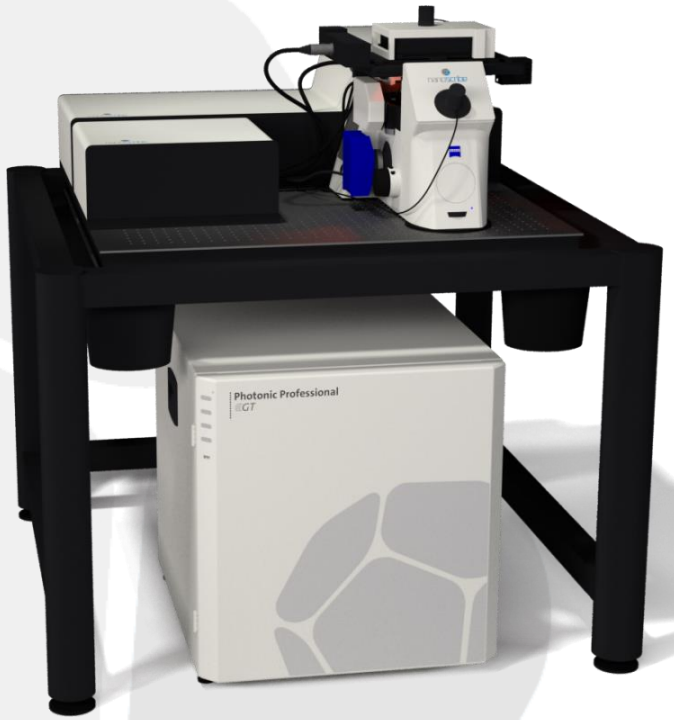
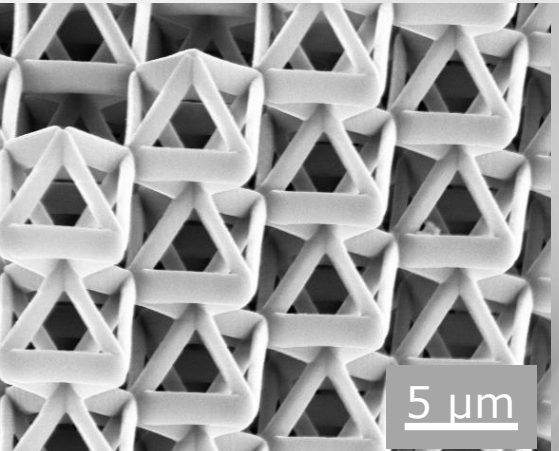
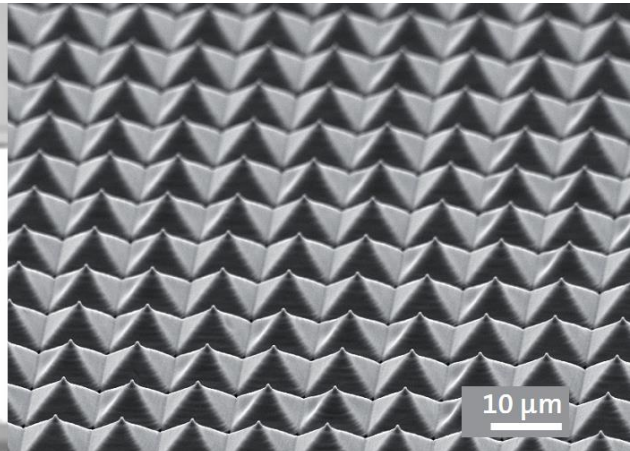
3D µ-Printing by Direct Laser Writing



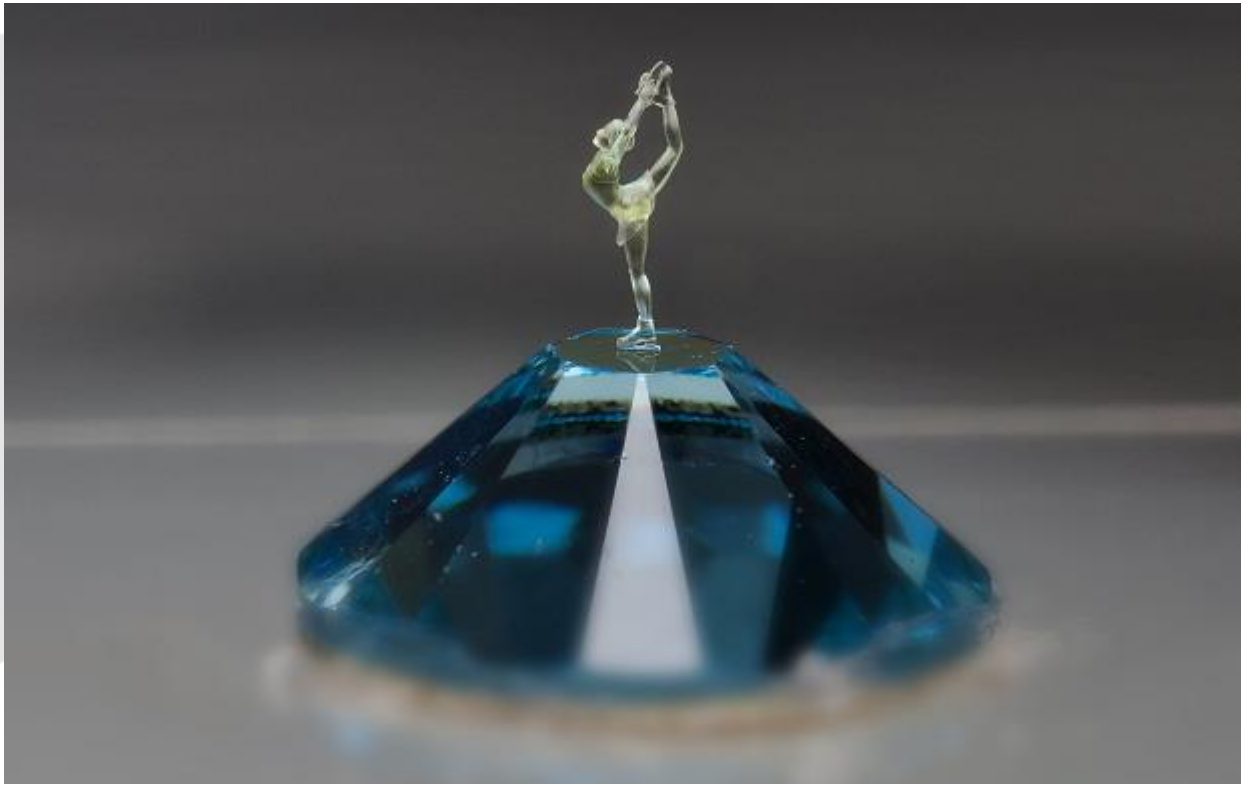
Nanoscribe GmbH
Sofía Rodríguez





Overview

- Introduction: Nanoscribe GmbH
- Technology: Direct Laser Writing
- Materials
- Applications
- Summary



Who We Are …

Company History:

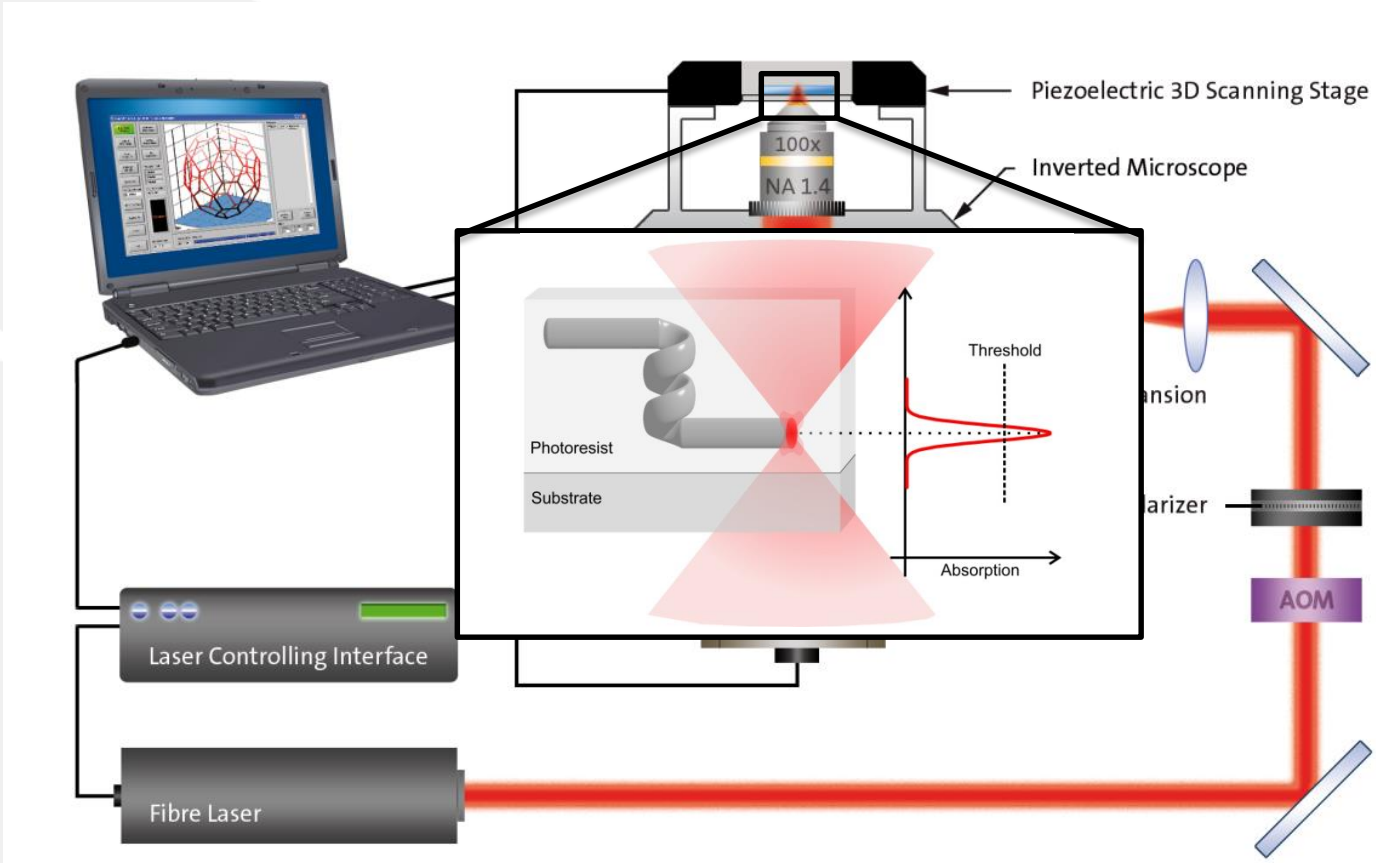
- Spin-off from the Karlsruhe Institute of Technology (KIT)
  group: Prof. Dr. Martin Wegener
- 2007: Foundation
- Market and technology leader
- 40 employees
- >100 systems sold
- Feb. 2014: Prism Award
  “Advanced Manufacturing”

Products:

- 3D laser lithography systems
- Photoresists

Photonic Professional GT

3D Printing by Direct Laser Writing



Two-photon polymerization (TPP):

- Near-infrared laser
- Ultra-short laser pulses
- UV-curable photoresists

3D Printing Workflow

nanoscribe

1. Preparation

CAD-Design

.stl File

DeScribe

Mesh fixing
Slicing
Hatching

.gwl File

2. Production

NanoWrite

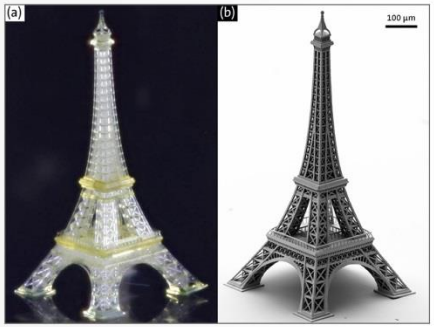
Print job controlling

Photonic Professional GT

3. Post-Processing

Finishing

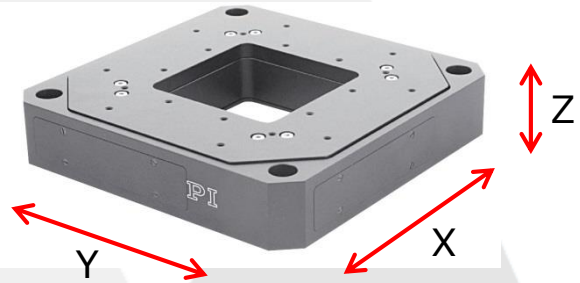
Removal of excess resin
Visual quality control



Easy Workflow

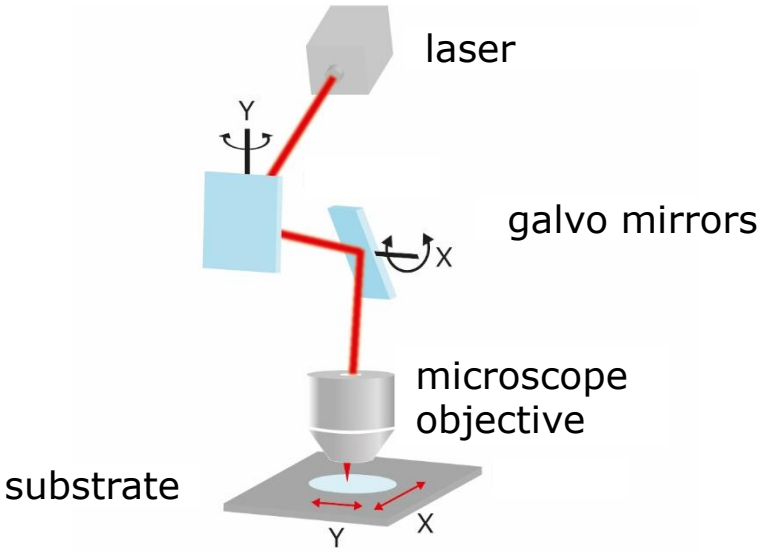
Embedded Writing Modes

Piezo mode



- Fixed laser focus
- Moving sample by piezoelectric stage
- 3-axes x-y-z-movement
- Arbitrary 3-dimensional trajectories

Galvo mode



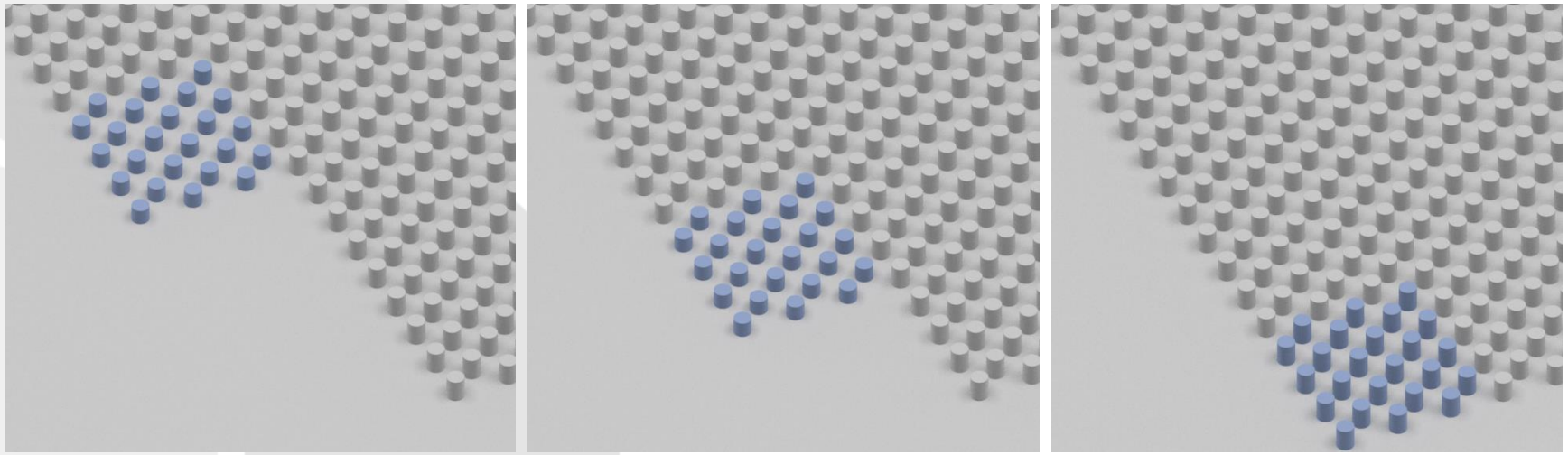
- Deflection of laser focus by galvo mirrors
- Lateral movement in x-y-plane
- High-speed in-plane laser focus movement

