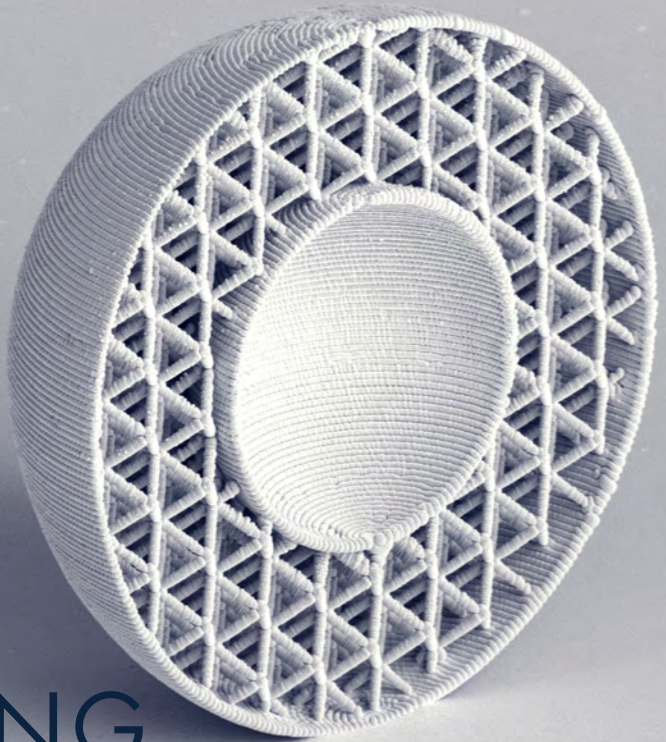
16.09.2021

EXADDON



ADDITIVE MICRO-MANUFACTURING OF METALS

-EPHJ & Swiss Photonics-

Imagine the unseen

AGENDA

CERES Print System Overview

Print Process, Materials, Size Range

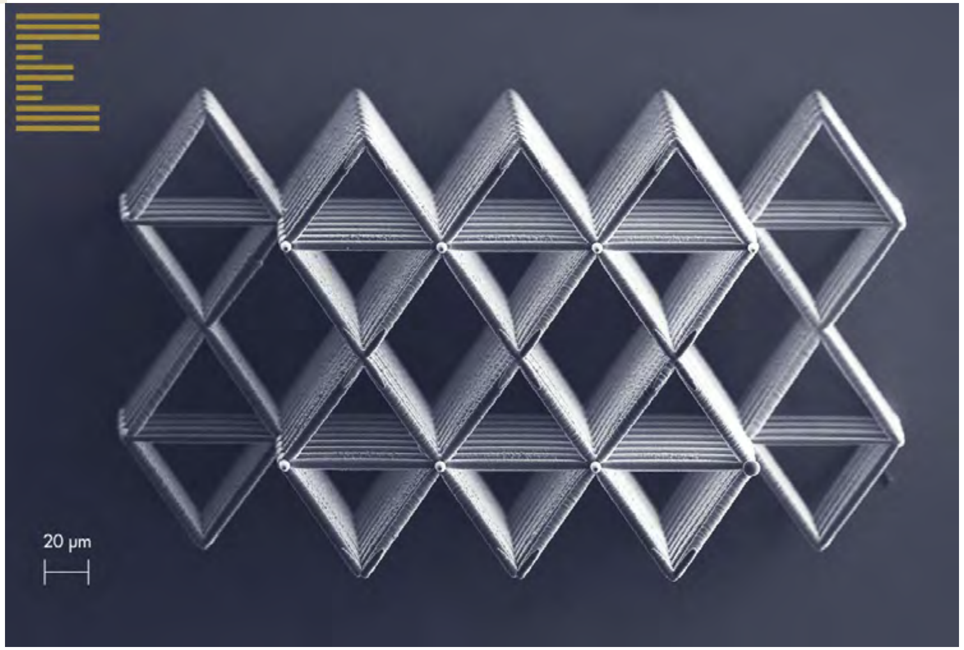
Material Properties

Typical Use Cases

Applications in Photonics

Q&A

EXADDON AG



- Formerly part of Cytosurge AG – developers of intra-nuclear cell-editing solutions (FluidFM)
- We have pioneered µAM: additive micromanufacturing of metals
- Exaddon has ongoing research collaborations with respected academic institutions

ETH zürich

Empa Materials Science and Technology

FBH Leibniz Ferdinand Braun Institut

MAX-PLANCK-INSTITUT FÜR EISENFORSCHUNG GMBH

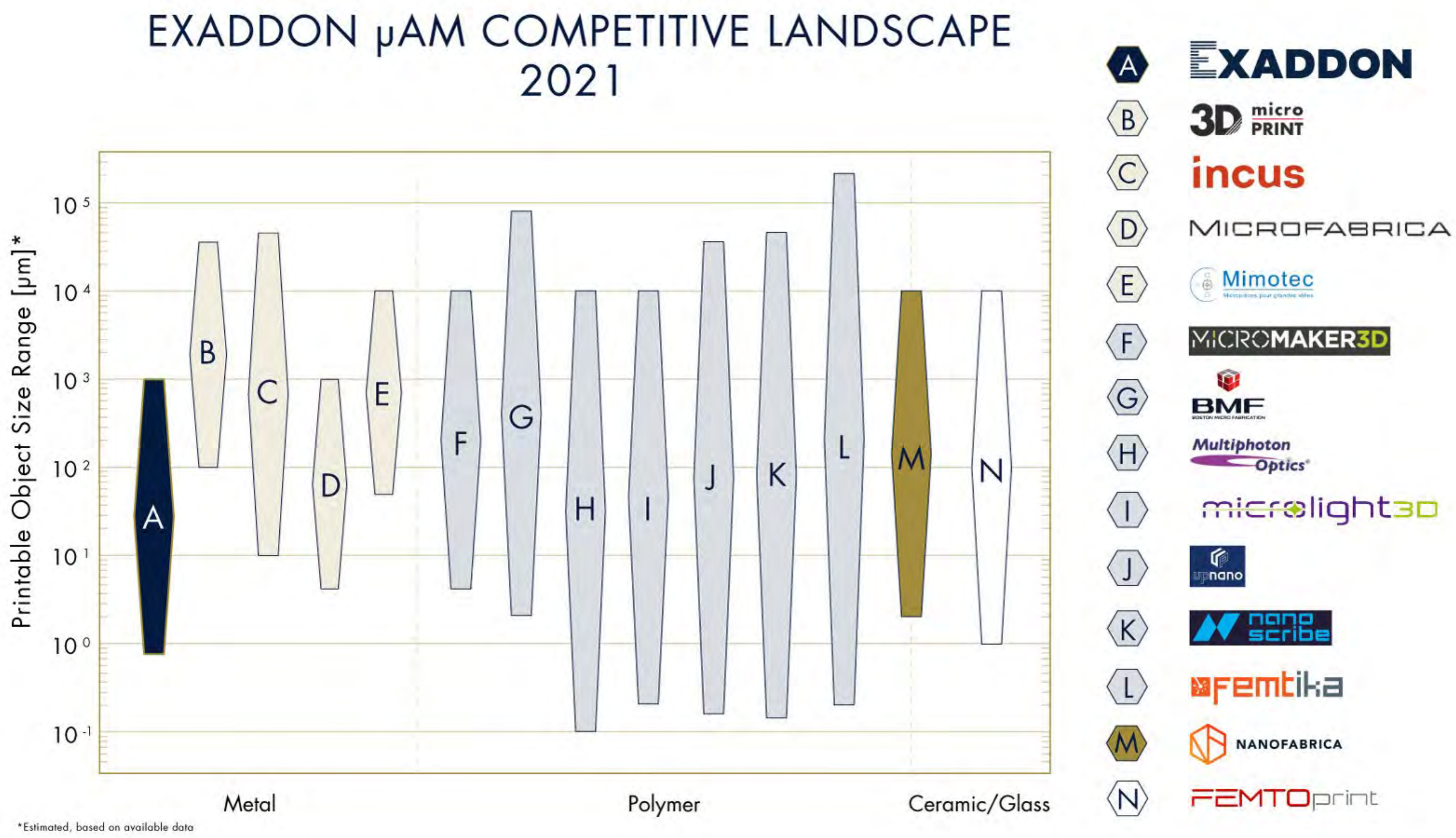
PUBLISHED RESEARCH

- Well integrated into the science community
- High impact publications published frequently
- Focus on cooperation and know how exchange

