Embedding Passive and Active Devices in Substrates

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Who is AT&S?

- Austria based global technology group focused on High Density Interconnect (HDI) Printed Circuit Boards, Advanced Packaging and IC Substrates.

- AT&S commercializes leading-edge technology for the mobile devices, automotive & aviation, industrial electronics, medical & healthcare and advanced packaging sectors.

- AT&S offers Embedded Component Packaging (ECP®) as a patent protected packaging solution. ECP® embeds active or passive components inside a PCB or IC Package.

- AT&S has 6 manufacturing sites in Austria (2), China (2), India, and South Korea.
Global Footprint ensures Cost Efficiency

- European production facilities: high mix/low volume
- Asian production facilities: high volume/low mix
- Sales network spanning three continents
- About ~8100 employees

AT&S Main Product Portfolio

- Double-sided printed circuit boards
- Multilayer printed circuit boards
- HDI micro via printed circuit boards
- HDI any-layer printed circuit boards
- HDI rigid-flex printed circuit boards
- Flexible printed circuit boards on aluminium
- Rigid-flexible printed circuit boards
- IMS printed circuit boards
- Semi-flexible printed circuit boards
- Flexible printed circuit boards
What is ECP®?

- ECP® (Embedded Component Packaging) is a patent protected packaging solution.
- ECP® offers miniaturization, performance, and reliability benefits.
- ECP® uses the space inside an organic, laminate substrate (Printed Circuit Board) to embed active and/or passive components.
- Components will be integrated in the core of the substrate and connected by copper plated micro vias.

Basic Process and Architecture
How is ECP® achieved?

Breaking it down into three main steps to build an ECP® core:
- Component assembly
- Lamination
- Structuring

Once this ECP® core structure is built a wide variety of stack ups can be created.

ECP® Stack Up Structures

Finish as 2 layer module

Structured 2 layer core with embedded component

Sequential 4, 6, 8,... layer build up

Multiple Core build ups
ECP® Cross Sections

X-section of embedded components

Surface mount CSP

Substrate with embedded IC

Why ECP®?

<table>
<thead>
<tr>
<th>Advantages</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Miniaturization</td>
<td>• Footprint reduction, z-height reduction</td>
</tr>
<tr>
<td></td>
<td>• Higher component integration (additional assembly layer 3 vs 2)</td>
</tr>
<tr>
<td>Electrical Performance</td>
<td>• Improved signal integrity</td>
</tr>
<tr>
<td></td>
<td>• Reduction of parasitic influence (higher data rates)</td>
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<tr>
<td>Mechanical Performance</td>
<td>• Higher durability and reliability through copper-to-copper connections (with copper filled micro vias)</td>
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<tr>
<td></td>
<td>• Package functions as protective enclosure</td>
</tr>
<tr>
<td></td>
<td>• High drop, shock and vibration tolerance</td>
</tr>
<tr>
<td>Thermal Management</td>
<td>• Improved heat dissipation through direct copper connection</td>
</tr>
<tr>
<td></td>
<td>• Improved heat dissipation FR4 versus air (compared to SMD)</td>
</tr>
<tr>
<td>Additional functions</td>
<td>• EMV shielding (partial or full shielding of a package)</td>
</tr>
<tr>
<td>- EMV Shielding</td>
<td>• Package is the housing no additional molding required</td>
</tr>
<tr>
<td>Supporting the trend toward</td>
<td>• Lower set-up costs compared to other packaging technologies (packaging versus substrate processes)</td>
</tr>
<tr>
<td>modularization</td>
<td>• Customization of module variants accomplished with digital imaging – no expensive tooling necessary (e.g. QFN,...)</td>
</tr>
<tr>
<td>Anti-Tamper / Security</td>
<td>• Hidden electronics preventing reverse engineering and counterfeiting</td>
</tr>
</tbody>
</table>
**ECP® Component Basic Requirements**

<table>
<thead>
<tr>
<th>Wafer Based Embeddables</th>
<th>Passive - Discrete Embeddables</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Pad finish: Cu plating needed for contacting with micro vias = existing process for WLP components</td>
<td></td>
</tr>
<tr>
<td>- Pad pitch: adaptation to organic substrate design rule through RDL</td>
<td></td>
</tr>
<tr>
<td>- Wafer thinning: 100-150µm (recommended thickness)</td>
<td></td>
</tr>
<tr>
<td>- Use of thin components with copper terminations</td>
<td></td>
</tr>
<tr>
<td>- Capacitors and resistors available</td>
<td></td>
</tr>
<tr>
<td>- Other discrete components in development</td>
<td></td>
</tr>
<tr>
<td>- Component thickness 100µm – 330µm</td>
<td></td>
</tr>
<tr>
<td>- Case sizes 0201, 0402</td>
<td></td>
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</tbody>
</table>

Components are connected by using copper plated micro vias

RDL... Redistribution layer
WLP... Wafer Level Package

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**What is needed for an ECP® project?**

AT&S works with the leading passive component suppliers and semiconductor companies and can provide support or take over component sourcing.