Real-time Printing Process

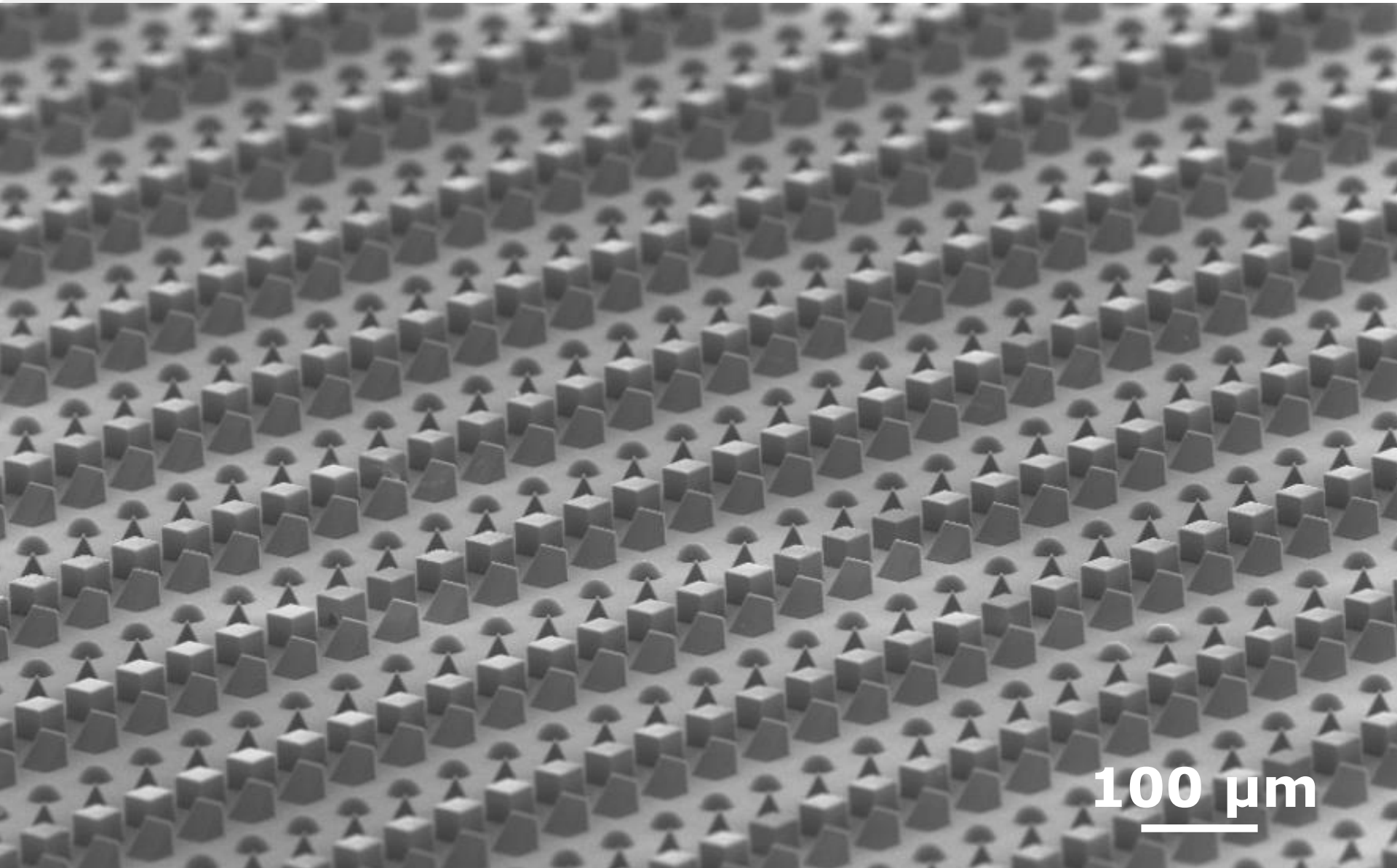
Application Video: 3D µ-Printing

Large Area

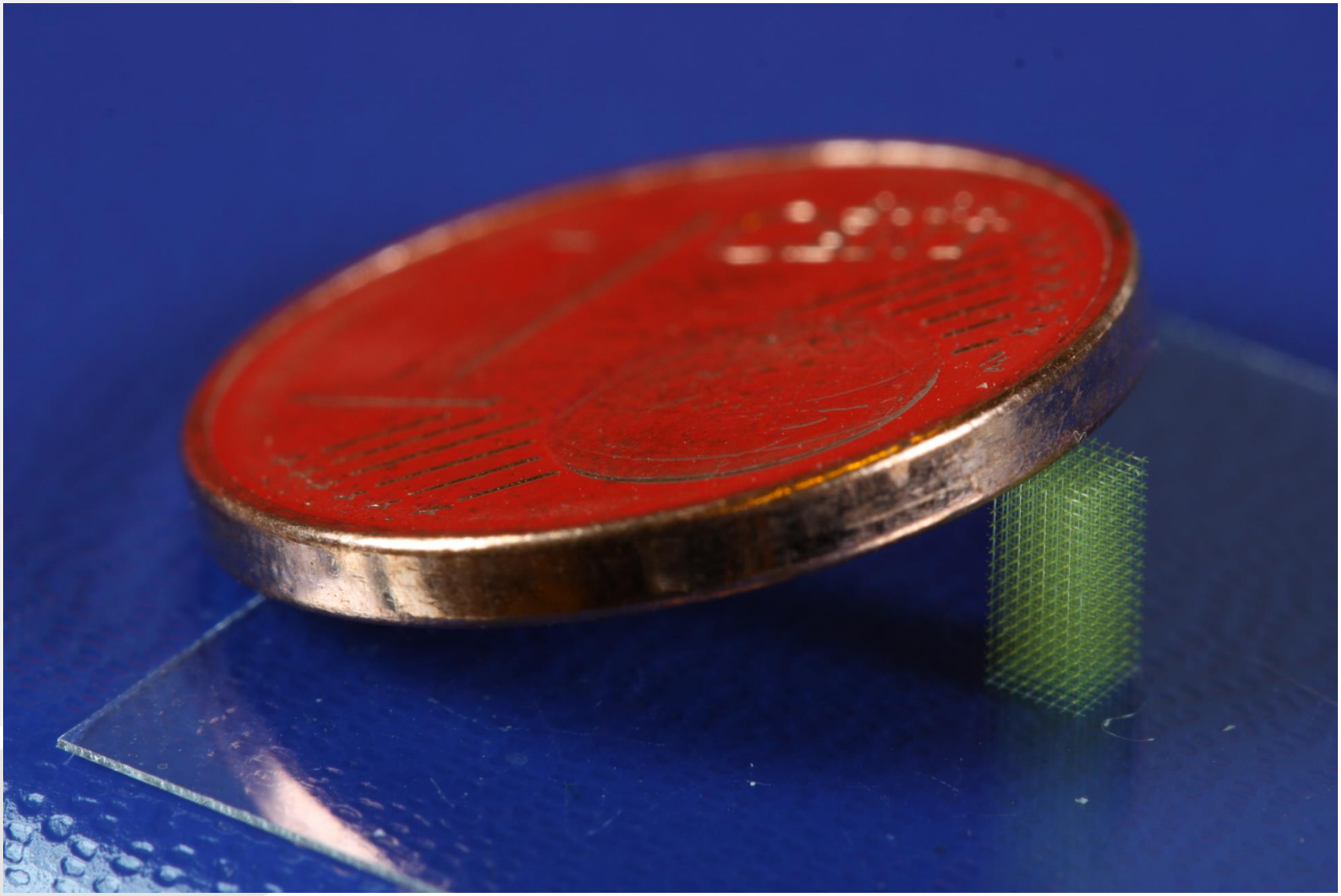
Stitching of micro-structured arrays



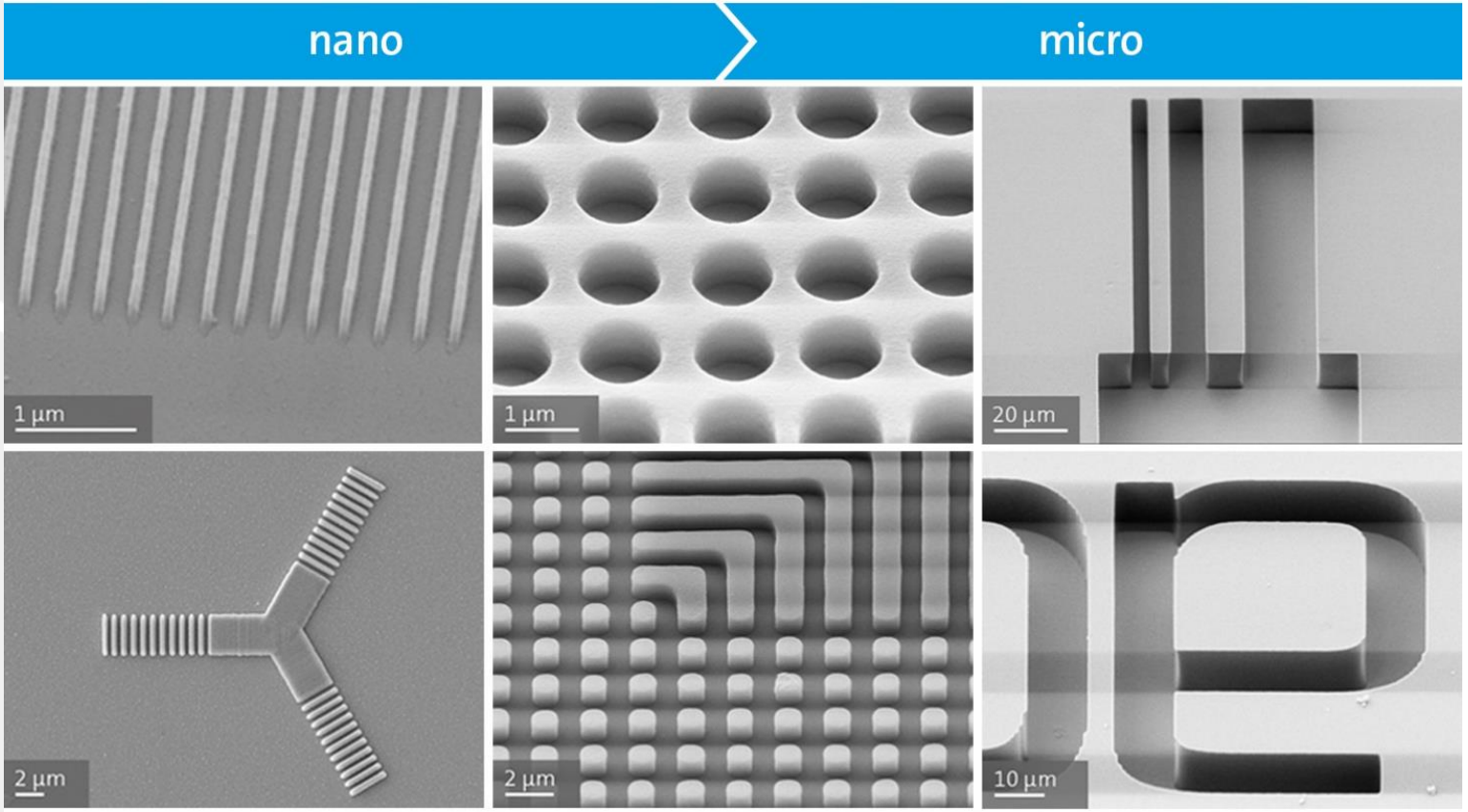
2.5D Micro-optics over large areas



Meso-scaled parts



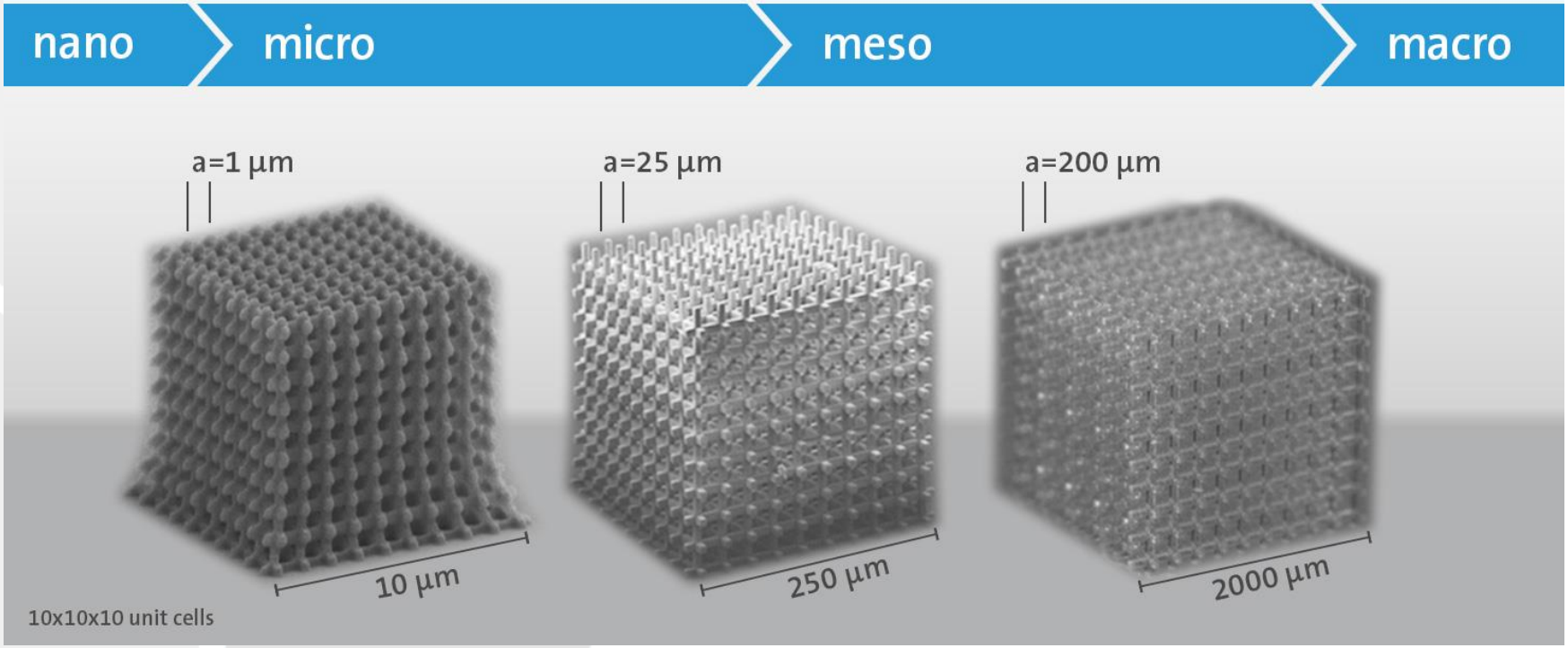
Maskless Lithography



2D & 2.5D: Maskless lithography –
beyond UV- and grayscale lithography

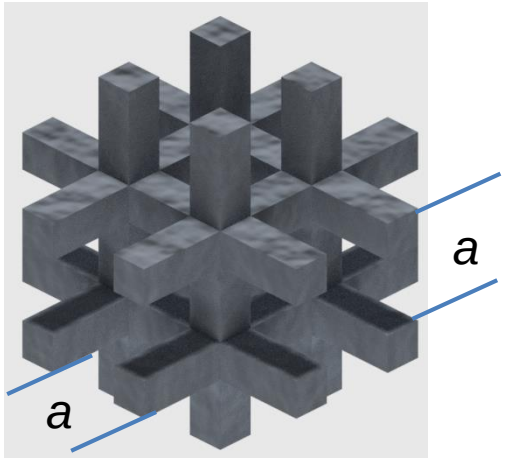
- Design freedom at will (2.5D)
- Ultra-high aspect ratios (2D)
- Resolution: Bridging the gap between e-beam and UV-lithography

3D Printing



3D: Additive manufacturing along
3D Print Workflow

- Highest resolution 3D printer:
  Feature sizes down to 200 nm
- Multi-scale: nm, µm and mm sizes
- High-speed fabrication
- Simple workflow



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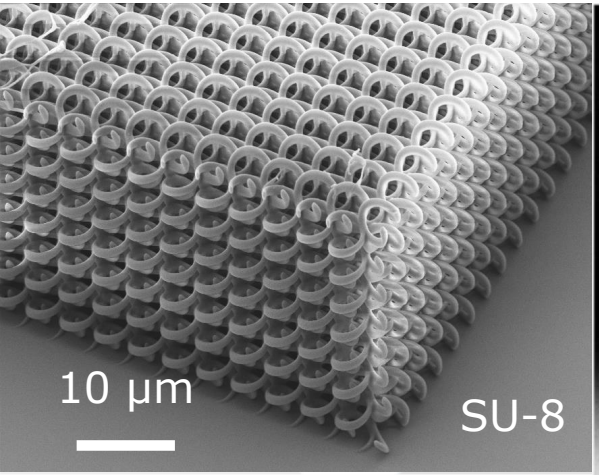
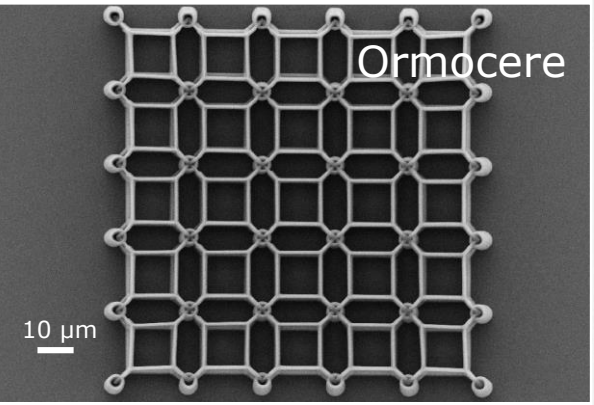
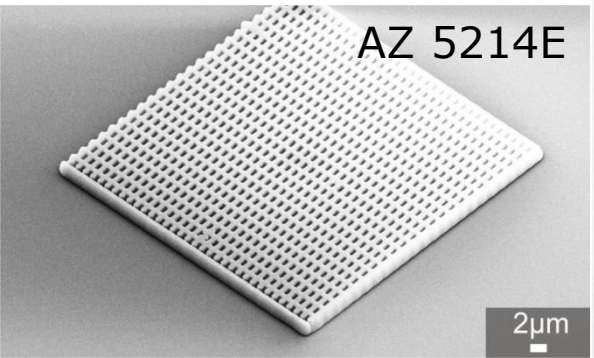
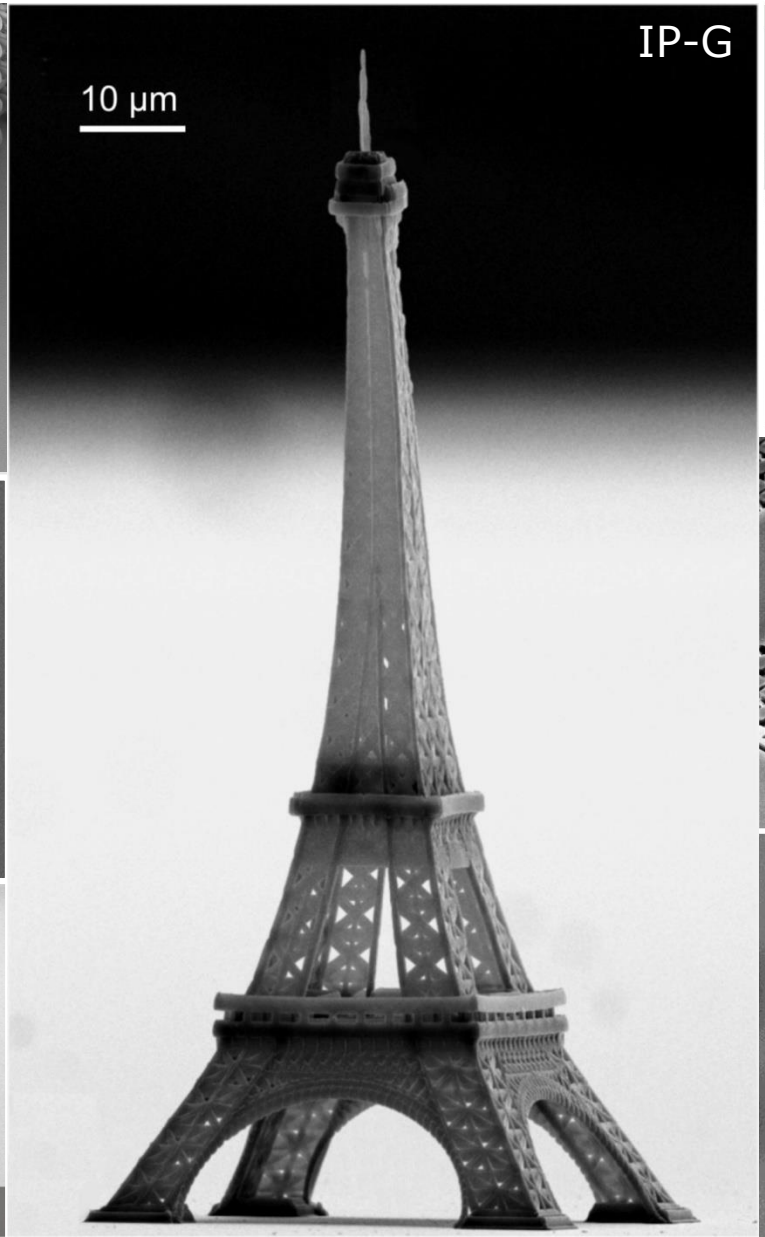
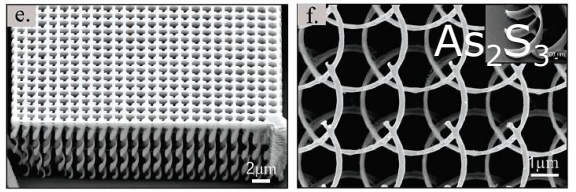
Materials – Printable Resins