Browse complete publications list online

CERES - PRINT SYSTEM

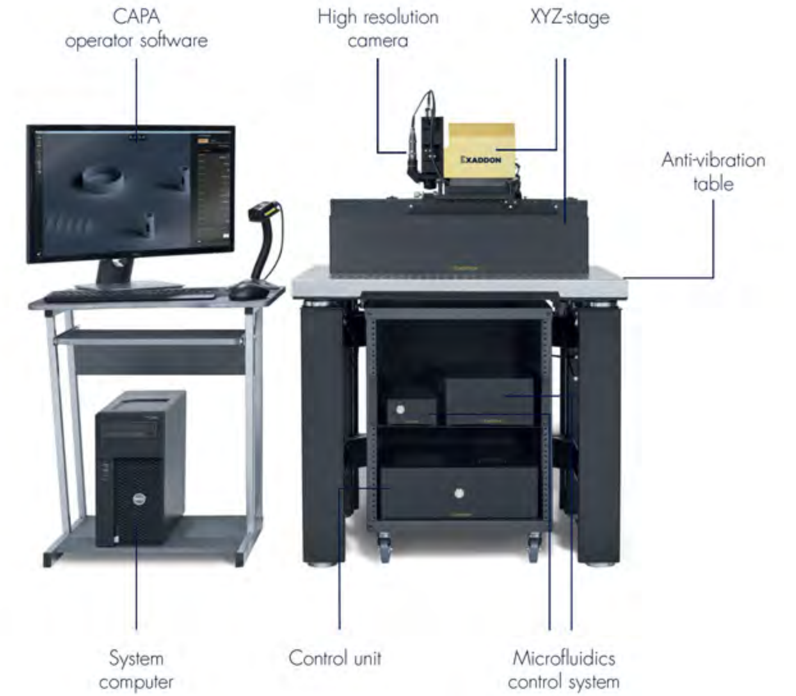
COMPETITIVE LANDSCAPE POSITION

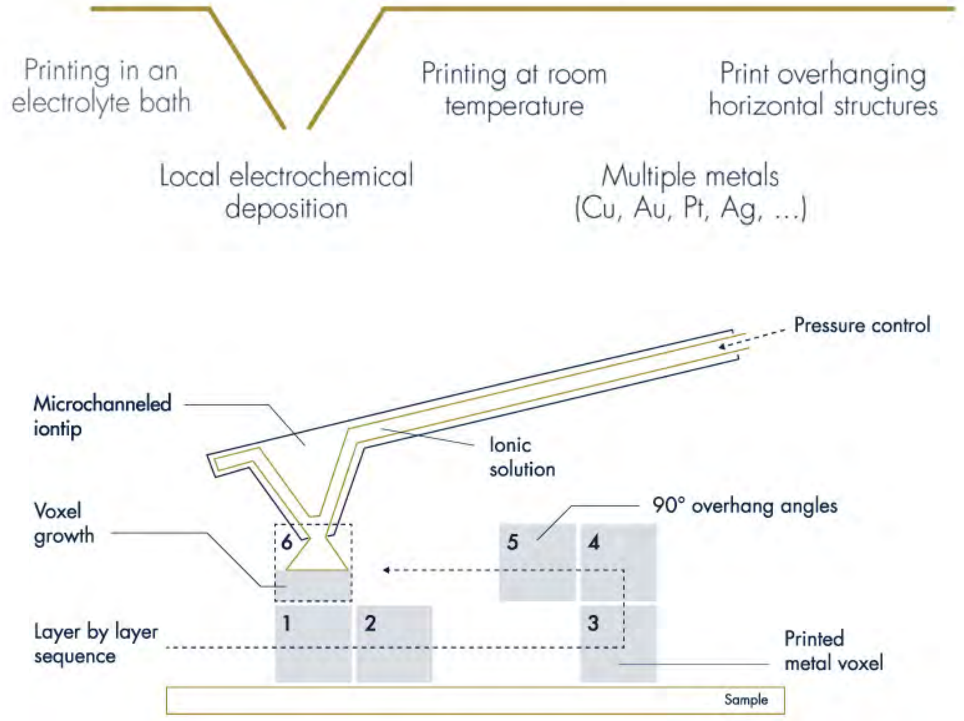


Read full analysis

CERES - PRINT SYSTEM

UNIQUE PRINTING TECHNOLOGY





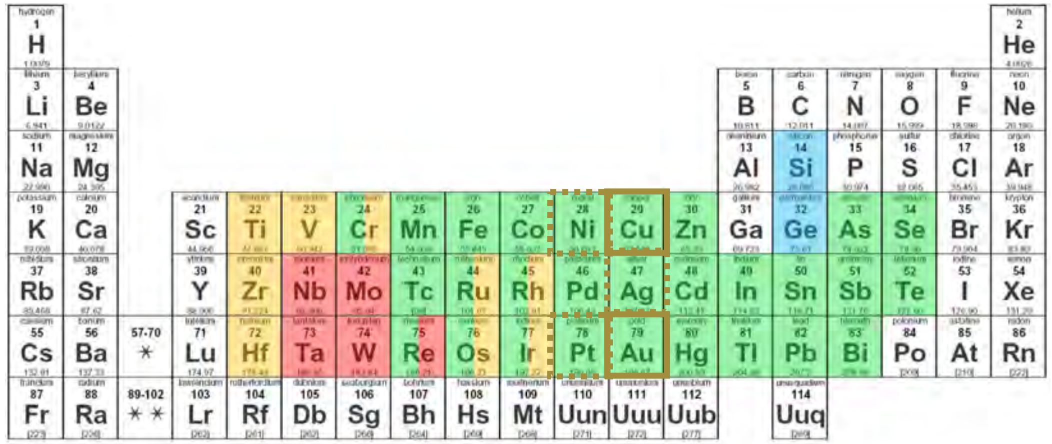
- Dispense liquids in 2D lines
- Print complex 3D structures out of metals
- **A system for innovators & visionaries in additive micromanufacturing**

EXADDON

ELECTRO-CHEMICAL DEPOSITION

WHAT CAN BE PRINTED?

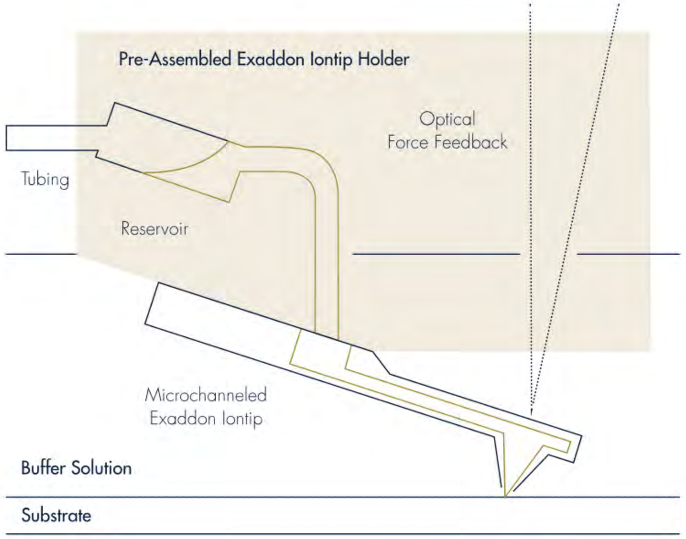
Possible Print Materials



Falola *et al. Curr. Op. in Solid State and Mat. Sci.* 2015

Metals that can be electrodeposited from aqueous solution

Substrate/Print Surface



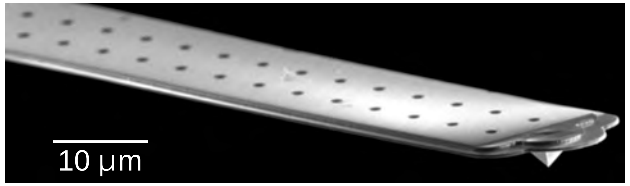
- Copper
- Gold
- PEDOT:PSS
- ITO

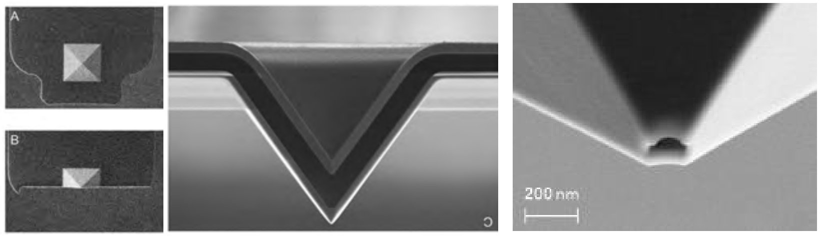
We have experience 3D printing Cu, Au, Ag, Pt, Ni

EXADDON
IONTIP

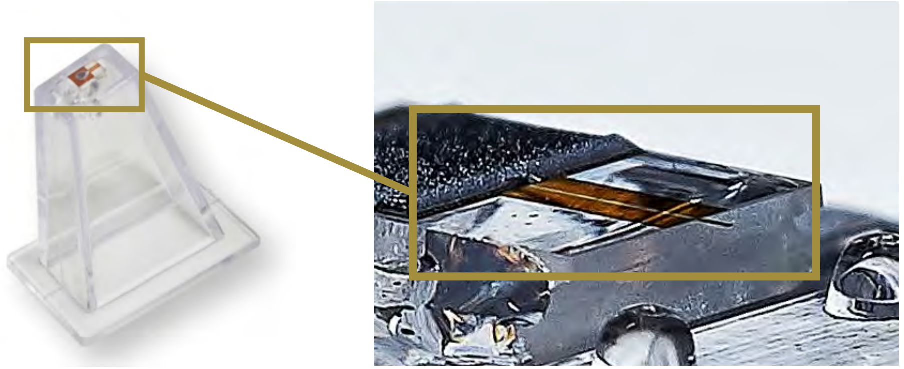
IONTIP PRINTING PROBE

- A hollow, micro-channeled cantilever mounted to a user-friendly plastic housing containing the ink reservoir (1 µl capacity)
- Ink reservoir (circled) is filled before printing with a micropipette
- Iontip aperture diameter is just 300 nm





