Embedding and miniaturization

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Megatrends till 2030

2030: 59% of global population will live in cities
Healthy living: Health is not only contrast of sickness

2030: Population 8.3 Billion

2020: 50 Billion things connected to the internet

Autonomous Driving
Energy Efficiency
Interconnection technology trends

Miniaturization

- IC Substrate
  - 7/7 um L/S
- ECPI+ / SAP
  - 25/25 um L/S
- Next gen: ELIC
  - Substrate-like PCB
  - 30/30 um L/S
- Interposer
  - 60/60 um L/S
- ELIC
  - 40/40 um L/S
- Micro via/HD
  - 60/60 um L/S
- Multilayer
  - 100/100 um L/S
- PTH
  - 250/250 um L/S

Modularization

Future: all-in-one-modules

Diversification:
Additional Functionalities

Functional Modules:
- System-in-board (SiB)
- System-in-package (SiP)

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- Embedding history & background
- Embedding reasons & details
- Embedding reliability
- Embedding future
### What the organic world has to offer (1/2)...

<table>
<thead>
<tr>
<th>General Description &amp; Technology</th>
<th>Application Areas</th>
<th>Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard &amp; HDI PCBs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCBs are the interconnection platform for electric, electronic &amp; mechanical components (such as resistors, capacitors, IC’s, connectors; etc.)</td>
<td>Computer, Consumer, Communication, Automotive Industrial, Medical</td>
<td>OEM’s Tier 1 Tier 2</td>
</tr>
<tr>
<td>Density: Line/Space &gt; 35 micron</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SIP / modules</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substrate-like PCBs are the next evolution of high-end HDI PCBs with higher density: Line/Space 20-30micron</td>
<td>Wearables and applications of the “Internet of Things”</td>
<td>OEM’s Tier 1 Tier 2</td>
</tr>
</tbody>
</table>

### What the organic world has to offer (2/2)...

<table>
<thead>
<tr>
<th>General Description &amp; Technology</th>
<th>Application Areas</th>
<th>Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IC substrates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IC substrates serve as interconnection platform with higher density (Line/Space &lt; 15 micron) between semiconductors (Chips) &amp; PCBs</td>
<td>High-end processors for Computer, Communication, Automotive, Industrial</td>
<td>OEM’s Semiconductor Industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Embedding</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Embedded Component Packaging allows to embed active/passive components (e.g. wafer level dies) within the layers of a PCB – contributes to miniaturization</td>
<td>Power Electronics, e.g. for Automotive, Industrial</td>
<td>OEM’s Semiconductor Industry</td>
</tr>
</tbody>
</table>
## Various possibilities

**New Technologies:**

- Advanced Package (SiP)
  - SiP & e-Interposer
  - 15µ Line/Space
- e-IC-Substrate
  - 10µ Line/Space
- Cavity
- e-ELIC & mSAP/ SiB
  - 25µ Line/Space

**Existing technologies:**

- PTH / Multilayer / HDI / ELIC / FPC

### The combination of new and existing technologies will offer new solutions
- Embedding is one of the key enablers
- Clear interfaces to the existing supply chain is a prerequisite

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## Embedding environment

- Passive component suppliers as well as semiconductor companies do already offer support for embedding-friendly components
- Main design platforms already support embedding components as existing features...
  - Mentor Graphics Expedition 7.9.x
  - Cadence Allegro 16.6
  - Zuken CR 5000
- Established vendor base to embed components into Organic substrates / materials.
- OSATs and others to finalize and finish modules incl. embedded components
**System-in-Board vs. System-in-Package**

**SiB**
- System in Board
- PCB technology
- Bigger size
- Higher layer count
- Many components
- Mostly passives

**SIP**
- System in Package
- Package technology
- Small sized modules
- Low layer count
- Few components
- Mostly actives

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Reasons for embedding...

Trends and challenges in electronics

- More functions
- Supply chain complexity
- Smaller devices
- Increased cost of high-end IC design
- Short cycles design-to-market
- Less power
- Increased component population
- Intelligent mechanical devices
- Fragile components
- Thermal management
- Miniaturization
- Performance
- Ease-of-use
- Reliability

Miniaturization broken down...

