Scalable 3D Printed Electronics – "Fully Additive" To High Volume Manufacture

Dr. Martin Hedges – Managing Director

10.06.2022
Agenda

1. Company Overview
2. Designing a 3D Printed Electronics Process
3. Application Examples
4. Beyond Simple Circuits
5. 3D Print Systems
Introduction

- Neotech AMT GmbH, Nuremberg, Germany
- Specialist machine tools for 3D Printed Electronics
- Pioneering 3D PE development since 2009
- First 3D capable system installed in 2010
- First mass-production capable system, 45X, built in 2012
- Active in a wide variety of industries
What is 3D Printed Electronics?

3D PE is the addition of printed electronics functionality, sometimes in combination with classical SMDs onto and/or into structural components to create mechatronic systems.
### Benefits of 3D Printed Electronics

<table>
<thead>
<tr>
<th>Design Flexibility</th>
<th>Economics</th>
<th>Environmental</th>
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<tbody>
<tr>
<td>Integrated Products</td>
<td>Reduced Part Count</td>
<td>Reduced Materials Mix</td>
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<tr>
<td>Flexibility of Shape</td>
<td>Shorter Process Chains</td>
<td>Simplified Recycling</td>
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<tr>
<td>Minaturisation</td>
<td>Reduced Materials Use</td>
<td>Reduced Material Quantity</td>
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<tr>
<td>New Functionality</td>
<td>Increased Reliability</td>
<td>Reduced Parts Tourism</td>
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</table>
Two basic process chains exist for 3D Printed Electronics:

**Route 1**: Print on 3D Substrates. Electronics are integrated onto the surface of a standard component (mouldings, composites etc.)

**Route 2**: “Fully Additive Manufacture” – classical structural AM (via FFF, SLA, IJ…) is combined with 3D PE processes
2. 3D PE Processes, Systems & Strategies
Machine Tools for 3D PE

3D PE machine tools containing a variety of print, pre- and post-processing tools with integrated software:

<table>
<thead>
<tr>
<th>Print Platforms</th>
<th>Print/Functionalising Tools</th>
<th>Pre/Post-Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeform 3D – 5 axis motion (CNC)</td>
<td>Piezo/Valve Jetting</td>
<td>Plasma Cleaning</td>
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<tr>
<td>+ CAD/CAM Software</td>
<td>Aerosol Based</td>
<td>Sintering (Light/Laser)</td>
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<tr>
<td></td>
<td>Ink Jetting (Single &amp; Multi-Nozzle)</td>
<td>UV Curing</td>
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<td></td>
<td>Dispensing</td>
<td>Adaptive Tool Path Vision System</td>
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<tr>
<td></td>
<td>Structural Build (FFF, Dispensing, Jetting)</td>
<td>Laser Ablation</td>
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<tr>
<td></td>
<td>SMD Pick &amp; Place</td>
<td>CNC Machining</td>
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</tbody>
</table>
## Print Technologies for 3D Electronics

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</thead>
<tbody>
<tr>
<td>Standoff Distance</td>
<td>1-5mm</td>
<td>1-10mm</td>
<td>&lt;1mm</td>
<td>1x Nozzle ID</td>
<td>N/A</td>
<td>&gt;5mm</td>
<td>&gt;5mm</td>
</tr>
<tr>
<td>Viscosity Range</td>
<td>50-200,000mPas</td>
<td>1-20mPas</td>
<td>to 20mPas</td>
<td>to 1,000,000 mPas</td>
<td>N/A</td>
<td>600-150,000mPas</td>
<td>ca. max. 50mPas</td>
</tr>
<tr>
<td>Particulate Size</td>
<td>Nano Scale-Micron (max. ca. D90=6um with 50um nozzle)</td>
<td>Nano Scale</td>
<td>Nano Scale</td>
<td>Nano Scale-Micron Max. size depends on nozzle diameter</td>
<td>Nanoparticles &amp; Micron scale</td>
<td>Nano Scale</td>
<td>Nano Scale</td>
</tr>
<tr>
<td>Printed Line Width</td>
<td>300-1000um</td>
<td>20-250um</td>
<td>50-1000um</td>
<td>50um-1000um</td>
<td>10um</td>
<td>Area</td>
<td>Area</td>
</tr>
<tr>
<td>Typical Thickness</td>
<td>&gt;20um</td>
<td>0,5-10um</td>
<td>0,5-10um</td>
<td>2-10+um</td>
<td>2-10+um</td>
<td>&lt;10um</td>
<td>&lt;5um</td>
</tr>
<tr>
<td>Typical Process Speed</td>
<td>15-100mm/s</td>
<td>1-10mm/s</td>
<td>5-50mm/s</td>
<td>10-20mm/s</td>
<td>1000-4000+mm/s</td>
<td>to ca. 300mm/s</td>
<td>to ca. 100mm/s</td>
</tr>
</tbody>
</table>

Note: exact capabilities depend strongly on factors such as materials deposited, substrate surface condition and 3D geometry.
Each print process has a unique combination of characteristics.

