TU/e Technische Universiteit Eindhoven University of Technology

High Tech Systems Center

TNO innovation for life

# Multi-technology Additive Manufacturing for 3D structural Electronics


## Erwin R. Meinders

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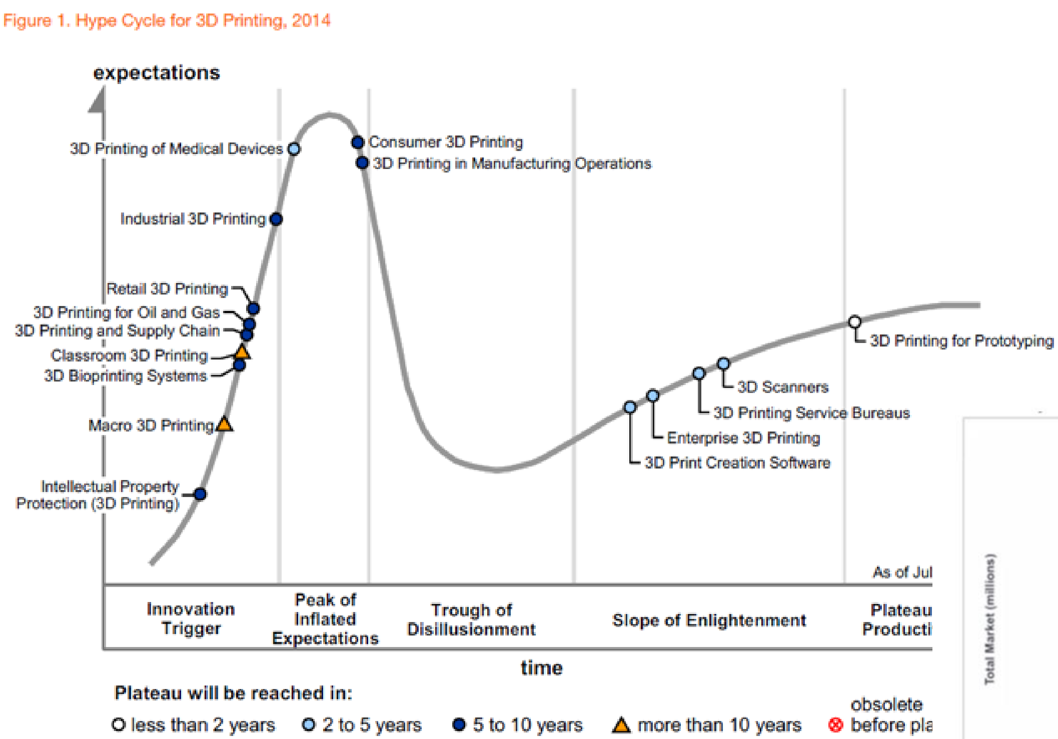
Contents

- **AM context and business potential**
- Structural Electronics – technology enables and demonstrators
- Conclusion and outlook

# Additive Manufacturing is hyping but offers at the same time great business potential for specific applications





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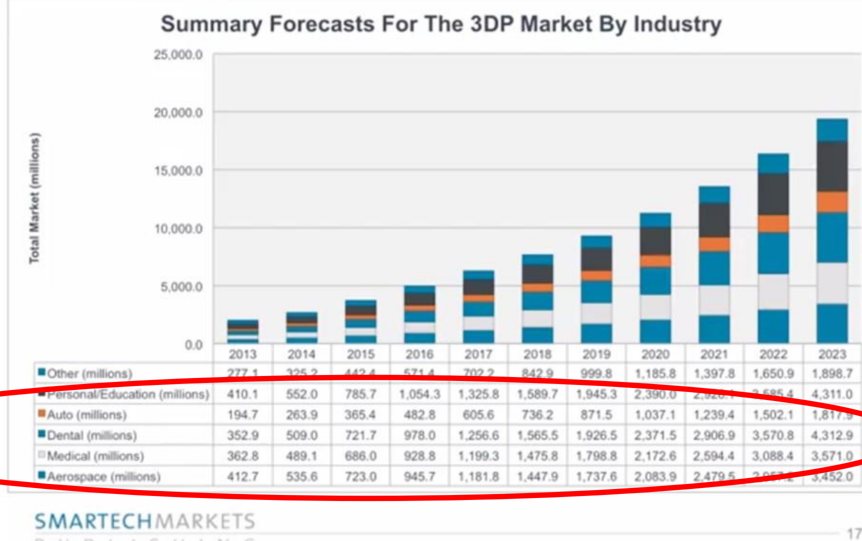
Manufacturing

**The third industrial revolution**

**The digitisation of manufacturing will transform the way goods are made—and change the politics of jobs too**

Apr 21st 2012 | from the print edition

THE first industrial revolution began in Britain in the late 18th century, with the mechanisation of the textile industry. Tasks previously done laboriously by hand in hundreds of weavers' cottages were brought together in a single cotton mill, and the factory was born. The second industrial revolution came in the early 20th century, when Henry Ford mastered the moving assembly line and ushered in the age of mass

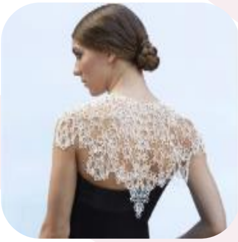



| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Other (millions) | 277.1 | 325.2 | 442.4 | 571.4 | 702.2 | 842.9 | 999.8 | 1,185.8 | 1,397.8 | 1,650.9 | 1,898.7 |
| Personal/Education (millions) | 410.1 | 552.0 | 785.7 | 1,054.3 | 1,325.8 | 1,589.7 | 1,945.3 | 2,390.0 | [illegible] | 3,585.4 | 4,311.0 |
| Auto (millions) | 194.7 | 263.9 | 365.4 | 482.8 | 605.6 | 736.2 | 871.5 | 1,037.1 | 1,239.4 | 1,502.1 | 1,817.9 |
| Dental (millions) | 352.9 | 509.0 | 721.7 | 978.0 | 1,256.6 | 1,565.5 | 1,926.5 | 2,371.5 | 2,906.9 | 3,570.8 | 4,312.9 |
| Medical (millions) | 362.8 | 489.1 | 686.0 | 928.8 | 1,199.3 | 1,475.8 | 1,798.8 | 2,172.6 | 2,594.4 | 3,088.4 | 3,571.0 |
| Aerospace (millions) | 412.7 | 535.6 | 723.0 | 945.7 | 1,181.8 | 1,447.9 | 1,737.6 | 2,083.9 | 2,479.5 | [illegible] | 3,452.0 |

## Human centric applications (medical, dental) and Aerospace have biggest business potential

# Applications and drivers

Textiles

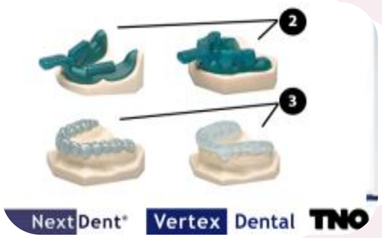


Jewellery

Implants

Toys/collectables

Dental



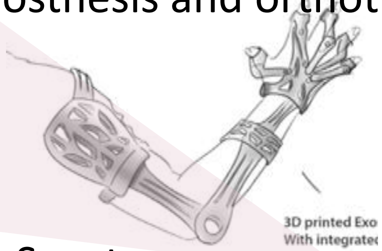

Surgical devices & aids

**Industries**

Electronics

Speciality food


Prosthesis and orthotics




Aerospace

Furniture

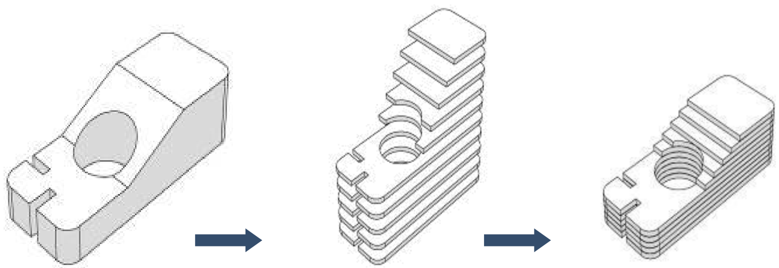
Armaments

Automotive

Sports

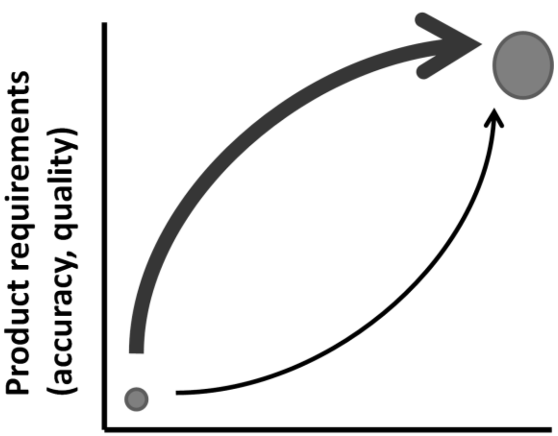
# Additive Manufacturing: A part of the puzzle

Manufacturing of three dimensional objects from a digital model by laying down successive layers of materials in an additive process.



