Highlights from the iNEMI Thermal Management Technology Roadmap

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iNEMI
Objectives

• Introduction to iNEMI does
• Overview of what's happening in the electronics manufacturing industry
• Highlights from the Thermal Management Roadmap chapter
  – Portable consumer
  – High end Systems
  – Netcom
  – LED
  – Power electronics
  – Automotive
  – Medical
About iNEMI


5 Key Deliverables:
• Technology Roadmaps
• Collaborative Deployment Projects
• Research Priorities Documents
• Proactive Forums
• Position Papers

International Electronics Manufacturing Initiative (iNEMI) is an industry-led consortium of over 100 global manufacturers, suppliers, industry associations, government agencies and universities. Working on advancing manufacturing technology since 1994.

Visit us at www.inemi.org.
iNEMI Methodology

Roadmap

- GAP Analysis/Technical Plan
- Competitive Solutions
- Projects
- Research
- Government
- Academia
- Disruptive Technology
- Product Needs
- Technology Evolution
- Available to Market Place
- Project Completion
- Industry Solution Needed
- No Work Required or Outsourced
- Global Participation

Implementation

iNEMI Members

Advancing manufacturing technology
Benefits of a Roadmap

- Assessment of where the industry is at

- Identification of where we/industry want to be

- Comparison of various technology paths

- Clarification on what is needed to get there

- Visibility to what is happening – the sooner the better

- Communication to the industry and along the supply chain is enhanced

- Define where collaboration and/or innovation is necessary
• > 650 participants
• > 350 companies/organizations
• 18 countries from 4 continents
• 20 Technology Working Groups (TWGs)
• 6 Product Emulator Groups (PEGs)
• > 8 Man Years of Development Time
• > 1900 pages of information
• Roadmaps the needs for 2013-2023
iNEMI Roadmap Biannual Process
21 Technology Working Groups (TWGs)

- Modeling, Simulation, and Design
- Solid State Illumination
- Large Area, Flexible Electronics
- Semiconductor Technology
- Photovoltaics
- Ceramic Substrates
- Organic PCB
- Information Management Systems
- Connectors
- MEMS/Sensors
- Packaging & Component Substrates
- RF Components & Subsystems
- Passive Components
- Optoelectronics
- Mass Storage (Magnetic & Optical)
- Energy Storage & Conversion Systems
- Test, Inspection & Measurement
- Thermal Management
- Environmentally Conscious Electronics

Red=Business  Green=Engineering  Purple=Manufacturing  Blue=Component & Subsystem

Advancing manufacturing technology
# Roadmap Development

## Product Sector Needs Vs. Technology Evolution

<table>
<thead>
<tr>
<th>TWGs (20)</th>
<th>Product Emulator Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semiconductor Technology</td>
<td></td>
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<tr>
<td>Business Processes</td>
<td>Portable / Consumer</td>
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<tr>
<td>Prod Lifecycle Information Mgmt.</td>
<td>Office Systems</td>
</tr>
<tr>
<td>Design Technologies</td>
<td>Defense and Aerospace</td>
</tr>
<tr>
<td>Modeling, Thermal, etc.</td>
<td>Medical Products</td>
</tr>
<tr>
<td>Manufacturing Technologies</td>
<td>Automotive</td>
</tr>
<tr>
<td>Board Assy, Test, etc.</td>
<td>High-End Systems</td>
</tr>
<tr>
<td>Comp./Subsyst. Technologies</td>
<td></td>
</tr>
<tr>
<td>Packaging, Substrates, Displays, etc.</td>
<td></td>
</tr>
</tbody>
</table>
Thirteen Contributing Industry Organizations

Semiconductors

iNEMI / MIG / ITRS / PSMA Packaging TWG

Interconnect Substrates—Ceramic

iNEMI / MIG / ITRS MEMS TWG

Organic Printed Circuit Boards

iNEMI / IPC / EIPC / TPCA Organic PWB TWG

Supply Chain Management

iNEMI Information Management TWG

Supply-Chain Council

iNEMI Roadmap

Magnetic and Optical Storage

iNEMI Optoelectronics TWG

Optoelectronics and Optical Storage

iNEMI Mass Data Storage TWG

Optoelectronics and Optical Storage
Ease of use Improvements Drive Growth

User Interface + Smaller Form Factor + Lower Prices + New Services

Source: Morgan Stanley Estimates
Consumer Segment has been driving Technology Changes

- Smart phones dominated unit volume growth for portable products, and the overall market volume growth has been driving other areas:
  - Increased focus on shrinking form factor and low power
  - High level of integration (SoC, SiP)
  - 3D packaging and Embedded Die market leaders
    - Significant focus on sustainability, eco-design and recycling
    - The MEMS/sensor technology for unleashing entertainment, medical, and security as well as perceptual computing