<table>
<thead>
<tr>
<th>Feature</th>
<th>Application</th>
<th>X,Y Reduction</th>
<th>Embedded Component advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>Voltage Converter</td>
<td>40%</td>
<td>Smallest footprint – integrated module – fully tested solution</td>
</tr>
<tr>
<td></td>
<td>Charge Management</td>
<td>40%</td>
<td>Stacked package for advanced Li-ion battery charge management</td>
</tr>
<tr>
<td>Media &amp; Wireless</td>
<td>Media Codec</td>
<td>30%</td>
<td>Integrated module – discrete passives stacked on eWLP</td>
</tr>
<tr>
<td></td>
<td>Mobile TV</td>
<td>50%</td>
<td>Single device solution for mobile TV tuner</td>
</tr>
<tr>
<td></td>
<td>NFC module</td>
<td>40%</td>
<td>Stacked package for smallest footprint solution</td>
</tr>
<tr>
<td>MEMS &amp; Sensor</td>
<td>MEMS µphone</td>
<td>50%</td>
<td>Superior performance MEMS µphone / pressure sensor with smallest form factor</td>
</tr>
<tr>
<td></td>
<td>Identification</td>
<td>New feature</td>
<td>Integrated biometric sensing</td>
</tr>
<tr>
<td></td>
<td>Position sensor</td>
<td>50%</td>
<td>High accuracy Hall-effect sensor – advanced micro joystick application</td>
</tr>
<tr>
<td>Shielding</td>
<td>Sensitive devices</td>
<td>50%</td>
<td>Implementation of shielding using the laminate package instead of metal can</td>
</tr>
</tbody>
</table>
Wearable miniaturization vs. technology

Based on a standard wrist-band wearable product a breakdown on possible miniaturization technologies comparing the PROs/CONs against each other

<table>
<thead>
<tr>
<th></th>
<th>HDI standard technology</th>
<th>HDI + SemiFlex (1 bend region)</th>
<th>HDI + SemiFlex (2 bend regions)</th>
<th>HDI Rigid-Flex</th>
<th>HDI + Embedding</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB Dimensions [mm]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>110%</td>
<td>116%</td>
<td>110%</td>
<td>about 55 – 75%</td>
<td></td>
</tr>
<tr>
<td>No. PCB’s per Prod. Panel</td>
<td>100%</td>
<td>90%</td>
<td>90%</td>
<td>86%</td>
<td>153%</td>
</tr>
<tr>
<td>Cost Reduction</td>
<td>Assembly</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Form Factor Improvement</td>
<td>Curved Display</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Wrist Band</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Supply Chain Reduction</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Design complexity</td>
<td>Low</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
<td>High</td>
</tr>
<tr>
<td>Option to add functionality</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
<td>Med</td>
<td>High</td>
</tr>
</tbody>
</table>

Architecture comparison

<table>
<thead>
<tr>
<th></th>
<th>QFN</th>
<th>SiP</th>
<th>ECP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die @ 3*3 mm</td>
<td>Die @ 3*3 mm</td>
<td>Die @ 3*3 mm</td>
<td></td>
</tr>
<tr>
<td>Passives @ 0402</td>
<td>Passives @ 0402</td>
<td>Passives @ 0402</td>
<td></td>
</tr>
<tr>
<td>Component distance @ 250 µm</td>
<td>Component distance @ 200 µm</td>
<td>Component distance @ 250 µm</td>
<td></td>
</tr>
<tr>
<td>Surface @ 45 mm²</td>
<td>Surface @ 21 mm²</td>
<td>Surface @ 16 mm²</td>
<td></td>
</tr>
</tbody>
</table>

Stack ups

|---------------------|------------------------|------------------------|------------------------|
Reliability broken down (1/2)...

**Mechanical stress: Drop test** [JEDEC JESD22-B111, 1000 drops @ 1500g / 0.5ms]

<table>
<thead>
<tr>
<th>Standard solution</th>
<th>Embedding solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daisy chain of passive components on top of an 8 layer substrate</td>
<td>Daisy chain of passive components within an 8 layer substrate</td>
</tr>
</tbody>
</table>

- Components / Cu tracks take full weight of impact
- Embedded components and laser-via interconnects are tightly surrounded with protective FR4

<table>
<thead>
<tr>
<th>Drops passed</th>
<th>304</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drops passed</td>
<td>1000</td>
</tr>
</tbody>
</table>

Reliability broken down (2/2)...

**Thermal stress: TCT** [1000 cycles @ -55 / 150 °C]

<table>
<thead>
<tr>
<th>Standard solution</th>
<th>Embedding solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daisy chain of passive components on top of an 8 layer substrate</td>
<td>Daisy chain of passive components within an 8 layer substrate</td>
</tr>
</tbody>
</table>

- Daisy chain on chip within a 4 layer substrate

<table>
<thead>
<tr>
<th>TCT cycles passed</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCT cycles passed</td>
<td>1000</td>
</tr>
</tbody>
</table>
Performance broken down...

