Case study: Bringing 3D Printed Electronics into Mass Production – Lessons Learned

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About Optomec

Leader in Printed Electronics and Additive Manufacturing

- Production Printers for Electronics, Sensors, Metals...
- Print Full Products or Add Functionality to Existing Parts
- Cost and Functional Advantages over Current Manufacturing Solutions

300+
Optomec Global Installations

50+ Issued
Optomec IP

60+ Pending
Optomec Material and Automation Partners

40+

75+
Optomec Employees
Albuquerque & St. Paul

Privately Held – Profitable – Recent Investment from GE
Founded in 1975, LITE-ON (Lite-On Technology Corporation) is a leading supplier in the global opto-electronic components industry. LITE-ON’s product offerings are leading the industry and widely applied in areas such as computer, communication, consumer electronics and car electronics. LITE-ON is committed to global citizenship and recognized with several CSR awards.
Aerosol Jet Print Solution Overview

• Patented Material Deposition Process
• “Input” Fine Particle Inks and Standard Pastes
  – Conductors, Insulators, Semiconductors, Biomaterial...
• “Output” Fine Features to ~10µm to mm & Coatings from 50nm
  – Non-contact process
  – 2D / 3D Printing
• Cost and Functional Advantages
  – Lower Material and Process Costs
  – Improved End-Product Performance

Application Examples

- EMI Sensor Array
- 3D Antenna
- Staggered Die

Aerosol Jet Process

Standard Systems
3D Solutions for Mainstream Electronics Production

<table>
<thead>
<tr>
<th>Process</th>
<th>2D Antenna</th>
<th>3D Antenna</th>
<th>Digital</th>
<th>Common Plastics</th>
<th>No Plating</th>
<th>Feature Size</th>
<th>Uniform Material Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Write Aerosol Jet</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>&lt; 50 µm</td>
<td>✓</td>
</tr>
<tr>
<td>Direct Write Dispense</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>&gt;150 µm</td>
<td></td>
</tr>
<tr>
<td>LDS Additive</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>150 µm</td>
<td>✓</td>
</tr>
<tr>
<td>2 Shot</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>400 µm</td>
<td>✓</td>
</tr>
<tr>
<td>Hot Foil</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>1000 µm</td>
<td></td>
</tr>
</tbody>
</table>

- **Direct Write Advantages over current antenna and sensor manufacturing processes**
  - Standard Plastics, No Additives or Special Coatings
  - No Plating, No Nickel, Environment Friendly
  - Fewer Steps, Less Floor Space, Simplified Logistics
  - Projected cost savings as much as 15% or more compared to LDS’
Optomec’s Scalable 3DP Solutions Family

• Aerosol Jet - From Material and Process Development to Full Scale Production
Printing in Mass Production for Antennas & Sensors
# LITE-ON Antenna Production Capabilities

<table>
<thead>
<tr>
<th>PRODUCT &amp; SERVICE</th>
<th>CAPABILITIES</th>
</tr>
</thead>
</table>
| Antenna Research, Design and Verification | • Three full scale antenna labs around the world, with world class Antenna Engineering R&D resources  
• Vast experience in design of the full spectrum of antennas used in mobile handsets and tablets today, as well as research for antenna technologies for the future |
| Stand-alone Antennas                  | • Laser-Direct Structuring (‘LDS’), Flex-Film antennas (‘FPC’), and Sheet Metal antennas  
• In-house tooling, injection molding, and metal punching of the full antenna product range  
• Manual, semi-automatic, and fully automatic manufacturing and production testing |
| Module Antennas                       | • LDS, FPC, and sheet metal antennas combined with other electromechanical components  
• Customized Speaker Box Antenna modules |
| Mechanically Integrated Antennas      | • Main, diversity, and complementary (BT, WLAN, GPS, NFC, etc) antennas, fully integrated into structural chassis and covers including ‘uni-body’  
• Antennas integrated into cosmetic cover products |
Production Drivers – Why printing?

- **Flexibility**: We need antenna variants for each local market.
- **Speed**: During development cycle we need new variants every day.
- **Green**: Production ramp-up will be steep.
- **Cost**: We care. So we request the lowest possible environmental impact.
- **Cost**: We want it for lowest possible cost.
- **Cost**: No product specific tooling cost.

We want an antenna that can take any shape and be placed anywhere in the handset and on any substrate.

Spec
- Antenna Performance
- Adhesion
- Temp cycle
- Humidity
- Drop Test
- Salt mist
- ...
What is LITE-ON 3DP?