Process selection driven by application requirements:
Complex Functionality for 3D Printed Electronics

3D PE can add circuits and other simple functionality such as sensors, antenna, heaters.

What about more complex devices?

On-going developments in 2D Printed Electronics for complex printed devices:

Passive Devices: Resistors, capacitors, inductors, transformers, diodes

Active Devices: transistors & transistor based circuits

Why not in 3D PE?

https://www.techdesignforums.com/blog/2014/04/04/printed-electronics-demonstrator/
Printed Interconnection of SMDs

Benefits

• Low temperature route, no soldering
• Simplified material mix, simplified re-cycling
• Simplified processing
• Robust package, especially when embedded
• Can exhibit low signal loss in high frequency applications >50GHz (compared to wire bonding)
3. Markets & Applications
3D Printed Electronics is a very transferable technology resulting in a large range of potential applications.

Wide and expanding range of multi-bn Euro Markets:

- **IoT**: US$ 300bn in 2020
- **Mobile Phones**: US$ 400bn in 2020
- **Automotive Electronics**: US$ 217bn in 2019
- **LED Lighting**: US$ 145bn in 2026
- **Power/Industrial Electronics**: US$ 51bn in 2023
- **Medical Devices**: US$ 6bn in 2021
- **Electronic Manufacturing Services**: € 46bn in 2019
- **Plus: Aerospace, White Goods...**
Enabling More Sustainable Electronics

AM of Electronics is CAD Driven

Potential to automate re-use and recycling

<table>
<thead>
<tr>
<th>Manufacturing</th>
<th>Recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create Print/SMD assembly/pre- &amp; post-processing tool-paths</td>
<td>Create machine readable code</td>
</tr>
<tr>
<td>Create machine readable code</td>
<td>Execute Machine Code to Manufacture Part</td>
</tr>
<tr>
<td>Auto-generate recycling route code</td>
<td>Store recycling route code in part/remote</td>
</tr>
<tr>
<td></td>
<td>Read recycling route code</td>
</tr>
<tr>
<td></td>
<td>Automated Reverse Manufacture/recycle and re-use components</td>
</tr>
</tbody>
</table>
Case Study - Reusable “Lumnaire”

Next few years, billions of LED products are going to reach the end of their useful life

Complex mix of materials make up and LED lightbulb:
1. Structural - Min. 10 materials plus
2. PCB (multiple resins, glass fibre, Cu, Ni, solder) plus
3. Electronic Components and (Controller, Resistors, Capacitors, LEDs)

Over 95% of an LED bulb is recyclable but via lengthy multi step processes:
LED bulbs crushed and separated (Ferrous & Non-Ferrous Metals and Glass)
Energy intensive remelted for re-use

E-Waste components PCB, LED strip have many more mixed materials that cannot be reused.

No direct reuse of any SMD components
First Prototype/Proof of Concept

Simplified Materials Mix:
- 1x mechanical body material (FFF printed PC)
- 1x circuit material (Ag/resin paste <0.2g)
- Plus SMDs

Full traceability of all components & materials

Refurbishable + reusable.

Easily Recyclable – Automated with low energy intensity.

To Do
- Optimise circuit & SMD mix
- Print LED lenses/encapsulation
- Glass Cover/Bulb
- Moulded body of reduced mass.
- Test & optimise refurbishment process methodology
MID Application Examples
Mobile Communications - Antenna

1. Printing Ag inks for antenna and circuits on moulded resins: PC/ABS, PA
2. RF Performance: matches industry standard, can show cost reduction (design dependent)
3. Adoption slowed by phone design changes: metal frame, 5G at chip level…
4. Potential in next generation phones (3D shaped glass)

Multi-station Printing.
Courtesy: LITE-ON Mobile Mechanical SBG

Demonstration Antenna
Courtesy: LITE-ON Mobile Mechanical SBG
Particle free Ag printed on PC

“Coarse” printing to reduce cycle time - Laser trimmed at over 1m/s

Good frequency matching at main frequencies (900mHz and 1.8GHz)

Efficiency matches production standard (LDS route)
Antenna for IoT Device

Project by Sentium/Murata/University Erlangen Nuremberg - FAPS Institute

Combination of 3D PE with a multi-stack LPWAN IoT device to complete the mechatronic system.