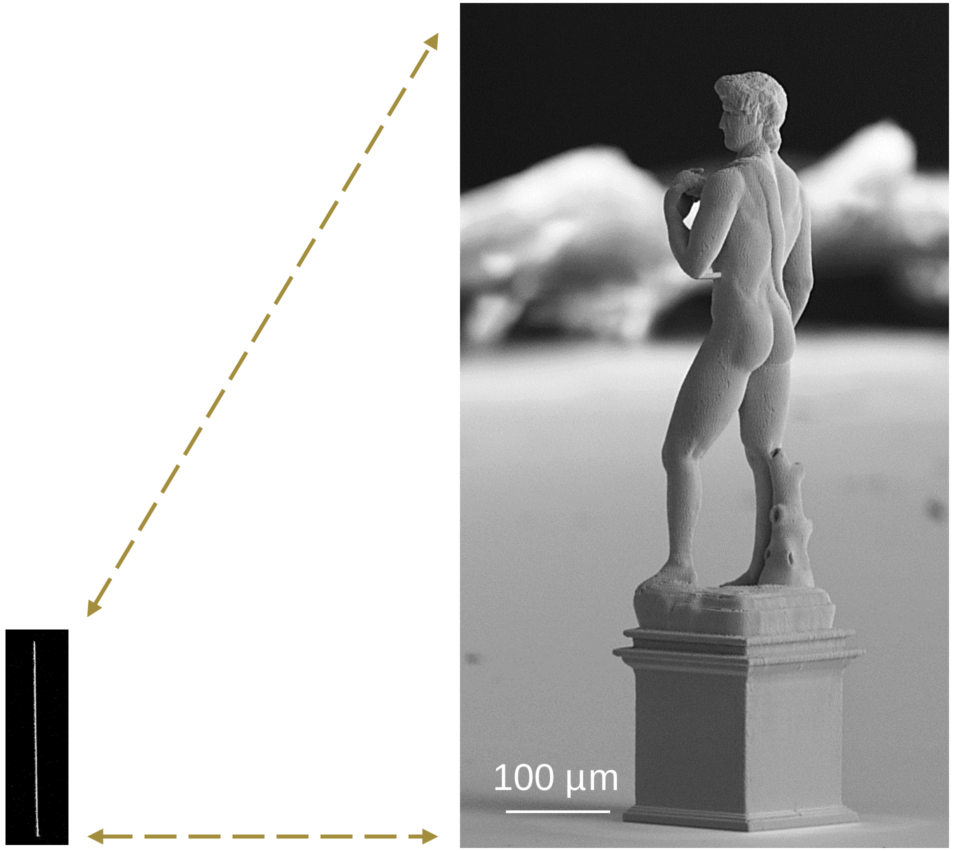
— 10 µm — 2 µm aperture Ø: 300 nm



3D OBJECT PRINTING SIZE

NANOMETER ↔ MILLIMETER OBJECTS

- Possible object dimensions:
  - Starts at nanometer sizes
  - Up to 1 mm
- Printing speed up to 4 µm/s
- Changing print parameters changes minimum feature size (through tuning voxel diameter)
- Voxel size tunable on-the-fly
- 15 x 15 mm / 25 x 25 mm substrates (standard sizes)
- Substrate thickness is 0.4 - 1 mm



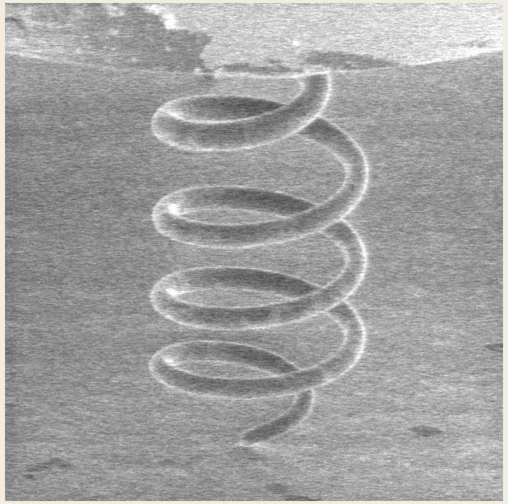
Nanopillar
~ 200 nm Ø

David
~ 1000 µm height

MATERIAL PROPERTIES

METAL UNIFORMITY & HOMOGENEITY

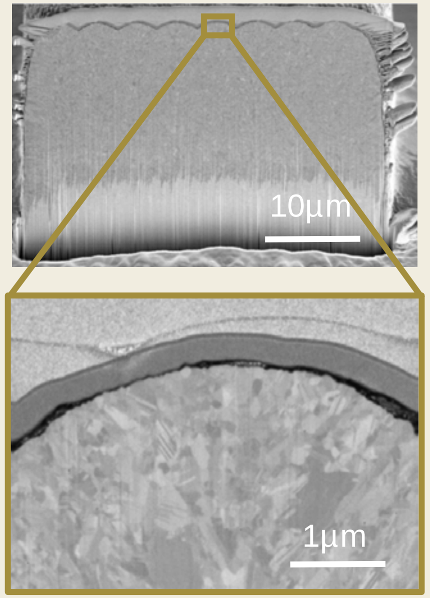
Mechanical hysteresis testing



(Click video to play)

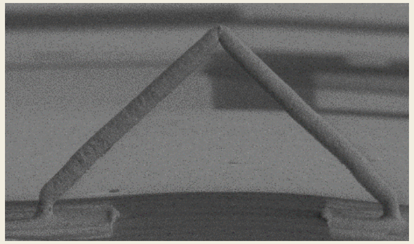
- The copper is mechanically stable
- The copper behaves elastically
- There is a good adhesion to the gold substrate

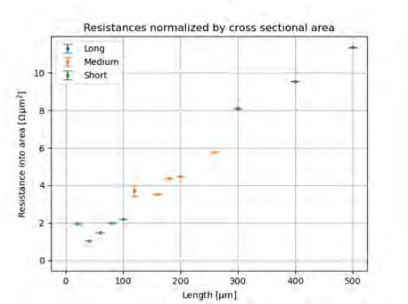
Material density inspection (FIB)



- The deposited material has >99% density
- Homogeneous grain structure - no visible traces of individual voxels

Electrical resistivity measurement



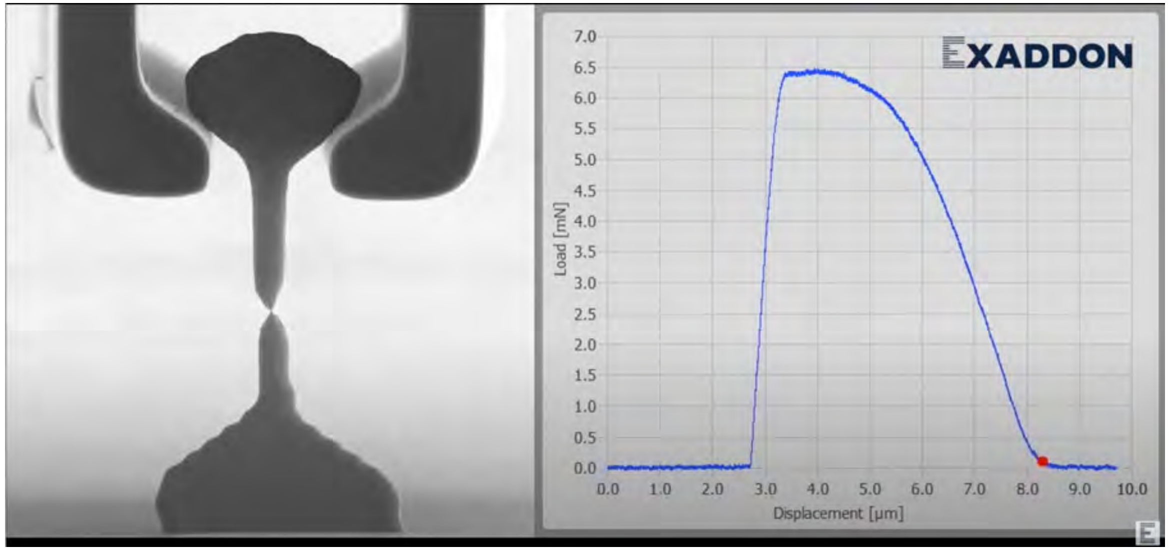


- Resistivity of printed structures: ρ_{copper} = 2.2E-8 Ω·m
- This equals 75% of the conductivity of bulk copper