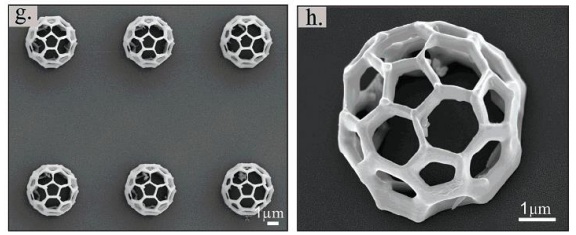


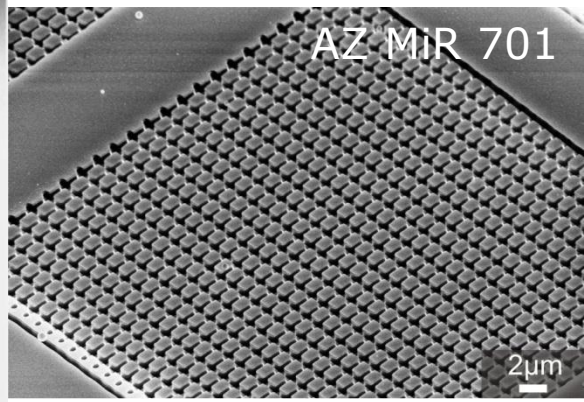


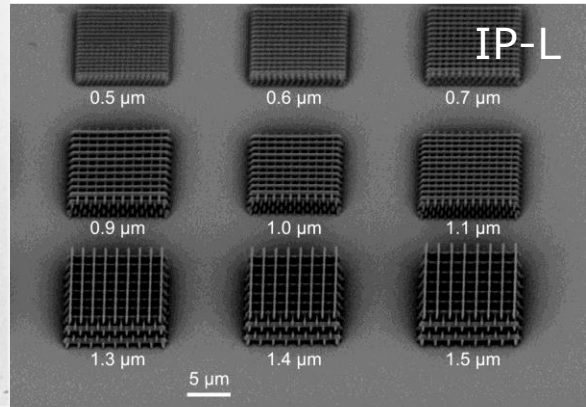












Nanoscribe's IP-resists

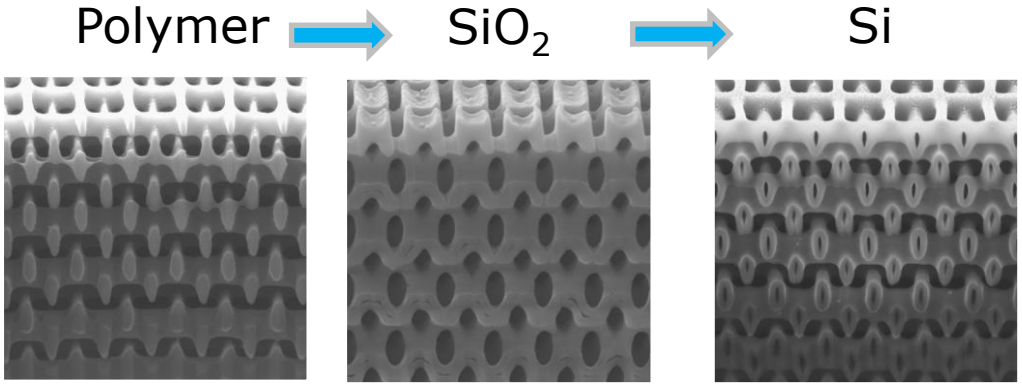
Beyond IP-resists

- Photoresists from other suppliers:
  - Negative-tone: Ormocomp, SU-8
  - Positive-tone: AZ MIR 701, AZ 9260, AZ 5214, AZ 40XT
- Hydrogels: PEG-based hydrogels, BSA protein hydrogel,...
- Chalcogenide glass with high refractive index: As_2S_3
- Polymer mixture: IP-resin with...
  - Nanoparticles (rare-earth doped for temperature measures)
  - Ionic liquids (Conductive composites for sensing applications)
- Liquid crystal elastomers (LCE; light-actuated microtools)

Materials – Casting from Polymers

Dielectrics:

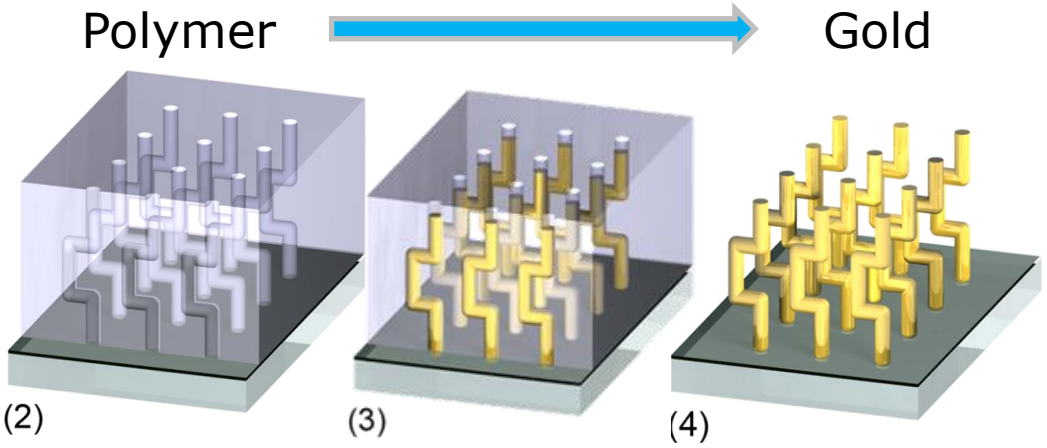
- Silicon Chemical Vapor Deposition (CVD)
- Silica Pulsed Layer Deposition (PLD)
- Titania Atomic Layer Deposition (ALD)



M. Hermatschweiler *et al.,* Adv. Funct. Mater. **17**, 2273 (2007)

Metals:

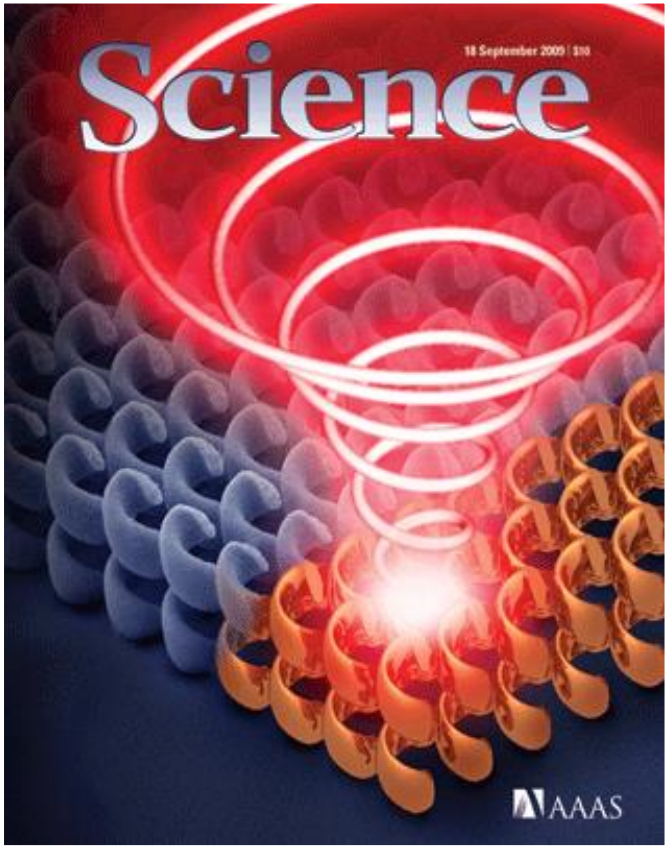
- Gold Electroplating / Galvanization
- Silver Chemical Vapor Deposition (CVD)



J. Gansel et al., Science **325**, 1513 (2009)

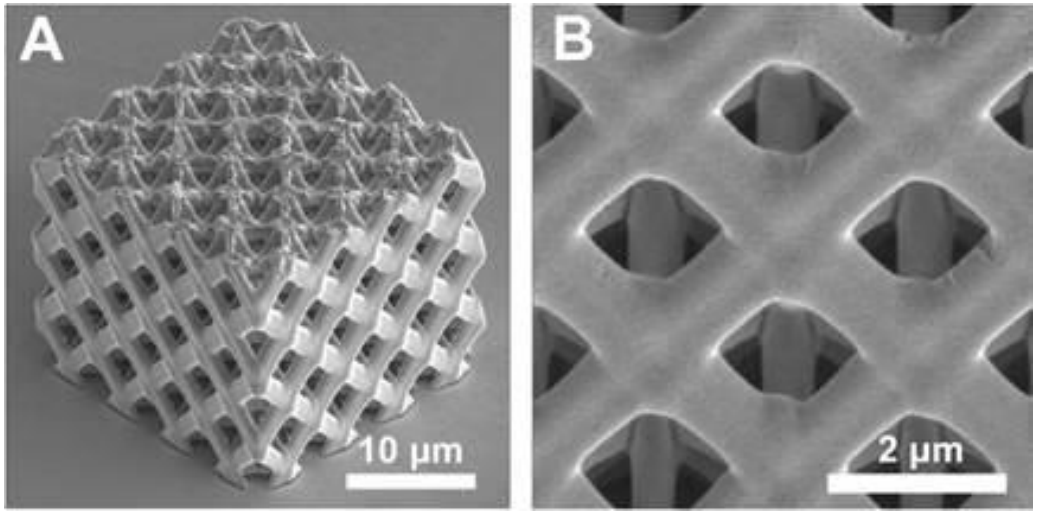
Casting from Polymers

Gold helical photonic metamaterials



J. Gansel et al., Science **325**, 1513 (2009)

Ultra-strong Copper Mesolattices

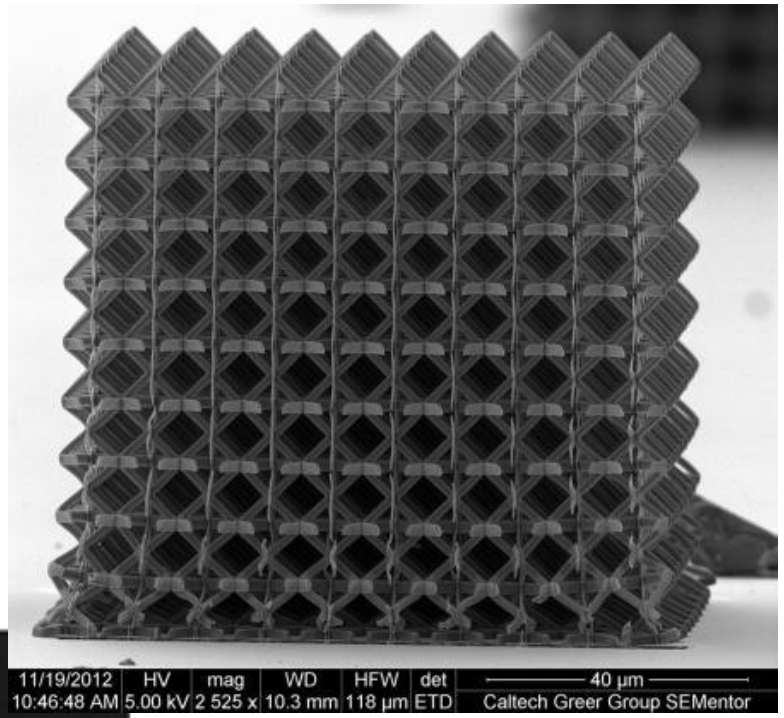


X. Wendy Gu et al., Extreme Mechanics Letters, 0, 2352 (2015), DOI: 10.1016/j.eml.2015.01.006

Coating

Stability tests of plant-like designed scaffolds:

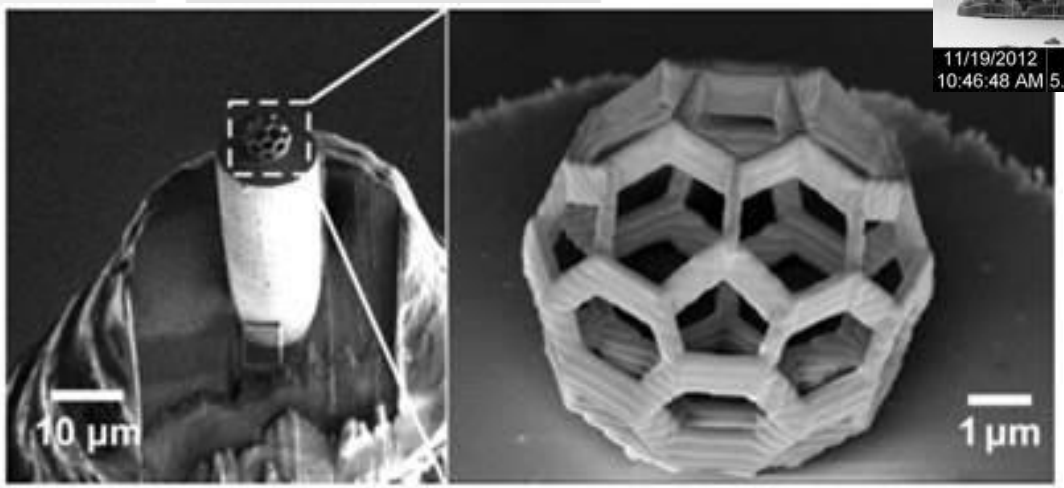
- Casting to titanium nitride (TiN) by ALD; deformation tests with hollow ceramic structures



J. R. Greer et al.,
Nature Materials **12**, 893 (2013)

Testsample for x-ray phase Tomography:

- 3D sample coated with Co



Claire Donnelly et al., Phys. Rev. Lett. 114, 115501 (2015);
DOI: 10.1103/PhysRevLett.114.115501

Metals, Semiconductors, Ceramics…

Subsequent processing via ALD, CVD, electroless plating, galvanization, etc. allows for transfer into different materials:

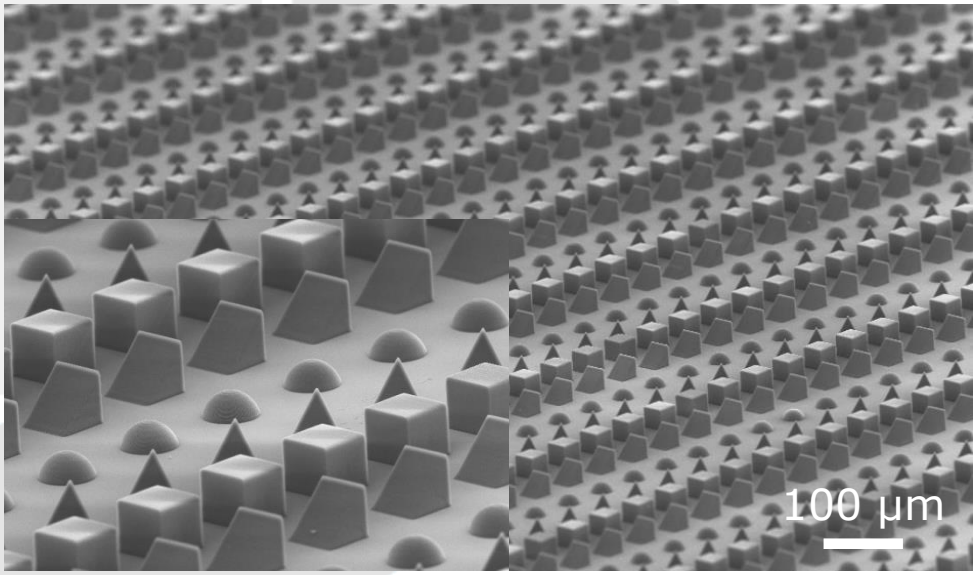
- Cu, Ag, Au
- Ni, Co
- GaAs, Si
- SiO_2
- Ti, TiO_2
- TiN, Al_2O_3
- …