**Example:** EMI-shielded module

<table>
<thead>
<tr>
<th></th>
<th><strong>Standard solution</strong></th>
<th><strong>Embedding solution</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Solder joints</strong> (less conductivity &amp; more parasitic)</td>
<td><strong>Cu-plated microvias</strong> (better conductivity &amp; less parasitic)</td>
</tr>
<tr>
<td></td>
<td><strong>Long path to other components</strong> (side-by-side components)</td>
<td><strong>Short path to other components</strong> (stacked components)</td>
</tr>
<tr>
<td></td>
<td><strong>No shielding</strong> (external shielding necessary increase of cost and z-dimension)</td>
<td><strong>Intrinsic shielding</strong> (shielding by ground layers and edge plating / via stitching)</td>
</tr>
<tr>
<td></td>
<td><strong>Cu-plated microvias</strong> (better conductivity &amp; less parasitic)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Short path to other components</strong> (stacked components)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Intrinsic shielding</strong> (shielding by ground layers and edge plating / via stitching)</td>
<td></td>
</tr>
</tbody>
</table>

“Ease-of-use” broken down...

**Example:** Mobile TV tuner

<table>
<thead>
<tr>
<th></th>
<th><strong>Standard solution</strong></th>
<th><strong>Embedding solution</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Components on PCB:</strong> 5</td>
<td><strong>Components on PCB:</strong> 1</td>
</tr>
<tr>
<td></td>
<td><strong>Solder pads on PCB:</strong> 44</td>
<td><strong>Solder pads on PCB:</strong> 28</td>
</tr>
<tr>
<td></td>
<td><strong>Footprint on PCB:</strong> 29 mm²</td>
<td><strong>Footprint on PCB:</strong> 16 mm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Components in BOM</strong> - 80%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Solder pads</strong> - 36%</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Footprint</strong> - 45%</td>
</tr>
</tbody>
</table>
Embedding visuals...

X-section of embedded devices

For Interconnection, same technology and processes as for HDI/microvia PCBs!

Fundamental embedding approach #1

ECP® Technology Embedded Component Packaging

Component are embedded inside an organic substrate / PCB core by combination of

- Component laminate
- Component Packaging
- PCB Manufacturing
Fundamental embedding approach #2

Standard embedding components

- **Active components**
  - Discrete Semiconductors
  - Diodes
  - FETs
  - IPDs
  -...
  - Integrated circuits
  - Customized ASICs
  - Microcontrollers
  - RFID...

- **Passive components**
  - Resistors
  - Capacitors
  - Varistors
  - Thermistors
  - Inductors
  -...

**Specification Outline**

- CSP type with copper termination
- Thinned to 150μm or below
- Delivery in Tape and Reel

- Termination surface must be copper
- Low profile (150μm preferred)
- 0402 or 0201 (inch)
- Delivery in Tape and Reel (preferred)
Panel-level vs. wafer-level packaging

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Reliability test-vehicle, details

Total test vehicle configuration...
- 8 layer ELIC technology
- Total target thickness of 1.00mm
- Standard FR4 material (no specific resin type)
- Board size of 77 x 132mm
- Passive & Active test vehicle
- Grid of 3x3 test circuits (2 blank areas)
- Test circuits setup as embedding only / embedding + SMD / SMD only
- Daisy chain structures used

Passive & Active test vehicle
- 112 components in total
- 8 components per daisy chain
- Components used:
  - 0402 (inch) 10 Ohm thick film resistor
  - Embedded version 150µm thick
  - SMD version: same supplier, standard version with tin termination and standard thickness

Active test-vehicle
- 7 components in total
- Components used:
  - 3x3 mm Si based daisy chain
  - 49 IOs
  - Embedded version 165µm thick
  - SMD version: same supplier WL – CSP, 550µm incl. solder balls
Reliability test-vehicle, methods and parameters

<table>
<thead>
<tr>
<th>Test</th>
<th>Method</th>
<th>Analysis method</th>
<th>Remark</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflow Sensitivity</td>
<td>IPC/JEDEC J-STD-020D.1</td>
<td>Visual and x-section inspection for delamination</td>
<td>MSL 3; 3x reflow 260° Peak before assembly</td>
<td>Passed, w/o failures</td>
</tr>
<tr>
<td>Thermal Cycle Test (TCT)</td>
<td>JESD22_A104</td>
<td>Online resistance change</td>
<td>-55/+125, 500 cycles</td>
<td>Failures on SMD only</td>
</tr>
<tr>
<td>High Temp Storage (HTS)</td>
<td>JESD22_A103</td>
<td>Online resistance change</td>
<td>125° for 1000 hours</td>
<td>Failures on SMD only</td>
</tr>
<tr>
<td>Drop Test</td>
<td>JESD22_B111</td>
<td>Online resistance change</td>
<td>1500g, 1000 drops</td>
<td>Failures detected</td>
</tr>
<tr>
<td>Monotonic Bend Test</td>
<td>JEDEC 9702</td>
<td>Online resistance change</td>
<td>2mm/min</td>
<td>Failures on SMD only</td>
</tr>
</tbody>
</table>