- Convergence of Entertainment, Computing, Communication drives integration
  - The world of OS and applications and middleware challenges, will drive major shifts and consolidations to enable seamless computing and interoperability
  - The pace of product enhancements is growing rapidly.
Overall Key Trends

• **Convergence**
  – Medical-Consumer
  – Automotive-Entertainment
  – Communication-Entertainment
  • Telecom-Datacom

• **Infrastructure (Business Model) changes:**
  – Fabless Semiconductor Fabrication
  – Redundant Elements
  – EMS and ODM roles grow; R&D Challenges

• **Quality, reliability, cost still paramount**

• **Counterfeit Products a growing issue**

• **Miniaturization and Thinner; Speed of Change Escalating**

• **Product Personalization**

• **Rare Earth and Conflict Materials**

• **Carbon foot printing is becoming a requirement**

• **Energy Storage**
  – Growth in Consumer electronics
  – New transportation market
  – Future opportunity for smart grid
Strategic Concerns

• Restructuring from vertically integrated OEMs to multi-firm supply chains
  – Resulted in a disparity in R&D Needs vs. available resources

• Critical needs for R&D
  – Middle part of the Supply Chain is least capable of providing resources

• Industry collaboration
  – Gain traction at University R&D centers, Industry consortia, “ad-hoc” cross-company R&D teams

• The mechanisms for cooperation throughout the supply chain must be strengthened.
  – Cooperation and risk sharing among OEMs, ODMs, EMS firms and component suppliers is needed to focus on the right technology and to find a way to deploy it in a timely manner
Paradigm Shifts

• Need for continuous introduction of complex multifunctional products to address converging markets favors modular components or SiP (2-D & 3-D):
  – Increases flexibility
  – Shortens design cycle

• Cloud connected digital devices have the potential to enable major disruptions across the industry:
  – Major transition in business models
  – New Power Distribution Systems for Data Centers
  – Huge data centers operating more like utilities (selling data services)
  – Local compute and storage growth may slow (as data moves to the cloud)
  – “Rent vs. buy” for software (monthly usage fee model)

• Rapid evolution and new challenges in energy consuming products such as SSL, Automotive and more

• Sensors everywhere – MEMS and wireless traffic!

• “More Moore” (scaling of pitch) has reached its forecast limit and must transition to heterogeneous integration - “More Than Moore”. 
Devices are getting more complex

Moore’s Law & More

More than Moore: Diversification
More Moore: Miniaturization
Combining SoC and SiP: Higher Value Systems
Baseline CMOS: CPU, Memory, Logic

130nm
90nm
65nm
45nm
32nm
22nm
...

Information Processing
Digital content System-on-chip (SoC)

Interacting with people and environment
Non-digital content System-in-package (SiP)

Functional Diversification (More than Moore)

Scaling (More Moore)
[Geometrical & Equivalent scaling]

Beyond CMOS

Beyond CMOS

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Situation Analysis: Technology
Consumers’ demand for thin multifunctional products has led to increased pressure on alternative high density packaging technologies.

• High-density 3D packaging has become the major technology challenge
• SiP:
  – Technology driver for small components, packaging, assembly processes and for high density substrates
• New sensors and MEMs:
  – Expected to see exponential growth driven by portable products
  – Motion gesture sensors expanding use of 2D-axis & 3D-axis gyroscopes
  – Segment maturing, encouraging industry collaboration
• 3D IC with TSV:
  – Driven by Performance and Size requirements
## IC PACKAGE GROWTH