See: http://www.nanoscribe.de/en/media-press/scientific-articles/

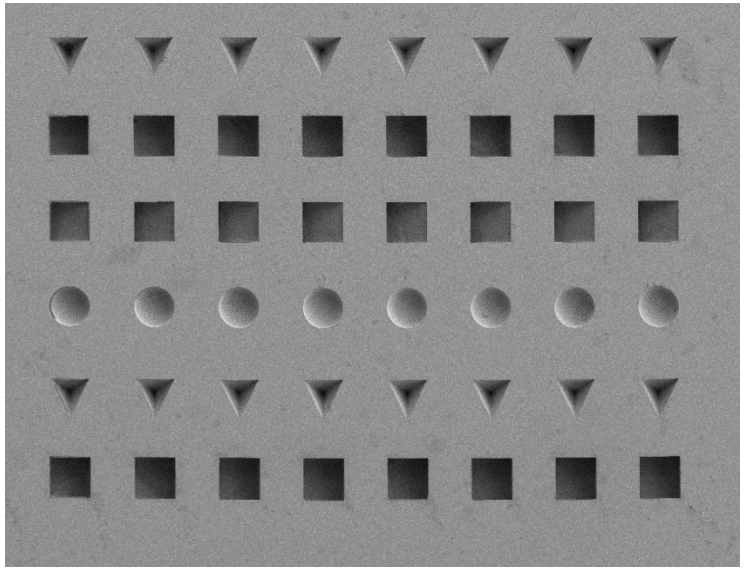
LIGA compatible in all dimensions

- Partners for electroplating:
- Mimotec SA
- microworks GmbH
- Eleoss GmbH

- Serving as masters for:
- Injection molding
- Nanoimprint



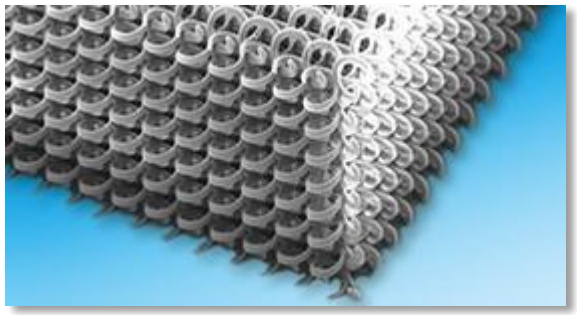
Nickel shim by microworks



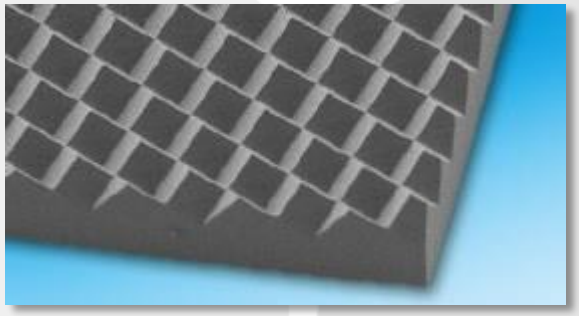
Applications

Scaffolds for Cells

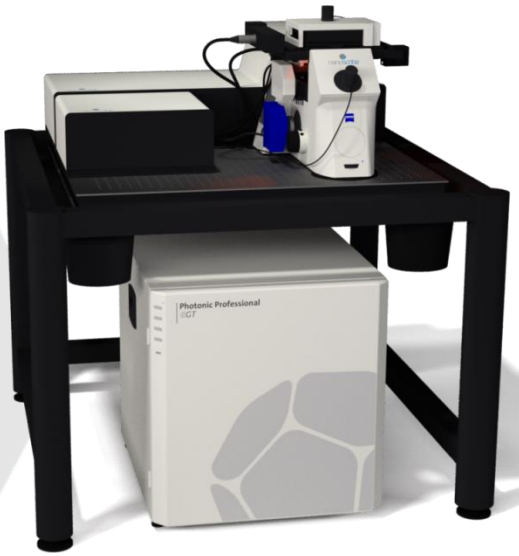
Photonic Wire Bonding
Optical Integration

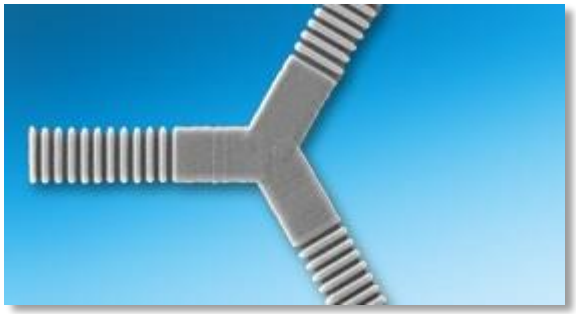


3D Photonics



Micro-optics



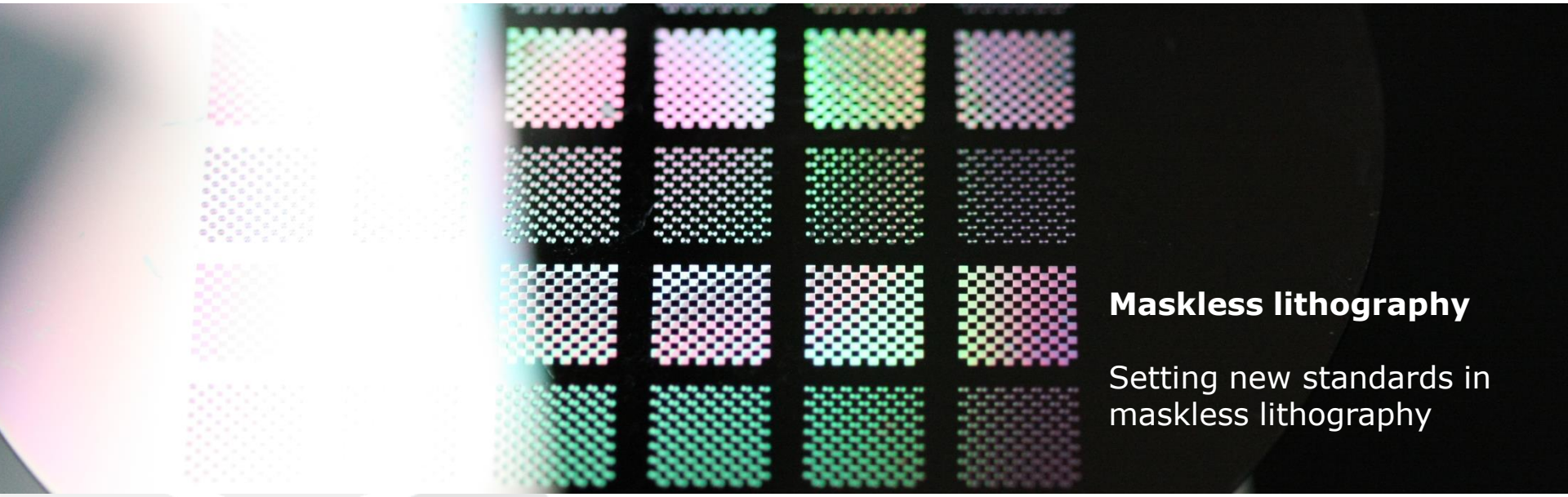


Maskless Lithography

Microfluidics

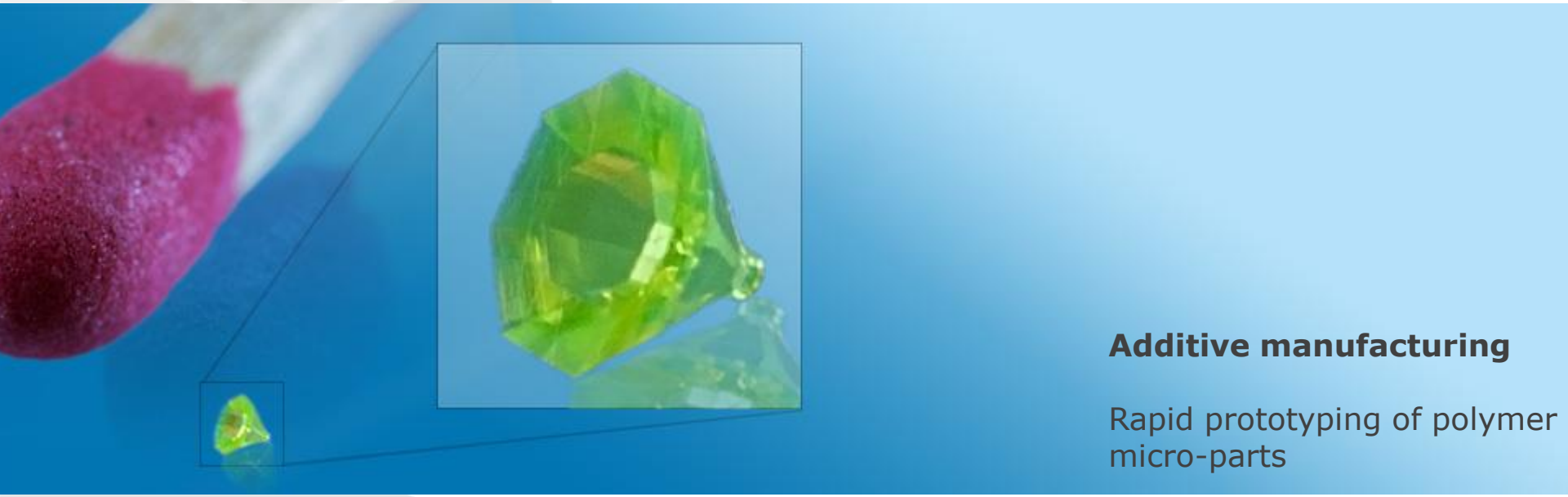
MEMS

Rapid Prototyping



Maskless lithography

Setting new standards in maskless lithography



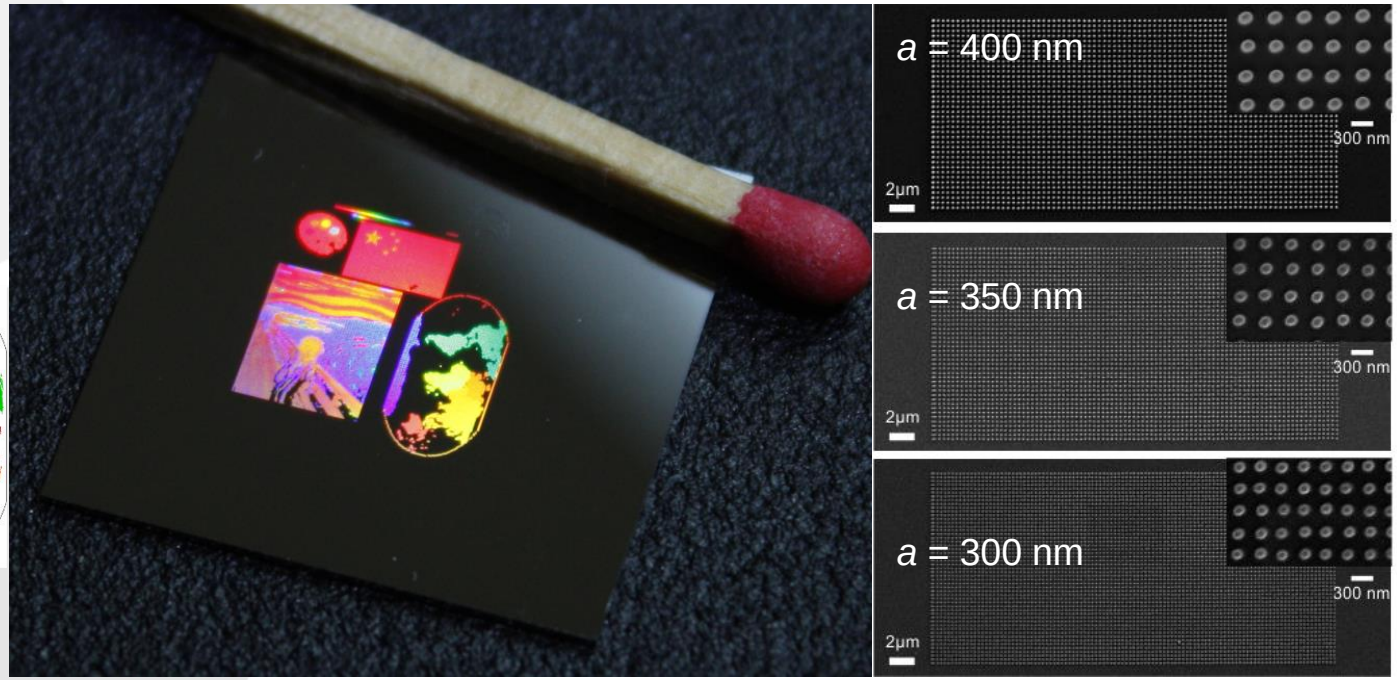
Additive manufacturing

Rapid prototyping of polymer micro-parts

Applications – Maskless Lithography

Photonic Colors / Security Labels

Graphical Input
(png, jpg,…)



Minimal lateral feature size down to 200 nm.

Nano-pillar array with periods of 600 nm to 1600 nm.

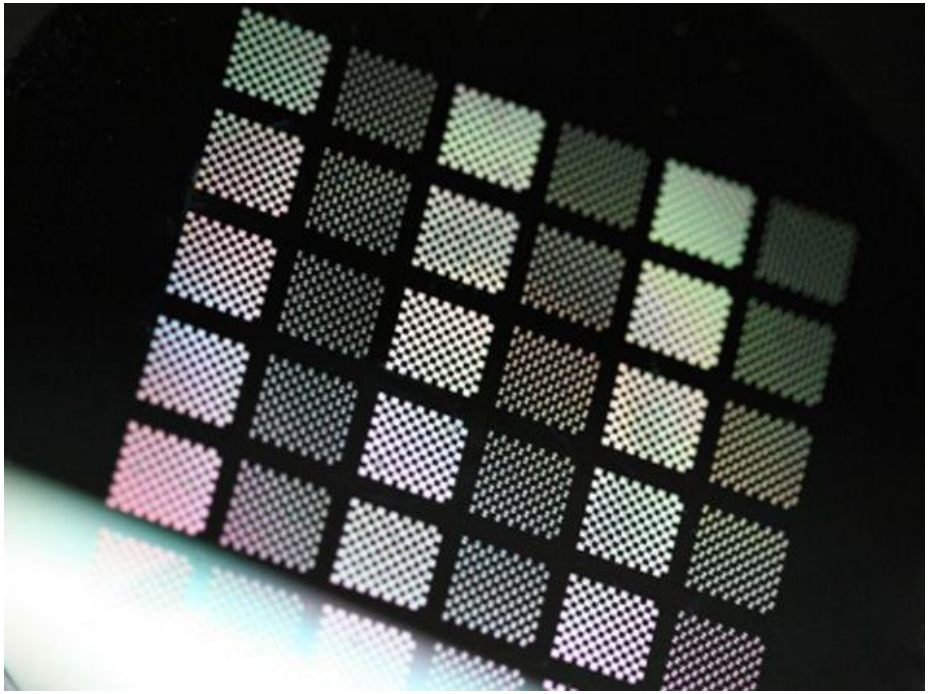
Maskless Lithography

Typical negative tone resists:

- SU-8 (MicroChem)
- IP-Resists (Nanoscribe)

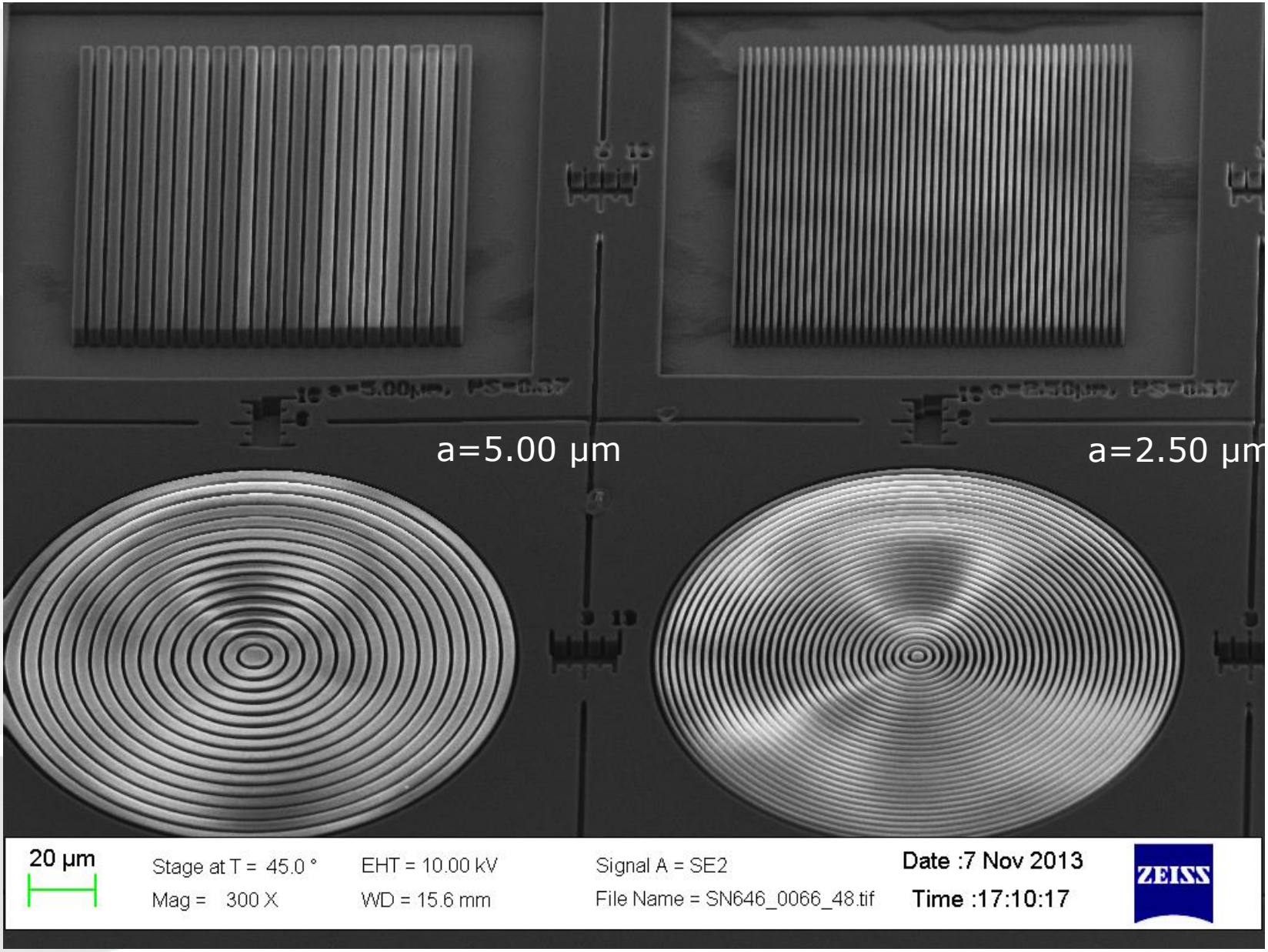
Positive tone resists:

- AZ 9260
- AZ MIR 701
- AZ 5214
- AZ 40XT



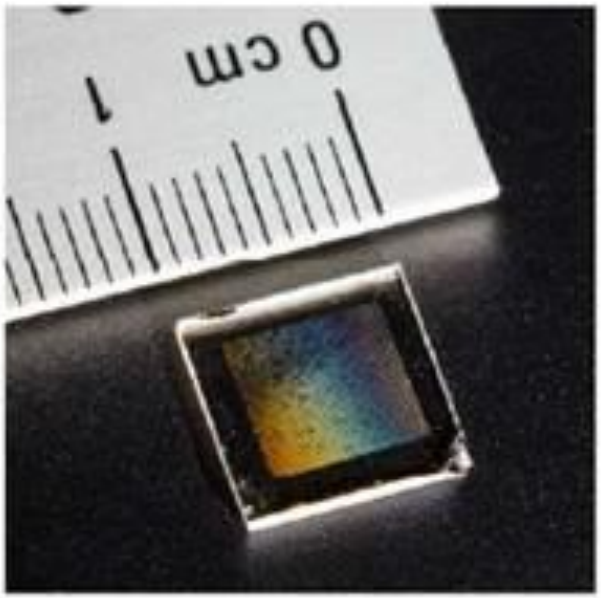
4’’ wafer with patterened positive tone resist