MATERIAL PROPERTIES

TENSILE STRENGTH & YIELD STRENGTH

- Conducted on 5 µm Ø copper test pieces printed with CERES
- Test pieces subjected to constant elongation using specialized nanoscale test platform (Alemnis AG, Switzerland)
- Behavior as expected; i.e. like a macroscale sample produced with conventional manufacturing techniques
- See more at: exaddon.com/material-properties



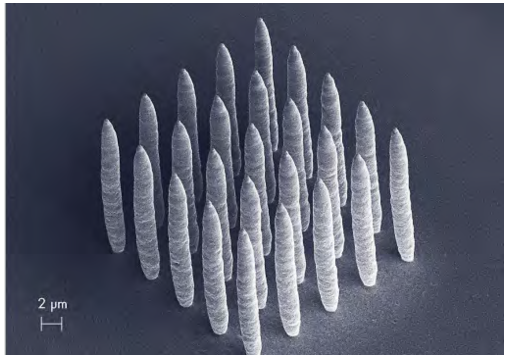
Tensile strength of µAM structures = **342.5 MPa**
Comparison: cold-drawn copper = 344 MPa*

Yield strength of µAM structures: **320 MPa**
Comparison: cold-drawn copper = 333.4 MPa*

*Copper, Cu; Cold Drawn (matweb.com)

