Fully Additive – The Convergence of 3D Printing and 3D Printed Electronics

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Agenda

1. Company Overview
2. Enabling a 3D Printed Electronics Process
3. Interconnection of SMDs and Printed Components
4. Fully Additive Manufactured 3D Electronics
5. Research Projects
Neotech manufactures systems for 3D Printed Electronics:

- Pioneering 3D PE development since 2009.
- First 3D capable system installed in 2010.
- 1st commercial sale & install of mass production system in Q3 2013.
- 1st commercial mass production started on Neotech systems in Q3 2015.
Benefits and Market Need for 3D Printed Electronics

Design Flexibility
- Integration of Mechanics-Electronics-Optics
- Flexibility of Shape
- Miniaturisation
- New Functionality

Economics
- Reduced Part Count
- Shorter Process Chains
- Reduced Materials Use
- Increased Reliability

Environmental
- Reduced Materials Mix
- Simplified Recycling & Disposal
- Reduced Material Quantity
- Reduced Parts Tourism

Printed Electronics

3D Substrate → 3D-MID → 3D Circuit Pattern

Courtesy: Research Assoc. 3-D MID e.V.
Strategies for 3D Printed Electronics

How to add electronic functionality to 3D shaped parts?

1. Printed Circuit structures
2. SMD components
3. Printed Device
4. Substrate Building and Embedding

Method 1: Print on existing 3D parts (moulded, composite…)
Method 2: Fully Additive – combine 3D PE with layer by layer process (FDM, SLS, SLA….)
Automated Process Chain
Method 1: Print on Existing Structures

Part Input
(Moulded, Composite…)

- Pre-processing
- SMD Placement

MODULE 3
- Dispense Adhesive
- Place SMD in Pocket
- Cure Adhesive

- Print

MODULE 4
- Print Main Circuit
- Print Interconnects (Adaptive Tool-path)

- Post Process

MODULE 5
- In Line Cure/Sinter (LBS, Laser, UV)
- Offline Line Sinter (Oven)

- Completed 3D PE Component

MODULE 2
- Machining SMD Pockets
- Machining Print Areas
- Plasma Clean

MODULE 6
- Central Process Control

Integrated System
Print Head Selection for Printed Electronics

Process selection driven by application requirements:

Process Cost

3D Capability

Fine Line Capability

Ink Viscosity Range

Materials Efficiency

Simplicity of operation/cleaning

Investment cost

Process Speed

Print Process

- A
- B
- C
- D
- Ink Jet

Ink (<1000mPas)

Paste (>>20.000mPas)

5 = High Performance

1 = Low Performance
Influences on the Selection of the Motion System

**Environmental Influences**

**Print Technology**
- Mass Output of Printhead
- Standoff Nozzle to Substrate
- Design and Complexity of Head
- Variation of Print Direction

**Part/Substrate**
- Parts dimensions
- Weight and Material
- Required accuracy for printed pattern (overall, local)
- Shape and Accessibility

**Axes Configuration and Performance**
- Performance and Capabilities PLC
- Design and Stiffness of Frame
Neotech’s Motion 3D CAD/CAM Tool - *path Generation Software*:

- CAD/CAM package that seamlessly interacts with the print platform to enable the printing of highly complex 3D circuits:
  - Optimised interaction with machine control system.
  - 3+2 indexed, 4 axis simultaneous and 5 axis simultaneous printing
  - Optimised cycle times via free definition of the print sequence.
  - Printing path & machine motion simulation
  - Machine specific ISO Standard G-Code post processor
  - Look ahead function for accurate start/stops of the print process
  - CAM Check Function – check programmed tool-path vs. machine process limits (point to point time, acceleration and axis speed)
Printed Antenna on Moulded Substrates

*Current Process Route using Aerosol Jet Printing:*

1. Printing of Ag-nanoparticle inks on filled PA resins and oven sinter
2. RF Performance: matches industry standard
3. Low temperature inks for PC/ABS
4. Production Costs: specific antenna designs show cost reduction of compared to current manufacturing techniques
Mass Production System 45X

Designed for complex 3D printing geometries on a 24/7 operational basis

High throughput: e.g. antenna capacity ca. 1-3m parts/year

4 Print Stations work with simultaneous 5 Axis Motion

EU, CN & US Patent Granted

Features Include:

- High Speed (1m/s) and High Accuracy (+/-5μm) motion
- Full 3D functional printing capability –
  - 500 x 300 x 180mm (X/Y/Z)
- High performance control systems (CANopen, OPC UA)
- Industrially proven – PLC, MOTION, PRINTING
- Simple operator interface/low maintenance
Process Video: Printing with 45X
Embedding of Surface Mount Devices

**Benefits:**

- No application of small volumes of interconnection material (ICA, Solder etc.)
- Single process step for printing and interconnection
- Low temperature processing (depending on ink)
- Processing of bare dies, mechanical fixing and protection of the component
Adaptive Tool Paths Process Flow

Risk:
Component Displacement

System enhancement:
Adaptive toolpath

- Locate fiducials on part. Autocorrect X,Y & Theta
- Print main circuit
- Automatically find LED contacts coordinates
- Interconnects to LED written with Adaptive Tool-path

Risk: Component Displacement

- Designed Position of SMD (CAD-Model)
- Designed Circuit Pattern
- Embedded Material
- Printed Circuit Pattern
- Real Position of SMD

Main Circuit: Red
Interconnect: Yellow
80μm
500μm

80μm
3D Printed Sensors

Tank Filling Sensor (Capacitive)