**However, technology is still in infancy stage:**

- Insufficient reproducibility and product quality
- Need for large format printing
- Required tight tolerances are not met
- Limited material portfolio
- Insufficient productivity



# Additive Manufacturing research at TNO

- Additive Manufacturing will become big in **specific B2B manufacturing chains**, based on the benefits of customization, personalization, freedom of design and on-demand manufacturing, enabling new or enhanced products and functionalities.

- AM will be an integral part of a '**next generation ICT driven industry**' approach.

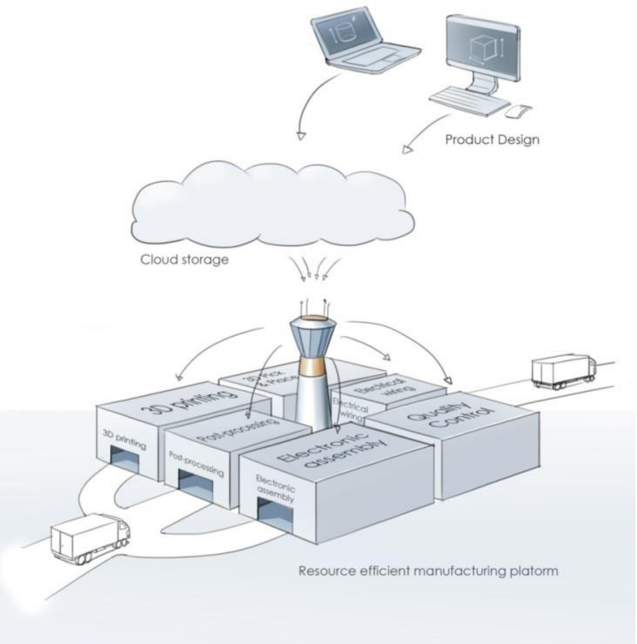
- We focus on **systems for multi-material additive and hybrid manufacturing for mass customization and manufacturability** to boost the competitive strength of the industry.

- We develop next generation additive manufacturing technology for the **leading high-tech and human-centric applications**, such as medical (prosthetics, orthotics, ) dental, free-form electronics (smart head protection, quantified self) and food and pharma (personalised medicines, organ on a chip, personalised food).

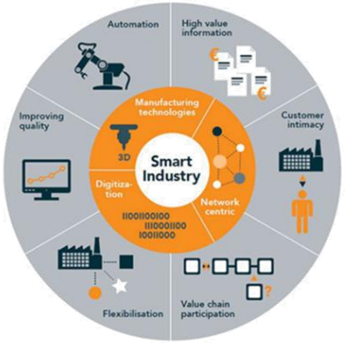
- We have built two ecosystems for materials and systems developments, together with BMC and HTSC

# In the centre of the Smart Industry ambition

- We envision a future factory in the personalized centric world, with an extensive ICT infrastructure in combination with flexible, single-product manufacturing cells, allowing small-series customization at large-series manufacturing cost level.
- TNO and TU/e-HTSC are initiators of the **MultiM3D FieldLab**, which will be a pilot factory for the envisioned industry and will focus on **human centric** and **high-tech customization**.
- The MultiM3D Fieldlab is positioned in the core of the collaboration between the HTSC and TNO on new concepts for multi-material digital manufacturing.

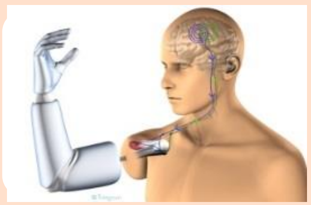



Copyright TNO 2015





# With focus on multi-technology system barriers for leading human-centric and high-tech mass-customization applications



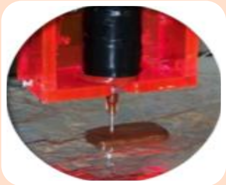
## Medical - Dental

- Orthotics – bio-mechanical interfaces, intelligent implants, multi-material, grading
- Prosthetics / exoskeletons – multi-property for multi-functionality, intelligent insoles
- Dentures – multi-material, full-colour prosthesis , bridge-crown, implants

## Structural / free form electronics

- Integrated sensors in lightweight structures (medtech)
- Embedded Electronics for smart systems
- Structure monitoring for building

Holst Centre
Open Innovation by imec and TNO



## Food / Pharma

- Printed food products (multi-material, personalized, multi-texture)
- Printed pills - multi-material for controlled release, smart pills)

## High-tech applications

- Large-area ceramics for lightweight stable stages
- Advanced cooling
- Multi-material sensors

# Application roadmap dental – from repair towards prevention

Biocompatible and mechanically strong prosthesis (mono-material dentures, drill supports, etc.)

Multi-color polymer denture, natural coloring, biocompatible, mechanically strong

Bridge-crown applications (with ceramics, composites)

Bone implants (bio-compatible ceramics, multi-material

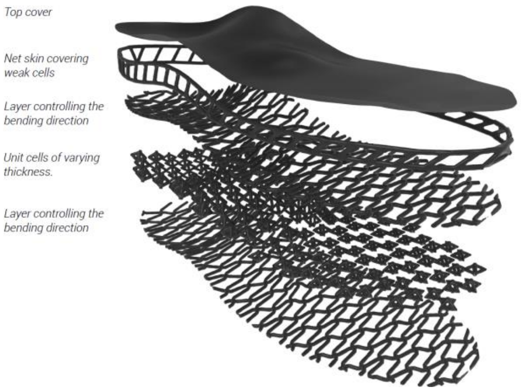
Multi-material dental applications

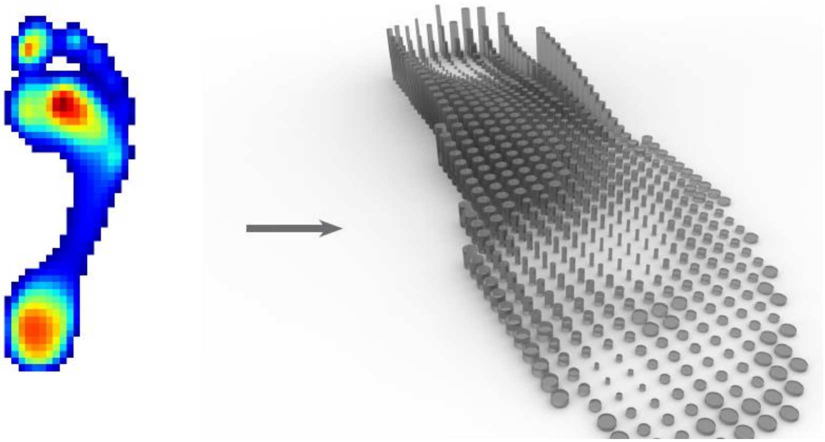
**AM technology is still in infancy stage:**

- Poor productivity
- Need for bio-compatible materials
- Insufficient reproducibility and product quality
- Required dimensional tolerances @ multi-material
- Limited material portfolio, towards multi-material

# 3D printed and personalized footwear

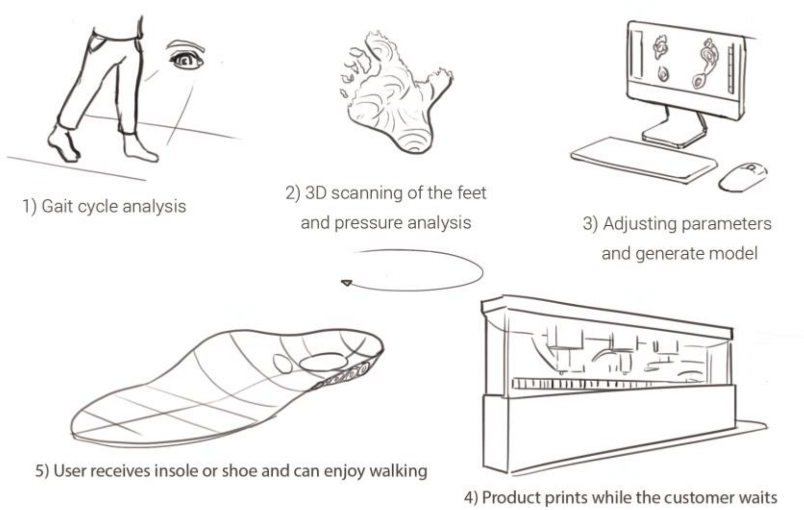
- Offer added functionality and increased customization for a cost efficient price.
- Allow industrial flexible production
- Multiple mechanical properties
- Generated personalized 3d models
- Material properties adjusted locally based on a scan



