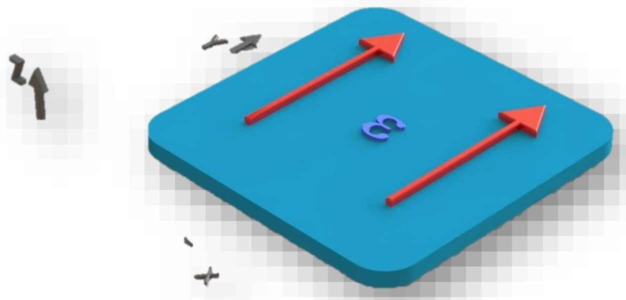
Features - Varied
- Potential ability to detect in plane anisotropy

Limitations
- Mostly home made / not turn-key
- Varying quality & performance
- Limitations for frequency & loss

Multiple frequencies per device

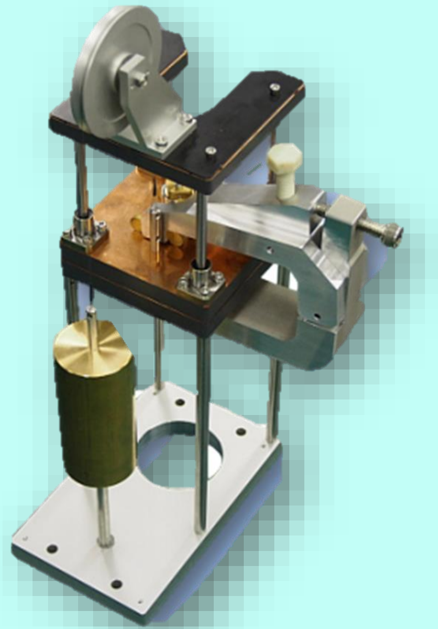


Provides linear in-plane permittivity



Out of plane

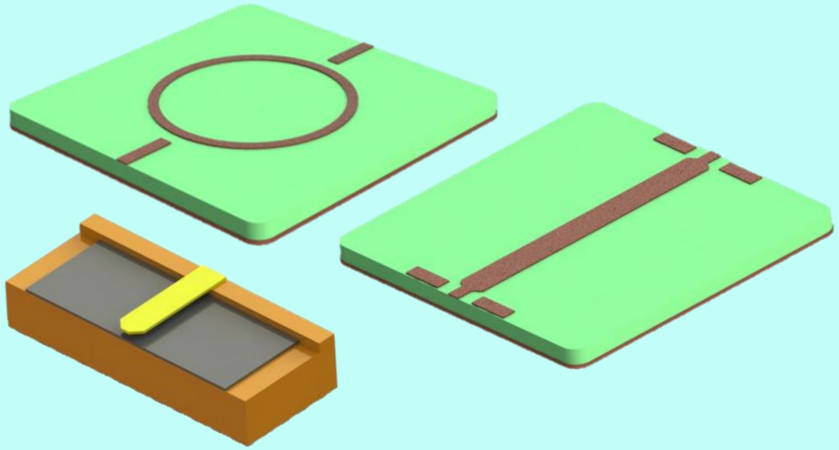
Balanced Circular Disk Resonator



Features
- Span to 120 GHz +

Limitations
- Challenging setup
- Requires 2 matched samples
- User variability

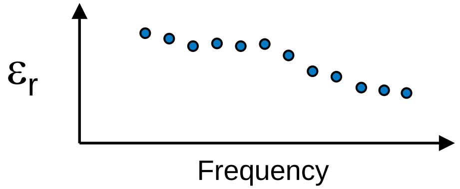
Transmission Line Methods



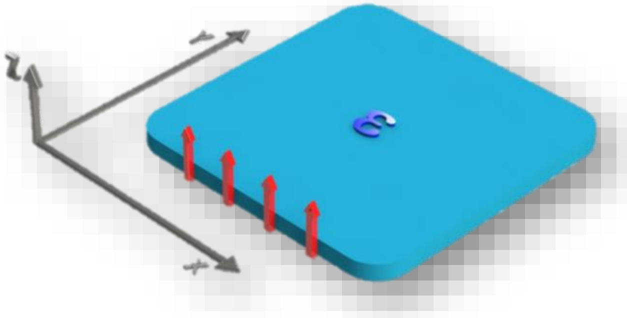
Features
- Abstracts details to empirical parameter