AT&S offers layout routing including embedded components, or directly supports customers during design creation.

AT&S has years of experience in production of PCBs and packages with embedded components and can combine embedding with different package stack up technologies.
Design Creation

Design Tools with ECP® design capability

Design systems:
- Mentor Graphics Expedition 7.9.x including embedding tool
- Cadence Allegro 16.5 or higher, including miniaturization tool
- Zuken CR 5000

- AT&S offers layout routing including embedded components, or directly supports customers during design creation
ECP® Reliability Tests and Results

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Specification/Requirement</th>
<th>Samples size</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflow Sensitivity (RS)</td>
<td>IPC/JEDEC J-STD-20: MSL2 cond. J x Reflow, no delaminations</td>
<td>5 Arrays (7500 single cards)</td>
<td>Passed</td>
</tr>
<tr>
<td>Temperature cycling test (T/1)</td>
<td>JEDEC JESD22-A104, increase of resistance not more than 10%</td>
<td>5 Arrays (7500 single cards)</td>
<td>Passed</td>
</tr>
<tr>
<td>Drop Test (DT)</td>
<td>JEDEC JESD22-B111, B104</td>
<td>9 Drop Test boards (Stopped at 1000 drops)</td>
<td>Passed</td>
</tr>
<tr>
<td>Temperature humidity storage (THS) (85°C/85%RH/1,000h)</td>
<td>IPC-TM-600 2.5.3, increase of resistance not more than 10%</td>
<td>5 Arrays (7500 single cards)</td>
<td>Passed</td>
</tr>
<tr>
<td>High temperature storage THS</td>
<td>JEDEC JESD22-A103, Increase of resistance not more than 10%</td>
<td>5 Arrays (7500 single cards)</td>
<td>Passed</td>
</tr>
<tr>
<td>HAST Electromechanical migration (130°C/85%RH – 96hrs)</td>
<td>JEDEC JESD 22-A110-8 No events with resistance below 1000 Ohm</td>
<td>9 EM Testboards</td>
<td>Passed</td>
</tr>
<tr>
<td>Soldier Kist test (280°C, 30min)</td>
<td>IEC J-STD-003, solderbath</td>
<td>Q-Lot, Process control</td>
<td>Passed</td>
</tr>
<tr>
<td>Soldier Dsp Test (170°C, 10sec)</td>
<td>IPC J-STD-003, solderbath</td>
<td>Q-Lot, Process control</td>
<td>Passed</td>
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<tr>
<td>Solderability Test (200°C)</td>
<td>IEC 61968-2-69, IPC J-STD-003, Must II wetting balance method</td>
<td>Q-Lot, Process control</td>
<td>Passed</td>
</tr>
<tr>
<td>Glass Transmission Point</td>
<td>IPC-TM-800 2.4.25</td>
<td>Q-Lot, Process control</td>
<td>Passed</td>
</tr>
</tbody>
</table>

ECP® Reliability

Reliability test board for embedded passives - Technology Qualification

- 112 components in total: 96 SMD, 96 EC
- 8 components per daisy chain
- 7 daisy chain for SMD and EC each

Test Vehicle Stack-up

- Standard 10 Ohm 9402 resistors
- Embedded and SMD same in x y axis dimension
- Difference in 2 axis (ECs thinner)
- Same manufacturer
- Terminals differ: Cu vs. Sn

White paper available
ECP® Reliability Results

Reliability test board for embedded passives - Results

**Temperature Cycle Test per JEDEC JESD22-A104**
-40°C/+125°C

All EC and SMD components passed 1000 cycles without failures

White paper available

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ECP® Reliability Results

Reliability test board for embedded passives - Results

**Drop Test per JEDEC JESD22-B111**
1500g/0.5ms

White paper available
**ECP® Reliability**

Reliability test board for embedded actives – Technology Qualification

- 7 active components in total
- 7 daisy chain each for SMD and Embedding

White paper available

7x7 pin Daisy Chain component with copper RDL

**ECP® Reliability Results**

Reliability test board for embedded actives - Results

- Drop Test per JEDEC JESD22-B111
  1500g/0,5ms

White paper available

- Earliest recorded drop failure for SMD was at 782 drops
- 3 out of 7 daisy chains received 1000 drops
- Daisy chain 4 exhibited the lowest drop survivability
- Three weak solder metrics observed near the SMD component on all 4 failures
- No failure detected for embedded component Daisy chains
ECP® Reliability Results