# Bringing the technology to continuous selective laser sintering

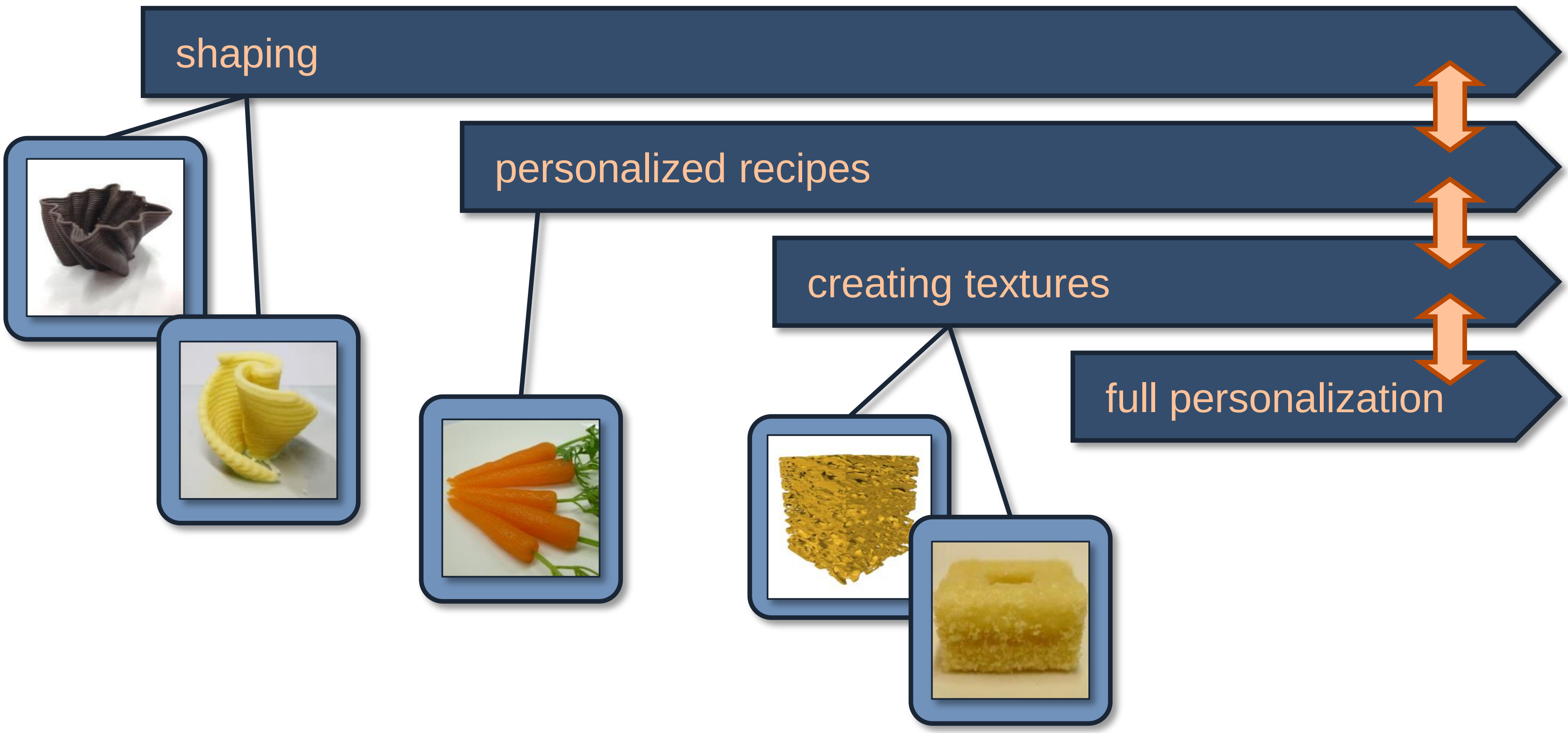
- Improved product quality (continuous SLS gives reproducible results)
- Produce-on-demand (shorter lead times, batch SLS takes typically 48 hours printing + cooling down, continuous SLS brings lead time back to 20 minutes)
- Lower costs (reduced production time, from hours to minutes (from 2 hours to ~20 minutes for 20X10 X2cm product)





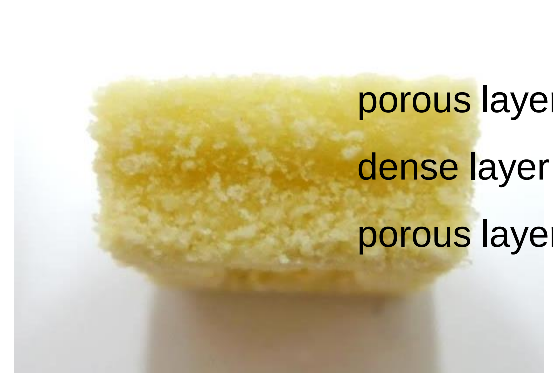

# Application roadmap food printing

*timeline*

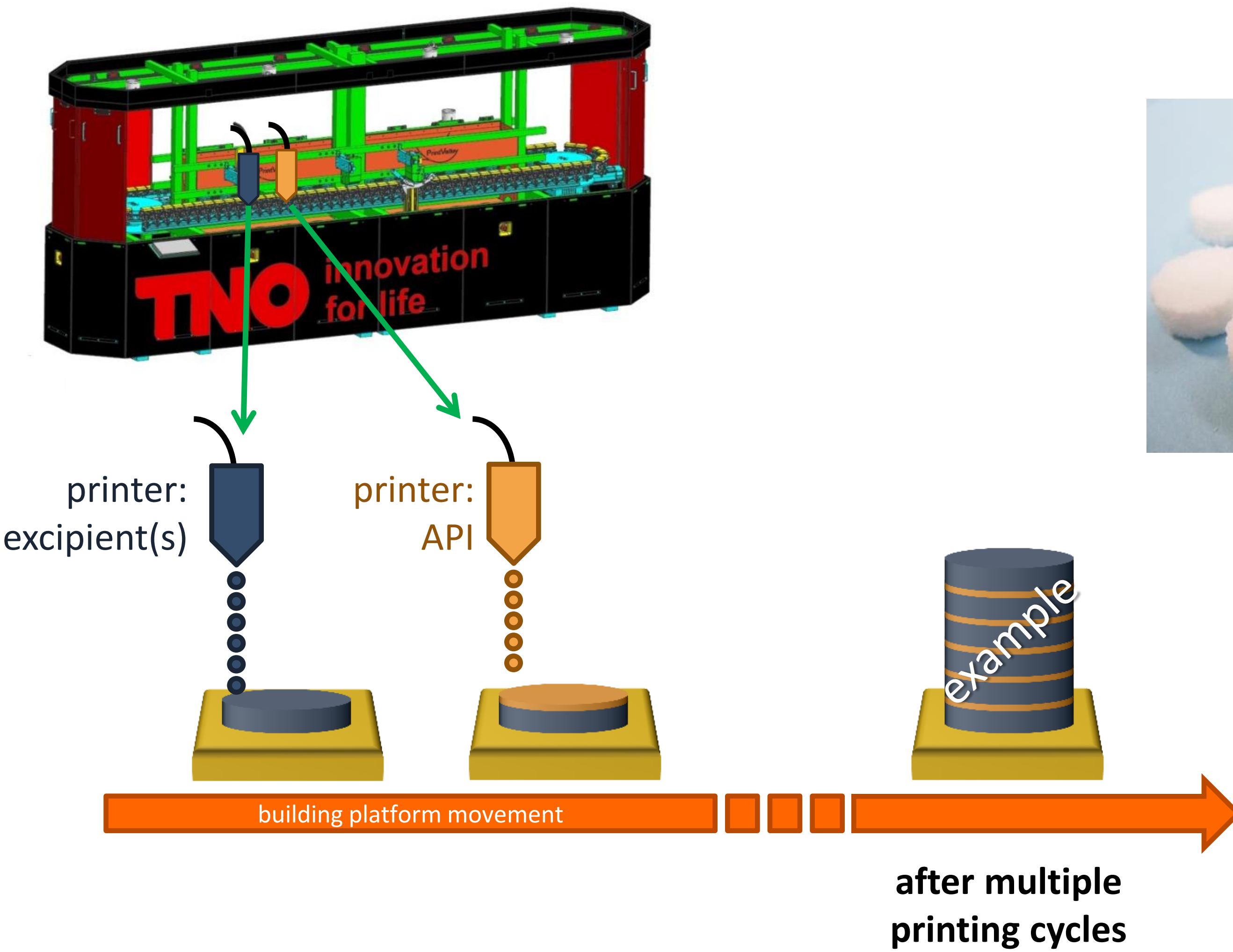


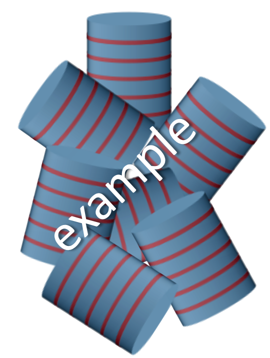
# Multi-texture 3D printing – bakery product

