Advanced SLP (mSAP) technology enables higher density interconnect miniaturization - 3D system modularization

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Agenda

- What is mSAP (mSAP vs. Subtractive)
- Why mSAP
- mSAP capability & Roadmap
- Summary
- Q&A
A world leading high-tech PCB & IC substrates company

High-end interconnect solutions for Mobile Devices, Automotive, Industrial, Medical Applications and Semiconductor Industry

Continuously outperforming market growth

#3 in high-end technology worldwide*

Among top 10 PCB producers worldwide*

€1bn revenue in FY 2017/18

10,000 employees**

Cost-competitive production footprint with 6 plants in Europe and Asia

* For CY 2017
Source: N.T. Information Ltd (July 2018); Prismark
** For AT&S FY 2017/18
Global footprint ensures proximity to supply chain & cost efficiency

- **977***: Leoben, Headquarters, Austria
- **401***: Fehring, Austria
- **1,144***: Nanjangud, India
- **2,335***: Chongqing, China
- **4,365***: Shanghai, China
- **301***: Ansan, Korea

*Staff, Average, FTE, Q1 2018/19; 74 employees in other locations

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## AT&S Applications

### Radio Frequency
- Wireless Communication, Sensing, Energy Harvesting (5G, M2M, IoT, RADAR, ...)
- HDI, mSAP, ECP®, XiB, FO-SiB, HF materials (low Dk,Df)
- High Integration, Antennas, Multi-material PCBs

### Thermal and Power Management
- Optical Sensors and Cameras, Environmental Sensors, Microphones and Speakers
- Medical Diagnostics, ...
- Thermal vias, insulated metallic substrates, thermal conductive PCB, heat pipes, ...

### Sensors and Actuators
- HDI, Anylayer, ECP®, XiB, FO-SiB, Flex PCB
- High integration, Special materials

### Computing & Data Storage
- Smartphones, PCs, Smartwatches, Data centers, SSD, ADAS/ Centralized Computing, ...
- HDI, Anylayer, IC substrates, ECP®, XiB, FO-SiB
- High integration, High density IO
Positioned as leading high-end interconnect solutions provider

From high-end PCB/substrate manufacturing to high-end interconnect solutions:

Core business + New technologies and solutions

Extended technology toolbox
- Enabling module integration

Additional customers

Additional applications
- Panel level manufacturing
- Broader positioning in the value chain

PCB/substrates
Embedding

More than AT&S
Agenda

What is mSAP (mSAP vs. Subtractive)

Why mSAP

mSAP capability & Road map

Summary

Q&A
## AT&S Product Portfolio – addressing increasing density

<table>
<thead>
<tr>
<th>Subtractive Plating</th>
<th>SAP Plating</th>
<th>mSAP Plating</th>
<th>Subtractive Plating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ECP®:</strong> Embedded Component Packaging</td>
<td><strong>ICS</strong> IC substrates</td>
<td><strong>Substrate-like printed circuit boards</strong></td>
<td><strong>HDI any-layer printed circuit boards (ELIC)</strong></td>
</tr>
<tr>
<td>Embedded Component Packaging allows to embed active/passive components contributes to miniaturization.</td>
<td>IC substrates serve as interconnection between semiconductors and PCBs (Line/Space &lt; 15 micron).</td>
<td>Substrate-like PCBs are the next generation of high-end HDI PCBs (Line/Space &lt; 30 micron).</td>
<td>HDI microvia printed circuit boards – high density interconnect</td>
</tr>
<tr>
<td><strong>HDI:</strong> high density interconnection with laser drilling (microvias). 4-layer laser PCBs up to 6-n-6 HDI multi layer PCBs</td>
<td></td>
<td>Enhancement of HDI microvia with any layer laser connection; contributes to miniaturization; 4 to 12 Anylayer HDI (Line/Space = 40)</td>
<td>Combine the advantages of flexible and rigid printed circuit boards, yielding benefits for signal transmission, size and stability.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Production site</th>
<th>Production site</th>
<th>Production site</th>
<th>Production site</th>
<th>Production site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leoben, Shanghai</td>
<td>Chongqing</td>
<td>Chongqing, Shanghai</td>
<td>Shanghai, Leoben</td>
<td>Shanghai, Leoben</td>
</tr>
<tr>
<td>Production site</td>
<td>Production site</td>
<td>Production site</td>
<td>Production site</td>
<td>Production site</td>
</tr>
<tr>
<td>Shanghai, Leoben</td>
<td>Leoben, Ansan</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SLP (mSAP) - The Next Level of Technology
Advanced SiP, Fan-out Modules, and Heterogeneous Packaging requires finer L/S