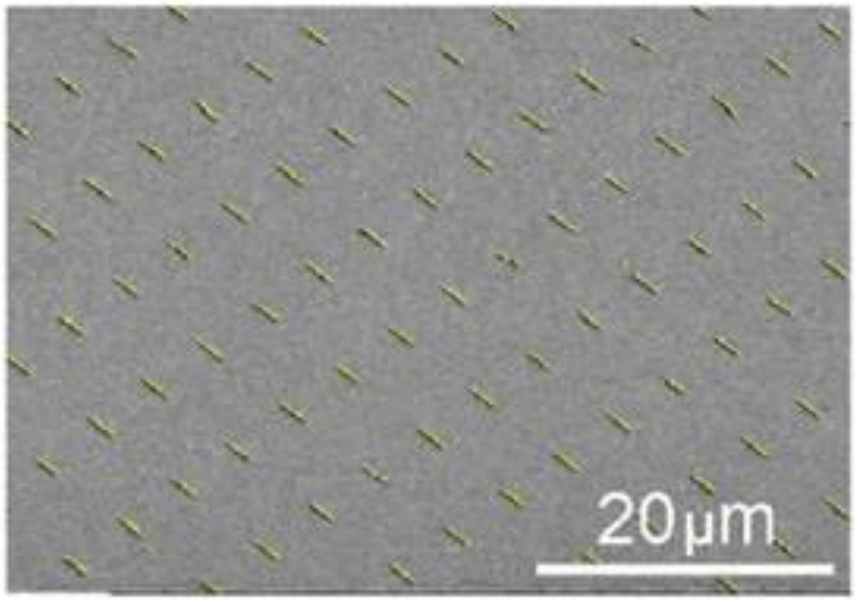
Positive Tone Resist Test Patterns



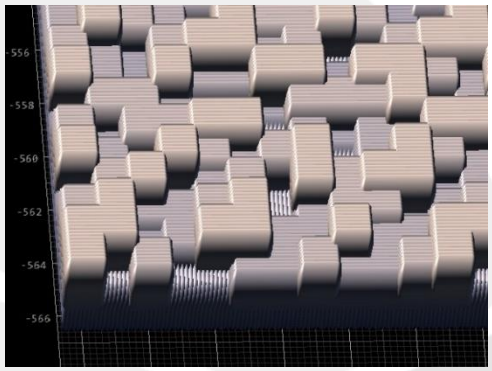
Plasmonic cm² nanoantenna array

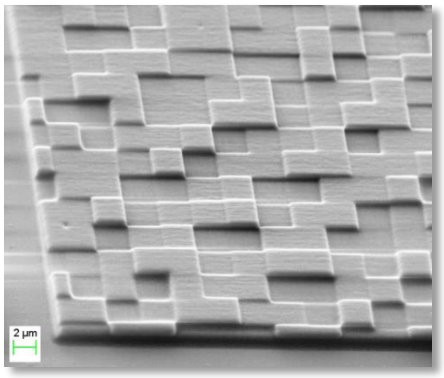
- Gold nanoantenna arrays for sensing applications
- Surface-enhanced infrared absorption (SEIRA).
- S. Bagheri et al. Fabrication of cm2 plasmonic nanoantenna arrays by femtosecond direct laser writing lithography: Effects of collective excitations on SEIRA enhancement, ACS Photonics, DOI:10.1012/acsphotonics5b00141

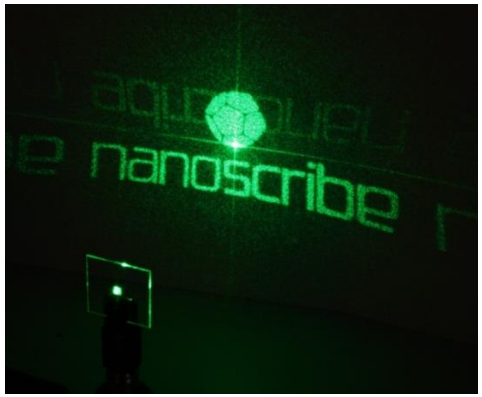




Optical Security Labels: n-level DOE





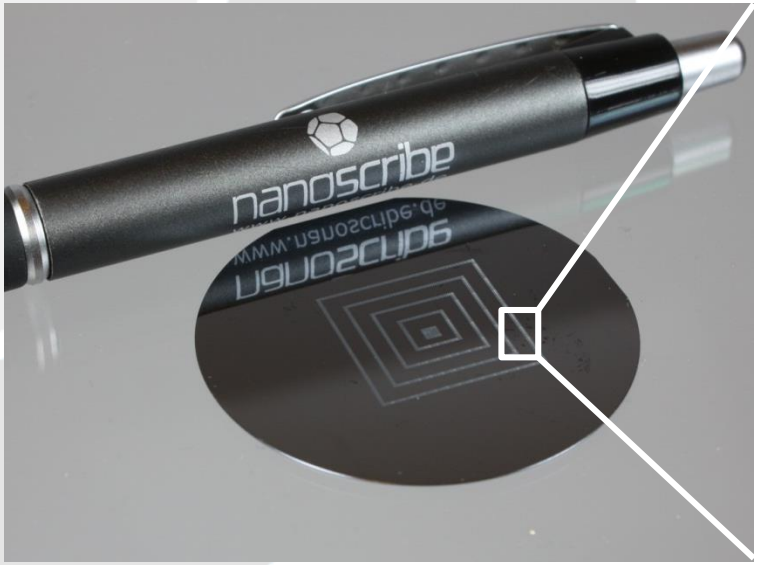


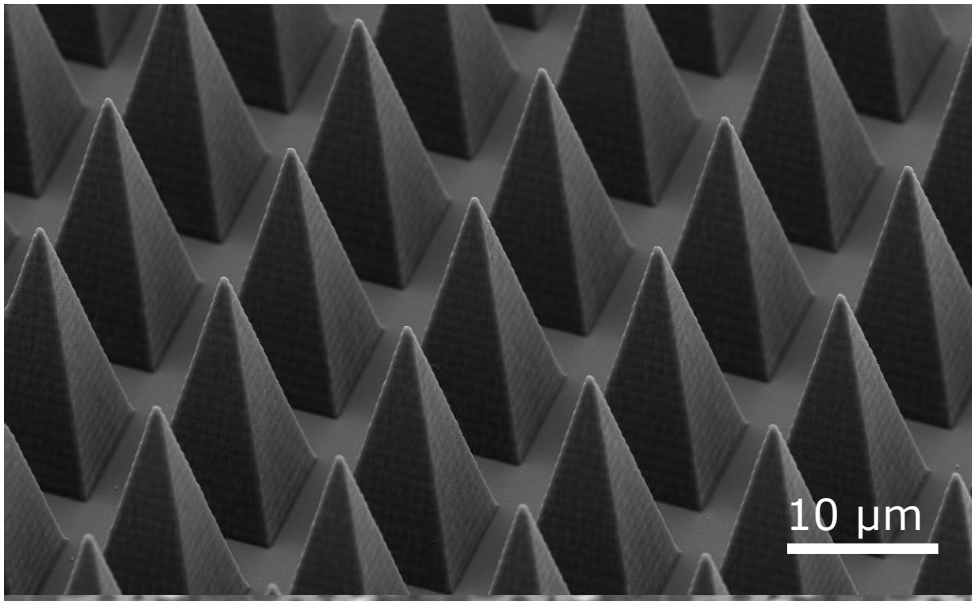
Product lifecycle leverage effects:

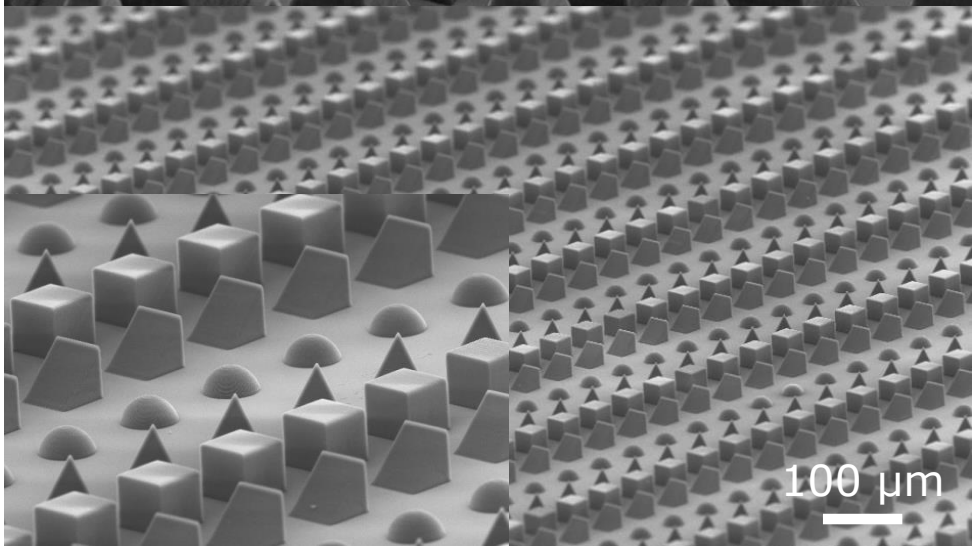
- **Removing process steps:**
  - 1 step instead of n steps
  - 1 printer instead of UV/e-beam + mask aligner
  - No spin-coater, no soft-bake, no hard-bake, just print!
- **Saving time & costs:**
  - 1 day instead of > 1week
  - Less equipment
  - No masks!

2.5D – Beyond Gray Scale Litho

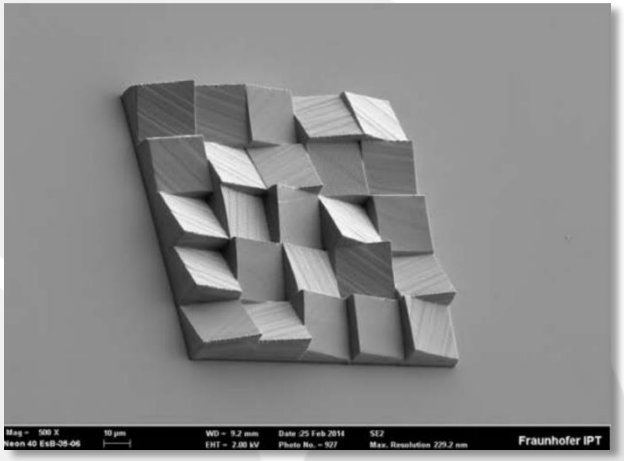
- Freedom of design
- Simple process for liquid resists
- Visual feedback
- High aspect-ratio



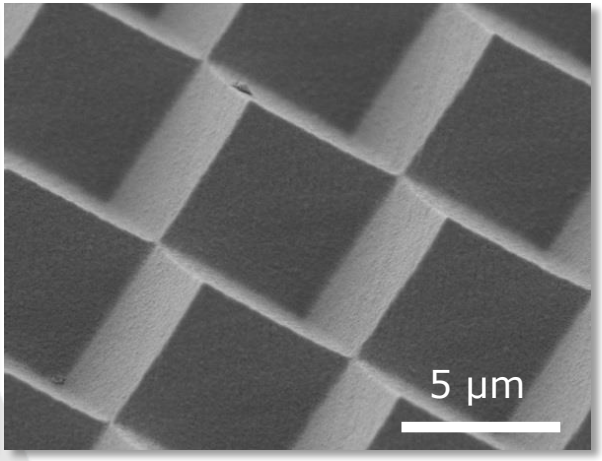




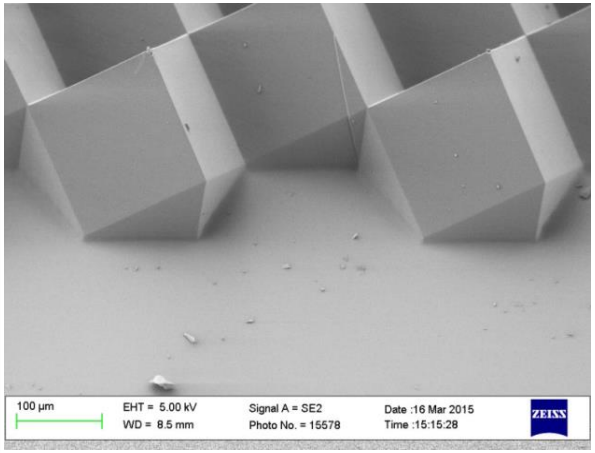
Microoptics



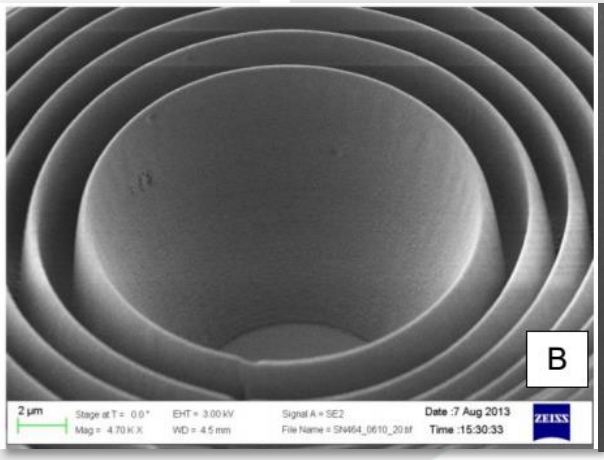
E. Harnisch *et al.*, Photonik 4 (2015)