- Boards have been tested with flying probe before and after SMT (Open/Short test)
- Samples for reflow sensitivity have gone through Open/Short test before and after the test
- Bend test only done on Active test-vehicle

Reliability test-vehicle, Thermal cycle test results

- Passive test-vehicle: - No failures detected
- Active test-vehicle: - 9 out of 70 SMD Daisy Chains failed
  - Remaining SMD passed 1000 cycles
  - First failures at 684 cycles
  - All embedded structures passed 1000 cycle

- Typical failure pictures (Corner balls)
Reliability test-vehicle, Drop test results

- **Passive test-vehicle:**
  - 17/18 boards showed failures on SMD structures
  - Earliest failure at 304 drops
  - 1 embedded Daisy Chain structure showed a failure at 832 drops
  - Remaining embedded structures passed 1000 drops

- **Active test-vehicle:**
  - 4 out of 70 SMD Daisy Chains showed failures
  - Earliest failure at 792 drops
  - All embedded structures passed 1000 drops

Typical failure pictures

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Reliability test-vehicle, Bend test results

- **Active test-vehicle:**
  - 1 out of 18 SMD Daisy Chains showed a failure
  - All embedded structures passed the test

Typical failure pictures

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- Blue and red represent highest rate of compression and tension respectively
- SMD components are more subject to these forces
- Green indicates where the EC's are located; i.e. along the neutral axis
Other specific Embedding test results

Application specific test-vehicles used with variety of active components / daisy chains...

<table>
<thead>
<tr>
<th>Test</th>
<th>Specification</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal cycling</td>
<td>-55°C / +150°C</td>
<td>1000 cycles passed (TC Grade 1)</td>
</tr>
<tr>
<td>Temperature / Humidity</td>
<td>85°C / 85%RH</td>
<td>1000 hours passed (TH Group A)</td>
</tr>
<tr>
<td>Board bending</td>
<td>5 mm/s</td>
<td>80k bends passed</td>
</tr>
<tr>
<td>Random vibration</td>
<td>3 g (rms) [5-500] Hz</td>
<td>30 min per axis passed</td>
</tr>
<tr>
<td>Shock</td>
<td>10k g @ 0.2ms</td>
<td>3 per direction passed</td>
</tr>
<tr>
<td>Reflow sensitivity</td>
<td>Pb-free profile (255°C)</td>
<td>30 cycles passed</td>
</tr>
<tr>
<td>HAST</td>
<td>110°C @ 85%RH @ 5VDC</td>
<td>264 hours passed</td>
</tr>
<tr>
<td>Drop test</td>
<td>1500g @ 0,5ms</td>
<td>10 drops passed (MS Group F)</td>
</tr>
<tr>
<td>High temperature storage</td>
<td>@ 125°C</td>
<td>1000 hours passed (TH Grade 2)</td>
</tr>
<tr>
<td>Moisture Sensitivity Level</td>
<td>Peak @ 260 °C</td>
<td>Minimum MSL 3</td>
</tr>
</tbody>
</table>

IEEE - Embedding and miniaturization, 09th August 2016
Packaging options breakdown...

Advanced Packaging Platforms

Integration: 2D → 3D

Leadframes w/o IC substrates IC substrates-based

Multiple Dies:
- GFL, GFPC
- Fan-in
- Fan-out

BGA (organic substrate)

Complexity:
- Increased functionality, I/Os, integration complexity

Embedding unit vs. market outlook

Embedded die unit shipment forecast

Breakdown by application area (Munits)

Yole Development © 2014
Market needs divided by applications

Integration
• Fine line/space (30um – 20 um LS)
• Alternative stack-ups

Power
• Thick copper (80 – 200 – 400 um copper)
• Large vias (Slot, Areas)
• Cooling

• Double-sided interconnection
• Small pads (100 um )
• Stacked dies
• High V components

• Thinner stack ups (6 L build up incl. Comp. Below 300 um)
• Ultra low CTE material (increase package / die ratio)
• Large components (10 x 10 mm)

Embedding conclusions
• Technology driven by module approach
• No clear reliability specifications but PCB based tests show embedding technology supremacy
• Market needs are driving technology
• Supply chain models extremely flexible
• Resources and prerequisites setup and available
• Technology is proven
• Various markets are making a move

“Everything new seems crazy until it isn’t”