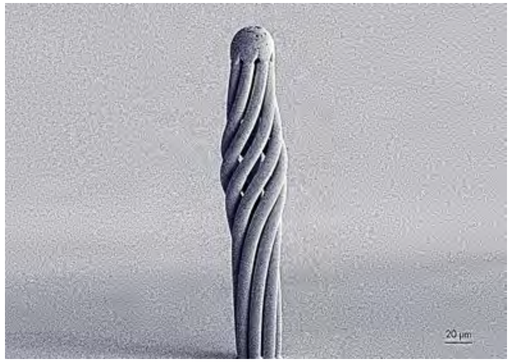
EXADDON USE CASE INDUSTRIES

Neural Interfaces & Electrodes

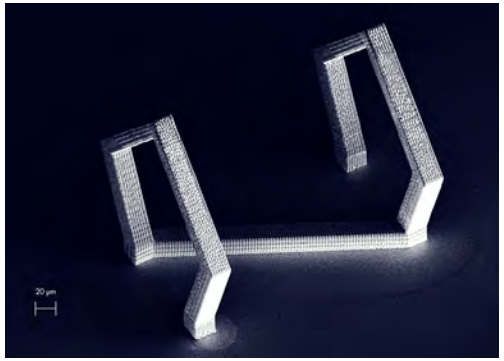


HF Receivers & Antennas

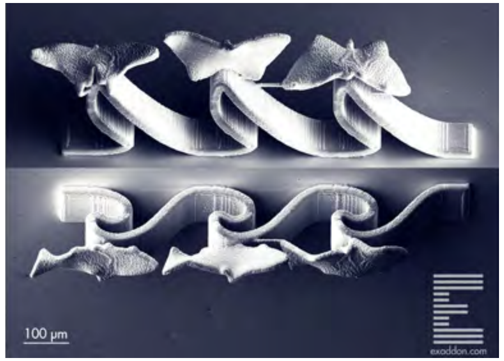
Microelectronics



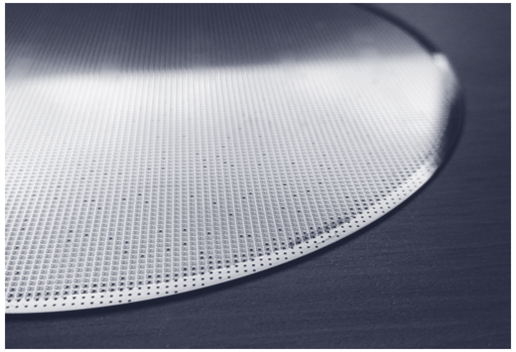
5G/THz Communications



Watchmaking



Semiconductor Modification



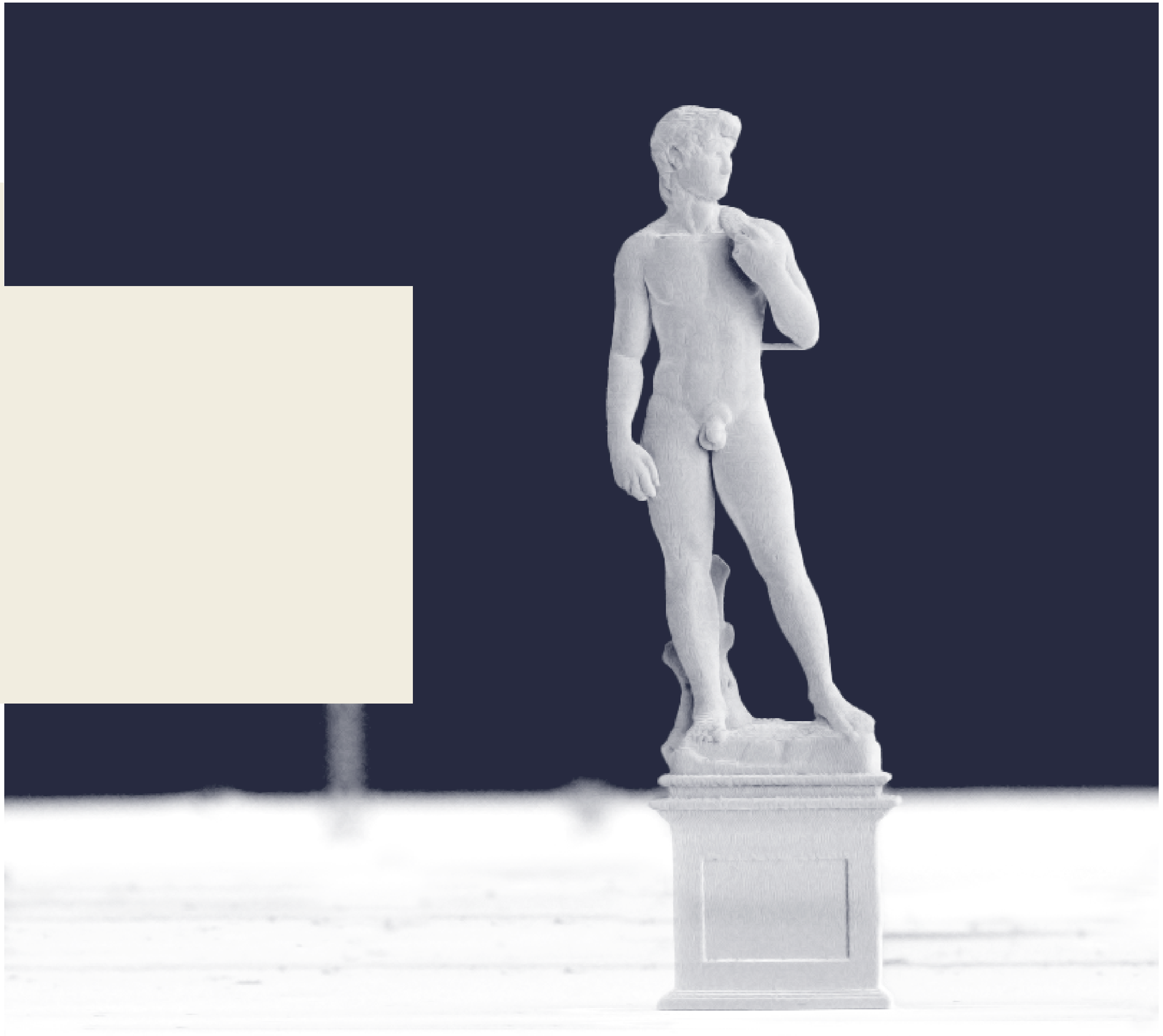
POTENTIAL APPLICATIONS IN PHOTONICS

Existing uses of 3DP in photonics

Helices & lattices

2D line printing

Micro object arrays



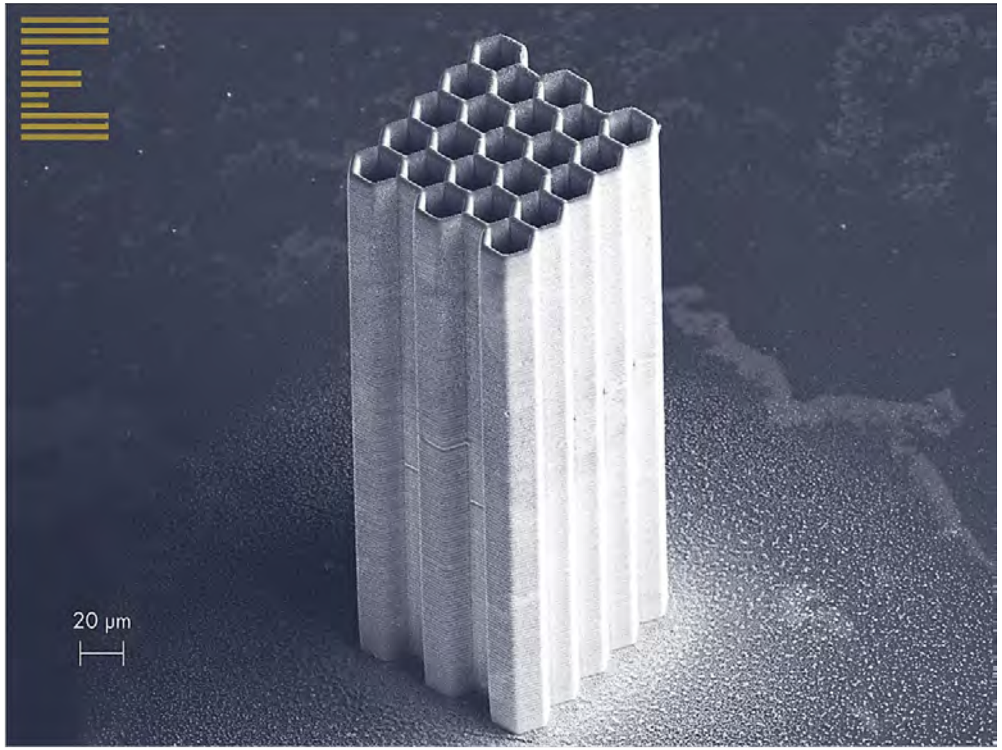
EXISTING USES OF μ3DP IN PHOTONICS

Waveguides	Bertoncini A., Liberale C. "3D printed waveguides based on photonic crystal fiber designs for complex fiber-end photonic devices," Optica 7, 1487-1494 (2020)
Micro lenses	Thomas R., Li J., *et al*. "In situ fabricated 3D micro-lenses for photonic integrated circuits," Opt. Express 26, 13436-13442 (2018)
Gold helices	Gansel J.K., M. Thiel M., *et al*. "Gold Helix Photonic Metamaterial as Broadband Circular Polarizer" Science, Vol 325, Issue 5947 pp. 1513-1515 (2009)
Photonic Crystals	Tubio C., Nóvoa López J.A., *et al*. "3D printing of Al_2O_3 photonic crystals for terahertz frequencies." RSC Adv. 6. 2450. (2016)

How could CERES be used to used for such applications?

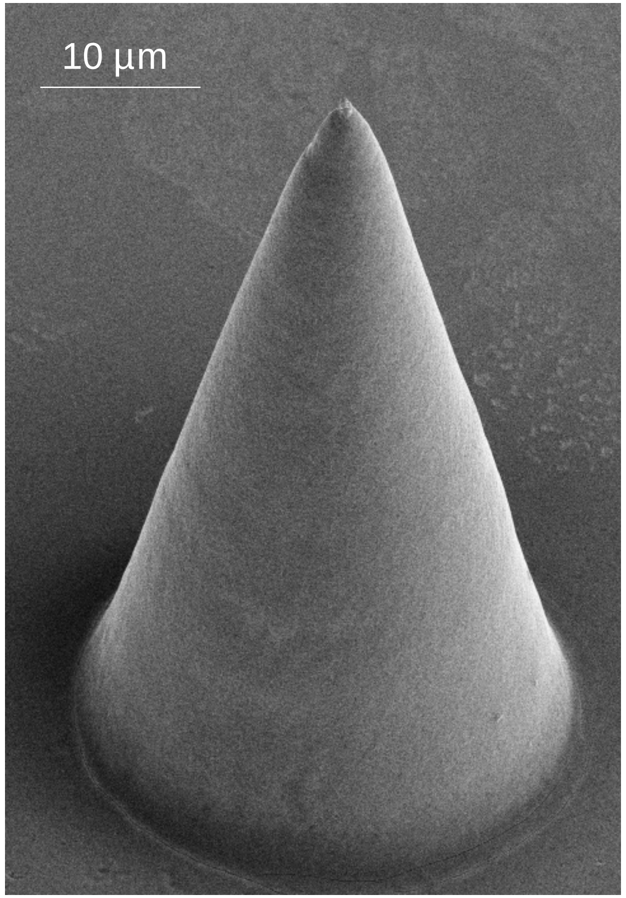
3D PRINTED HOLLOW OBJECTS

Organic, non-linear geometries are possible

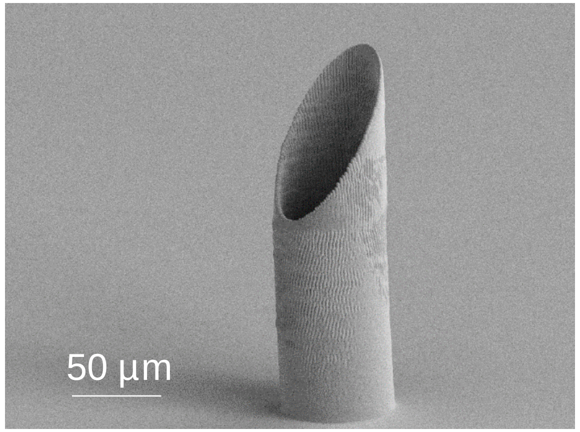


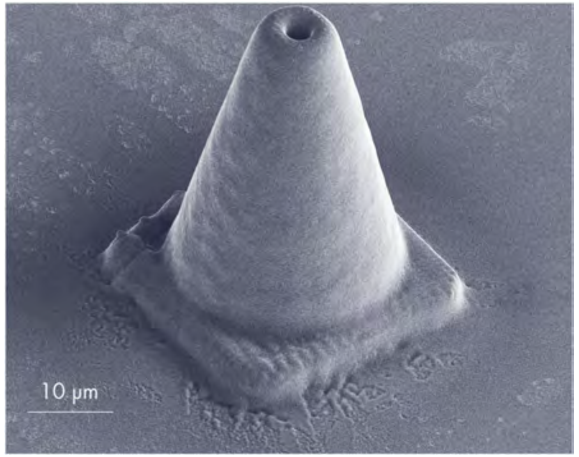
Copper microchannels printed on a flexible polymer substrate (PEDOT:PSS)

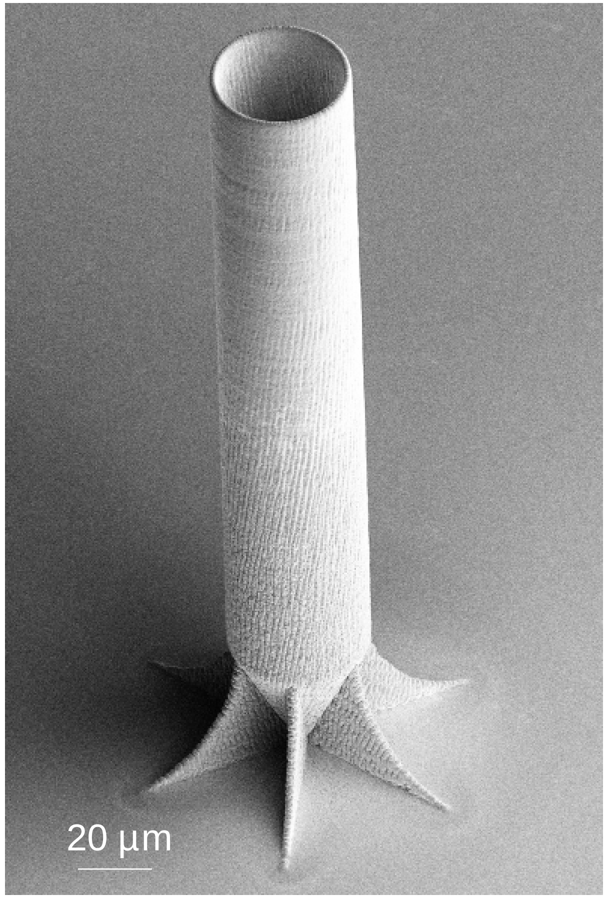
3D PRINTED HOLLOW OBJECTS



Hollow cone (aperture could be created by FIB milling)