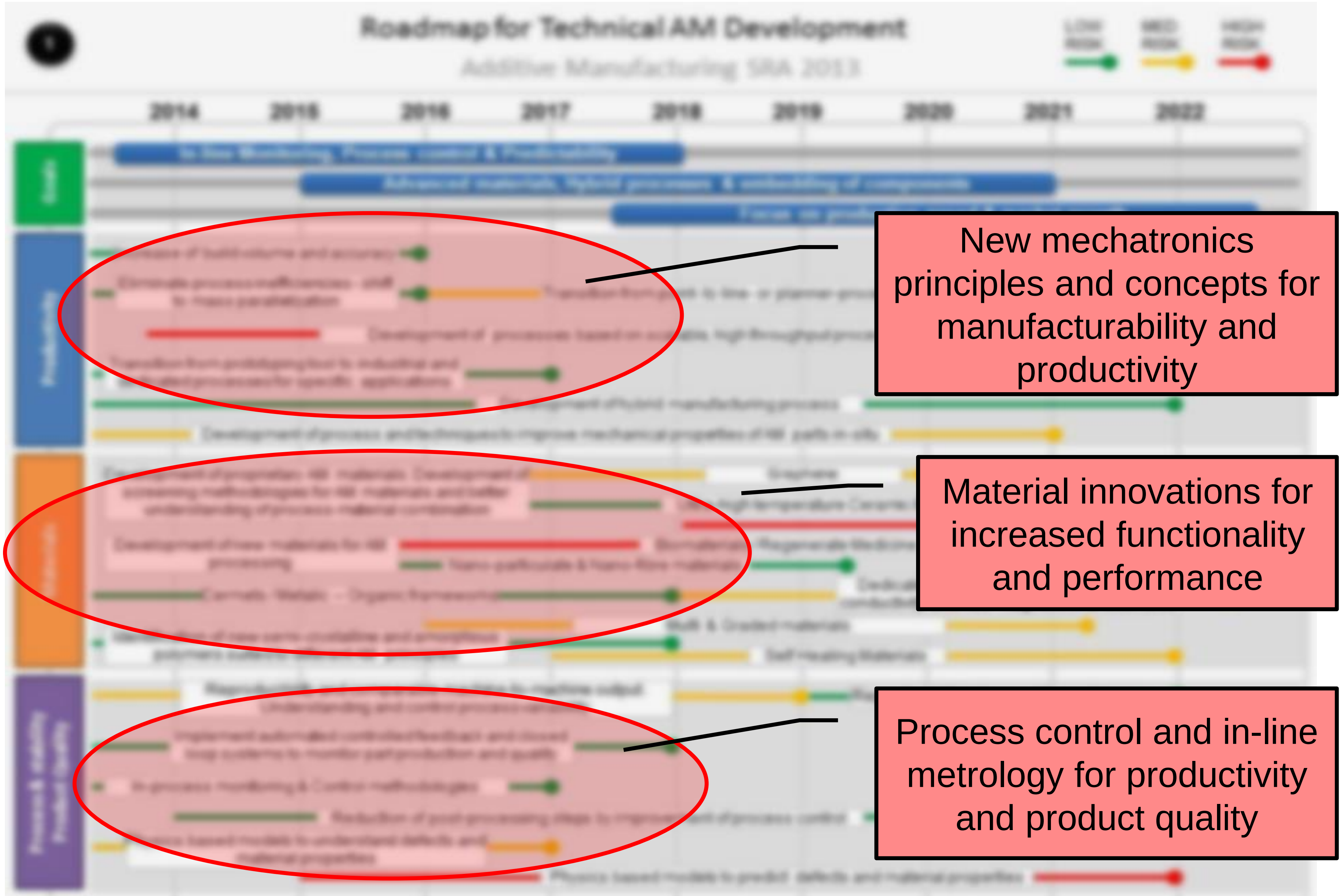
- Development of structuring and texturing technology – example laser-based printing of bakery product



# Example of system for mass-customization of personalized tablets

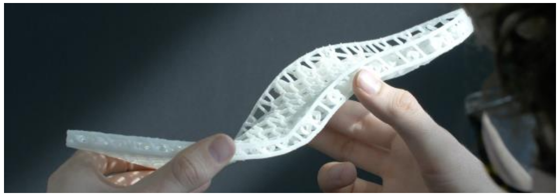


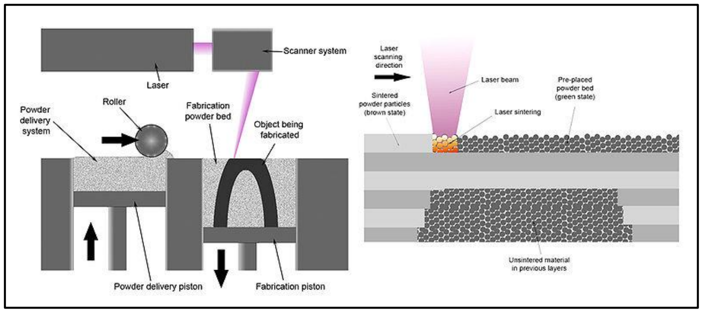

Roadmap for Technical AM Development
New mechatronics principles and concepts for manufacturability and productivity
Material innovations for increased functionality and performance
Process control and in-line metrology for productivity and product quality

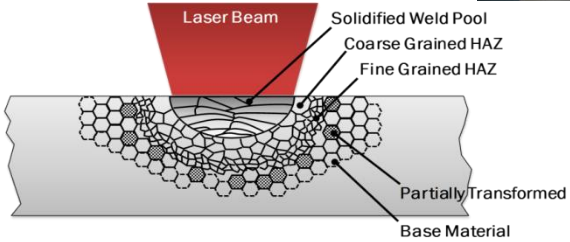


# Laser-based Additive Manufacturing



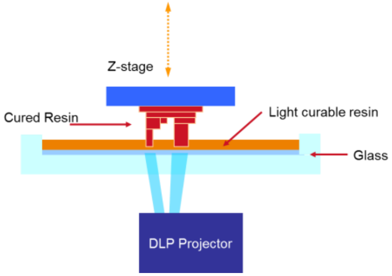
- Thermal processes: SLS, cladding, SLM

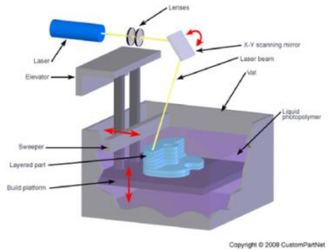


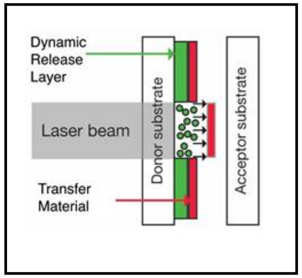


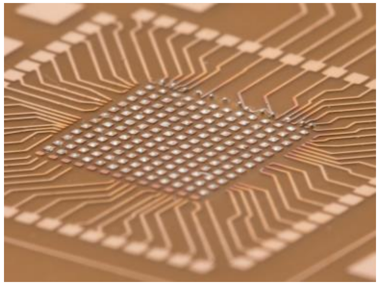
- Photo-polymerization: DLP, SLA,

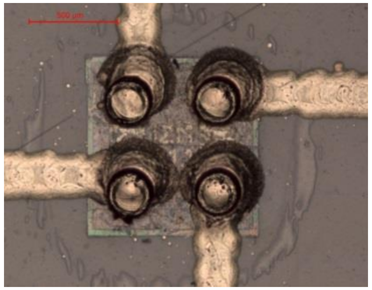



- Other: laser-induced forward transfer, 2-photon, reactive





# Unique technology base 'Systems for AM'


- Multi-laser beam AM technology, for large-area, high-speed
- Technology for multi-material deposition
- Solutions for mass customization, data management and in-line process control
- Proof-of-concept scalability (resolution and scale)
- Model-based engineering (thermal models)

**Multi-material mass customization applications**

2014 - Research platform for high-viscous mono-materials materials, with recoating technology, with 20 micron feature size. A4 build size

2017 - Research platform for multi-material (polymer, ceramic, metal), hybrid deposition with 20 micron feature size. A4 build size. Integration Pick and place, non-AM.