<table>
<thead>
<tr>
<th></th>
<th>2011 Units (Bn)</th>
<th>2012 Units (Bn)</th>
<th>2012/2011</th>
<th>2017 Units (Bn)</th>
<th>CAAGR 2012 – 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIP/SOT</td>
<td>4.3</td>
<td>4.1</td>
<td>-4.7%</td>
<td>4.0</td>
<td>-0.5%</td>
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<tr>
<td>SO/TSOP/SOT</td>
<td>78.5</td>
<td>76.8</td>
<td>-2.2%</td>
<td>94.0</td>
<td>4.1%</td>
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<tr>
<td>QFP/LCC</td>
<td>18.3</td>
<td>17.5</td>
<td>-4.4%</td>
<td>21.5</td>
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<tr>
<td>QFN</td>
<td>20.5</td>
<td>19.8</td>
<td>-3.4%</td>
<td>31.5</td>
<td>9.7%</td>
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<tr>
<td>Wire Bond CSP</td>
<td>8.1</td>
<td>7.4</td>
<td>-8.6%</td>
<td>10.2</td>
<td>6.5%</td>
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<tr>
<td>Stacked CSP</td>
<td>6.7</td>
<td>6.9</td>
<td>3.0%</td>
<td>10.5</td>
<td>8.8%</td>
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<tr>
<td>BOC/DRAM</td>
<td>13.5</td>
<td>12.5</td>
<td>-7.4%</td>
<td>6.0</td>
<td>-13.7%</td>
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<tr>
<td>Wire Bond BGA</td>
<td>1.1</td>
<td>1.0</td>
<td>-9.1%</td>
<td>0.8</td>
<td>-4.4%</td>
</tr>
<tr>
<td>COB (Wire Bond)</td>
<td>10.7</td>
<td>11.4</td>
<td>6.5%</td>
<td>15.8</td>
<td>6.7%</td>
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<tr>
<td>Flip Chip CSP</td>
<td>1.3</td>
<td>2.3</td>
<td>84%</td>
<td>5.7</td>
<td>19.9%</td>
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<td>Flip Chip BOC/DRAM</td>
<td>0.2</td>
<td>0.7</td>
<td>250%</td>
<td>7.7</td>
<td>61.5%</td>
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<tr>
<td>Flip Chip BGA/PGA/LGA</td>
<td>1.1</td>
<td>1.1</td>
<td>-7.5%</td>
<td>1.3</td>
<td>3.5%</td>
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<tr>
<td>DCA Flip Chip</td>
<td>5.5</td>
<td>5.5</td>
<td>0.0%</td>
<td>9.5</td>
<td>11.6%</td>
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<td>Wafer CSP (FC)</td>
<td>9.0</td>
<td>9.8</td>
<td>8.9%</td>
<td>19.2</td>
<td>14.4%</td>
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<tr>
<td>COG</td>
<td>4.6</td>
<td>4.9</td>
<td>6.5%</td>
<td>7.5</td>
<td>8.9%</td>
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<tr>
<td>COF</td>
<td>3.3</td>
<td>3.2</td>
<td>-3.0%</td>
<td>3.5</td>
<td>1.8%</td>
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<tr>
<td>Subtotal Wire Bond</td>
<td>161.7</td>
<td>157.4</td>
<td>-2.7%</td>
<td>200.0</td>
<td>4.9%</td>
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<tr>
<td>Subtotal Flip Chip</td>
<td>25.0</td>
<td>27.5</td>
<td>9.9%</td>
<td>50.9</td>
<td>13.1%</td>
</tr>
<tr>
<td><strong>IC TOTAL</strong></td>
<td><strong>186.7</strong></td>
<td><strong>184.8</strong></td>
<td><strong>-1.0%</strong></td>
<td><strong>250.8</strong></td>
<td><strong>6.3%</strong></td>
</tr>
</tbody>
</table>
3D Integration potential Roadmap

3D Packaging (No TSV)
- 3D Stacking (wirebonds)
  - CMOS image sensor with TSV
  - CMOS image sensor with DSP and TSV

3D IC Integration
- C2C/C2W/W2W; microbump bonding; 5 ≤ TSV ≤ 30μm; 20 ≤ memory stack ≤ 50μm; 100 ≤ interposers ≤ 200μm
- Memory (50μm) with TSV and microbump
- 32 memory (20μm) stacked
- Active TSV Interposer (e.g., Memory on Logic with TSVs)
- Passive TSV interposer to support high-performance chips

3D Si Integration W2W
- pad-pad bonding (TSV ≤ 1.5μm)
- Cu-Cu bonding
- SiO2-SiO2 bonding

Low Volume Production
- 2008
- 2010
- 2012
- 2011-13
- 2013-15
- 2015-17

Mass Production
- Don’t care to guess!

Don’t care to guess!

Low volume production = only a handful of companies are SHIPPING it; Mass production = many companies are SHIPPING it.
Technologies Enabling 3D Integration

- Through Silicon Via – active wafer & interposers
- Two side wafer level Processes
  - RDL and MicroBumping
- Embedded Components (active & passive)
- Wafer thinning & Handling
- Wafer to Wafer Bonding
- Die to Wafer Bonding
- Micro bump assembly
- Design Tools
- Micro fluidics Cooling
- Assembly of TSV die
- Test of TSV Die
Thermal Management Challenges in Key market areas
Primary Contributors

• Azmat Malik, Acuventures, (Chair)
• Mikhail Spokoyny, Cool Technology Solutions, San Diego
• Eckhard Wolfgang, European Center for Power Electronics/Professor
• Sherwin Kahn, Alcatel-Lucent
Thermal Management