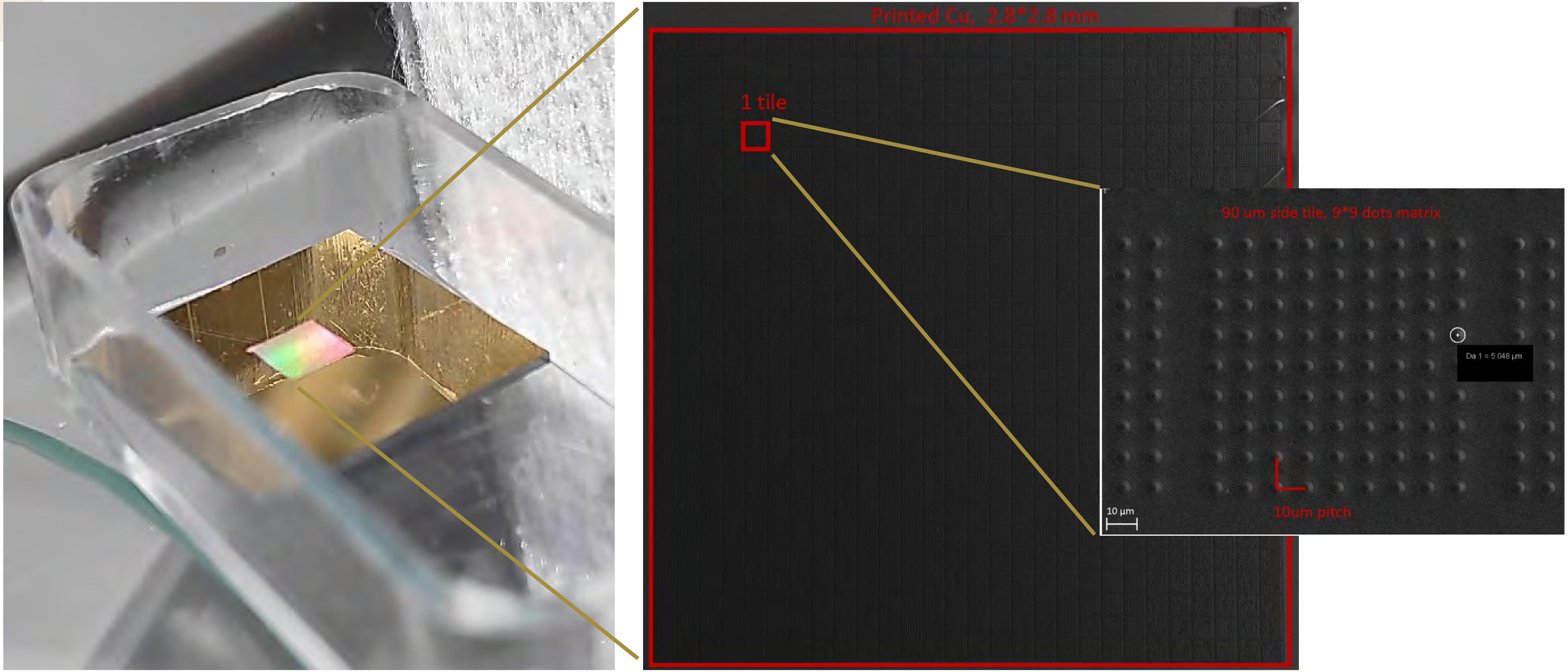




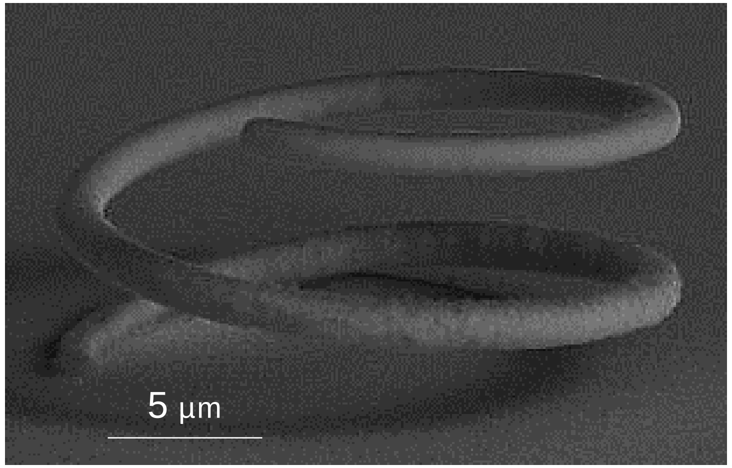


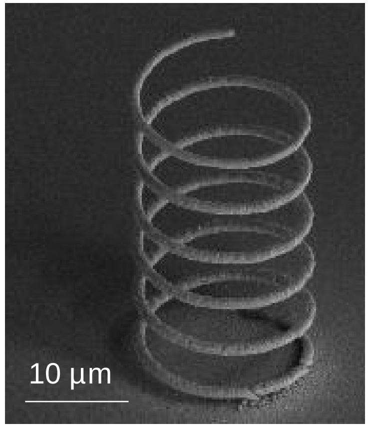
Height 400 µm

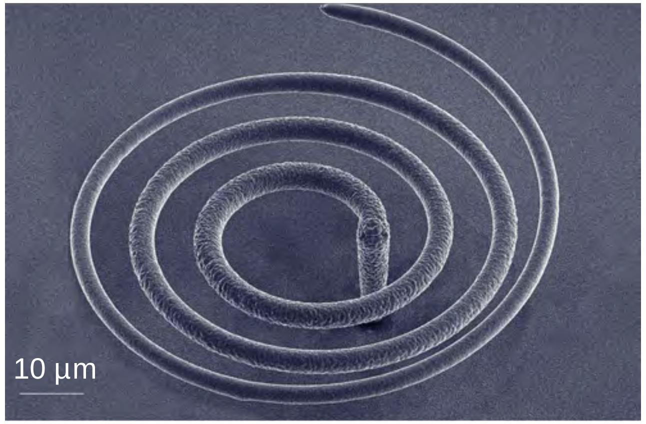
MICRO DOTS @ LARGE AREA



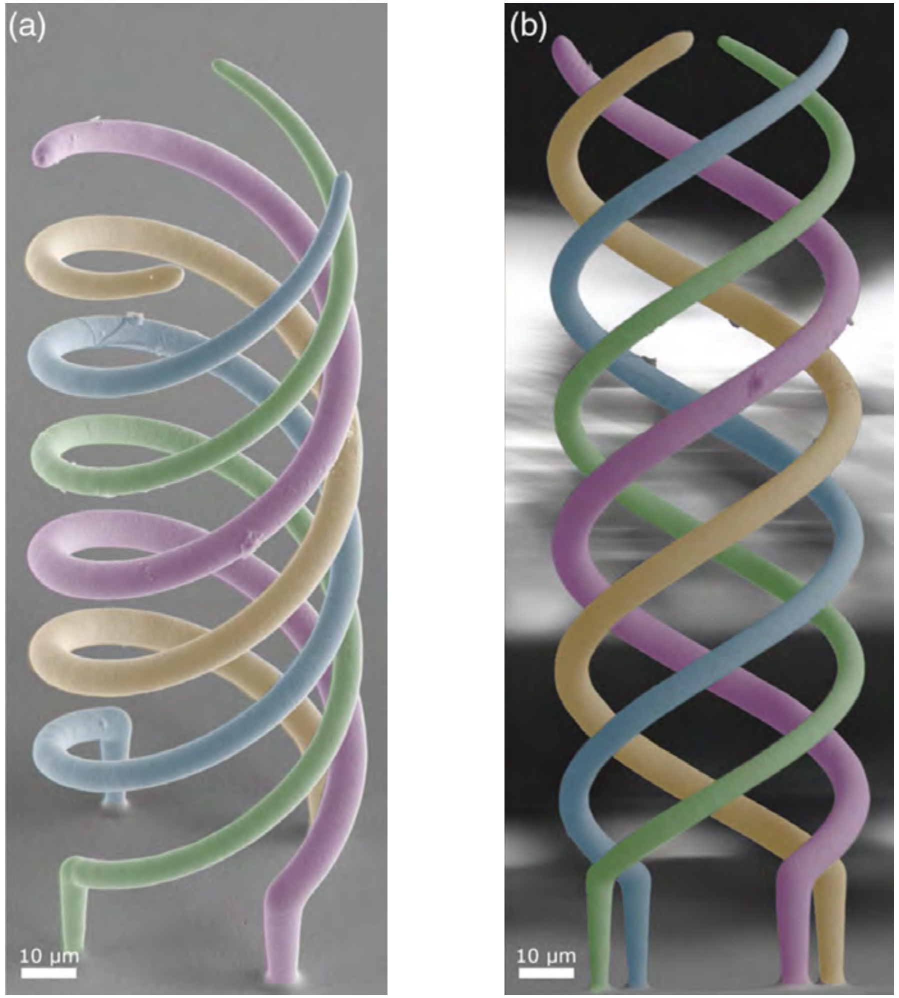
HELICES AND COIL STRUCTURES







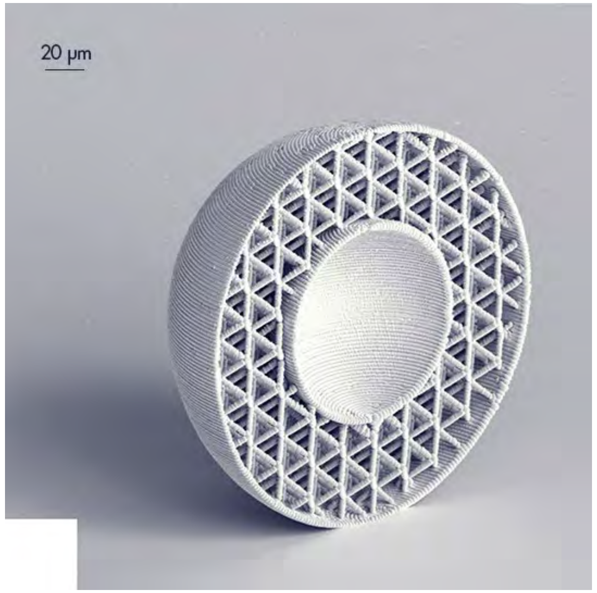
TUNING PRINT PARAMETERS

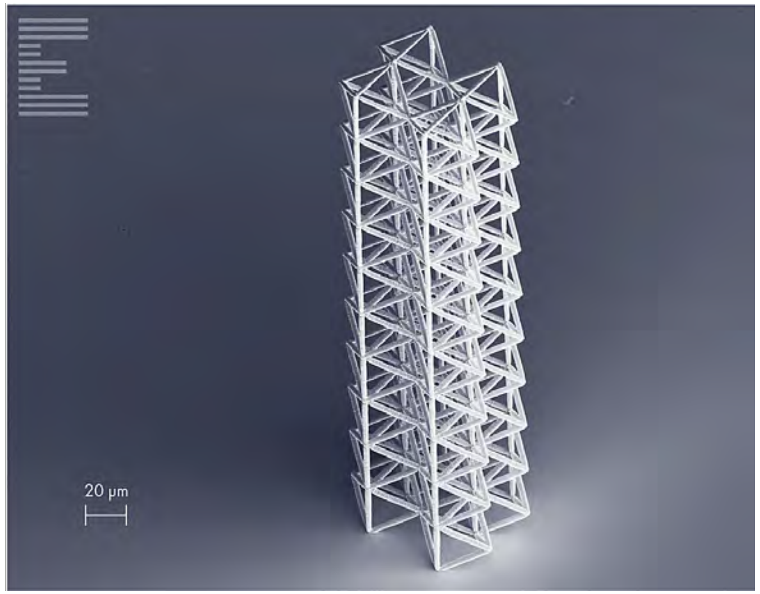


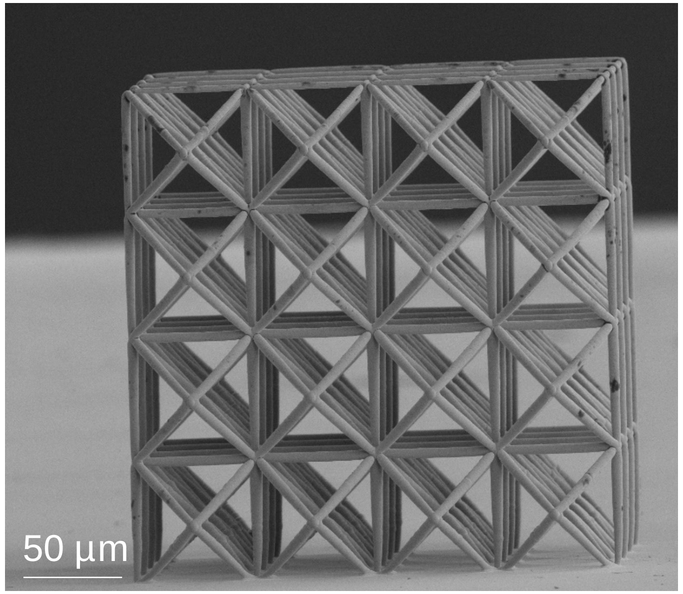
Ercolano *et al. Adv. Eng. Mater.* 2019

- CERES offers tunable print parameters on-the-fly