Two Antenna printed on PC housing for the IoT Device:

- Base Antenna is NFC for writing and reading data to and from the device motherboard.

- Wall Antennas are combined LoRa (Long Range Wide Area Network) and NB-IoT (Narrowband Internet of Things) antennas for communicating with gateways.

IoT device was sent into the stratosphere with a helium balloon.

The sensor covered a distance of nearly 200 km and reached an altitude of over 40,000 meters with sensor data as well as the position of the device could be monitored during the mission.
Key Trends¹ in Automotive:

1. Electric vehicles. Petrol/diesel fuelled vehicles phased out worldwide through the 2030s. Opportunities from electrification and weight reduction requirements.

2. Increased levels of autonomy. ‘Advanced Driver Assistance Systems (ADAS)’ becoming the norm. Opportunities for sensor, heaters and antenna.

3. Differentiation shifts from powertrain to interior/cockpit. Marketing battleground. Opportunity for additional functionality on conformal surfaces in the cockpit while facilitating more efficient manufacturing.

¹ Shift to electric vehicles to drive printed electronics automotive market to $12.7 bn by 2031
### Automotive Applications in Development

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Current Development</th>
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<tbody>
<tr>
<td>Heater Patterns</td>
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<tr>
<td></td>
<td>Lidar/Radar</td>
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<tr>
<td></td>
<td>Rear Windscreen</td>
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<td></td>
<td>Steering Wheel, Cabin Interior (PTC)</td>
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<tr>
<td>Lighting</td>
<td>Cabin Interior (LEDs) with touch sensor control</td>
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<tr>
<td></td>
<td>Optical Waveguides</td>
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<tr>
<td>Sensing</td>
<td>Touch Sensor</td>
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<td></td>
<td>Temperature Sensor</td>
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<td>Pressure Sensor</td>
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</table>
Commercial Aerospace

Cabin Interior - Ag circuit with PTC resistive heater: light weight, safe & integrated into cabin side wall

Additional applications include sensor structures, antenna, lighting

Long lead time to move to production – slow/complex adoption of new technology

Printed Pattern on Honeycomb Composite

Decorative foil

Thermal Analysis

DLR: FeVedis Project
Fraunhofer PYCO, FAPS & Neotech
After suffering a stroke patients are often accompanied by unilateral motor dysfunction resulting in weak finger strength, grip, and poor circulation.

The rehabilitation ball has printed circuits and embedded electronic components on curved, flexible substrates.

It is held in the palm of the hand for close-and-open exercises and effectively increases finger strength and stroke recovery.

The device provides real-time feedback the patient’s grip strength and monitors the training process for patients.
Traditionally edge wrap was done by flex PCB.

To save space printing techniques are being investigated:

a) Screen print – multiple steps, re-alignment but has yield issues
b) Direct printing via Aerosol – can print in 3D but circuit thinning at glass edges and is slow (<20mm/s) /expensive

Process Flow:
1. Fast printing of particle free Ag (front & rear at 45° angle to coat edge)
2. Dry/Cure
3. Laser Abate

Fast & Low cost Manufacture - potential to produce 160,000 interconnects per hour with single print/laser station
Wearables – Anti-fog & scratch-resistant safety glasses

Scratch-resistant and fog-/ice-free protective goggles with "built-in lens heating"

Unveiled at A+A 2021 - International Trade Fair for Safety, Security and Health at Work

Inside
1. Anti-fog coating

2. Transparent, thermally conductive coating defrosts down to -20 °C

Outside
3. scratch & chemical resistant coating

4. 3D conductor tracks

Courtesy: UVEX ARBEITSSCHUTZ GMBH

3. Markets & Applications

Route 2 - Fully Additive 3D Printed Electronics
Printing Electronics on 3D Printed Surfaces

All 3D Printed substrats show some surface texture that affects the printed electronics. Surface quality depends on process: SLA and IJ show smoothest, SLS can be rough/open, FFF has texture from the extruded seam.

