3D Printed Electronics & New Design Thinking

A New Age in PCB, RF Design & Packaging

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Agenda

- Nano Dimension introduction
- Why AME? And Why Now?
- AME RF Components
- Innovative Antennas and Arrays
- System in Package (SiP) Development Flow
- RF SiP Case Study
- Power Transistor AME Packaging Case Study
- Summary

Acronyms:
AM = Additive Manufacturing
AME = Additively Manufactured Electronics
SiP = System in Package
Who is Nano Dimension?
We make...

...all of these advanced deep learning-AI led manufacturing solutions that are used by industrial-level organizations to 3D print and assemble High Performance Electrical & Mechanical Applications.
Innovative Products for True Industry 4.0 Solutions
The Critical Pieces to Manufacture High Performance Electronic and Mechanical Devices

Additive Manufacturing
- DragonFly IV: Additively Manufactured Electronics
- Fabrica 2.0: Micro AM
- Admatec: Ceramic and Metal AM

Advanced Materials & Processes
- Conductive and Dielectric Inks
- Ceramic
- Polymer
- Metal

Wireless Connectivity
- DeepCube: Deep Learning Based AI Platform

Robotic
- SMT Suite of Products: Surface Mount Technology for Electronics
- Digital Printing Platform: Printer control systems and software

FLIGHT
- Design-to-Manufacturing Testing, simulation, and management

Software
Worldwide Presence Poised for Accelerated Growth
Close to Where We Need to Be For the Most Advanced Manufacturing Markets

- 555 employees across the globe
- ~46% in R&D & Tech/App Support
- ~36 Data scientists & Algorithm Engineers dedicated to AI development
Why AME? And Why Now?
Motivation

CURRENT WORLD OF ELECTRONICS

1. Technical Limitations:
   preventing improvement of performance and reduction of other factors such as weight and size

2. Supply chains:
   hurting most in the high variety small mix and when prototyping (long R&D cycles)

Weight and size over 90% down
Motivation (cont.)

LONG LINES FOR PACKAGING AND PROTOTYPING

Very long lead time for small & medium-sized enterprises and very long R&D-cycles

- To produce a prototype, 4 R&D cycles are required
- Each cycle has a 3-4 months lead time until supplied from the global packages & electronics manufacturer
Motivation (cont.)

TRADITIONAL MANUFACTURING VS. SUSTAINABLE AM SOLUTIONS

3. Sustainability

A holistic approach towards functional electronics with net zero carbon emissions
Motivation (cont.)

TRADITIONAL MANUFACTURING VS. SUSTAINABLE AM SOLUTIONS

1 Based on a 2021 study by HBSMI, a UK-based sustainability consultant.
But how it works?

ADDITIVE MANUFACTURING ELECTRONICS (AME) - PROCESS DESCRIPTION

• Inkjet technology that combines UV-cured dielectric material (acrylic monomers) with silver nanoparticles (Ag NP) that undergo sintering upon IR radiation.

  Result in solid objects with highly conductive patterns in shapes unachievable through traditional processes
Additive Manufacturing Electronics (AME) - DragonFly

DragonFly IV video
From a Digital design file to a Printed Hi-PED

1. Gerber / ODB++ / STL
2. Pixels in a digital file
3. Printed layer
4. Cured, dried and sintered layer
5. Printed multi layers HiPED
Endless Possibilities

HETEROGENOUS INTEGRATION

- Free form 3D electro-mechanical designs
- Devices miniaturization/condensation
- Any layer routing
- Any angle routing
- Via-less routing
- "Real" twisted pair routing
- 3D shape routing
- 3D line-spacing
- Printed 3D antennas/coils
- Eliminating loss generators
New Design Thinking

NON PLANAR TRANSMISSION LINES

- Coaxials, twisted pairs, waveguides. Freedom of via interconnects

Source: J.A.M.E.S
New Design Thinking

3D PRINTED COAXIAL

- Reduced microstrip effects
New Design Thinking

HIGHER DENSITY ROUTING

- Homogeneous Z-axis structures allow to 45 degrees vias with increased performance and space reduction
**Why Now?**

**DF IV**

- Technology maturity: DFIV represents the 4th generation of our AME machine;
- New materials
- AME allows industry players to unleash the next level of innovation!