- Voxel diameter changed by adjusting the applied pressure of print ink through the tip
- Same print tip throughout
- Each strand is a different diameter
- Strands printed layer-by-layer
- Unique technology; unrivalled at these dimensions in metal printing

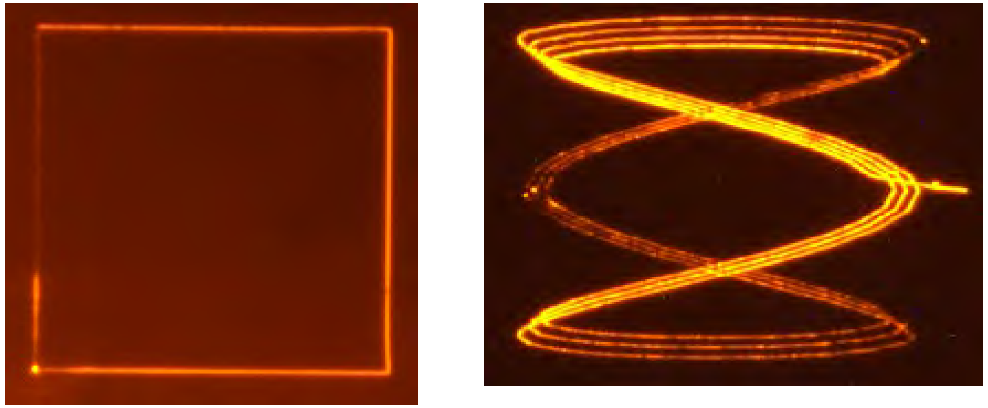
LATTICES FOR FUNDAMENTAL RESEARCH



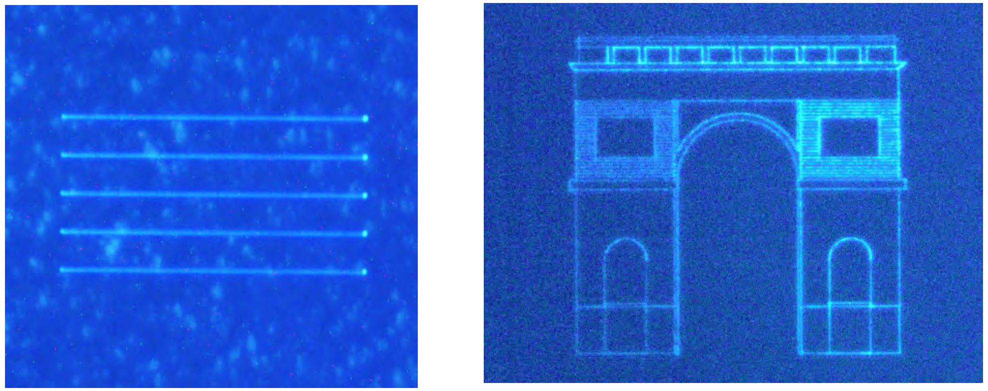




2D SURFACE PATTERNING



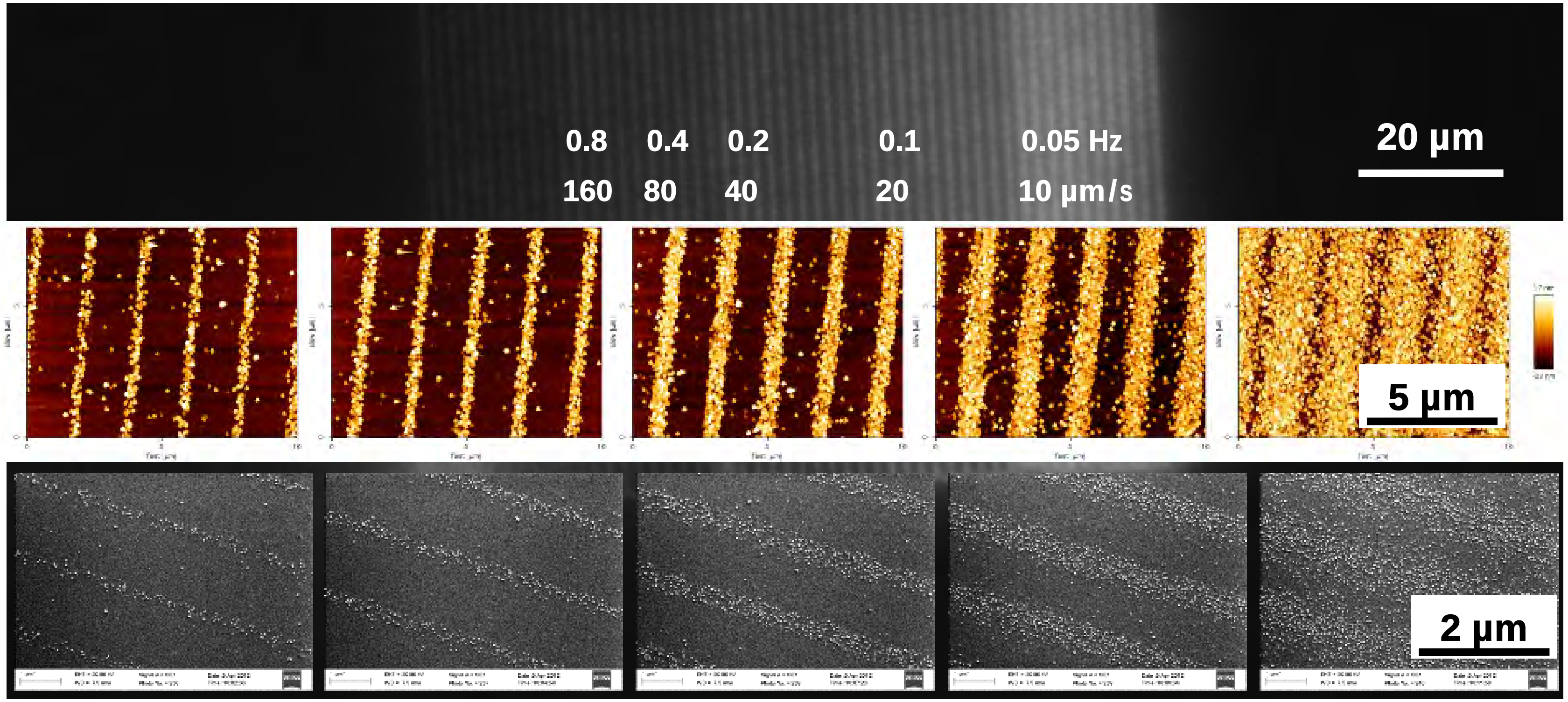
Fluorescently labeled polystyrene beads (20nm) on glass