Limitations
- Low accuracy
- Limited to larger loss tangent values
- Fabrication required (typically)
- Not strictly out of plane

Multiple frequencies per device

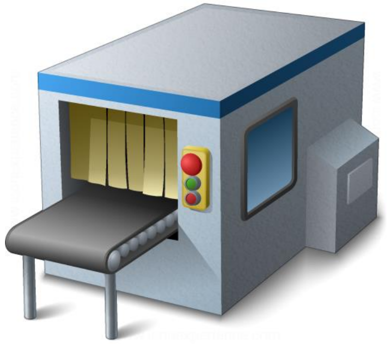


Provides out of plane permittivity



Challenge Vectors

- Sample Ideality
- Thickness Measurement
- Anisotropy
- Thermal / Humidity Compatibility
- Frequency Range
- Traceable Reference Standards



Ideal Tool

Recommendation: Pick a vector and work on it

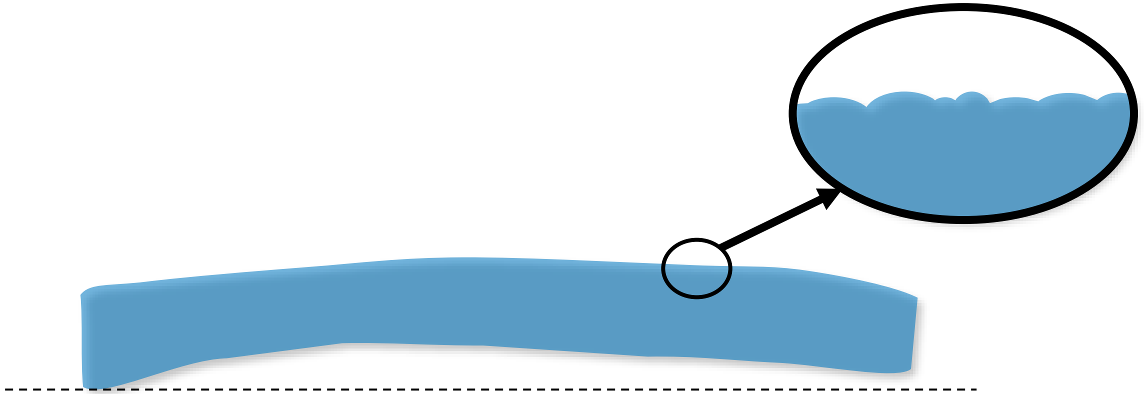
Improving any individual vector has huge value

Ideal tool may not be possible

Key Challenge – Realistic samples

Sample Ideality

Today's assumptions:
- Uniform thickness
- Flat surfaces
- No bows
- Known thickness



Realistic samples:
- Thickness variations
- Bow
- Surface features
- Thickness definition

Ideal Tool:
- Insensitive to imperfections

or
- Capable of corrections for imperfections

10-20 μm imperfections are significant portion of a 100um thick sample

Key Challenge – Anisotropic materials

$\overrightarrow{XYZ}$ Anisotropy

Today

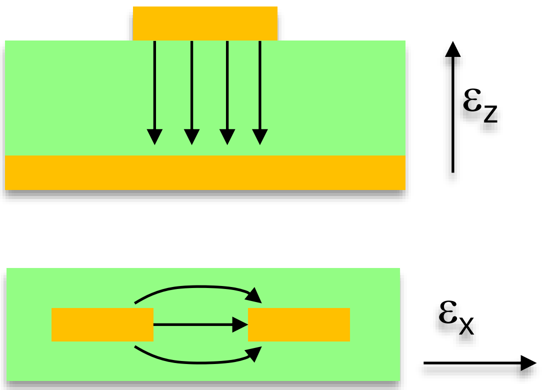
- Different tools required
- Incompatible samples
- Varying accuracy
- Complicated process
- Impractical