- PCBs are now approaching semiconductors with regard to feature sizes <30um creating substrate-like PCBs (SLP)
- The modified semi-additive metalization processes (mSAP) achieves the tighter sub-30 micron features required for Data-centric mobile devices
- Leverages larger panels than substrate technology for HVM

Source: PCB Magazine Sep, Oct 2018, Yole Adv Substrate report 2018
Market trends - miniaturization & modularization

Source: Yole, AT&S AG (2018)
SLP Helps Accelerate Modules and Heterogeneous Systems

Modules and Smart Systems

Interchangeable, complex element in a system or sub-system which performs one or more specific functions, and contains a minimum of two components with at least one being active.

Generic Module Functions for Smart Systems

- Energy harvesting
- Power management
- Energy storage

- Processors (CPU, GPU, ...)
- Memory
- Sensors
- Connectivty
- System software

Industry driver - miniaturization & modularization

<table>
<thead>
<tr>
<th>Year</th>
<th>TYPE</th>
<th>PCB</th>
<th>FORM FACTOR</th>
<th>LINE/SPACE</th>
<th>TECHNOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003/04</td>
<td>Mobile Phone</td>
<td>125x55mm</td>
<td>1</td>
<td>100/100µm</td>
<td>1-n-1</td>
</tr>
<tr>
<td>2013</td>
<td>Smartphone</td>
<td>85x20mm</td>
<td>0.25</td>
<td>40/40µm</td>
<td>Any-layer</td>
</tr>
<tr>
<td>2017</td>
<td>Smartphone</td>
<td>80x20mm</td>
<td>0.23</td>
<td>30/30µm</td>
<td>mSAP – Any-layer</td>
</tr>
<tr>
<td>202X</td>
<td>All in One</td>
<td>25x25mm?</td>
<td>0.06?</td>
<td>10/10µm</td>
<td>FO/SAP/mSAP</td>
</tr>
</tbody>
</table>

Industry driver - miniaturization & modularization

- Industry driver: miniaturization & modularization
Substrate-Like PCB (SLP) Concept - mSAP

Miniaturization & Modularization

HDI Boards / MLBs
- Smart Phones
- Tablets
- Automotive
- Consumer Products

SiP / Modules
- Wearables
- Automotive
- “Modularize & Standardize”
generic elements (eg. WiFi, NFC,...)

IC/Substrates:
- Microprocessors
- CPU, GPU
- Servers, Networking
- Gaming Consoles

HDI

SLP

mSAP

SAP

Feature Sizes (µm)

40/40µm

10/10µm

Subtractive

Global Market Size Dollars 2017 - SLP Production

Estimated by JMS (JMS 推定)

*After 2020, SiPs are expected to be adopted in the most advanced smartphones.

Source: JMS Substrate Like PCB report 2018

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Substrate-like PCBs (mSAP) Drivers

- **Improved signal integrity**
  - Rectangular X-section → reduced impedance variation
  - Reduced surface roughness → lower RF transmission losses

- **Board thickness reduction**
  - Reduced z-height of electronics
  - Increased space for batteries in mobile devices
  - Thinner laminate layers

- **Routing density increase**
  - Increased trace density and routing
  - Controlled shape, smaller pads, antenna integration
Line shape: mSAP vs. Standard HDI

Subtractive process

mSAP – optimized shape/roughness

mSAP – fine L/S

Source: Georgia Tech, Atotech paper – Sep2018

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Board thickness/Impedance: mSAP vs. Subtractive

- Thickness reductions and Impedance improvement – controlled

<table>
<thead>
<tr>
<th>Layer</th>
<th>Min. Board thk.(um)</th>
<th>50 ohm impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 12</td>
<td>664</td>
<td>12.8%</td>
</tr>
<tr>
<td>Layer 10</td>
<td>552</td>
<td>12.3%</td>
</tr>
<tr>
<td>Layer 8</td>
<td>440</td>
<td>11.6%</td>
</tr>
</tbody>
</table>