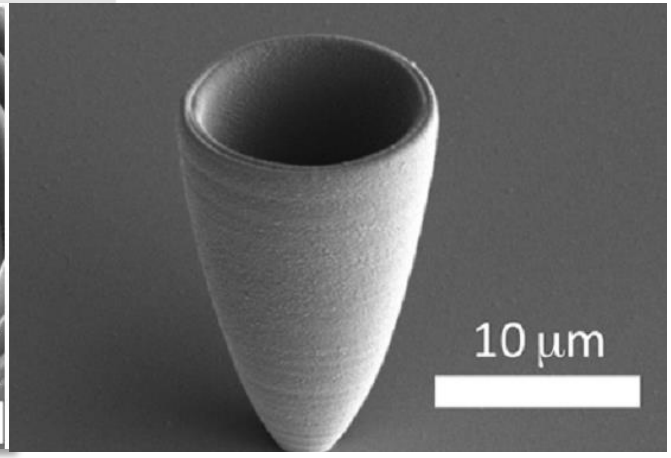
Retro-reflector



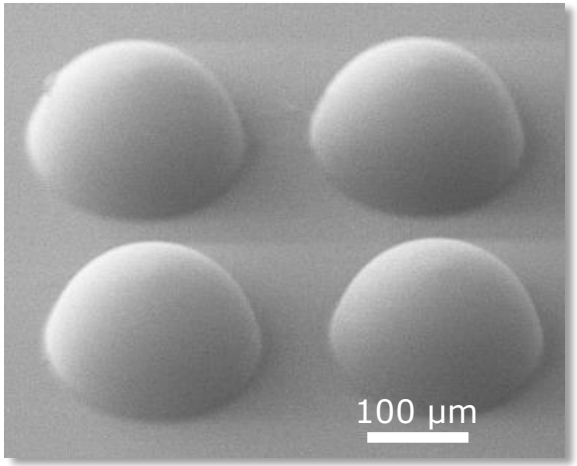
Cornercube retro-reflector



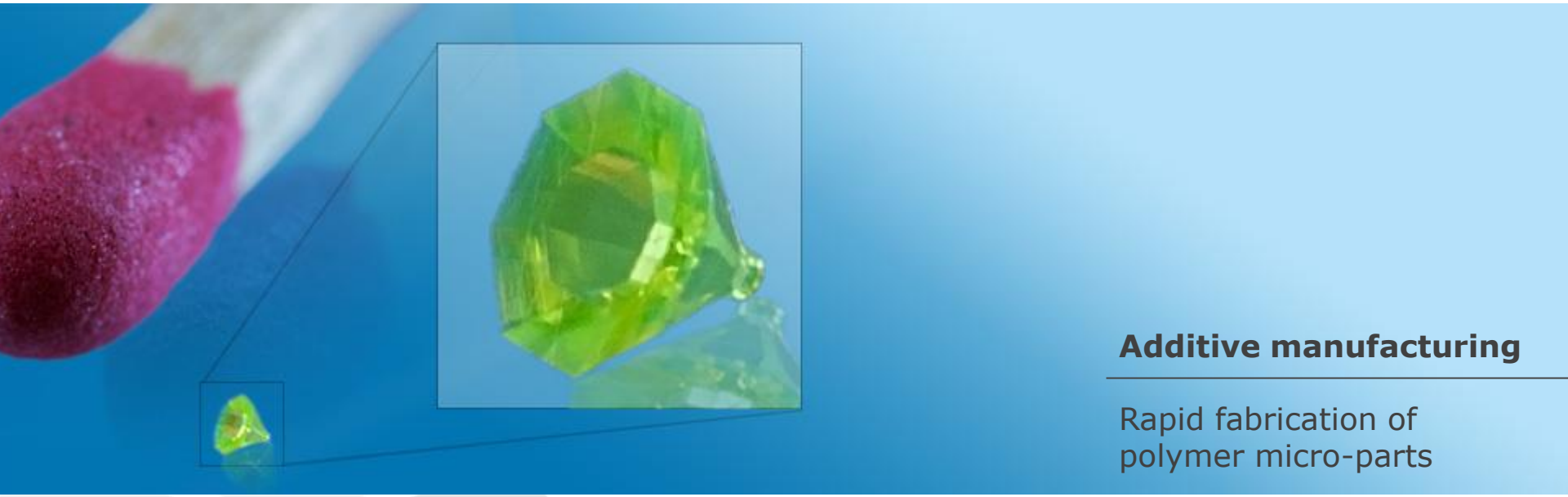
Fresnel lens



J. H. Atwater et al., APL 99, 151113 (2011)

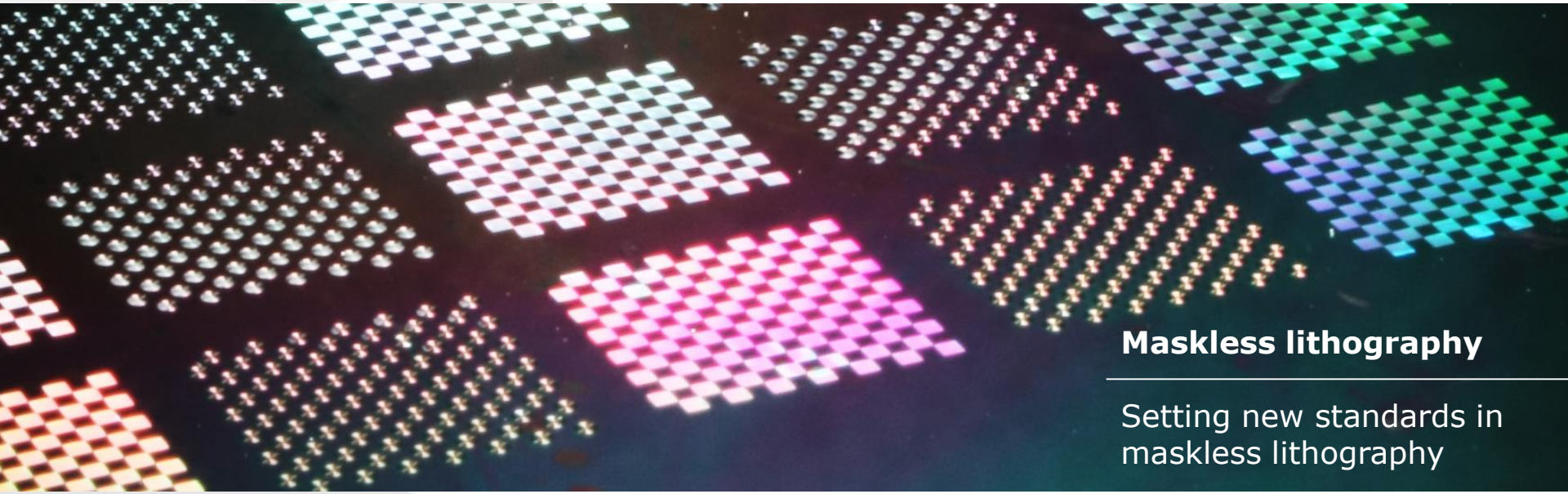


Half-spheres



Additive manufacturing

Rapid fabrication of polymer micro-parts

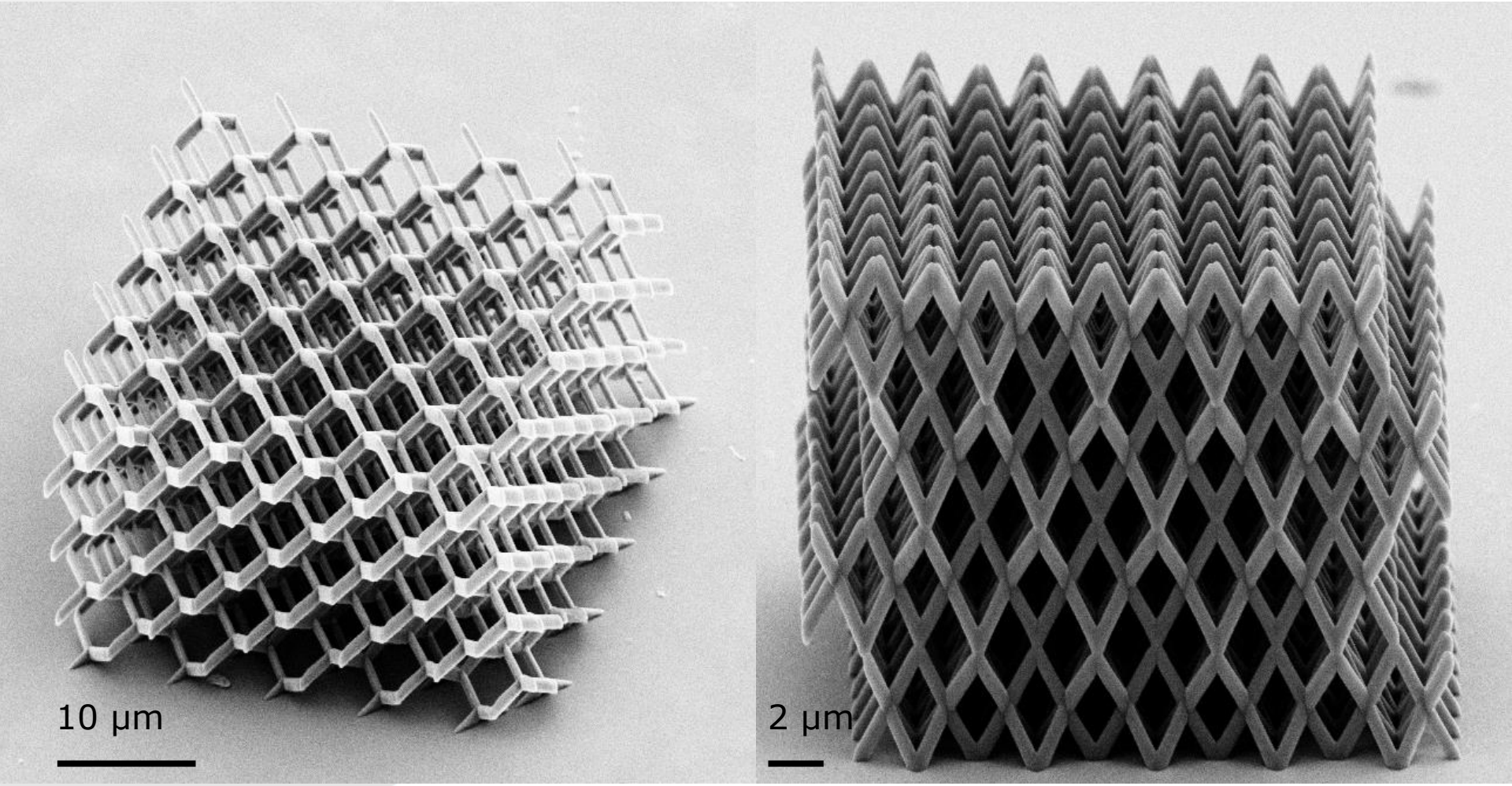


Maskless lithography

Setting new standards in maskless lithography

Applications – Additive Manufacturing

3D Photonic Crystals



according to K. Edagawa *et al.*, PRL 100, 013901 (2008)

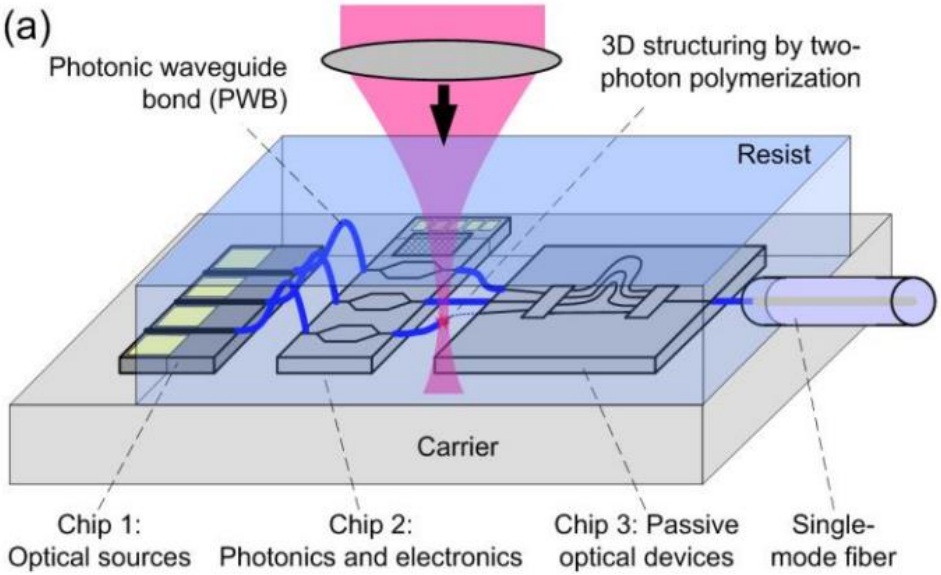
Design provided by ITMO, Russia

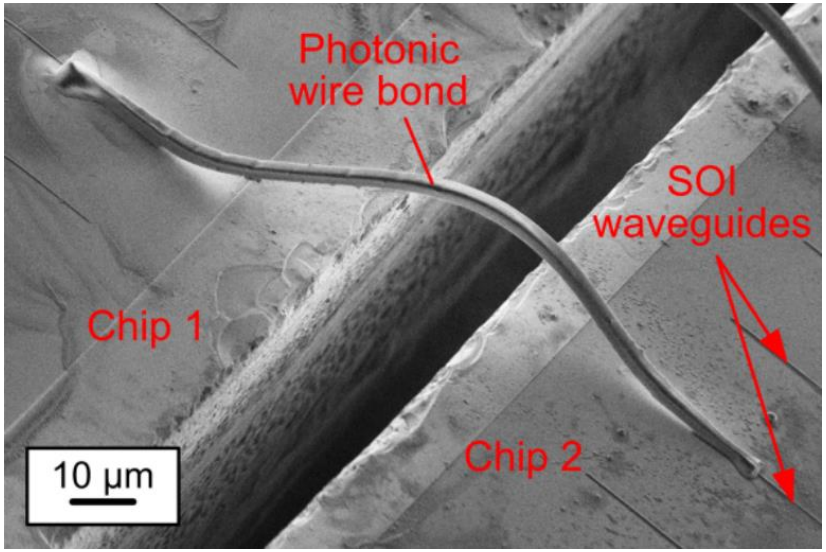
Photonic Waveguide Bonds

Optical Interconnects:

- Optical integration from chip-to-chip
- Optical analog to electrical wire bonds of electrically integrated circuits (IC)
- Data rates in information processing: >5 Tbit/sec
- BMBF funds project „Phoibos“ www.phoibos.de

PHOIBOS

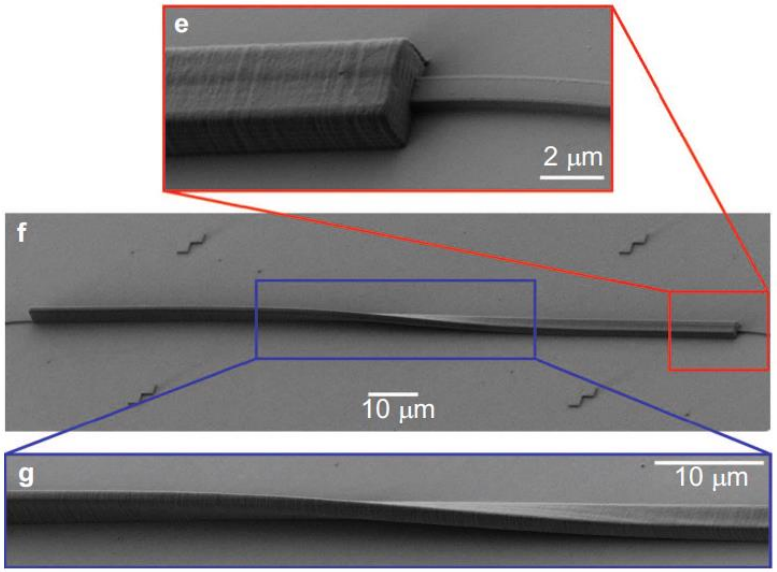




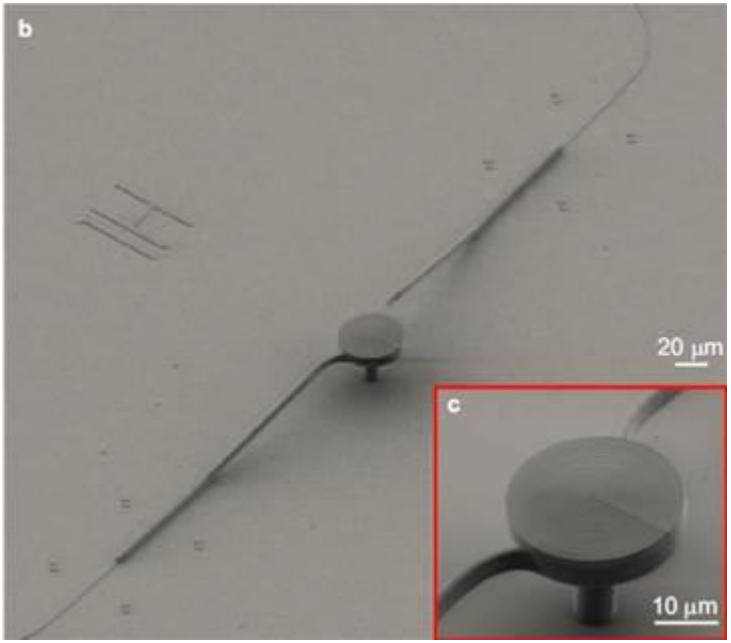
Optics Express, Vol. 20, 17667 (2012)

Integrated Optics

- Broadband polarization rotator connecting two nanophotonic waveguides



- Whispering-gallery-mode optical resonator connected to Si_3N_4 waveguides

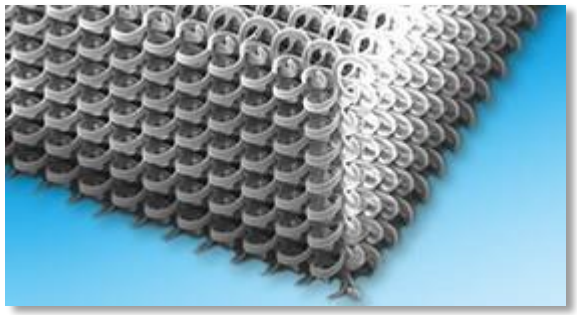


M. Schumann et al; Light: Science & Applications (2014) 3, DOI:10.1038/lsa.2014.56

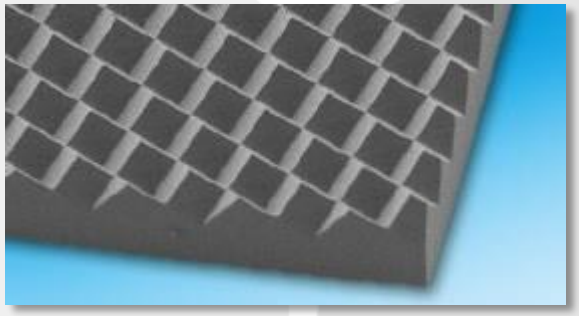
Applications

Scaffolds for Cells

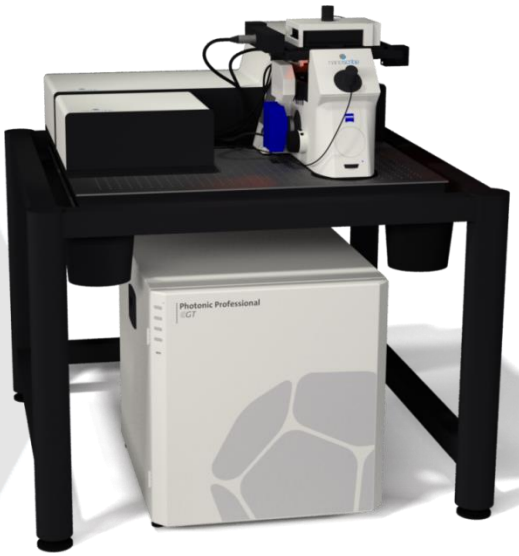
Photonic Wire Bonding
Optical Integration