2020 - Research platform for multi-material, hybrid deposition with 10 micron feature size. A3 build size. In-line process control. Integration pick and place, non-AM.


Contents

- AM context and business potential
- **Structural Electronics – technology enables and demonstrators**
- Conclusion and outlook

# Structural electronics via Hybrid Advanced Manufacturing

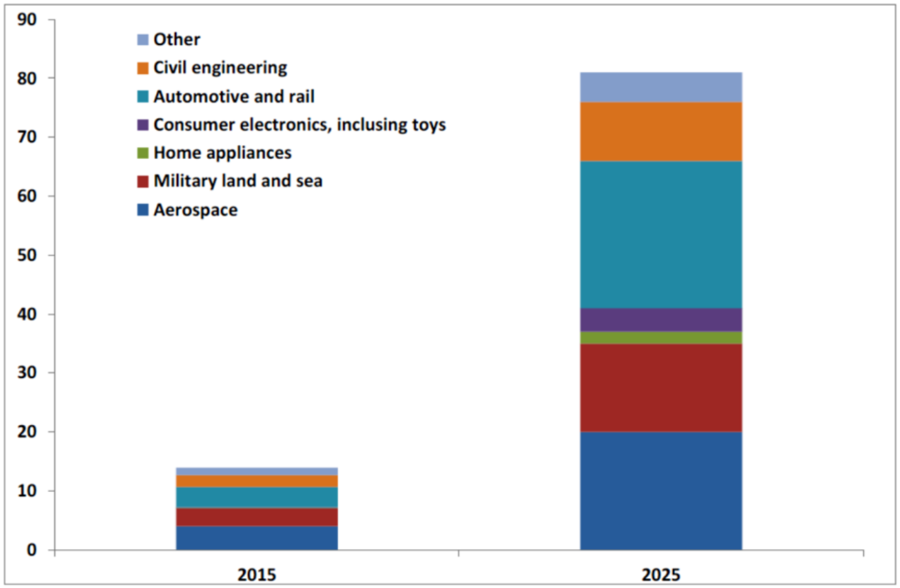

**Hybrid Additive manufacturing: from 2D printing to 3D integration**

***"Transforming dumb objects into smart devices"***

# STRUCTURAL ELECTRONICS

"Structural electronics involves electronic and/or electrical components and circuits that act as load-bearing, protective structures, replacing dumb structures such as vehicle bodies or conformably placed upon them."*

**Fig. 1.8 Structural electronics market 2015 and 2025 $billion globally, excluding BIPV**

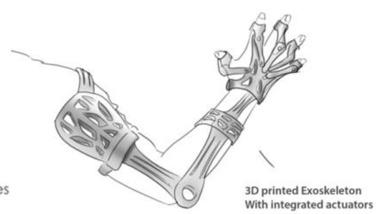


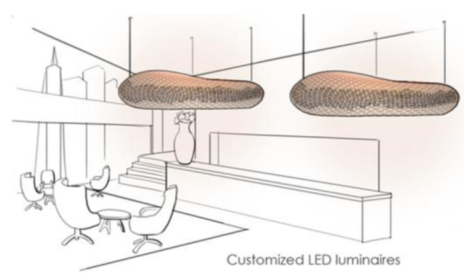

Source: IDTechEx

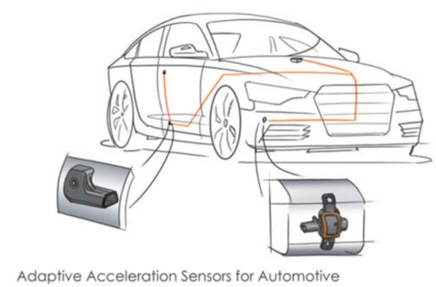
*http://www.idtechex.com/research/reports/structural-electronics-2015-2025-applications-technologies-forecasts-000408.asp

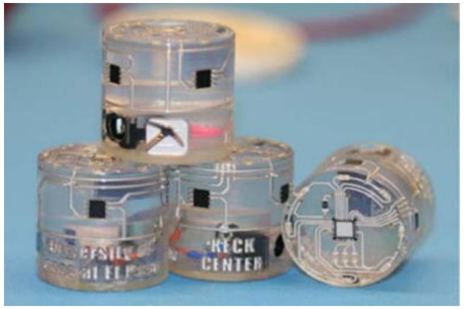
# 3D structural electronics

- Drivers: personalization, customization, cost-efficient manufacturing, new functionality, fast time to market, first-time right manufacturing of integrated devices
- Status today: 2D printed electronics start to get introduced (solar, OLED, medical patches)
- Technology barriers: 3D integrity of printed parts, integration conductive tracks, high-accuracy embedding of functionality, mechanical properties
- Applications: lighting, MEMS, packaging, medical patches, smart pills, smart connectivity

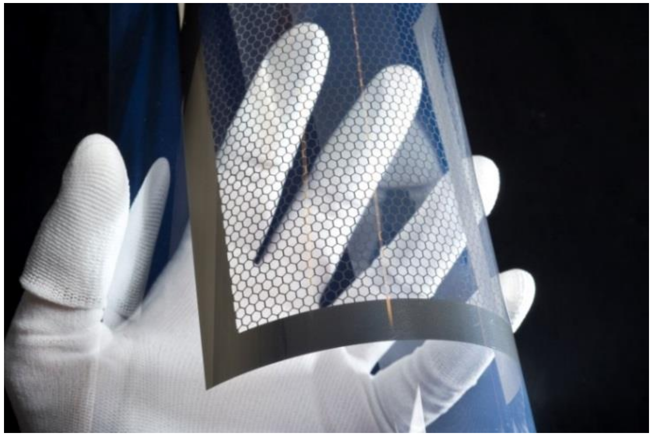



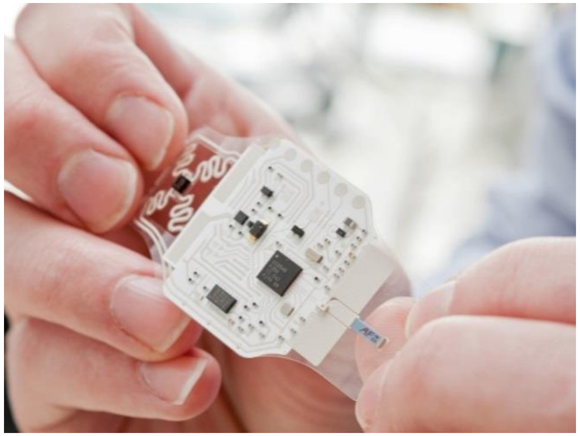



# Enabling technology: metal track deposition

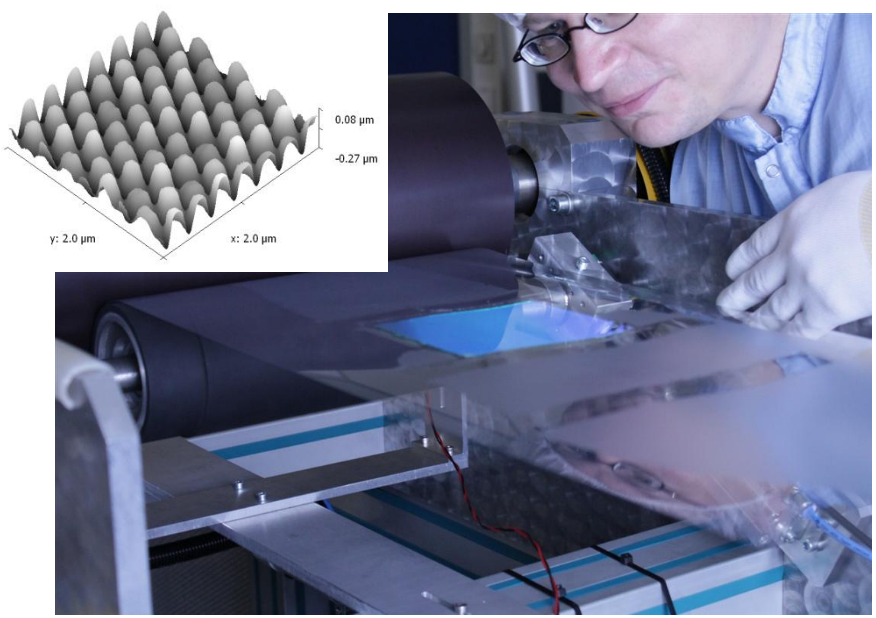
- Baseline inkjet deposition technology with nano particle Ag (6-8x resistivity bulk Ag) and silver complex (4-5x resistivity bulk Ag) inks, feature sizes ~30 µm line width
- Continuous flash sintering technology developed with conductivity better than 5X bulk Ag @ seconds exposure
- Laser-induced forward transfer - high-resolution laser printing based on laser-induced material transfer. Features sizes down to 10 micron printed.