Touch Sensor on moulded PC (Capacitive)

Strain Gauge on 3D Printed PLA (courtesy: Fraunhofer IFAM)
3D Heater Patterns on Honeycomb Composite
Aerospace – Cabin Interior

Ag circuit with PTC resistive heater

- light weight, safe & integrated into cabin side wall.
- Rear side cooled to under -20°C, heater at 38°C
- Combination with printed sensors

LuFo V-II Project FeVediS in cooperation with Fraunhofer PYCO and FAU, Institute FAPS
### Additional Functionality for 3D Printed Electronics

<table>
<thead>
<tr>
<th>Printed Component on 3D</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductors</td>
<td>Carry Current</td>
</tr>
<tr>
<td>Antenna</td>
<td>Broadcast/Receive</td>
</tr>
<tr>
<td>Sensors</td>
<td>Input</td>
</tr>
<tr>
<td>Heater</td>
<td>Heat Part</td>
</tr>
<tr>
<td>Resistors</td>
<td>Control Current Flow</td>
</tr>
<tr>
<td>Capacitors</td>
<td>Filter, Charge Storage</td>
</tr>
<tr>
<td>Inductors</td>
<td>Filter, Transform/Transfer</td>
</tr>
<tr>
<td>Diodes</td>
<td>Valve</td>
</tr>
<tr>
<td>Transistors</td>
<td>Amplify, Switch</td>
</tr>
<tr>
<td>Memory</td>
<td>Information Storage</td>
</tr>
<tr>
<td>Emitters</td>
<td>Display Output</td>
</tr>
<tr>
<td>Power Source</td>
<td>Energise Circuit</td>
</tr>
</tbody>
</table>

1 Courtesy Optomec Inc.
2 Courtesy Fraunhofer IKTS
Automated Process Chain
Method 2: Fully Additive

MODULE 1
5 Axes AM
Structural Build

MODULE 3
Dispense Adhesive
Place SMD in Pocket
Cure Adhesive

MODULE 2
Machining SMD Pockets
Machining Print Areas
Plasma Clean

MODULE 4
Print Main Circuit
Print Interconnects (Adaptive Tool-path)

MODULE 5
In Line Cure/Sinter (LBS, Laser, UV)
Offline Line Sinter (Oven)

MODULE 6
Central Process Control

Integrated System

Pre-processing
SMD Placement
Print
Post Process
Completed 3D PE Component
Fully Additive
5 Axis 3D Printed Parts

5 Axes Fused Filament Fabrication enables the fully additive manufacturing of 3D Printed Electronics:

- Variety of materials commercially available (PLA, PC, ABS…) and under development (e.g. thermally conductive materials)
- 5 Axes FFF allows novel geometries to be built without support structures, improved mechanical properties compared to classical anisotropic 3D builds
- FFF module combined with Print Modules and Pick&Place allows the encapsulation/embedding of the printed electronics
- Improvement of surface quality by machining or laser treatment; alternatively printing of filler material
- Combination with 4 station print system for higher throughput
5 Axes Manufactured Parts

**Embedded Heater Pattern**
5 Axes Fused Filament Fabrication of PLA base structure
Printed Ag heater pattern added to main body
Encapsulated with orange PLA (4 axis simultaneous print)

**3D-FFF part**
Machined channels for conductors

In cooperation with FAU, Institute FAPS
Hyb-Man exploits the combination of additive manufacturing and 3D integration of assembly and electronic parts.

Specific aims are:
1. To develop and integrate essential technology for hybrid 3D manufacturing, meeting the real needs of industry.
2. To enable first time right production of systems with integrated mechanical and electrical functionality by creating design rules based on understanding of product-process relationships and by developing in-line testing and quality monitoring as integral part of the complete production chain.
3. To demonstrate the hybrid 3D manufacturing approach in two innovative product cases covering different applications and sectors (LED luminaires and automotive sensors)

**Product Cases**
- Automotive
- Adaptive Sensors
- LED Luminaires

**Technology Development**
- Design Rules
- Inline testing
- Quality Monitoring

**Project Timeframe**: 01.04.2017 - 31.03.2021
EU PENTA Project: Hyb-Man
First Demonstrator

Design of Component and Toolpath:

Functional Component:

5 Axes Manufacturing:
EU Manunet Project: AMPECS

Aims of the Project:
1. Development of fully Additive Manufacturing Process for 3D Printing Electronics with Ceramic Substrates

2. The German-Spanish consortium will develop 3D printable ceramic materials for creating the structural body and integrate printed electronics into and onto this component.

3. End use applications will cover areas where harsh environments exists such as automotive and aerospace as well as in mobile communications.

Project Timeframe: 01.06.17-31.05.20
Summary

The intention of the presentation is to provide an overview on following topics:

▪ 5 Axes motion systems are combined with product specific contactless printing techniques to enable printing of electronic structures onto 3D substrates (3D-MID).

▪ An adapted software tool is available for designing 3D print toolpaths.

▪ Currently the focus of the applications is on “simple” printed electronic functions applied on substrates ranging in size from a few Millimetres up to approx. 2m x 1m.

▪ For the manufacturing of hybride electronics a Pick&Place module and a camera based system control for adaptive toolpaths can be integrated.

▪ Technologies adapted from the Additive Manufacturing will enable a fully additive manufacturing 3D electronic devices “starting from zero”, even in lot size 1. Process routes are currently under development e.g. in the EU-Penta Project “Hyb-Man”.

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Thank you for your attention!

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