• Demand for more effective and cost efficient ways of removing heat from electronics systems continues to grow

• Cooling cost are typically a small percentage of total system cost

• Not always considered until late in the design stage

• What technology used depends on systems power and the financial budget available

• Also constrained by market and application requirements

• Recognition that reducing system power will reduce the requirements of the thermal management solution and as well as direct and indirect energy savings

• ideally it will Invisible, inexpensive and immortal
Common Needs Across all Markets

- Improved thermal interfaces
- Improved thermal spreaders
- High performance air cooling solutions
- Advanced modeling tools
- 3D designs cooling
Some Key trends noted in 2013 Roadmap

• Expanded adoption of multicore CPUs helps lower the thermal impact of high performance devices

• Seeing the growth of and focus on power electronics
  – renewable energy sector and development of eVehicles

• Cost and time to markets are becoming more sensitive in all product sectors thus enhanced thermal design tools are critical to
  – Integration of electrical, thermal fluid flow and mechanical analysis and simulation in one user friendly package
Produced in high volumes, cost is the primary driver, handheld battery powered products are also driven by size and weight reduction.
Portable/Consumer

- Limited by battery and size constraints
- Major shift from single die to 3D packaging
- Reliability not critical
Portable Consumer - challenges

• Aggressive packaging technologies are challenging the thermal management - demanding new materials development and modelling tools

• Stacked die are not good from a thermal management perspective

• Future Gaps/challenges:
  – Additional functionality will have impact on thermal performance - Advent of streaming HDTV may have to use micro pumps and micro fans
High End

Products that serve the high performance computing/storage markets including networking, datacom and telecom and cover a wide range of cost and performance targets.
High End systems challenges

• Overall systems power is key
• Thermal solutions that add to the platform power are not attractive
• Now systems availability required 100% of time – achieved through redundancy and more monitoring
• Junction temperature will be required to be 70 deg. C

• Gaps/ challenges:
  • Improved heat transfer path
  • More efficient heat sinking: high fin density; air flow across the heat sink, use of water cooled plates
  • Liquid cooling applications
High End systems - Developments

- Thermal integration with EMC shielding
- Low cost, compact and reliable water cooling
- Low cost, compact, reliable and efficient refrigeration
- Low cost, compact, and reliable dielectric liquid cooling
- High heat flux, efficient thermoelectric cooler
- Abatement of heat load impact on installation
- Outdoor structure (sheds) for remote stations: use materials that can passively reduce the need for active HVAC/ fan load.
- Quieter fans with efficient airflow design
- No compromise in relability
Netcom challenges

Future:

• Challenges of using the heat generated rather than just wasting it
• Need collaboration/co design between the building designers, system integrator and OEMs to optimize the thermal solution for the entire installation
• Development of optical networks should lead to less power hungry systems.
LEDs

Low cost energy-efficient light sources
LED Based Devices

• LED Devices continue to improve
  – Remote phosphor technology developing
  – Novel thermal management designs emerging
LED – Growth

Yole, Status of the LED Industry, August 2012.
LED challenges

• Very high heat flux from a relatively small device
• Need to keep tight control on the thermal performance to maximise the lifetime and reduce luminosity fall off.

http://electronicdesign.com/components/great-thermal-design-enhances-led-reliability
LED challenges

- Development of LED packaging with low thermal resistance
- SSI LED products have color shifts and lower lifetime performance. And Develop thermal management technologies to dissipate heat associated with high brightness light sources.
- SSI specific software and modeling tools to optimize assembly of LED and OLED SSI devices are limited. Develop SSI specific software for designing and fabricating LED light engines and light sources within environmental and thermal constraints.

http://electronicdesign.com/components/great-thermal-design-enhances-led-reliability
Power electronics
Power Electronics

![Diagram of various power electronics applications ranging from 1W to 1GW](image)
Power electronics – areas of focus

- Geometries of electrolytic capacitors and magnetic components should be optimized to transfer and exchange heat better.

- To best take advantage of the SiC JFETs (capability for higher voltages and higher operating temperatures in contrast to Si devices) packages must be improved: Materials, inductive wiring, creepage distances, etc.

- Overall lower thermal resistance within powerelectronics system, especially in solders, glues, etc. Silver sintering as an attachment medium is in early stages of commercial use, and may be offer other benefits.

- Heat spreading: reliability of joining of heat pipes need improvement; MMCs (such as Al/Carbon) should be explored.