Example - Antenna Prototype
Substrate: Multijet printed thermoset photopolymer.
Exhibits fine resolution but still exhibits surface topography.
Inaccurate contour impacts on frequency matching and efficiency
Laser trim creates perfect contour

Courtesy: SUNWAY COMMUNICATION
Printing Electronics on 3D Printed Surfaces

3D Printed substrates can show surface texture that affects the printed electronics. SLA and IJ printed mechanical structures show smoothest and closed surfaces. SLS¹, FFF², can benefit from pre-processing with lasers (smoothing, ablation) or Xenon flash lamps.

²Pulse-Width Modulated Light Technology for Enhancing Surface Properties and Enabling Printed Electronics on FFF-Printed Structures - Graef, Neermann, Stuber, Scheetz, Franke – MID Congress 2018
³Laser-based generation of conductive circuits on additive manufactured thermoplastic substrates - Niese, Amend, Roth, Schmidt - 9th International Conference on Photonic Technologies - LANE 2016
3D Printed Egg Timer
FAPS – University Erlangen-Nuremberg

• 20 white LEDs mounted in five rings on the outer shell
• Embedded PIC16F627 microcontroller
• Powered by two 3 V button cells in series
• Touch switch realized by two comb-shaped pads and a transistor
• Piezo buzzer for acoustic signals
• Conductive path cumulative length of 2m
Luminaire Demonstrator

Cold-Warm LED Device
"Fully Additive Manufacture"

1. Mechanical Structure: FFF PC/ABS
2. Piezo Jet of Ag circuits
3. P&P of SMDs:
   8 Cold & 4 Warm White LEDs
   + Controller, Capacitors, Resistors
4. Pellet Extrusion of transparent TPU

https://www.youtube.com/watch?v=obbZR7KrVpM&t=26s
4. Active Research & Future Perspective
1. Further Develop “Fully Additive” 3D Printed Electronics – both flexible and scalable from small series mass customisation to higher production volumes.

2. Integrated mechanical, electrical and optical functionalities.

3. Develop scalable and reliable industrial production systems in combination with the essential technology and smart processes.

4. Demonstrate the hybrid manufacturing approach in three innovative product cases covering different applications and sectors (LED luminaires & signal and power electronics & medical devices).
AMPERE Project Partners

Project Timeframe: 1.4.21 - 31.3.24
<table>
<thead>
<tr>
<th></th>
<th>Key technology</th>
<th>SotA</th>
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<tbody>
<tr>
<td>1</td>
<td>Additive Manufacturing/3D printing materials &amp; processes</td>
<td>Demonstrated “Fully Additive” Process – Low power (mA range) printed electronics in AM polymer substrates, small lot size</td>
</tr>
<tr>
<td>2</td>
<td>AM Structural Materials</td>
<td>Monolithic thermo-plastics and UV Cured Acrylic Substrates</td>
</tr>
<tr>
<td>3</td>
<td>AM Optical Materials</td>
<td>Simple devices (waveguides) can be 3D Printed</td>
</tr>
<tr>
<td>4</td>
<td>Structural AM Scalability</td>
<td>Multiple printers - some limited machine throughput scaling under development</td>
</tr>
<tr>
<td>5</td>
<td>3D electronics integration/assembly</td>
<td>R&amp;D processes (20um at &lt;20mm/s) for fine line 3D circuit printing. SMD pick and place &amp; interconnection possible</td>
</tr>
<tr>
<td>6</td>
<td>Software processes</td>
<td>CAD-CAM for manufacturing tool-path generation with all process steps</td>
</tr>
<tr>
<td>7</td>
<td>In-line metrology and control platform</td>
<td>Basic Metrology in process (mainly optical inspection)</td>
</tr>
<tr>
<td>8</td>
<td>Design Tools</td>
<td>Software to predict residual stresses demonstrated</td>
</tr>
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## AMPERE Objectives (beyond SotA)

