Empowering the Industrial Internet of Things with 3D Printed Sensors and Antennas

Agenda

- What is the Industrial Internet of Things (IIoT)
- Focus on Structural Health Monitoring
- Benefits of Structural Health Monitoring
- Optomec’s Solution for the IIoT
- Antenna and Sensor Applications
- Summary
What is The IoT or IIoT?

Internet of Things (IoT): 50 Billion …When? …Where?

  - Breakdown shows ~30% M2M/industrial
  - Growth: M2M Exponential; Human Linear
  - Penetration Rate at ~3%

- IHS (Source: AMAT): 50 Billion by 2025.
  - 13 Billion New Units per Year in 2025
  - 2025 New: 48 Mobile Device; 48 Industrial

- Multiple Sources estimating 1 Trillion to 10+ Trillion Sensors per Year.
  - Qualcomm, Bosch, TI, Intel, HP, etc.
Structural Health Monitoring

Impact of No or Limited Monitoring
Communicating Data

200 sensors across the turbine generate 300 data points per second of performance and operation every hour.

Projected Structural Health Monitoring Savings

<table>
<thead>
<tr>
<th>Industry</th>
<th>Segment</th>
<th>Time to service (Million hours per year)</th>
<th>Estimated Value (Billion US dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>Steam &amp; gas turbines</td>
<td>52 Million</td>
<td>$7 B</td>
</tr>
<tr>
<td>Aviation</td>
<td>Aircraft engines</td>
<td>205 Million</td>
<td>$10 B</td>
</tr>
<tr>
<td>Rail</td>
<td>Freight</td>
<td>52 Million</td>
<td>$3 B</td>
</tr>
<tr>
<td>Healthcare</td>
<td>CT+MRI scanners</td>
<td>4 Million</td>
<td>$250 million</td>
</tr>
</tbody>
</table>

Source: GE estimates, 2013
Optomec Enabling Technology for the IIoT

Fully Print 3D Parts or Print-on 3D™ Parts
- Print Structural metals, Electronic inks, …
- Add material to existing components
  - Micron to Meter scale

Provide Value Across Product Lifecycle
Functional prototypes to volume production
- Preventative maintenance to part repair
  - Cost effective

Open Systems Approach
- Coexist with existing processes
- Integrate with existing machines
  - Use commercially available materials

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 100nm
  - Non-contact process
  - 2D / 3D Printing
- Cost and Functional Advantages
  - Lower Material and Process Costs
  - Improved End-Product Performance
- Standard System Products
  - Standard Development Platform
  - Medium Volume Production Systems
  - High Volume OEM Print Modules
Aerosol Jet Technology Basics

1. 1-1000cP fine particle inks
2. Mist of 2-5um Highly Dense, Highly Load Droplets
3. Non-contact deposition, 1-5mm standoff height from nozzle tip to substrate surface
4. Continuous Flow Exits at >50m/s remains collimated for up to 5mm
5. Process is highly scalable in terms of both feature size and multiplexing

Aerosol Jet Process (Art to Part)

Design
- CAD Model
- Convert to DWG file
- Tool paths generated with Optomec software

Process
- Liquid raw material
- Create fine (femto Litre) aerosol
- Focus to tight beam (~10μm >)
- Post-process (dry, cure, sinter...)

Part
- Fine line traces
- 3D Conformal printing
- Interconnects
- Embedded passives
- Coatings
Aerosol Jet Process Key Advantages

- Print-On 3D™ structures enables:
- Conformal Antenna printed on industrial and consumer products
- Conformal Health Monitoring Sensors Printed on Structures where needed
- Condensed packaging reduces product size, weight, and cost
- Reduced time to service and focused on pending failures vs. needless replacement of expensive components.