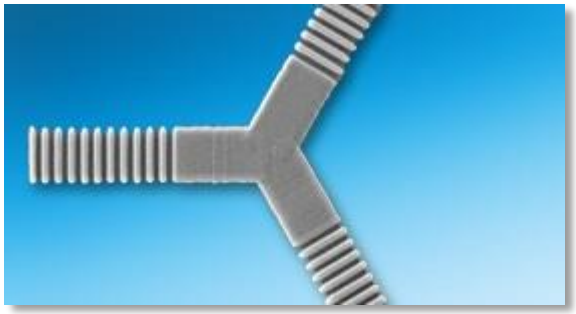


3D Photonics



Micro-optics





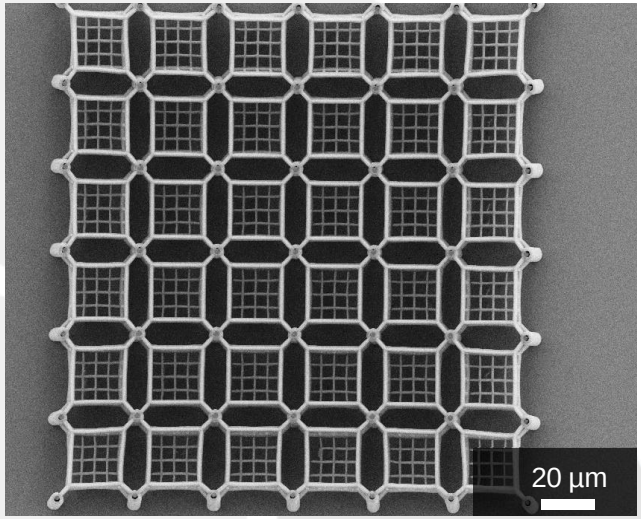
Maskless Lithography

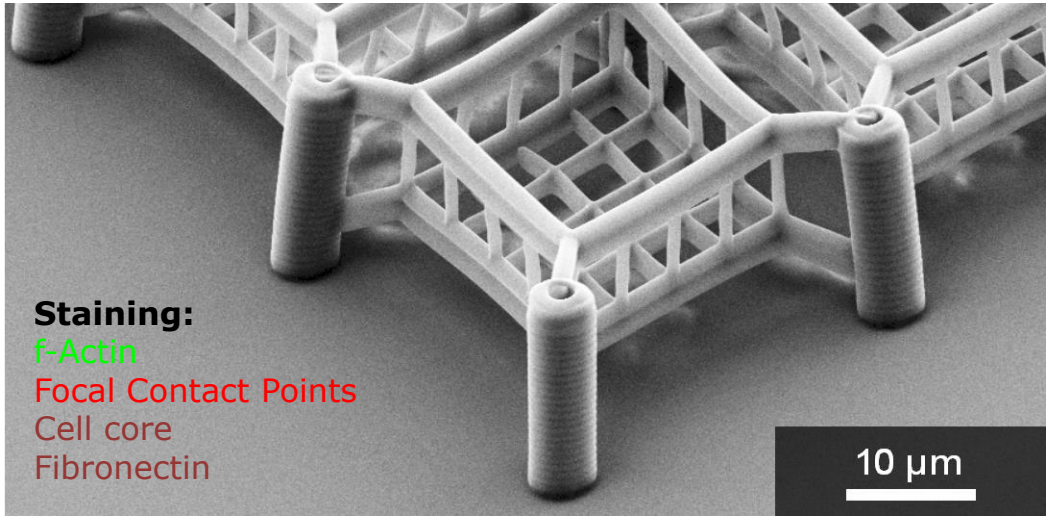
Microfluidics

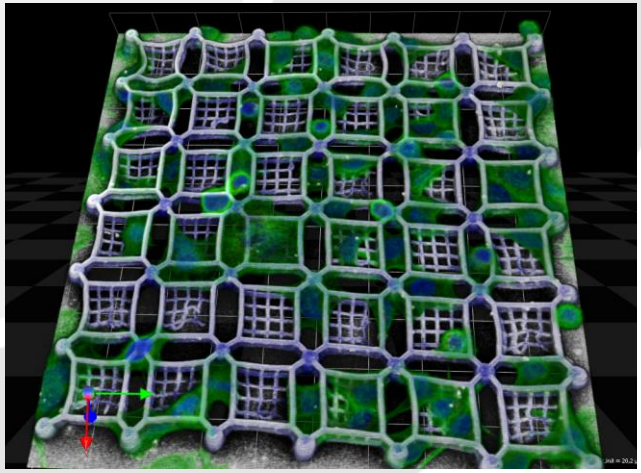
MEMS

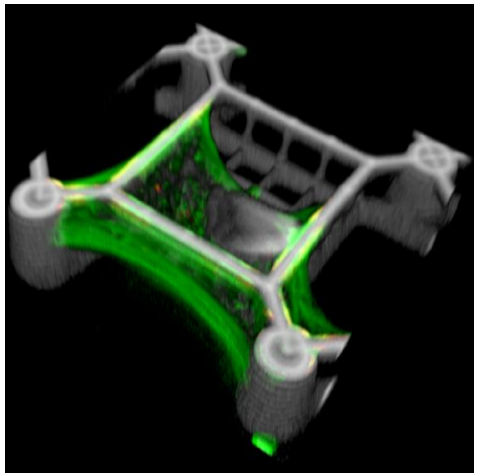
Rapid Prototyping

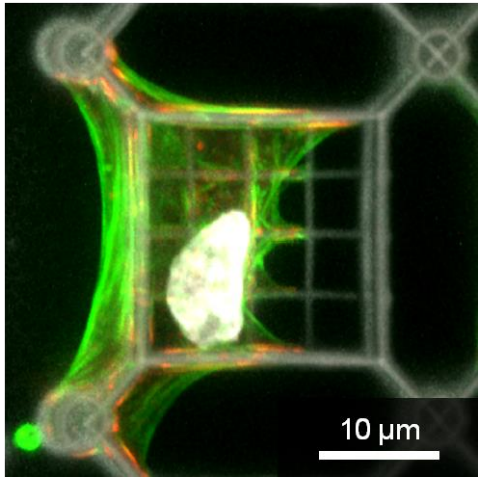
Scaffolds for Cells







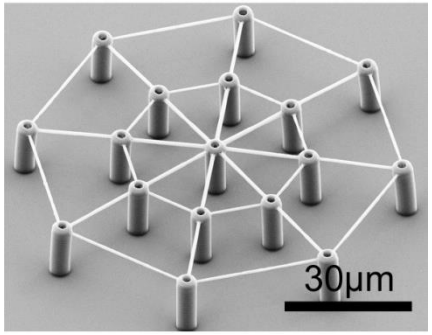


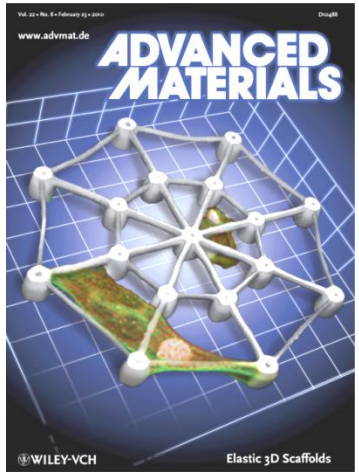


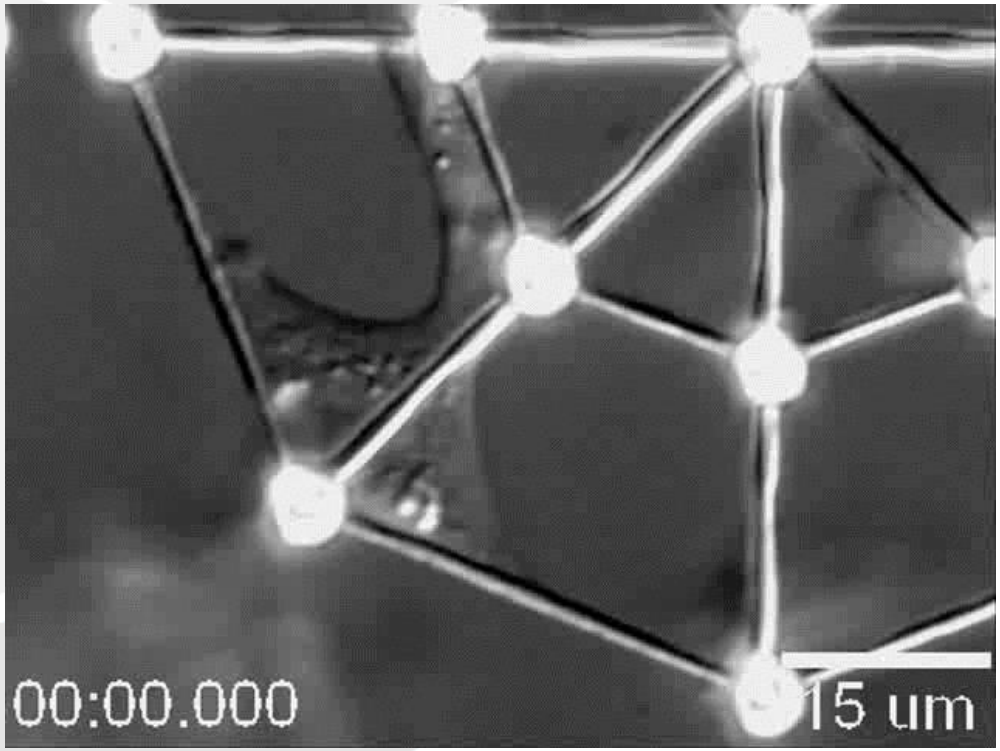
ORMOCERE, J. Fischer, F. Klein, T. Striebel, M. Bastmeyer, Karlsruher Institut für Technology (KIT)

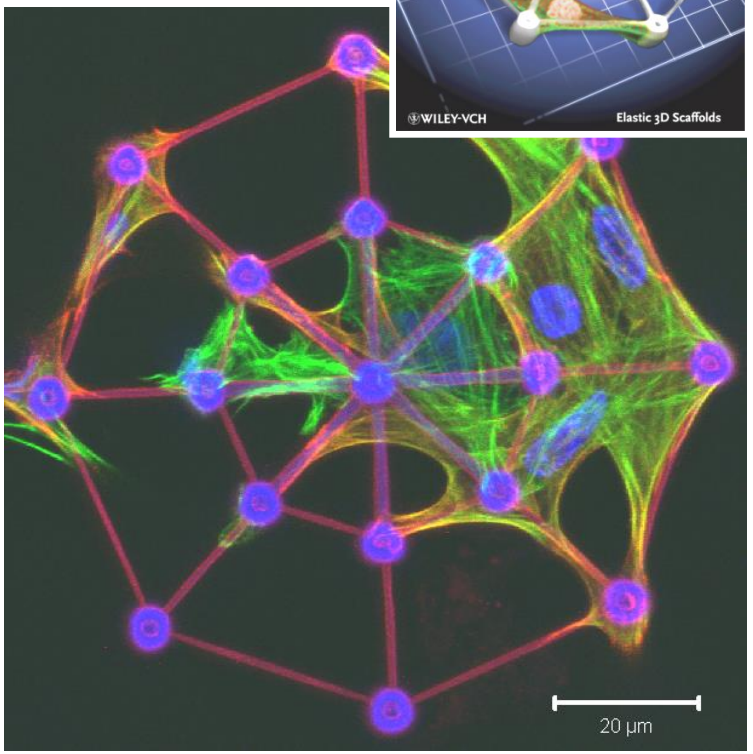
A Gym for Cells

- Primary culture of chicken heart cells
  F. Klein *et al.*, Adv. Mater. **22,** 868 (2010)

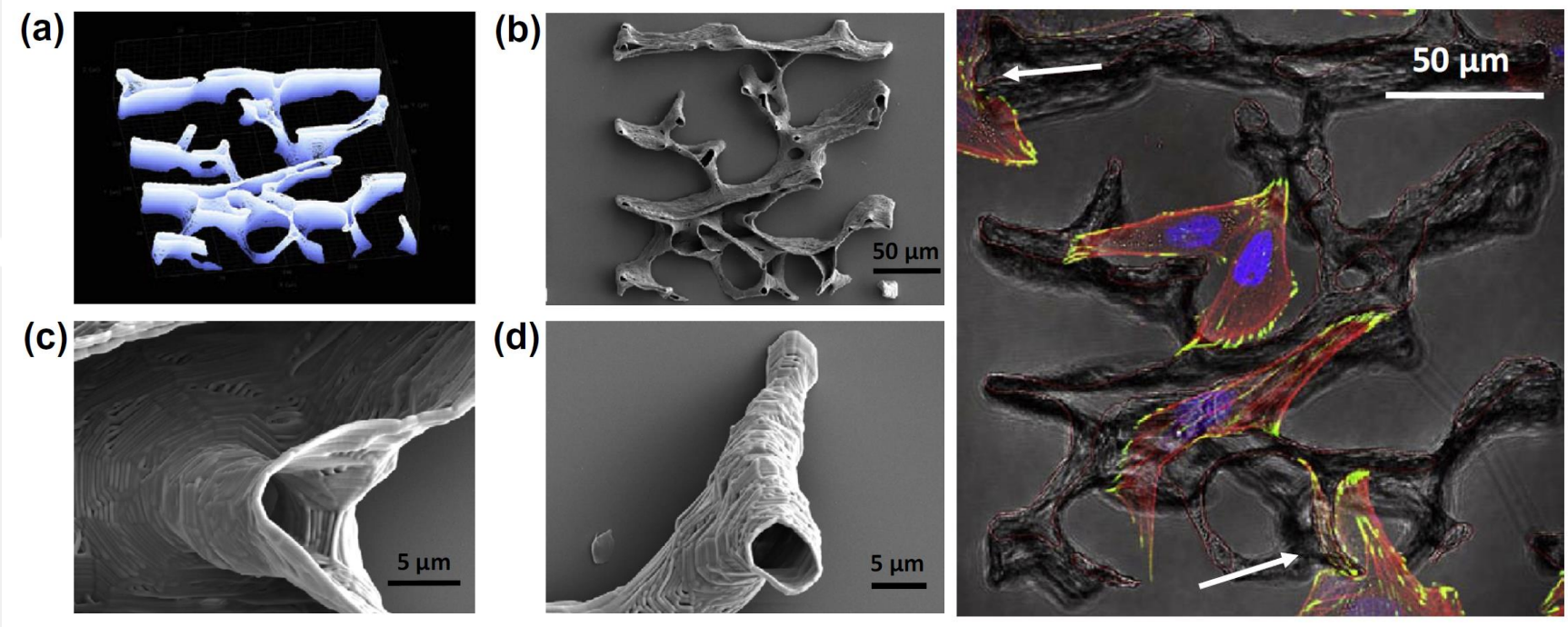








The Osteoprint



A.Marino et al., Acta Biomaterialia Vol.10 Issue 10, (2014) 4304-4313

- Artificial trabecula-like structure
- For bone-like cell differentiation

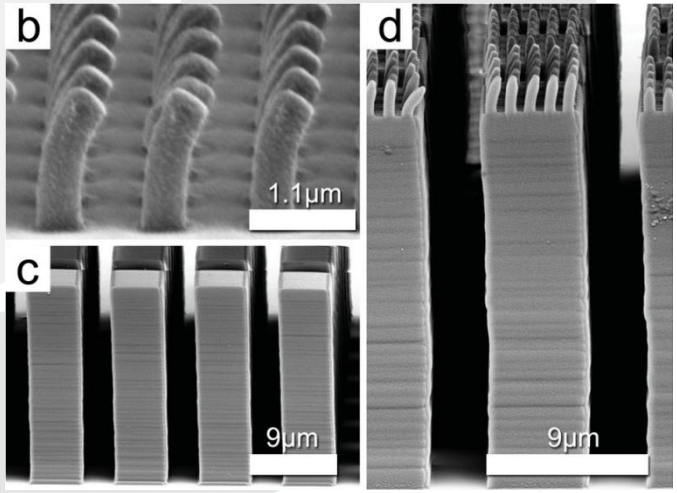
Biomimetics

Salvinia effect:

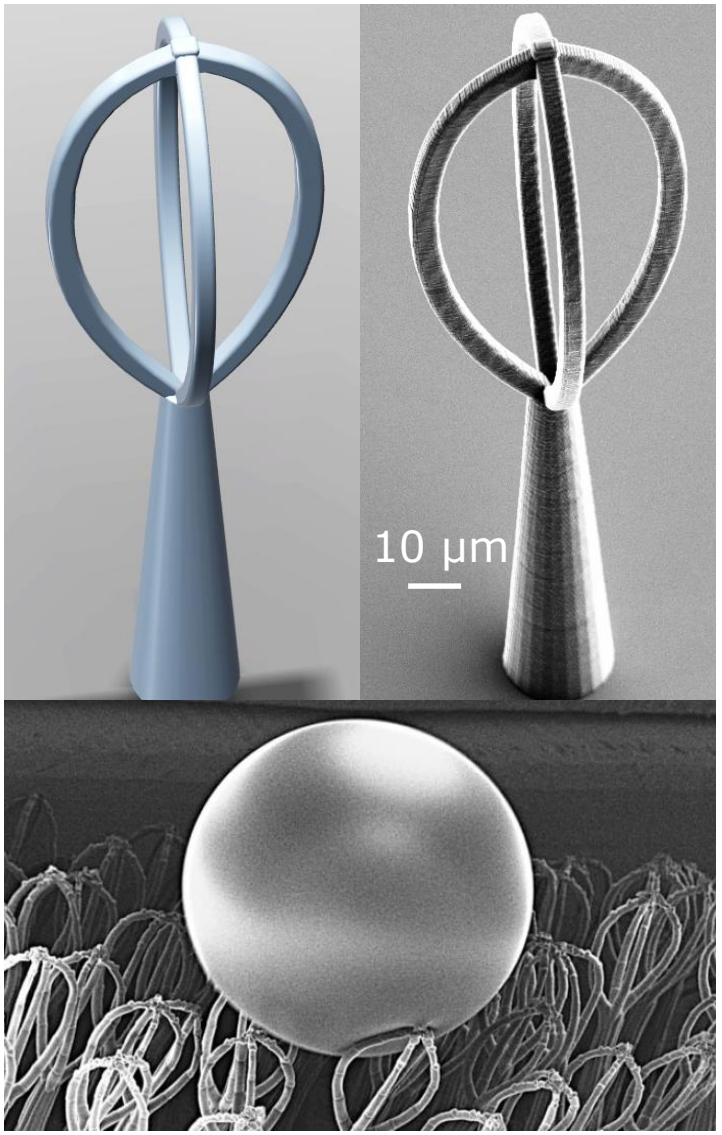
- Floating fern
- Air retention prevents getting moldy when drowned under water
- Application: Friction reduction of ships

Gecko effect:

- Application: Adhesion based on hierarchical structure

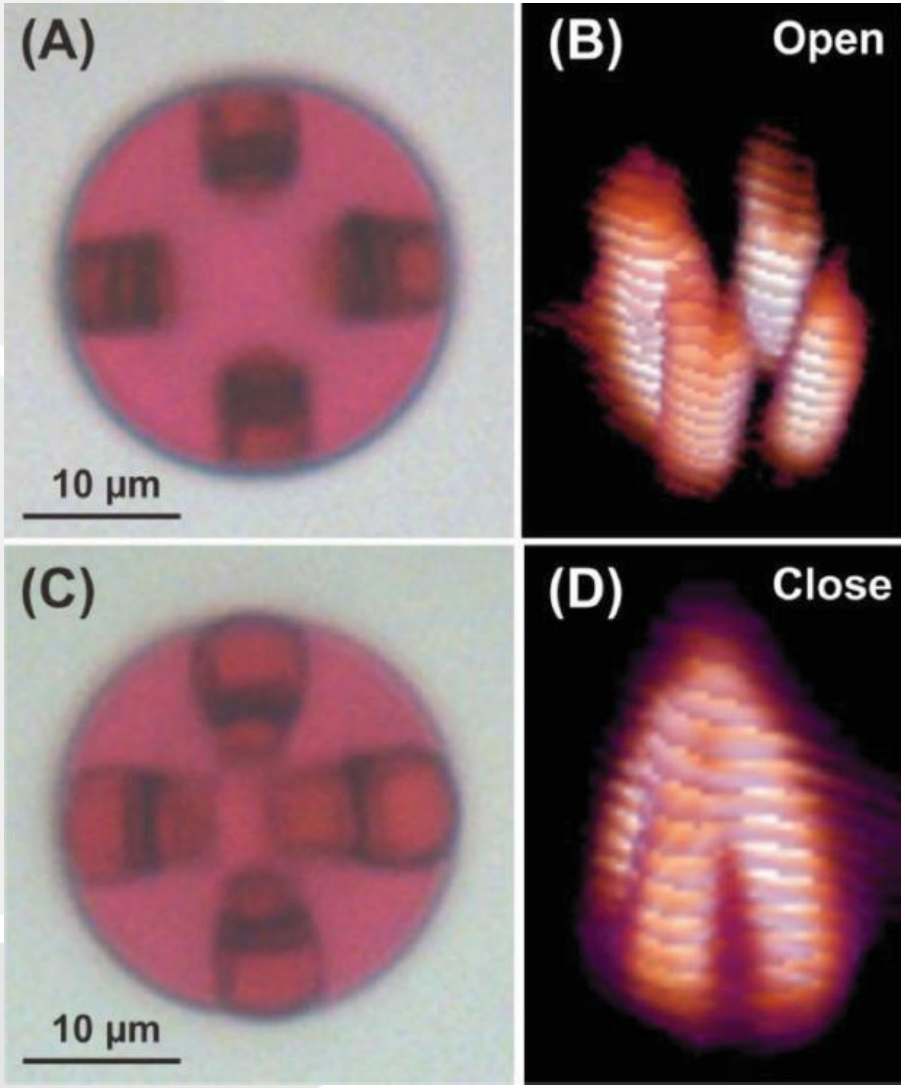


M. Röhrig *et. al.,* Small 19, 2918 (2012)



W. Barthlott, *et al.* Adv. Mater. 22, 2325 (2010)

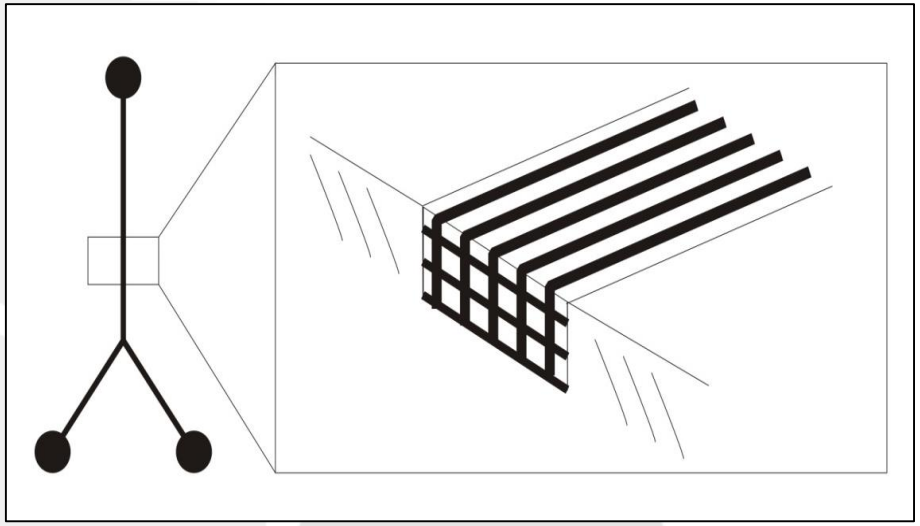
Protein hydrogels

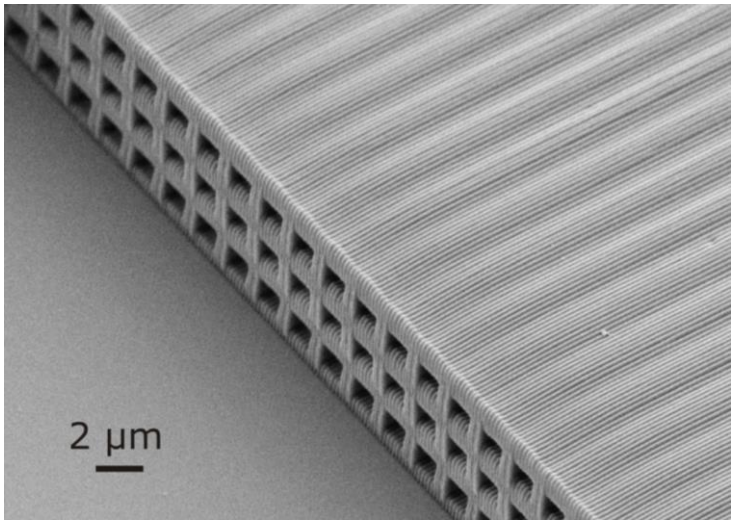


Direct fabrication of chemically responsive microactuators.