• LITE-ON leading the development for printed mobile antennas in 3D for 5 year. Development partners Optomec for Aerosol Jet print engine and Neotech for motion system

• Aerosol jet technology used to print highly conductive nano-particle ink, onto 3D surfaces, without need for masks, screens, or plating

• 4 parallel print stations with 5 axis motion system, 3 linear and 2 rotational axis, enables full access for all surface to be printed with high production throughput
Printing in 3D – Technology Challenges

• Sources of ink for production manufacturing
• Ink process development for a series of substrates
  – Kapton, PA, PC, PC/ABS, Glass, etc.
• Print Quality
  ![Image of print quality graph]
  Speed: 20 mm/s
  Width: 150um
  Thickness: 4 um
• Resistivity
  ![Table of resistivity data]

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Time (min)</th>
<th>Resistivity (Ω-m)</th>
<th>X Bulk Ag</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>60</td>
<td>$1.29 \times 10^{-7}$</td>
<td>8.1</td>
</tr>
<tr>
<td>200</td>
<td>60</td>
<td>$7.74 \times 10^{-8}$</td>
<td>4.8</td>
</tr>
</tbody>
</table>

• Environmental Testing – Customer Specific
  – Humidity/Damp Heat
  – Salt Spray Testing
• Adhesion
  – ASTM D3359-02 Adhesion Tape Test
Printing in 3D – Technology Challenges

• Printing on complex geometry in 3 dimensions presents new challenges

• Convex and concave double curvature surfaces

• Capillary action effects
Printing in 3D – Technology Challenges

• Sharp radius and parting lines, “via” hole

• Surface energy variation, ink wetting
LITE-ON 3DP – Meeting 3D Technology Challenges

- Access to a wide variety of inks that are performance and environmental test qualified
- Printing on a wide range of resins and materials, plastics, glass, ferrites, metals...
- Full three-dimensional printed features with consistent widths & thicknesses
- High efficiency & consistent RF performance
- High output due to multi-station set-up, cost competitive
- LITE-ON in-house technology enabling rapid design changes and product supply lead-times

Additive with no plating required - an environmentally conscious technology
Design Flexibility

• With 3DP, Antennas can be placed anywhere and can take any form
• Placing the antenna as far out as possible in the corners of the device increase signal reception
• For sensor application narrow lines are often needed. Fine line printing also possible with 3DP
• Printing on any plastics, glass panels, outer surface, inside concave undercut corner
Prototype to Production Turnaround

First pattern design

Print Fixture

Print program

Print

Test

Samples

1-3 day

First samples

<1 day

Pattern design update

Print program

Print

Test

Samples

<1 day

Updated pattern samples
Cost Efficiency

- 3DP product cost is driven by value adding **trace size**, as opposed to LDS where **process steps** and **product size** are heavily affecting product cost.

**LDS**
- Metal Additive
- Injection Mold
- Laser Ablation
- Surface Clean
- Copper Plate
- Nickel Plate

**3DP**
- Injection Mold
- Print
- Cure
3DP Green Profile

- **Printing, not Plating**
  - No electroless plating
  - No Nickel used

- **Green Materials**
  - Additive process, very little process waste
  - Thin trace layer compared to other solutions
  - Recyclable and bio-degradable resins possible

- **Optimized Logistics**
  - 100% in-house – no big transportation impact
  - All manufacture steps in one production cell

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March 2016 3DP technology won LITE-ON group CSER award for its reduction of waist and lowering the environmental impact for production of antennas and sensors.
Application - Antenna & Speaker Module

• 3DP of smartphone antennas on electro-mechanical assembly
• Assembly has speaker and gaskets inside before printing
• 4G/LTE Antennas printed on outside of the assembly for late customization
• Speaker inside - LDS cannot be used
Application - Sensor Trace

- 3DP Printing of sensor and connection trace
- Structural smart phone frame. Metal plastic hybrid. Al/Mg die-cast with insert-molded glass filled poly carbonate
- Connection done through electrical via-hole
- LDS is not an option due to die-cast component
Application – SmartPhone Cover

- 3DP of antennas on cosmetic/visual smart phone cover
- Main, Diversity, GPS, WiFi and BT antennas printed inside of cover
- Antenna traces placed in undercut areas difficult to be reached
- Cover material is poly carbonate in several color variants and high visual requirement
3DP Further Improvements

• Areas where we are still progressing and will continue to work
  – Process speed, print output
  – Ink conductivity – specially for low temperature sinter <120 deg C
  – Sintering technologies
  – Printing on new materials, foams and porous materials
  – Copper based ink

• New applications; wearable smart devices and IoT devices,
  – Flexible and stretchable products
Conclusion and Summary

- Aerosol Jet is a cost effective option for mass production of 3D Printed Electronics today.
- LITE-ON MM SBG 3DP is a viable contract manufacturing source for mass production
- LITE-ON has been leading the development of 3D printed antennas and sensors for over 5 years
- LITE-ON have successfully deployed and are currently using 3DP Aerosol Jet based solutions for mass production
- 3DP Aerosol Jet capabilities enable unique solutions and provide significant benefits for:
  - Increased Design flexibility
  - Maximizing Development speed
  - Minimizing Product total cost
  - Reducing Environmental impact
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