Material Availability

<table>
<thead>
<tr>
<th>Metal Inks</th>
<th>Resistor Inks</th>
<th>Non-Metallic Conductors</th>
</tr>
</thead>
<tbody>
<tr>
<td>An Cuig</td>
<td>Acheson</td>
<td></td>
</tr>
<tr>
<td>Applied Nanotech</td>
<td>Asahi</td>
<td>Heraeus</td>
</tr>
<tr>
<td>Clariant</td>
<td>DuPont</td>
<td>Nanointegris</td>
</tr>
<tr>
<td>DuPont</td>
<td>Lord (carbon)</td>
<td>SouthWest Nano</td>
</tr>
<tr>
<td>Henkel</td>
<td>Methode Development</td>
<td>Semiconductors</td>
</tr>
<tr>
<td>Intrinsiq</td>
<td>Dielectrics and Adhesives</td>
<td>Aldrich</td>
</tr>
<tr>
<td>Novacentrix</td>
<td>Aldrich</td>
<td>Alfa</td>
</tr>
<tr>
<td>Paru</td>
<td>BASF</td>
<td>Merck</td>
</tr>
<tr>
<td>PV NanoCell</td>
<td>DuPont</td>
<td>Nanointegris</td>
</tr>
<tr>
<td>Sun Chemical</td>
<td>Henkel</td>
<td>Reactive Chemistry</td>
</tr>
<tr>
<td>UTDots</td>
<td>Loctite</td>
<td>Rohm &amp; Hass</td>
</tr>
<tr>
<td>Xerox</td>
<td>Norland</td>
<td>Shipley</td>
</tr>
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Partial Listing 0115
Printed Antenna Capability Overview

**Market Driver**

- Lower Cost/COO than Existing Methods

- Printed Antenna for SmartPhones/Tablets, Notebooks, Automotive...
  - Main, Broadband, WiFi, Bluetooth, GPS, NFC, etc.
  - Printed Directly onto Standard Cases, Inserts, MiDs

- Benefits: Lower Total Cost of Ownership
  - Eliminates Environmental/Health Issues with Plating/Nickel
  - Greater Design Flexibility → Reduced Form Factors
  - Scalable Manufacturing envelop

- Current Status: In Production

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**Printed Antenna Capability Overview**

- One Shot Injection Molding
  - Standard Polymers – No Additives

- Print Antenna Pattern
  - Digital process - No hard tooling
  - Silver Nanoparticle ink
  - Patterns printed in 2D or 3D on polymer inserts

- Post Processing
  - Thermal cure – No plating, No Nickel

- Benefits
  - Fewer Process Steps (no plating)
  - Environment Friendly
  - Lower cost
  - High Throughput ~40,000 antennas / week / system
Printed Sensors Capability Overview

Market Driver

- AJ Supports Many Different Sensor Types.
- Print in 2D or 3D, directly onto target products.
- High Fidelity Printing Improves Data Resolution.
- Digital Input allows Mass Customization / Serialization.

Preventative Maintenance

- SAW Device 6um Features
- Glucose Sensor
- 3D Temp Sensor on Catheter
- 3D Creep Sensors
- 1mm Strain Gauge
- CNT-Based Gas Sensor
- 3D Current Sensor for EV
- 3D Interdigitated Ica Sensor
- EMI Sensor Array
- EMI Sensor Array

Aerosol Jet Example: Predictive Maintenance

- Health Monitoring for High-Value Components
- High Temp (>1800°F) In-Situ Creep Sensors
  - Optical sensors detects fatigue and creep
  - Unique serialization for each gage
- Enabled by Aerosol Jet Printing
  - 3D Conformal Printing directly onto parts.
  - Digital input enables Serialization
  - Supports High Temp YSZ Ceramic Ink

Health Monitoring for High-Value Components

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Summary

Optomec and the IIoT

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<tr>
<th>Feature</th>
<th>Benefits</th>
</tr>
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<tbody>
<tr>
<td>Aerosol Jet Process</td>
<td>Conformal printing with features from ~10µm to mm</td>
</tr>
<tr>
<td>Inks / Materials</td>
<td>Full Range of Conductive Materials, Dielectrics, Epoxies…</td>
</tr>
<tr>
<td>Platform Flexibility</td>
<td>2D and 3D Antenna and Sensors</td>
</tr>
<tr>
<td>Digital Process</td>
<td>No tooling – allows easy conversion to new antenna patterns</td>
</tr>
<tr>
<td>Complimentary</td>
<td>Fills gaps where current solutions are deficient</td>
</tr>
<tr>
<td>Environmentally Friendly</td>
<td>Direct Printing - no subtractive or plating processes – simplified logistics, reduces floor space, eliminates health hazardous materials</td>
</tr>
<tr>
<td>Cost Effective</td>
<td>Scalable Print Engine to Full solutions with lower overall operating cost than many current manufacturing solutions</td>
</tr>
</tbody>
</table>

Thank You…Danke!

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