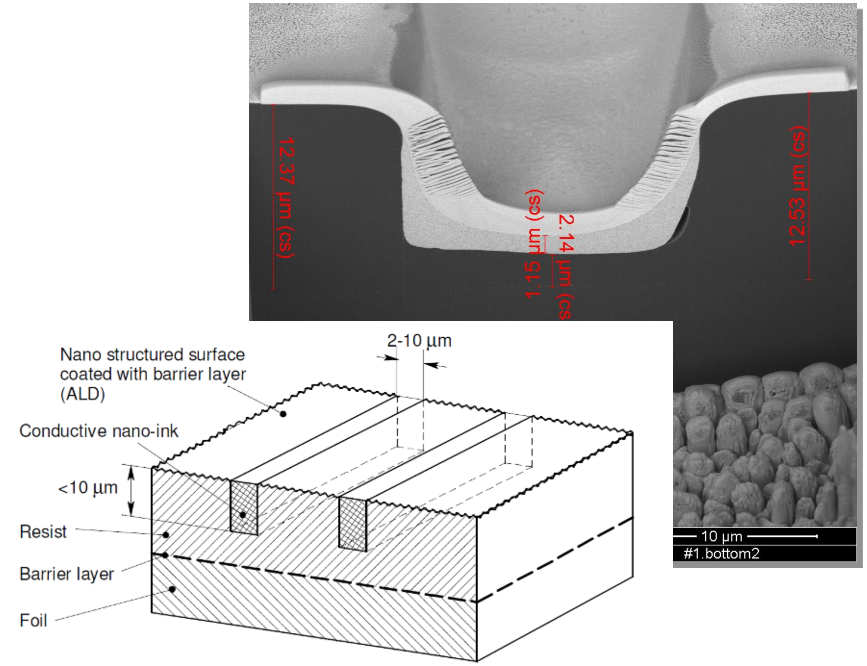


# Enabling technology: embedded electrodes

- Low-cost high conductive grids for large-area electronics (OLED, OPV, thin-film solar, flexible displays, removal of topology
- Proof-of-concept embedded shunt via embossing/printing, seed transfer process and grid transfer.




R2R embossing of out-couple structures for OLED stacks

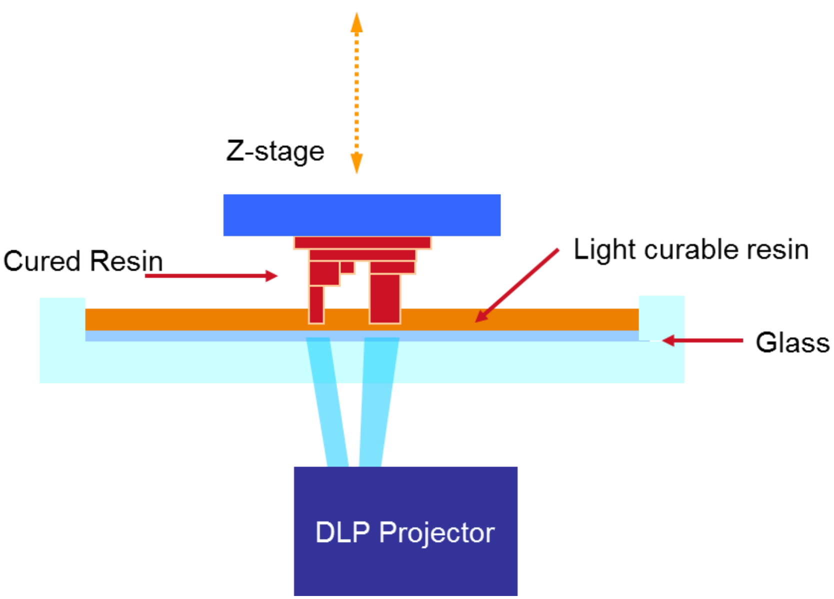



*Schematic drawing of a cross section of a power and light management foil*

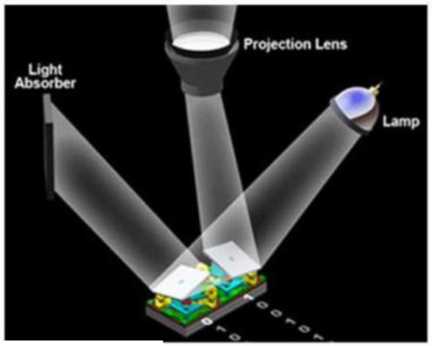
Embedded shunt via embossing and deposition of metal ink

# Enabling technology: high-resolution 3D printing (SLA)

- Photo-polymerization of resin via selective exposure by light-source
- DLP typically used as light source, forced feedback to improve speed and product quality
- Used for relatively small size, mono-material, low speeds at high pattern definition accuracy
- Expanded to filled resins (for ceramic or metallic materials)







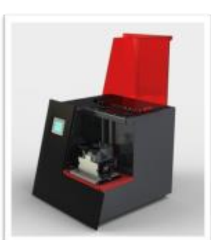

# Enabling technology: high-resolution 3D printing (SLA)

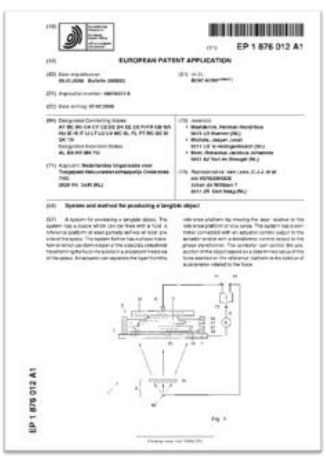
- TNO track record: system concepts, high-resolution build systems (down to 4 micron), light engine development (mirror device, LEDs and laser), material systems (polymers, ceramics)
- Current applications: hearing aids, jewellery, dental



**The Lepus® System.**

- Closed Loop
- Force feedback
- Licensed to RapidShape

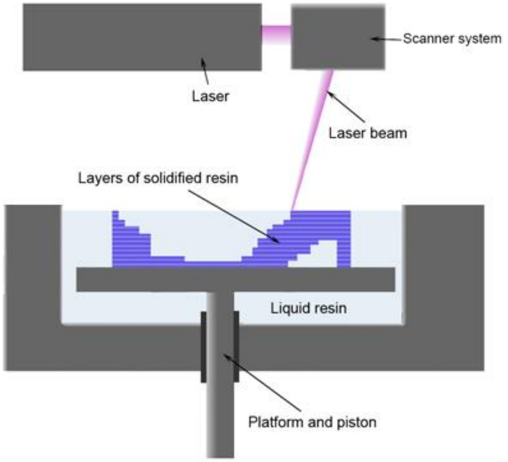


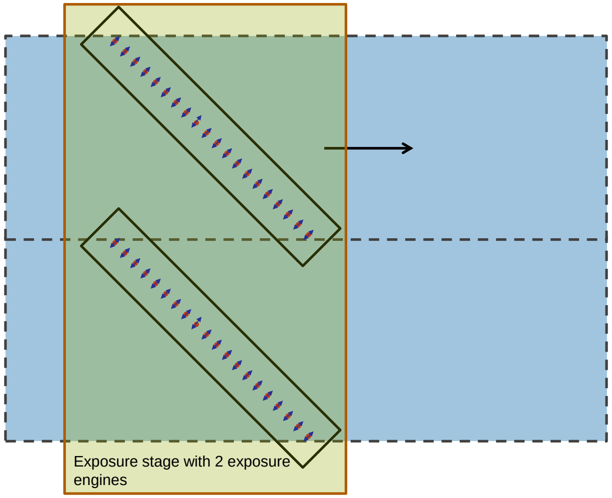


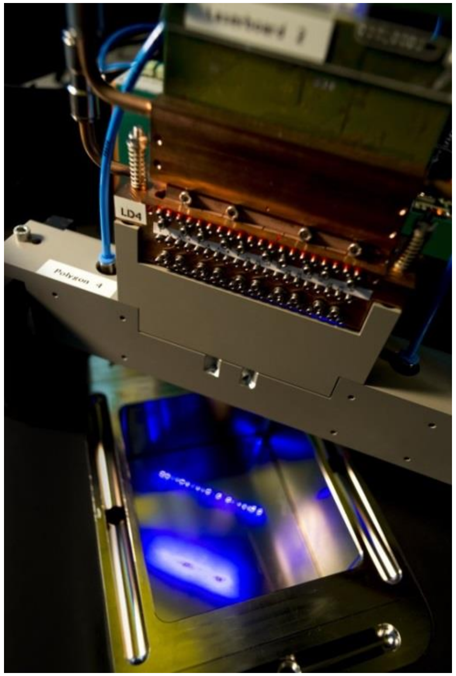


# Enabling technology: high-resolution 3D printing (multi-material )

- New exposure engine based on multiple array of laser sources.
- New AM machine concept for large-size, high-resolution (20 µm) and high-speed (scan speed 100 mm/s, 10 s per layer) additive manufacturing.
- Multi-laser for photo-polymerization and thermal processes (selective sintering)
- Multi-material, hybrid manufacturing platform