- Thickness reductions and Impedance improvement – controlled
Pattern Capabilities: mSAP vs. Standard HDI

- Developed for finer package pitches, improved electrical performance & routing

<table>
<thead>
<tr>
<th></th>
<th>Standard HDI (Subtractive)</th>
<th>Advanced HDI (Subtractive)</th>
<th>SLP / HDI+ (mSAP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line/Space (Cu. Thicknk)</td>
<td>60/60 µm (18±10µm)</td>
<td>40/50 µm (18±10µm)</td>
<td>30/30 µm (18+/−10)</td>
</tr>
<tr>
<td>BGA Fan-out Inner Layer (2 Channels)</td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td>Prepreg Thk.</td>
<td>&lt; 55 µm</td>
<td>&lt; 45 µm</td>
<td>&lt; 42 µm</td>
</tr>
<tr>
<td>Laser Dia.</td>
<td>70 µm</td>
<td>70 µm</td>
<td>70 µm</td>
</tr>
<tr>
<td>Min. Pad Dia.</td>
<td>200 µm</td>
<td>170 µm</td>
<td>140 µm</td>
</tr>
</tbody>
</table>
Why mSAP

Coverage of MSAP has spread from IC substrate to Smartphone Motherboard

**MicroThin™ Applications**
- IC Substrate
- DRAM
- Application Processor
- Smartphone Motherboard

**Cross section of Smartphone**

<table>
<thead>
<tr>
<th>DRAM</th>
<th>AP</th>
<th>Mother Board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Change of patterning method on Mother Board**

- LS=50/50
- LS=40/40
- LS=30/30
- LS=25/25

**Subtractive Method**

**MSAP**

**Reason for using MSAP for Smartphone Motherboard**
- Miniaturization and densification of Mother Board to enlarge battery space.
- Narrower BGA ball pitch to improve the function of IC package.
- Improvement of signal characteristics in high speed signal.

Source: JMS Substrate Like PCB report 2018
Agenda

- What is mSAP (mSAP vs. Subtractive)
- Why mSAP
- mSAP capability & Roadmap
- Summary
- Q&A
mSAP Capability – Improved Tolerances, Shape, Roughness

Examples of Major Mfgrs Electrodeposited Copper Plating for Via Filling

Source: JMS Substrate Like PCB report 2018, Atotech

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mSAP Layers in Smartphone Teardown

Multiple Layers of mSAP in recent smartphone

- In the Processor area, the minimum trace width is measured at 30µm and the line space width is measured at 55µm.

Source: Yole, System Plus Teardowns – Samsung Galaxy S9
**mSAP Layers for Performance, Tighter Routing Smartphone**

Multiple Layers of mSAP in recent smartphone

Source: Yole, System Plus Teardowns – iPhone X 2018
SLB PCB Optimized for Performance, Density, Size Reduction

Board Cross-Section – PCB

10 layers SLB PCB
Total thickness: 572.6 μm
Copper layers thickness: 19.9 μm
Dielectric layers thickness (Mid Value): 51.7 μm
Micro-via diameter: 78 μm

8 layers HDI PCB
Total thickness: 447.3 μm
Copper layers thickness: 19.04 μm
Dielectric layers thickness (Mid Value): 52.8 μm
Micro-via diameter: 85 μm

Source: Yole, System Plus Teardowns
Process steps: mSAP vs. Standard HDI

Subtractive process

E-less Cu
12μm base copper

mSAP

E-less Cu
3 μm base copper

via filling Cu plating
Panel plating

Dry film
(Exposure/Developing)

Etching
Etch away
base Cu + plated Cu

Dry film stripping+

Dry film
(Exposure/Developing)

Laser filling Cu plating
Pattern plating

Dry film stripping+

Copper Annealing

Flash Etching
Etch away
base Cu

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What is the trend in Smart Phones

1. **Advanced Processor**
   - Picture Resource: Qualcomm

2. **Better signal & Low noise**
   - Picture Resource: Qualcomm

3. **Thinner Board**
   - Picture Resource: Gionee Mobile

4. **Bigger Battery**
   - Smaller/modularized main board
   - Picture Resource: Qualcomm

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## What does it mean for the PCB