<table>
<thead>
<tr>
<th>AMPERE Objectives (beyond SotA)</th>
<th>Benefit</th>
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<tbody>
<tr>
<td><strong>AM Processes</strong></td>
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<tr>
<td>Scalable process suitable for industrial use to lot sizes of 10,000</td>
<td>Lowest cost scalable product manufacture</td>
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<td>Unique new product offering for machine tool manufacturers</td>
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<tr>
<td><strong>Process Control</strong></td>
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<tr>
<td>Closed loop process control - combination of (in-line) metrology with AI/machine intelligence/learning</td>
<td>New SW &amp; Consultancy Services</td>
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<tr>
<td>Robust/reliable manufacture</td>
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<td></td>
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<tr>
<td>Added functionality of machine tools</td>
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<tr>
<td><strong>AM Generated Functionality</strong></td>
<td></td>
</tr>
<tr>
<td>Extend capabilities to enable signal and power electronics</td>
<td>New application range addressed</td>
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<tr>
<td>Unique feature combinations in end products, extend market addressability</td>
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<tr>
<td>Addition of optical structures, such as wave guides, light shaping or lens structures</td>
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<tr>
<td>Scalable fine line circuits</td>
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<tr>
<td>Miniaturisation of devices on a scalable production level</td>
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Outcomes & Benefits

Outcomes
1. Hybrid multi-material AM production methodologies.
2. Demonstrated integrated production environment architecture.
3. Prototypes of mechatronic products in three application areas: medical, lighting, and power electronics.

Benefits
1. Faster response to changes in the market - localized production and reduced component and tooling lead times.
2. Increased product diversity - flexible manufacturing technologies
3. Cost effective scalable manufacturing of small series and high volumes
4. New product designs - improved functionality, new form factors.
AMPERE  First Technical Demonstrators

Philips Medical – Interconnected (20µm line & Space) ASIC/CMUT on SLA printed body
Signify – 3D Printed CoB LED Housing

Process Flow

1. FFF Structural body
2. P.I Power supply lines
3. FFF Embedding supply lines
4. P.I Contact Pads
5. Registration
6. P&P flipped COB LED
7. Pinning COB LED
8. Sintering

Additive manufacturing
Assembly & measuring
Electronic structure
KAM EI Project – Vision Based Automated QA

Development of a camera-based monitoring system for “Fully Additive” 3D Printed Electronics

Record and classify the manufacturing process and automatically correct processing errors dependent on type:

1. Vision system will record the printed electrical structures in 3D space.

2. Images compiled, compensating for distortion and depth of field elements.

3. Artificial Intelligence (AI) to check for potential defects such as line breaks, short circuits and geometrical errors in width and thickness.

4. Defect is identified, one of three options that can be executed: automated correction, correction with operator input or part rejection (abort print).

Verification of the ink segmentation algorithm with different filament colours. (University of Hamburg)

Project funded by:

Bundesministerium für Wirtschaft und Energie

Timeframe: 1.10.20-30-9.22
„Fully Additive“ 3D PE with Ceramic Substrates

1. EU Manunet Project AMPECS developed base process for Additive Manufacturing process for 3D Printing Electronics with Ceramic Substrates.

Ceramics based on LTCC analogue with embedded nano-particle Ag circuits.

2. Additive4Industry project PE3D Printed Electronics on 3D Substrates

ContiTemic microelectronic GmbH, FAU – Institute FAPS, GSB-Wahl GmbH, TNO (NL)

Development of Additive Manufacturing processes for LTCC ceramic substrates with integrated circuit tracks for high temperature automotive applications including HF/antenna and sensor units.
MRO PrinE - Automated Repair of Printed Conductor Tracks

Approaches for Maintenance Repair and Overhaul of Printed Electronics in Aircraft Cabin Interior components for establishing printed electronics in aircraft applications

Process flow:

• Identify damaged area
• Remove printed conductors by laser ablation
• Surface reconstruction and preparation
• Re-printing and curing of conductor patterns

Funded by:

Grant: 20Q1728A
What does the future hold for 3D Printed Electronics?

3-5 Year Timeline
First Complete Automated Processing Lines – Agile, on-demand digital manufacture
Smart Systems with AI/Machine Learning
Wider functionality: eg. power electronics (many A), optics, miniaturisation, large parts...
Wider adoption across many end use cases/industries

10 Year Timeline
Completely new product architectures
Sustainable 3D Printed Electronics - resource efficient, reduced materials mix
Automated Recycling, Repair and Reuse
Summary

1. What is 3D Printed Electronics, reasons for use and benefits.

2. 3D Printed Electronics Manufacturers, Systems & Strategies

3. Markets & Applications
   Route 1 - MID Application Examples (Mechatronic Integrated Devices)
   Route 2 – “Fully Additive” 3D Printed Electronics

4. Active Research & Future Perspective
Thank you for your attention!

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