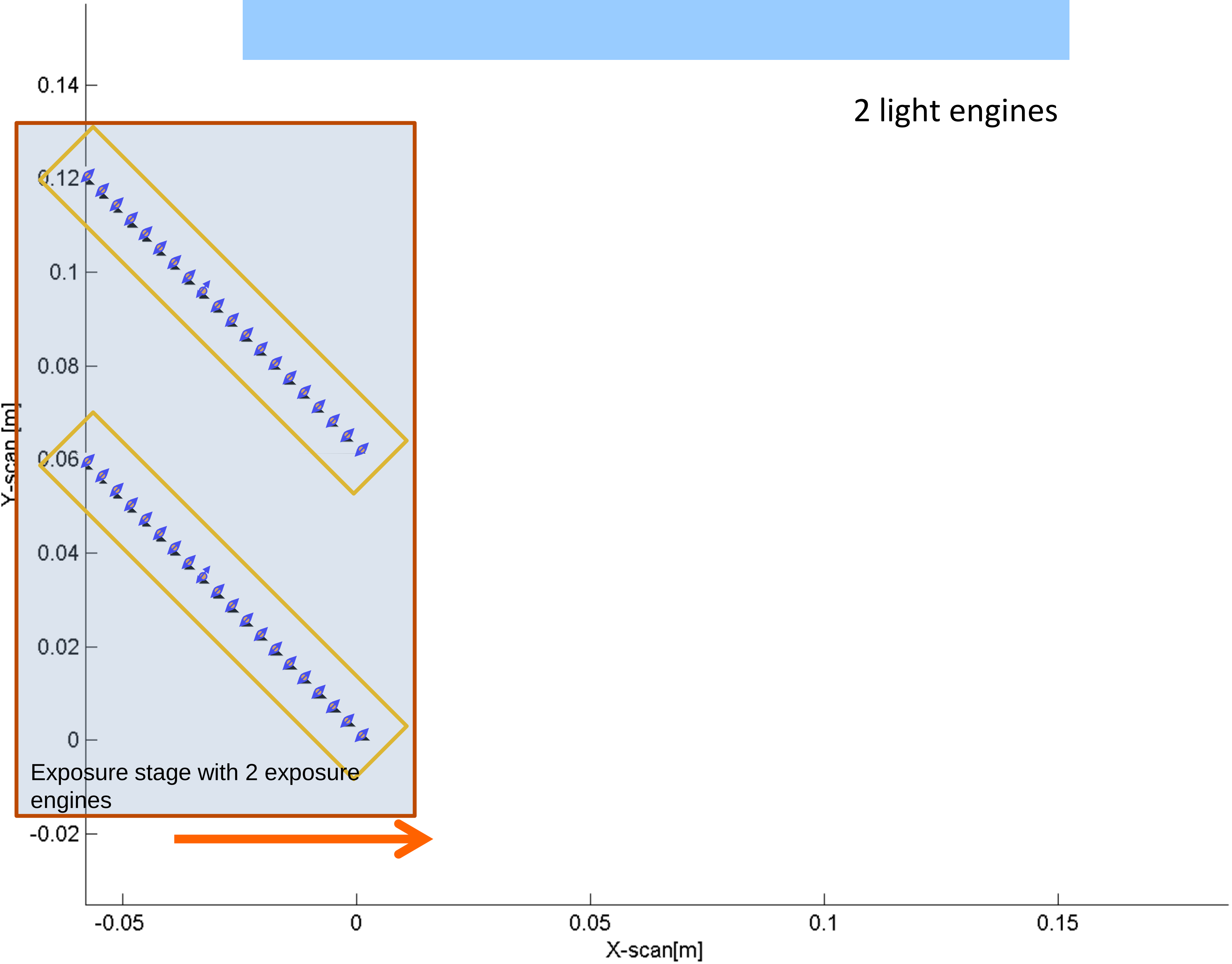


# Scan principle

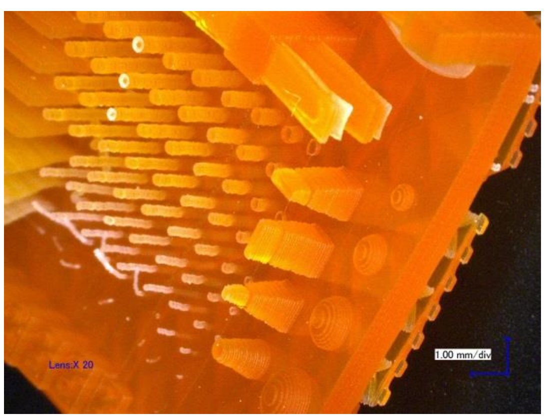
2 light engines



# Enabling technology: high-resolution 3D printing (multi-material )

**Research platform for laser-based additive manufacturing:**

- Research platform for large-size polymer-based Additive manufacturing
- High-speed single-pass laser-based additive manufacturing technology.
- Development of laser-array technology for single pass AM
- proof-of-concept laser array @ SLS technology
- 3D slicer software
- Data path and system control