### 3D AME Fabrication – End-to-End Solution
- Multi-materials: conductive and dielectric
- Integration of 3D components in PCB
- 3D designed Hi-PEDs (High Performance Electronic Devices)
- FLIGHT SW Suite – enabler for 3D electro-mechanical devices

### Support of HDI Level Elements
- 75µ traces; 100µm spacing
- 150µ VIA
- 350µm ball pitch

### Enhanced Print Process, Optimizing Yield with Predictable Conductivity
- Excellent functional connectivity and structural integrity
- High predictable conductivity (30% ± 5% vs. bulk copper)
- Low thickness variation <5%
RF components
RF Examples

HIGH FREQUENCY FILTERS

- Complex tuning iterations and extra laser trimming process is replaced by an overnight print
Performance of LPF

LOW PASS FILTER

- The AME capacitor and the strip line can be placed on any layer or on different layers in the AME board whereby:
  - Increasing design board flexibility.
  - Maximizing area / volume utilization.
  - Mounting other components on the board to reduce the total size of the electronic board.
- AME capacitors exhibit a tolerance accuracy value of less than 1.5%, compared to 5% offered by off-the-shelf SMD capacitors. Therefore, AME boards with AME LPF devices offer superior stable capacitance characteristics.

S21 - AME transmission and capacitors vs AME transmission with SMT commercial capacitors
**DC PERFORMANCE SUMMARY**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>AME Capacitor</th>
<th>Commercial Capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance Range</td>
<td>0.1nF to 3.2 nF (at 25°C)</td>
<td>~100 pF</td>
</tr>
<tr>
<td>Capacitance Variations</td>
<td>&lt;1.5%</td>
<td></td>
</tr>
<tr>
<td>Leakage current</td>
<td>&lt;1pA</td>
<td></td>
</tr>
<tr>
<td>Break down voltage</td>
<td>&gt;1 kV</td>
<td></td>
</tr>
<tr>
<td>Temperature stability factor</td>
<td>25°C-95°C: 0.2 [%/°C], 95°C-125°C: 0.4 [%/°C]</td>
<td></td>
</tr>
</tbody>
</table>

**Better Performance than Ceramic SMT Capacitors by Elimination of Soldering and Package**

RF Examples

RF CROSSOVER

• The 3D AME hybrid structure is crucial for RF signal distribution in antenna applications. It utilizes a 3-dimensional crossover RF design and RF simulation for optimal performance.
Innovative Antennas and Arrays
New Design Thinking

3D-PRINTED ANTENNAS AND RESONATORS

- AME technology is an enabler for new designs of antennas
- Design freedom in the 3D space enables unique antennas such as: Omni directional antennas, coils antennas, special shaped phased-array antennas, etc.

Multilayer Array of Stacked Patches

Metamaterial Antenna

Phased array Antenna
AME X-Band Dual-Polarized Stacked Patch Phased Array Antenna with Dielectric Lens

Phased array antennas are very sophisticated radiating structures which are costly and time consuming to prototype. An AME X-Band (10GHz) stacked patch antenna has been designed in 3 boards that put together via lego-like structures printed in between boards. Air dielectric provides minimum loss. Splitting geometry in 3 parts significantly reduces the print time.