- For optimization of heat exchange to ambient developments in 2-phase cooling, pumpless liquid loops.
New and novel things to be discussed in 2015 roadmap

• Smart polymers for thermal material solutions
• Advances LED Packaging solutions
• Power electronics materials development
Review of Technology needs

- Thermal Materials and interfaces
- Thermal spreaders
- Heat pipes
- Air cooling
- Liquid (water) cooling
- Direct immersion Cooling
- Refrigeration
- Thermoelectric
- Thermal design & modelling tools
Technology needs

• Thermal Materials development
  – Improved Packaging materials
  – Have to have required thermal, mechanical, processability, reliability performance at an acceptable cost
Technology needs

- Thermal interfaces
  - Thermal pastes, epoxies, and elastomers loaded with high thermal conductivity nanoparticles.
  - Innovative new interface materials.
  - Novel techniques / materials to minimize interfacial stresses.
  - Correlations and analytic relations to predict fatigue life of bonded interfaces.
  - Standardized method to characterize thermal performance of interface materials.
  - Self-contained solid-to-solid phase change materials or micro-encapsulated materials as suitable interface materials for a range of applications including harsh environment.
Technology needs

- Heat pipes
  - Flexible heat pipes.
  - Heat pipes that handle high heat fluxes.
  - Low cost heat pipes that can transport heat effectively over large distances (>0.5 m).
  - Designs to reduce the gravitational orientation impact on heat pipe efficiency, especially for avionics applications.
  - Heat pipes that can effectively operate over greater distances - irrespective of orientation.
  - Heat pipe technology capable of withstanding harsh environments.
  - Sound numerical models and optimization tools for predicting the performance and operational limits, including dry-out, in heat pipes.
  - Correlations and algorithms for the designs of thermosyphons (i.e. wickless heat pipe).
Technology needs

• Air Cooling
  – Models and correlations to predict heat transfer in transition and perturbed low Reynolds number flow over packages and in heat sink passages.
  – Heat sink design and optimization procedures for the minimization of heat sink thermal resistance, subject to mass and volume constraints.
  – Advanced manufacturing techniques for metal and composite material heat sinks.
  – Concepts for higher head-moderate flow, low noise, compact fans.
  – Novel, low power consumption, low acoustic emission micro-fans for forced convection cooling in notebook computers and handheld electronics, including low-frequency and ultrasonic piezoelectric fans.
  – Novel miniature fan concepts including low-frequency and ultrasonic piezoelectric fans for minimal noise emission and power consumption.
Technology needs

• Direct Immersion Cooling
  – Miniaturized components that have high reliability and provide enhanced performance (e.g. pumps and heat exchangers).
  – MEMS and meso-scale components to create low-cost, low-noise, water-to-air heat exchangers.
  – MEMS and mesoscale components to create low cost, package-size cold plates.
  – Micro-channel heat sinks with novel integrated micro-pumps to minimize package volume for high heat flux applications.
  – Methods to enable direct water cooling of chips or chip packages.
Technology needs

- Sub ambient and Refrigeration cooling
  - Highly reliable miniaturized components such as compressors, condensers and evaporators.
  - MEMS and mesoscale components to create low-cost, low noise refrigerators using solid-state, vapor compression, or absorption cycles.
  - MEMS and mesoscale components to create low-cost, package-size cold plates using solid-state, vapor compression, or absorption cycles.
  - New thermoelectric materials and fabrication methods that can improve the performance of thermoelectric coolers, particularly for hot spot remediation.
Technology needs

• Liquid (Water) Cooling
  – Verification of safe-reliable operation.
  – Single-phase and two-phase heat transfer correlations for new families of dielectric coolants.
  – Development and characterization of dielectric nano-fluids with enhanced heat transfer characteristics in distinct domains of heat transfer.
  – Convective and phase change cooling correlations to account for highly non-uniform heat flux boundary conditions, including localized “hot spots”.
  – CHF (critical heat flux) models to account for highly non-uniform surface heat fluxes, including localized hot spots.
  – Characterization of boiling and two-phase flow in narrow passages and 3-D structures, including the effects of non-uniform heat flux and localized hot spots.
  – MEMS and mesoscale components to enhance convective, as well as pool and flow boiling, heat transfer.
Technology needs

- Thermal Design and Modelling Tools
  - User-friendly tools for simultaneous optimization of thermal device, and system performance for optimization of leakage power and performance.
  - Optimize thermal conduction modelling and Computational fluid dynamics (CFD) approaches to minimize computational time; also look to integrate with EDA and CAD tools.
  - Develop Thermal stress modelling and simulation capabilities
  - Tools for the optimization of thermal and reliability performance as reliability of devices is a strong function of temperature.
Get involved

Invitation to participate through email and webex meetings over the next 3 months to update and add to the 2015 roadmap chapter.
www.inemi.org

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