Reliability test board for embedded actives – Results

Temperature Cycle Test per JEDEC JESD22-A104
-40°C/+125°C

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Card</th>
<th>Structure No.</th>
<th>Failed at cycle</th>
<th>Surface/Embedded</th>
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</thead>
<tbody>
<tr>
<td>ITE2000_18_1004</td>
<td>18</td>
<td>4</td>
<td>664</td>
<td>5</td>
</tr>
<tr>
<td>ITE2000_20_1006</td>
<td>20</td>
<td>6</td>
<td>764</td>
<td>5</td>
</tr>
<tr>
<td>ITE2000_14_1008</td>
<td>14</td>
<td>6</td>
<td>766</td>
<td>5</td>
</tr>
<tr>
<td>ITE2000_15_1016</td>
<td>15</td>
<td>6</td>
<td>803</td>
<td>5</td>
</tr>
<tr>
<td>ITE2000_21_1014</td>
<td>20</td>
<td>4</td>
<td>818</td>
<td>5</td>
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<tr>
<td>ITE2000_11_1012</td>
<td>11</td>
<td>4</td>
<td>835</td>
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</tr>
<tr>
<td>ITE2000_14_1018</td>
<td>14</td>
<td>4</td>
<td>851</td>
<td>5</td>
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<td>ITE2000_19_1010</td>
<td>19</td>
<td>4</td>
<td>800</td>
<td>5</td>
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<td>ITE2000_13_1015</td>
<td>15</td>
<td>4</td>
<td>999</td>
<td>5</td>
</tr>
</tbody>
</table>

White paper available

Application Examples
Trends in the Electronics Industry - Module / Packages

Integration of Electronics in our daily lives - Technology meets Design

Module / Packages
- Integration of new features in devices (Example: Sensors) – smallest packages and highest performance – ECP Technology opens up new possibilities

Flexibility due to modular design
- Tightly spaced electronic devices
- Modular design to shorten time-to-market cycles

Where ECP® is being used
- Smartwatches
- Activity Trackers
- Heart rate monitors / pulse oximeters
- Sensors

Picture: AT&S
Optical Heart Rate Monitoring System with 1 embedded IC controller

5.5mm x 3.9mm x 1.2mm
**Trends in the Electronics Industry - Module / Packages**

**Flexibility due to modular design**
- Customers require design flexibility
- Increasing density requires higher complexity of the circuit board
- Adoptions in design cause time- and cost intensive approval processes

**Where ECP® is being used**
- Connectivity modules (M2M communication)
- Power Modules
- Interface Modules
- Control units

*Picture: AT&S Engine Control Module: 416 I/O Processor embedded*

**2.3mm x 2.9mm x 1.0mm**

**DC/DC Converter with embedded active**

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**Trends in the Electronics Industry - Power Modules**

**Steadily increasing demands for Power Management**
- Every operational unit has to have a power supply
- Smaller energy sources require more efficient use of available capacity
- Thermal Management

**Where ECP® is being used**
- Battery Management
- Power Modules
- Power MOSFETs

*Picture: AT&S Power Module: 4 MOSFETs embedded*

*Picture: AT&S Power Module: 4 MOSFETs embedded*
Trends in the Electronics Industry - GaN / SiC

Market for advanced power modules
- Automotive
- Infrastructure
- Industrial

Technology shift coming – move to high efficiency semiconductor – GaN / SiC

Packaging = Significant Value-Add

Further Application Examples

Active shielding - complete
Active shielding - partial
Data protection

3D Integration
User authentication
Authentication
2.5DC Cavity integration
Standardization

- **System-in-Package**
  - ECP as Package
  - Standard qualification process
    - AEC Q100, JESD-22, MIL-STD-883...

- **System-in-Board**
  - ECP as Substrate
  - No standard in place yet
  - AT&S working with IPC Committee
    - Embedding-specific standard (IPC-7092)

Technology Outlook

**Further development of ECP®**

- We are developing our ECP® technology further in terms of
  - Embedded die size (beyond 10 x 10 mm)
  - Embedded die thickness (less than 100µm)
  - Embedded passive component thickness (01005, 0201, 0402, 0803,...)
  - Wider height combination range for embedded components (active and passive)
  - Material selection (wider variety of Cu foils and prepregs)
  - Flexibility of build up concepts

Source: Fraunhofer IZM
## AT&S ECP® Technology

### Summary

- Key benefits of ECP®
  - Miniaturization
  - Improved Electrical Performance
  - Improved Mechanical Performance
  - Enhanced Thermal Management
  - Embedded component / no additional housing required
  - Security / Anti-tamper
  - Shielding

- ECP® has been in volume production at AT&S for several years (>200 Mio units in the field today)
- ECP® can be combined with various substrate buildups
- We can support product development, production and even take over part of the supply chain, if required
- We possess the necessary IP Portfolio for supporting your projects

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## AT&S – first choice for advanced applications

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