<table>
<thead>
<tr>
<th>Application</th>
<th>Radar, 5G/mmWave Networks</th>
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<tbody>
<tr>
<td>Design Consideration</td>
<td>Air spaced stacked patch antenna boards, LEGO-like assembly, hemispherical dielectric lens for wide angle scanning optimization</td>
</tr>
<tr>
<td>Sample Features</td>
<td>50mm square, 6mm overall thickness</td>
</tr>
<tr>
<td>Printing Time</td>
<td>9 hours</td>
</tr>
<tr>
<td>Ink Consumption</td>
<td>0.4ml CI, 7.7ml DI</td>
</tr>
</tbody>
</table>
RF Examples

AME ANTENNA ARRAY CONCEPT

• The assembly of RF-PCBs often requires special care, with time-consuming manual mountings and a large number of screws that must be positioned precisely. One goal of this AME design concept is to simplify assembly by using a 3-dimensional but flat formfactor for radiation elements and an RF-distribution motherboard.

• Direct-printed coaxial wires can distribute RF-transporting signals while preserving signal integrity and power, thus avoiding connectorized interfaces.
RF Examples

CONFORMAL ARRAY

• Conformal antenna arrays have many benefits, including improved radiation patterns and wide angle scanning. This flexible conformal aperture coupled antenna array was 3D printed in under 6 hours.
RF Examples

METAMATERIALS AND METASURFACES

• Additively Manufactured Polarization Insensitive Broadband Transmissive Metasurfaces for Arbitrary Polarization Conversion and Wavefront Shaping
RF Examples

DUAL BAND METALENS ANTENNA

• Additively Manufactured Millimeter-Wave Dual-Band Single-Polarization Shared Aperture Fresnel Zone Plate Metalens Antenna
• Measured peak gains of 20.3 dBi and 21.9 dBi @ 75 GHz and 120 GHz
Flex and Flex-Rigid boards
New Design Thinking

FLEXIBLE AND FLEX-RIGID STRUCTURES

- Flexible structures
- Flex-rigid assemblies
- MID (Molded Interconnect Devices)
Outlook on future developments (new design thinking)
New Design Thinking

3D-PRINTED METAMATERIALS

- Conventional technologies rely on time consuming precise assembly
- AME is an enabling technology for agile design of 3D metamaterials with isotropic or quasi-isotropic behavior
New Design Thinking

3D-PRINTED METAMATERIALS

- 3D Metamaterial cells and structures possible with AME:
RF Examples

ARCHIMEDEAN SPIRAL ANTENNAS

• Feeding point is in the center of the spiral
• Normally a coaxial is used to feed the antenna
• Low profile design (z) are not possible
RF Examples

AME SOLUTION

- Embedded stripline within the spiral metallization!
RF Power Amplifier Board
RF Power Amplifier Board

L3HARRIS TECHNOLOGIES

- 3D printed functional RF amplifiers.
- Size: 101mm x 38mm (4” x 1.5”) x 3mm thick circuit
- Print time: 10 hours.
- Materials: Silver nanoparticle conductive and dielectric inks were used for the functional electronic parts in a single print
- Components were manually soldered to the PCB.

Test results compared to conventional amplifiers
- No noticeable difference in the input or output return loss response over the frequency range from 10 MHz to 6 GHz.
- No noticeable difference detected in the gain of the 3D printed circuit and the conventionally manufactured amplifier. The gain difference between the 3-D printed circuit and the conventionally manufactured circuit was less than 1 dB up to 4.7 GHz and less than 1.3 dB up to 6 GHz.

“The ability to manufacture RF systems in-house offers an exciting new means for rapid and affordable prototyping and volume manufacturing.”
- Dr. Arthur Paolella, Senior Scientist, Space and Intelligence Systems, L3Harris
Packaging & SiP development
History (cont.)

AME SENSOR APPLICATIONS

Compact and flexible meander antenna for Surface Acoustic Wave sensors

Artificial Hair Cells for Flow Sensing

Sensor direct print packaging (3D printed wirebonding)

3D embedded sensor in electrical packaging

Optoelectronic Neural Surface
History (cont.)