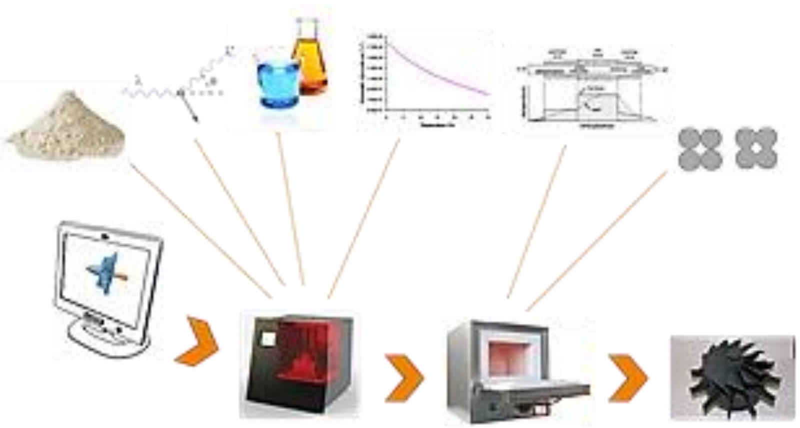


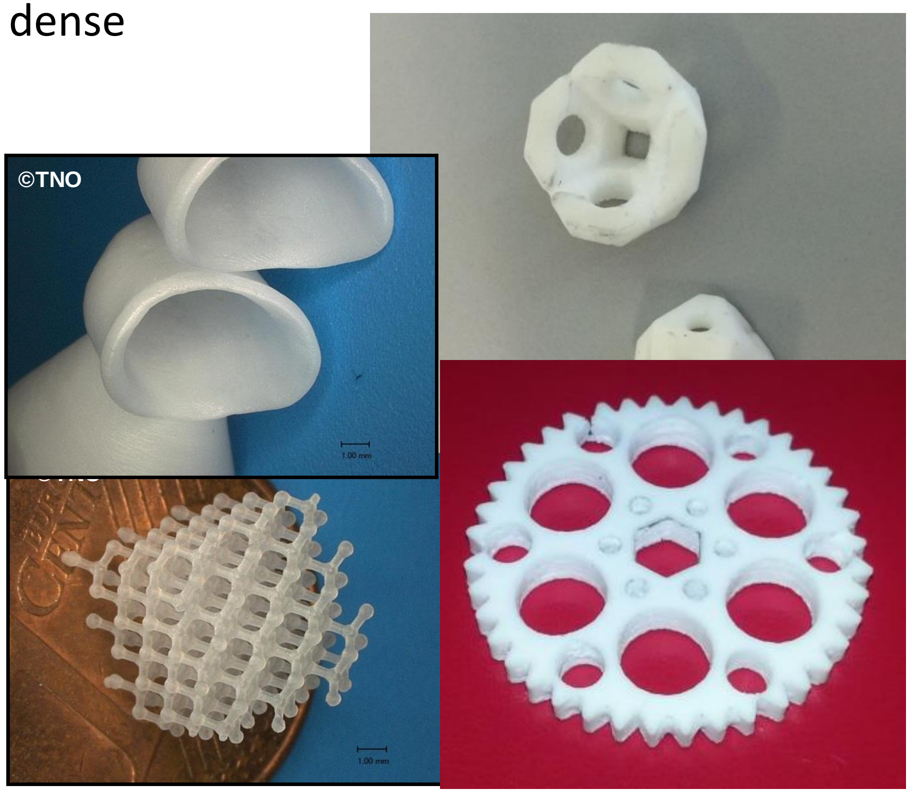




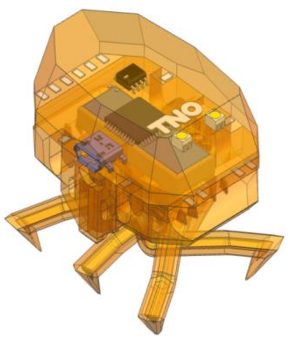

# Enabling technology: Polymer-enabled ceramic and multi-material

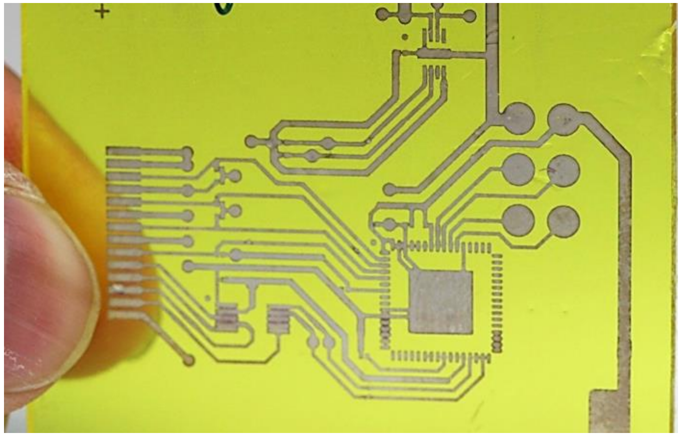
- Engineered Polymer dispersants and binders for ceramic (alumina, ZrO) applications, like dental prosthesis and high-tech
- Multi-material solutions for meta-materials (radar and piezo applications)
- Defect-free, freeform $Al_2O_3$ products, > 99% dense
- Increase product size from 5 mm to 50 mm

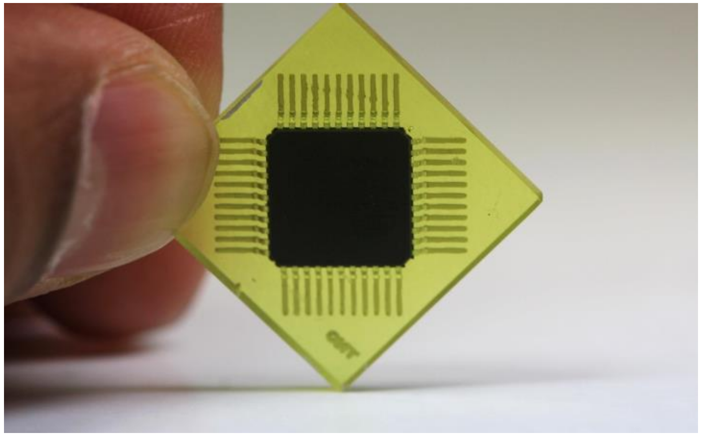


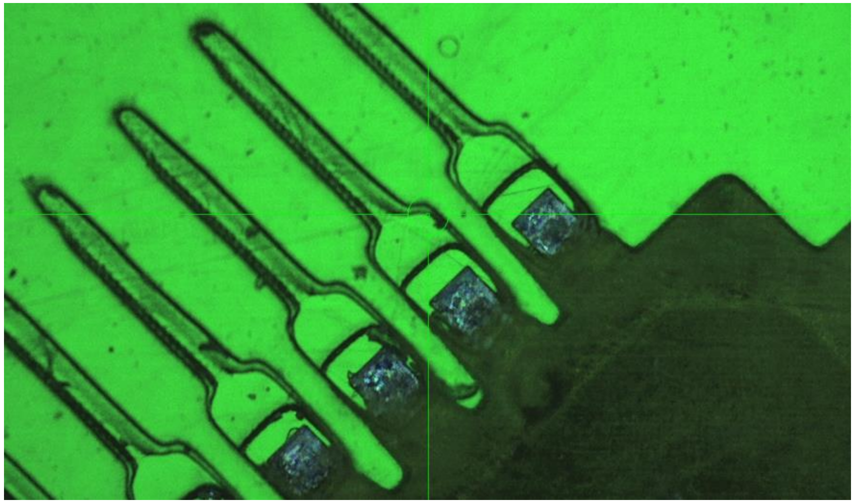


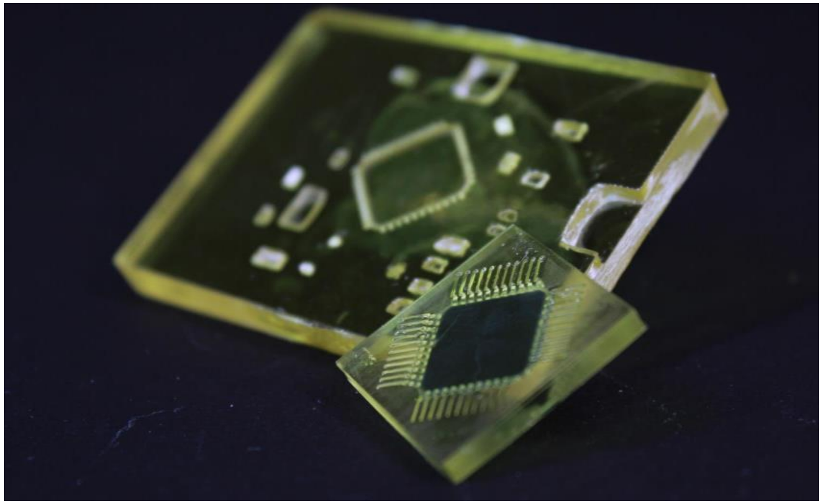
# Functional demonstrator









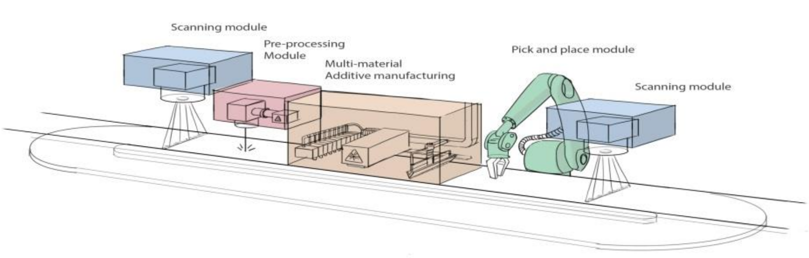
Contents

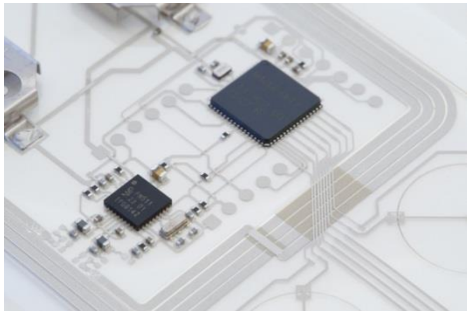
- AM context and business potential
- Structural Electronics – technology enables and demonstrators
- **Conclusion and outlook**



# Conclusion and outlook

- Technology building blocks for 2D electronics and high-speed industrial Additive Manufacturing are in place.
- Next steps:
  - Develop these technology building blocks for 3D printed electronics, for improved performance @ conductive tracks, capability of multi-material AM, high-accuracy and fast pick&place, and in-line inspection.
  - Demonstrate technology in appealing high-tech demonstrators
  - Develop pilot line with baseline process for flexible, single-product manufacturing of complex and integrated products.



# Thanks for your attention! Questions?