Future Needs

- Fundamentally new methods
- Cross tool sample compatibility
- Turnkey / ease of use

Why we care:

- Many real materials are anisotropic
- Impacts design targets



Ideal Tool:

- Single tool provides

  εx, εy, εz

- Same sample
- Retains accuracy

Future designs will take advantage of accurate anisotropic characterization

Key Challenge – Environmental Conditions

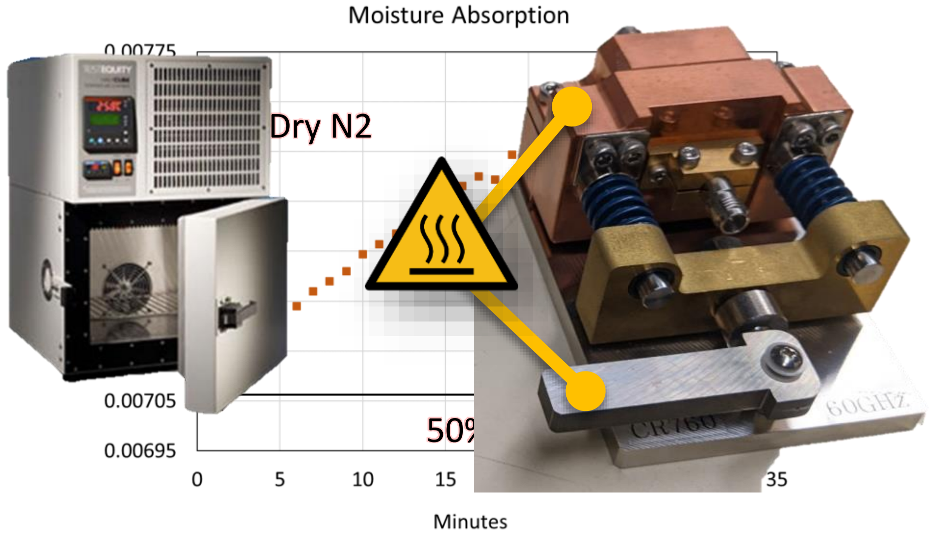
Thermal / Humidity Compatibility

Today

Limited Tool Sets
- Temperature – very limited
- Humidity – fast measurements only
- Home grown setups
- Increased errors

Future Needs

Expanded Tool Sets
- Evolutionary design changes
- Easier temperature support
- Fast data collection / humidity
- Turnkey / ease of use
- Operator safe / EHS ready



Ideal Tool
- No / Low operator interaction
- Compatible with temperature
- Fast
- Turnkey

Precise knowledge of environmental effects improve design choices

Key Challenge – Lack of traceable standards

Traceable Reference Standards

Today

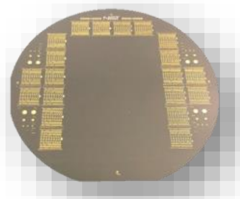
Wild West
- No trusted accuracy
- Literature based references
- Tool vendor variations
- Left to user to handle
- Two 1% tools are 6% apart

Near Future

NIST Traceable Standard
- ε_r δ @ 28 GHz
- Compatibility with common tools
- Standards adopted by tool vendors
- Used by advanced users

Future Needs

Multiple Traceable Standards
- Span to 100+ GHz
- Widely used for calibration
- Used by non-experts



Lack of traceable standards hinders development, reduces accuracy

Summary: Research Is Needed

- Revolutionary ideas required
- Lots of opportunities for graduate student projects
- Think about industry needs

Thanks to everyone who participated in the creation of this roadmap!

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