TESTPATCH AGCITE® BONDING

Print on foil
success

Print on wafer
success

Connect two foil on flex substrate
success
History

AME SOCKETS & INTERPOSERS

• Very first encapsulation concept: Stacking of packaged ICs and interposers
New Design Thinking

RF SYNTHESIZER

- 3D Heterogeneous Integration
- Includes DC, digital signals and also RF
- Shielded coaxial lines to keep signal integrity/Impedance controlled interface
- Printed passive components (coils, capacitors)
- Miniaturization
New Design Thinking

RF SYNTHESIZER – CONT’

• 3 steps process
RF SiP
Schematic

- Main component:
  - MMIC 4W X-band die (QPA1022D)
- Other: Resistors (6), capacitors (3) and MOSFET dies.

13.2x13.2x1.5mm
Layout and BOM

- Main component:
  - MMIC 4W X-band die (QPA1022D)
- Other: Resistors (6), capacitors (3) and MOSFET dies.
- Overall physical dimensions:
  - 13.2x13.2x1.5mm
- Minimum pad size on die 80um.
Layout and BOM –cont’

• QFN on bottom side.
• Main 50-Ohm line
• Shielding for the RF line (walls)
Layout and BOM – cont’

• **CAVITIES**

![Cavities]

• Before components placement
Layout and BOM –cont’

• COMPONENTS PLACEMENT

• After components placement
Fabric Systems

AME (Additively Manufactured Electronics)
AM (Additive Manufacturing)
SMT (Surface Mount Technology)

Digital Deposition Technologies

Driven by DeepCube Group:
Deep Learning software embedded in systems for realtime self-learning and correction

Digitalize analog manufacturing
Environmentally friendly & efficient digital production:
Smarter, Better, Faster

AME enables free from 3d electronics design and manufacturing

THE NANO DIMENSION JOURNEY
Layout and BOM –cont’

• Before components placement

• After components placement.
Layout and BOM –cont’

• FINAL TOP & BOTTOM VIEW
Power Transistor AME Packaging
Power Transistor SiP

GAN-ON-SILICON

• Enhancement mode GaN-on-silicon power transistor (650V)
• Top-side cooled configuration
• High current $I_{ds(max)} = 60A$
• $R_{ds(on)} = 25m\Omega$
• Very high switching frequency (> 100MHz)
• Small 9 X 7.6 mm PCB footprint
Power Transistor SiP

GAN SYSTEMS (GS66516T)
Power Transistor SiP

GAN-ON-SILICON

Process:

a) Printing dielectric cavities & pause the print (keeping chuck at 100°C)

b) Placing the silicon dies and adding Epotek conductive glue on the bare pads

c) Print DI “soldermask alike” and fill gaps

d) Print CI pads connection

e) Print interconnecting tracks

f) Print cover layer
Power Transistor SiP

RI.SE DESIGN FOR AME

• A very compact module with four GaN discretes was designed.

Challenges:
• Meeting the application targets – High voltage, high current
• Effective heat dissipation – High current
Power Transistor SiP

GAN-ON-SILICON
Power Transistor SiP

GAN-ON-SILICON

Module with four GaN HEMTS ($V_{DS} = 650\ V$, $I_{DS} = 60\ A$, $R_{DS(ON)} = 25\ \text{m} \Omega$)

- The AME method have proven to be very time efficient!
  - 2-3 complete packaging iterations within 2-3 months – this normally takes years

“The device’s mechanical characteristics are approximately 64% smaller than the smallest similar functional devices existing in the market and will create the highest power density for this kind of device. Furthermore, this is the first attempt to use 3D AME technology to reduce size, reduce manufacturing time and improve power density in this kind of circuit.”
New Design Thinking

EMBEDDING & ENCAPSULATION

- Image sensor Die
- 3D printed wire bonding
Summary
Solving Large and Growing Challenges
Providing Solutions that Industry, OEMs, and Researchers Need Now

**Problems**
- Supply chain disruptions
- IP theft
- Limits of mass production
- Ongoing environmental disaster

**Solutions**
- Re-shoring manufacturing
- Digitally secure manufacturing
- Custom products for many
- Technology to address environmental impact
THANK YOU!

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