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

WP3 Report: Implementation Strategy

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https://www.inemi.org/maestro
Roadmap contributors are leaders in this field from industry, universities and research institutes.

For further information and to get involved, please contact Dr. Urmi Ray (urmi.ray@inemi.org)
Project Objective

Create a technology roadmap

- Develop a comprehensive 10-year hardware roadmap for mmWave materials development & electrical characterization and testing.

Develop a U.S.-focused implementation strategy

- Recommend a U.S.-centric, cross-supply-chain consortium to execute the vision of the roadmap, the foundations for a strong U.S. manufacturing ecosystem in RF materials and testing.
- Promote the growth of a strong and diverse U.S. workforce in RF communication technologies, by proposing a plan of university curricula development and training.
5G/6G MAESTRO: Technology Scope

110GHz-170GHz (D-Band), 220-350GHz (G Band)

- mmWave frequency bands
- Roadmap materials to meet functional requirements on the loss tangent and dielectric constant
- Mechanical and thermal properties in scope
- Constraint: right cost-point & manufacturability at scale

- Identify techniques for repeatable fast low-loss material characterization
- Address lack of standard reference materials (SRM)
- Propose cross-industry approaches, enabling cross-supplier comparisons

- Transition from contact testing to over-the-air testing, particularly with pervasive use of massive MIMO at mmWave frequencies
- Consider changes in RF front-end packaging, including emergence of antenna-in-package technology
- Scaling up from lab-level testing to high-volume manufacturing environments
iNEMI 5G/6G MAESTRO: Project Flow

5G/6G Maestro

- Market survey
- Design Analysis
- Materials Landscape
- E-Test Landscape
- WP1: Tech & Market Assessment
- WP2: Roadmap Generation
- Proof of concept white paper
- Location, Budget
- WP3: Implementation Strategy
- Dissemination: Webinar, Conferences, Technical Papers, Community college/University curricula

5G RF Cluster Manufacturing Institute
WP3 Update
<table>
<thead>
<tr>
<th>Need, Challenges and Potential solutions</th>
<th>Challenges</th>
<th>Potential Solutions</th>
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<tbody>
<tr>
<td>Massive Capacity and Performance</td>
<td>High pathloss and sensitivity to beam blockages Molecular Absorption</td>
<td>Spatial multiplexing in base stations and point-point links 3D Beamforming</td>
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<td>Active Device Performance</td>
<td>Managing Gain over broadband</td>
<td>New III-V devices; Innovations in Scalability of device integration; e.g, III-V on Silicon; CNT-FET Ultra Wideband filters</td>
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<tr>
<td>Packaging &amp; Integration</td>
<td>Extreme miniaturization High part complexity Low loss materials development and characterization</td>
<td>2.5D/3D Heterogeneous integration Ultra low loss materials/Metamaterials 3D RFFE</td>
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<td>Antenna &amp; Antenna Subsystems</td>
<td>High Performance</td>
<td>AIP (Antenna in Package), Antenna on Chip (AoC) Reconfigurable Intelligent Surfaces (RIS)</td>
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<td>Thermal</td>
<td>Thermal management at high heat flux densities</td>
<td>New TIM materials Active and Passive cooling Single and double sided cooling</td>
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<td>Electrical test</td>
<td>Cost effective manufacturable test across frequency range</td>
<td>Design for Test, RF BIST and Boundary scan; Chip level self calibration and repair System level test OTA (over the air test)</td>
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<td>Design and Simulation</td>
<td>Co-Design tools</td>
<td>ML based solutions for tool time optimization</td>
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Implementation Strategy Based on Roadmap Highlights

• Ultra Low Loss Materials Characterization Team:
  • Project team under the auspices of iNEMI
  • Developing a “permittivity” standard reference material (further details in following pages)
  • Handing off to NIST for SRM development in 2024

• Packaging, Integration including Antenna Subsystem
  • Teams launched exploring pre-competitive R&D and prototyping to augment US leadership:
  • ASIC (www.asicoalitions.org) – Advanced Packaging team: Advanced SIP Coalition of Excellence
  • Mid Atlantic Semiconductor Hub (MASH): Preparing proposal for Manufacturing USA Institute
IMPLEMENTATION STRATEGY

Ultra Low Loss Materials Characterization
Motivation:
- 5G Solutions require ultra-low loss laminate materials and PCBs/substrates for efficient design of 5G communications equipment. Industry needs for standardized measurement methods were addressed by a 26-member iNEMI team in 2020-21
- https://community.inemi.org/content.asp?contentid=639
- The results identified an urgent need for the development of reference material that can be used reliably for low loss material measurements using commercially available tools

Objective:
- Develop reference material for consistent Df/Dk measurement methodologies for characterizing ultra low loss laminate materials in the range of 30 – 100GHz

Strategy/Approach:
- Identify candidate material(s)
- Develop methodology of characterization and validation at NIST using on wafer techniques and other metrology
- Validate across industry
- Hand off to NIST for SRM (Standard Reference Material) process

Status:
- Co-Chairs : Nate Orloff (NIST), Michael J. Hill (Intel)
- Project on schedule for completion 1Q’24 and hand off to NIST for SRM development
Co-Project Leads:
  • Nate Orloff (NIST),
  Michael J Hill (Intel)

iNEMI Project Lead:
  • Urmi Ray

Project Team:
  • Intel
  • NIST
  • Keysight
  • QWED
  • 3M
  • ITRI
  • AGC-MM
  • Dupont
  • Dell
  • Nokia
  • Panasonic
  • Resonac
  • Mosaic Microsystems
  • Georgia Tech
  • Zestron USA
  • SyTech