### Main board

**Structure:** 10-14 layer any layer

**Density of pattern layout**
0.35mm BGA (with 2-3 line in between)

**Material:** Thin PP/Core(1027/1017, 50/40μm)
- Low Dk (3.4)
- Low Df (0.002)
- High Tg
- Low CTE(x,y,z)

**Others:** Good line shape
- Tight line tolerance

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### Advanced Processor

### Bigger Battery

### Smaller/modularized main board

### Thinner Board

### Better signal/ Low noise
mSAP Plants Overview

Plant: Shanghai Plant
Location: Xin Zhuang Industrial Park
Products: HDI PCB, 4-16 layer

Plant: Chongqing Plant
Location: Yuzui Industrial Park
Products: HDI PCB, 4-16 layer, SLP
AT&S – SLP Factory brings large scale SLP Capacity and Capability

State-of-the-art facilities  World-Class factory

Data driven Quality System with strong automation & process control
SLP-mSAP Industry Technology Development Examples

Finer Pitch FIWLP and FOWLP Drive Tighter Ball Pitch and PCB/Substrate Routing

Figure 6: Effect of trace count on dimensions. (Source: Altera)

Table 1: L/S required for given pad dimensions.

<table>
<thead>
<tr>
<th>Number of Traces</th>
<th>Required Line / Space Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$g \geq \text{Line Width} + (2 \times \text{Space Width})$</td>
</tr>
<tr>
<td>2</td>
<td>$g \geq (2 \times \text{Line Width}) + (3 \times \text{Space Width})$</td>
</tr>
<tr>
<td>3</td>
<td>$g \geq (3 \times \text{Line Width}) + (5 \times \text{Space Width})$</td>
</tr>
</tbody>
</table>

Table 2: Outline comparison of PCB production techniques.

<table>
<thead>
<tr>
<th>Achievable L/S (µm)</th>
<th>Subtractive</th>
<th>mSAP</th>
<th>amSAP</th>
<th>SAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu clad thickness (µm)</td>
<td>2–9</td>
<td>2–5</td>
<td>&lt;3</td>
<td></td>
</tr>
<tr>
<td>L’less Cu thickness (µm)</td>
<td>0.35–0.50</td>
<td>0.35–0.50</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Flash Cu thickness (µm)</td>
<td>2–5</td>
<td>1–3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panel plating thickness (µm)</td>
<td>15–20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pattern plating required</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Etch resist</td>
<td>Dry film or LER</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu to be etched</td>
<td>17–29</td>
<td>4–10</td>
<td>&lt;3</td>
<td>0.7–1.2 (Rz)</td>
</tr>
</tbody>
</table>

Source: Atotech paper - PCB Magazine Sep, 2018

Figure 7: Critical factors within the HDI Roadmap. (Sources: IPC, Jisso, Atotech, customer base)
SiP / Modules
- Wearables
- Automotive
- “Modularize & Standardize” generic elements (eg. WiFi, NFC,...)

Main challenges

- Strong technical capability (Fine line/Pad/thin material)
- Foreign material
- Thin board handling
- Design optimization & routing

SLP

mSAP
Thin panel handling required - Equipments & Automation

Advanced equipment & Inline automatic system for ultra thin panel (*min 150µm*)

- Touchless Vertical developer
- Touchless vertical copper plating line
- Automatic lay-up
- Roller coater Solder mask for ultra thin panel
- AT&S own trolley & tray design for thin panel transportation
- Less manual Handling
- Better design for thin panel capability
Agenda

What is mSAP (mSAP vs. Subtractive)

Why mSAP

mSAP capability & Roadmap

Summary

Q&A
Summary – New System Integration Design Opportunities

- **Substrate-like PCB: mSAP** – enables miniaturization through higher functional integration of components reducing Z-height, improving signal integrity, and better thermal management.

- **Advanced Substrates** – provide Lines/Spaces below 10µm for integrating high-end nanoCMOS Integrated Circuits such as processors.

- **Embedding** – is an enabling technology for module integration, especially for large numbers of electronic components, RF filters, antennas, or thermal management devices (Cu plates, heat pipes).

- **System in Board** – combines PCB, substrates and embedding in a single technology platform (FO-SiB™) to enable single-function, multi-function, and „All-in-One“ module integration solutions.
AT&S first choice for advanced applications