DAPI in gylcerol (1mg/ml) on coated glass

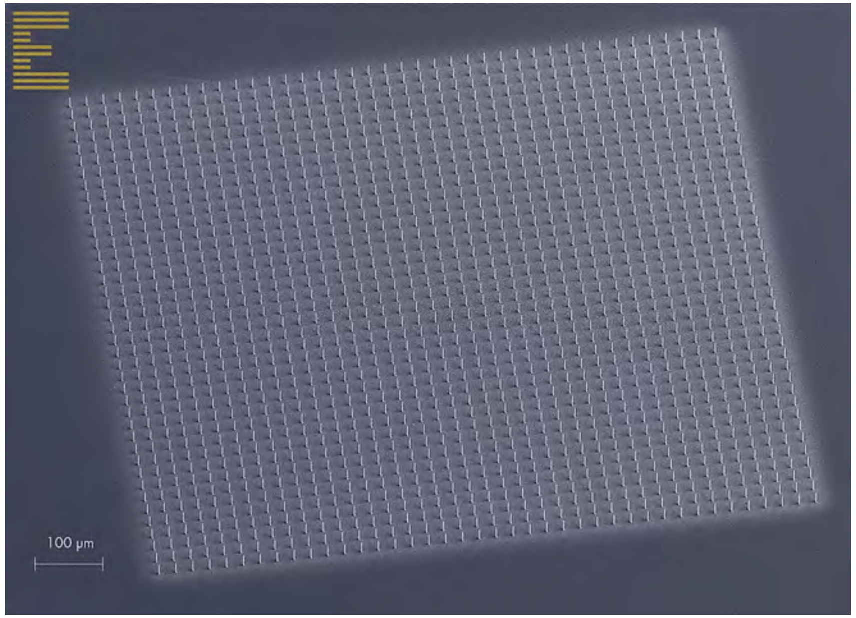
- Microscopic nanolithography printer
- Printing of vectors and complex structures
- Dispensing liquids enables printing of
  - Metals
  - Alloys
  - Polymers
  - Nanoparticles
  - In general, particle sizes <= 200 nm, suitable viscosity
- Up to 100 µm/s writing speed
- Precision liquid/particle control
- µm to cm lines and movements
- Fluid rate as low as femtoliters/s

2D SURFACE PATTERNING

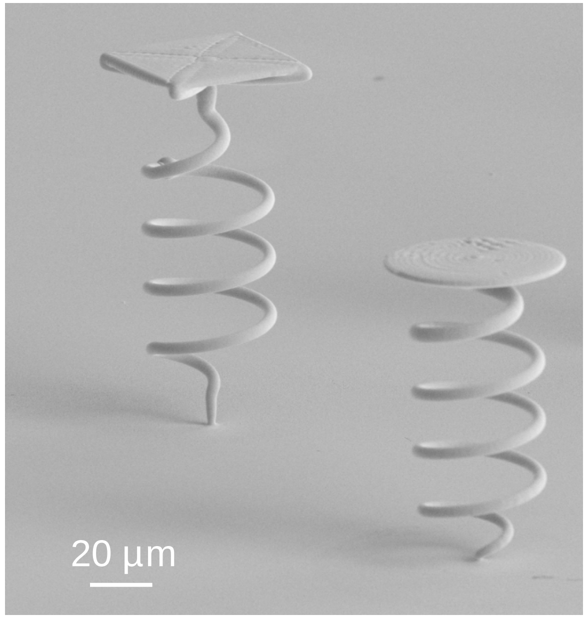


Grüter et al., Nanoscale (2013)

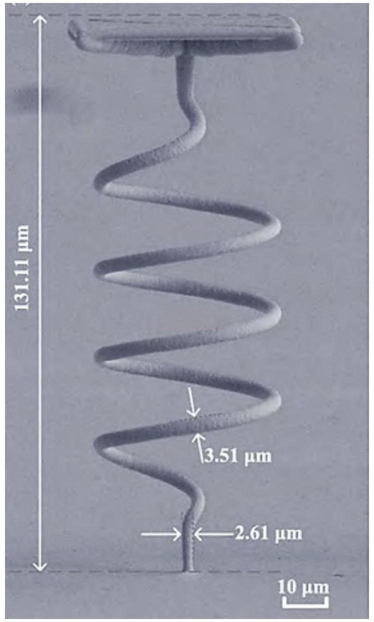
MICROSCALE OBJECT ARRAYS



1600 pillars printed on a 1mm x 1mm grid.
Each pillar is ~1.6 µm Ø

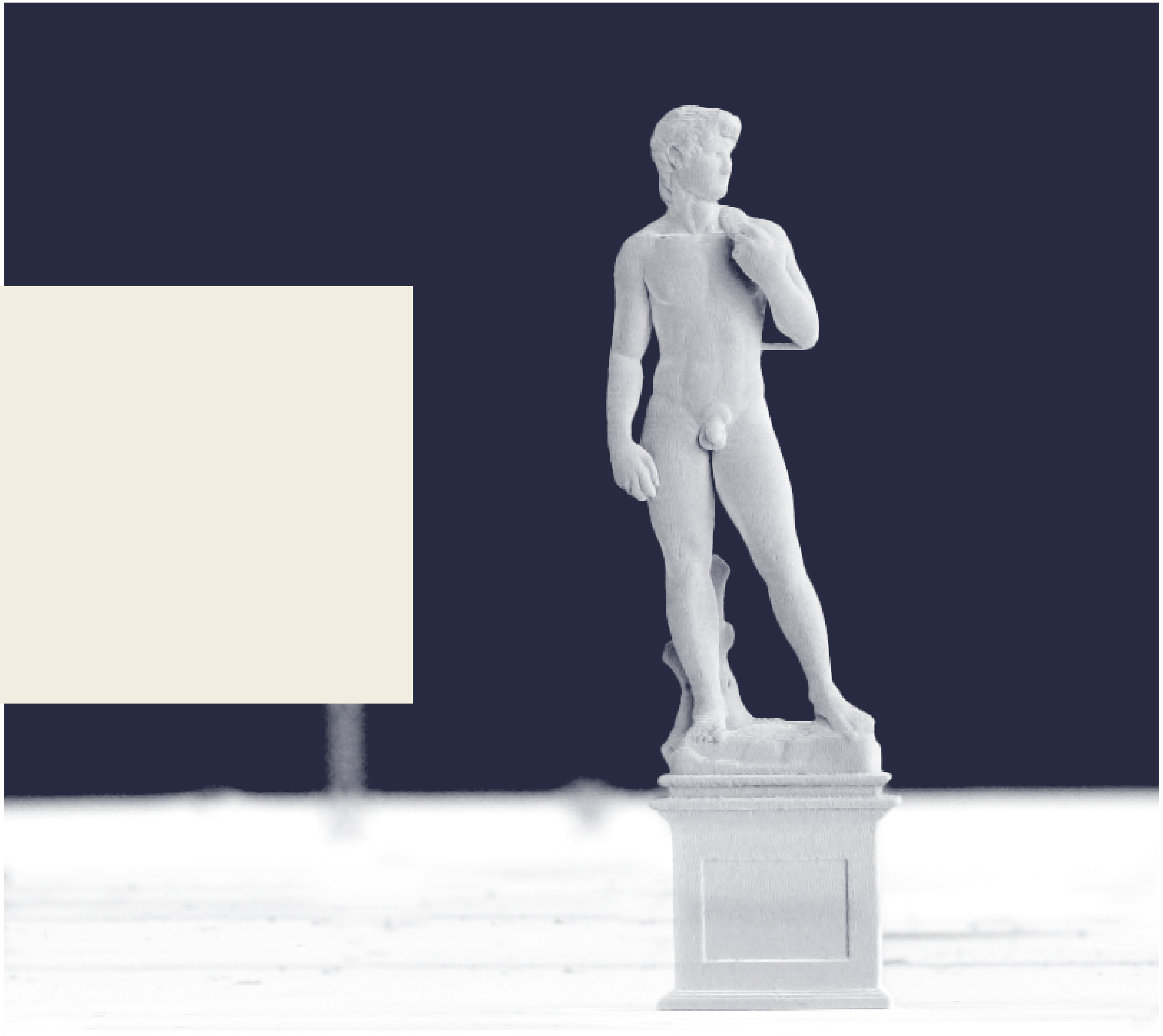


Printed objects



Ren W., *et al*. Materials. 2020

Q&A



THANK YOU FOR YOUR ATTENTION

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CEO

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