Communication Methodology:
Small Technical Working Group (TWG) meet weekly
Project Team Meetings Monthly (or as needed)
Project Timeline

Development activities

- 1st Proof of concept (POC) construction
- Multi lab testing of 1st POC
- Dimensional traceability & analysis
- 2nd POC construction
- Multi lab testing of 2nd POC
- End of project
- *NIST Formalization of SRM / International approval*

Project Completion Target: 1Q’24 AHEAD OF SCHEDULE
The Timeline

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We are here

Finding:
- 130µm FS w/o Healing etch might be too fragile
- 150µm HPFS +Healing etch reduces breakage to acceptable levels

NIST continues on certification path

- NIST Optical tool operational, needs certification
- NIST Computation and error study & validation ongoing
- Optical tool capable of processing sample volumes
- 150µm HPFS +Healing etch reduces breakage to acceptable levels
IMPLEMENTATION STRATEGY

Packaging, Integration including Antenna Subsystem
MASH: MUSA Proposal: Glass Packaging for THz Applications

• Led by Penn State University (Prof M. Swaminathan)

Mid-Atlantic Semiconductor HUB (MASH)
Manufacturing USA Institute
HUB & SPOKE Model

- Innovate through the spokes
- Prototype through the HUBS
- Scale to manufacturing through the pilot lines
- Enable wide outreach for Workforce Development
MASH: MUSA Proposal: Glass Packaging for THz Applications

Manf. USA Institute – What needs to happen ....

- Glass core substrates: Surface roughness, CTE, modulus, moisture absorption like Si but dielectric insulator and large area (500mm) to reduce cost.
- 10um/20um pitch through core vias with 20:1 aspect ratio
- 10um L/S (mmWave)
- 8+ Metal Layers
- 1um L/S with good adhesion (mixed signal)
- No cracking or delamination

Low Dk (3.0), Low Df (10^-4)
dielectrics; 5-100 um thick
Air Dielectrics

Antenna in Package
Patch/Slot antennas
Base station / Handset

Through & Blind Cavities
CMOS/InP 75-150um die thickness
<1dB loss

Thermal Insulator (1W/mK)
Thermal Mgmt (>400W/mK)

End User
EDA Optimization
Substrate
Assembly & Test
Equipment Manf. Materials

Supply Chain Eco-

System needs to come together

Courtesy: SIP RF Team, ASIC

PennState
College of Engineering
ELECTRICAL ENGINEERING
AND COMPUTER SCIENCE

June 30, 2023
MASH: MUSA Proposal: Glass Packaging for THz Applications: Teams

- **System Drivers, Applications & Exemplars:** Keren Bergman (Columbia) & Tim Lee (Boeing)
- **EDA & Co-Design:** Vijay Narayanan/Madhavan Swaminathan (Penn State) & Industry (Cadence, Synopsys)
- **Glass Core & TGV:** John Mauro (Penn State) & Jeb Fleming (3DGS)
- **Metrology:** Mike Lanagan (Penn State) & Industry (Anritsu)
- **Glass core & TGV metallization:** Univ. (?) & Industry (MKS, KOTO)
- **Panel Scale PVD:** Univ (?) & Evatec
- **Dry film Dielectrics:** Univ. (?) & Industry (Ajinomoto)
- **Photoimageable dielectrics & processes:** Univ (?) & Industry (Taiyo Ink)
- **Fine pitch Assembly:** Univ (?) & Industry (KNS, Sunray Scientific)
- **Glass based MEMS sensors:** Daniel Lopez (Penn State) & Aric Shoney (Menlo Microsystems)
- **Semiconductor Tools (Laser, Maskless Lithography, Pick/Place, Dicing, ...):** Univ (?) & Industry (AMAT)
- **Reliability:** Abhijit Dasgupta (UMD) & Industry (?)
- **Security:** Sundeep Rangan/Ramesh Karri (NYU) & Industry (?)
- **Thermal:** Herschel Pangborn (Penn State) & Industry (?)
- **RDL Process:** Madhavan Swaminathan (Penn State) & Jeb Fleming (3DGS)
- **Electrical Test:** Krish Chakraborty (ASU) & Industry (?)
- **Digital Twin:** Rahul Panat (CMU) & Industry (Lam Research)
- **Power Management:** Madhavan Swaminathan (Penn State) & Bud Fischer (Ferric)/Matt Wilkowski (enachip)
- **E-Less and Electroplating:** Univ. (?) & Industry (Chemcut, Atotech)
- **Photonics:** Univ. (?) & Industry/MUSA (AGC, AIM Photonics)
- **Workforce Development:** Osama Awdelkarim (Penn State) & Urmi Ray (iNEMI)
- **Supply Chain:** SoundarKumara (Penn State) & Urmi Ray (iNEMI)
5G Semiconductor And Package Integration Challenges for mmWave

- New Materials, Packaging and Testing Needs
- Complexity of challenges including architecture to overcome losses (including hybrid beamforming)
- Collaborative pre-competitive approaches are needed
  - Roadmap Implementation strategies being discussed with multiple organizations
- Many new areas of research are emerging – opportunities for ground-breaking research and development
Acknowledgement

MAESTRO Team
NIST Office of Advanced Manufacturing

https://www.inemi.org/maestro