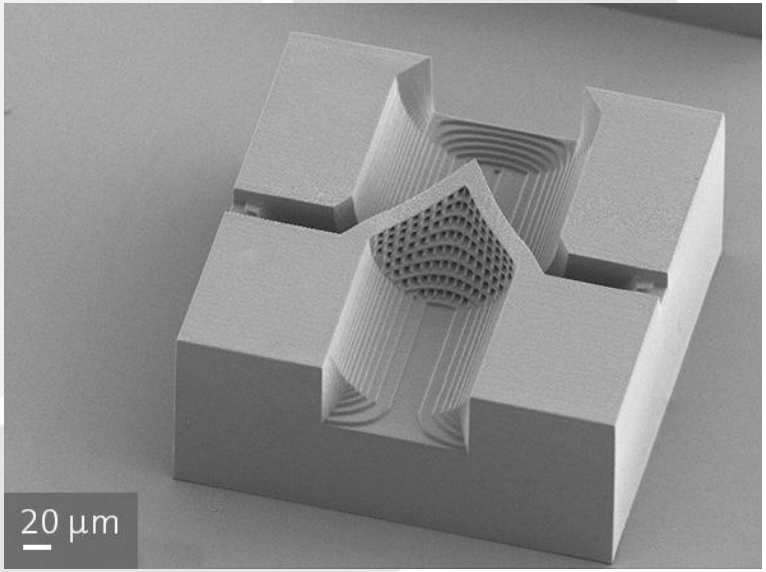
M.R. Lee et al., Small 2014 DOI:10.1002/smll.201401343

Writing of Microfluidic Elements

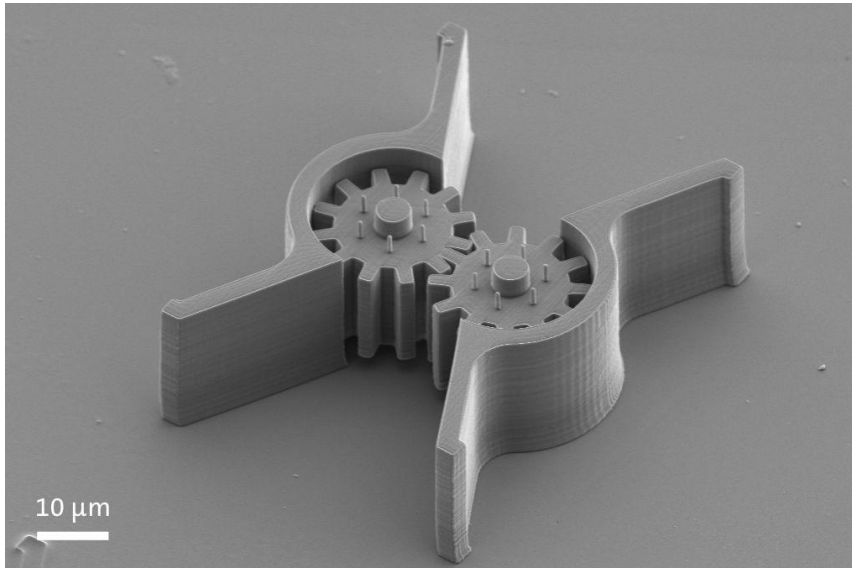




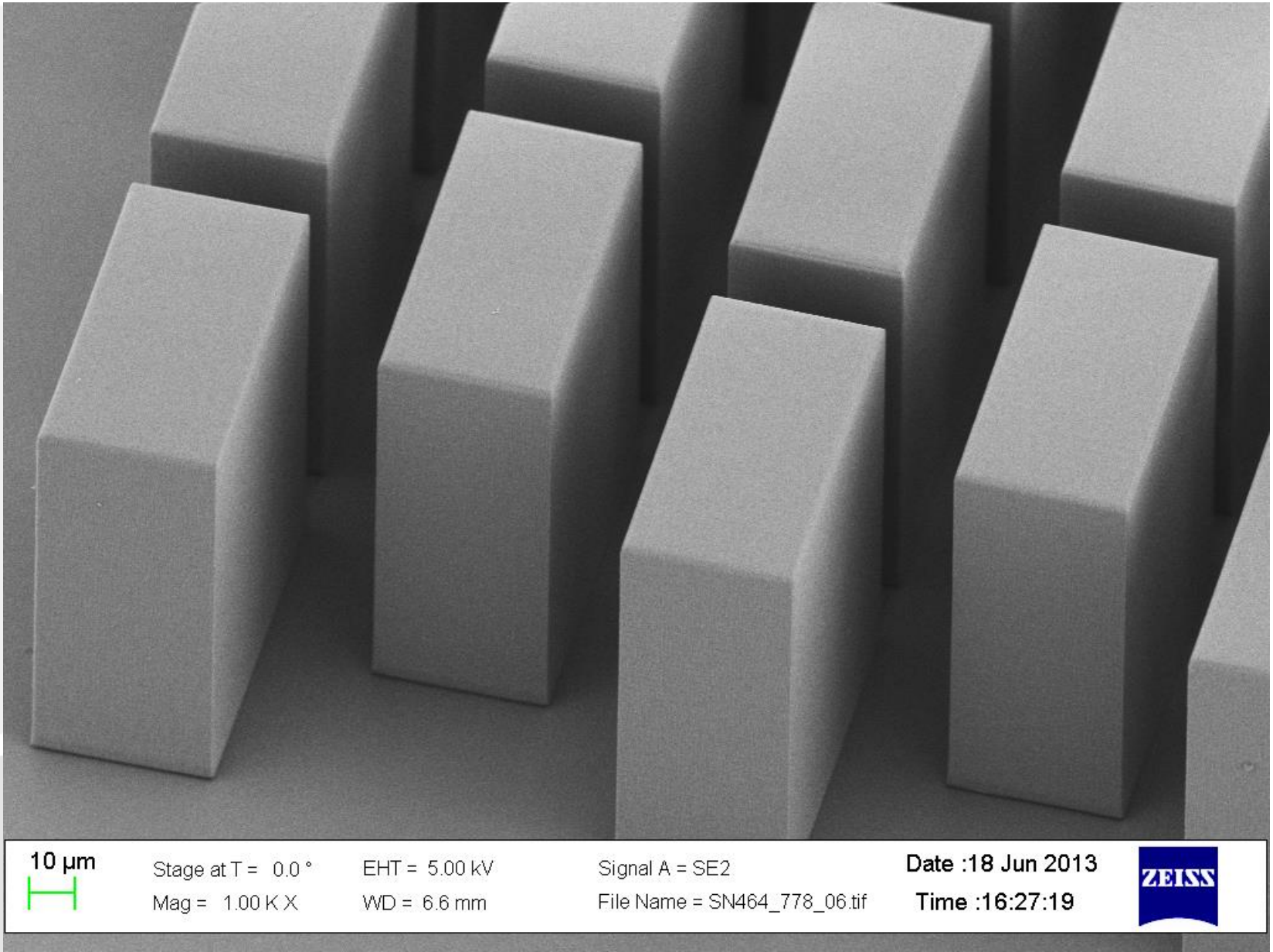
Design by A.-M. Haghiri-Gosnet, LPN-CNRS, France



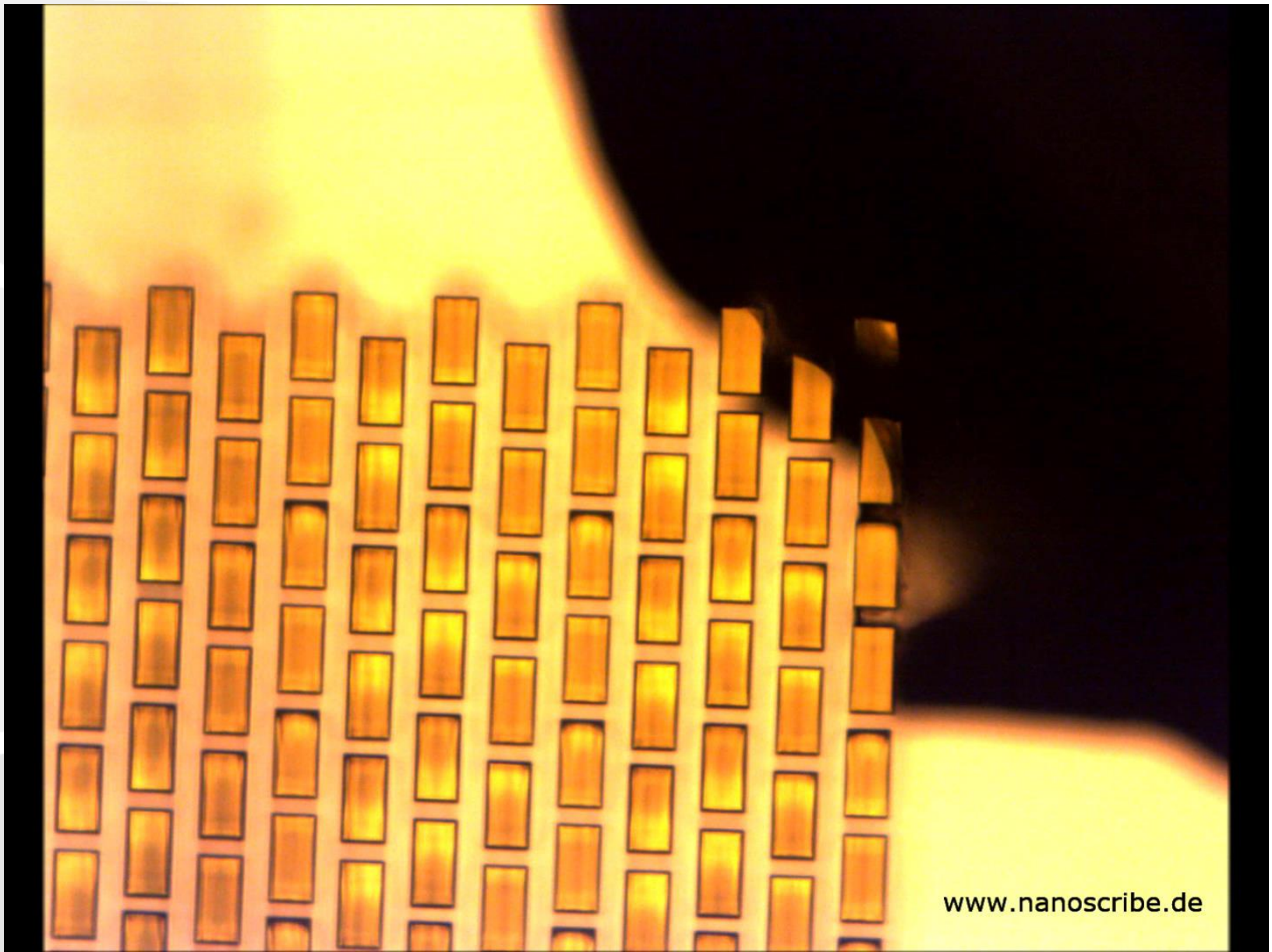
Microfluidic filter element structured in SU-8
(design provided by IMSAS)



Capillary Micropump

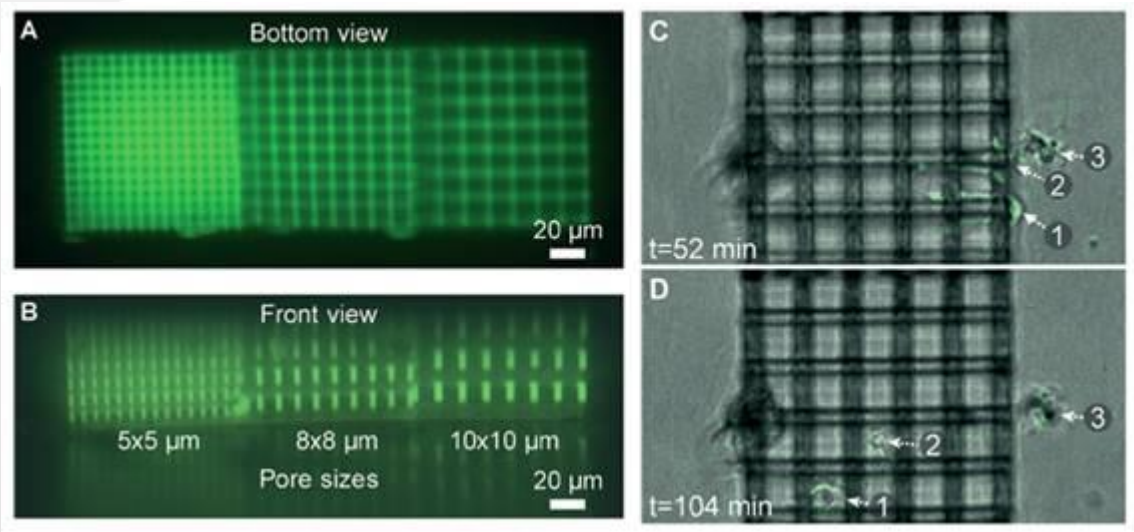


Capillary Micropump



In-chip 3D networks for cell studies

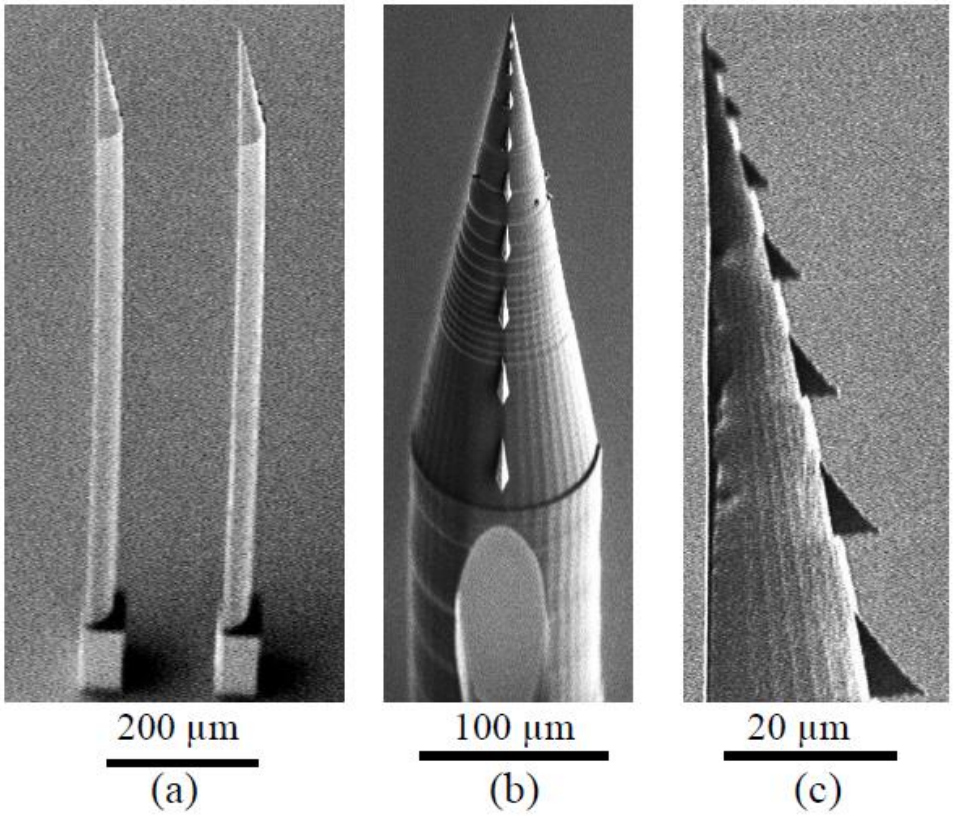
- In-chip fabrication inside of commercial microfluidic chip
- 3D networks with different pore sizes
- Dendritic cell motility studies through the confined spaces of the 3D structure (cells labelled as 1,2,3):



- M.H.Olsen et al. In-chip fabrication of free-form 3D constructs for directed cell migration analysis, Lab Chip, 2013, 13, 4800-4809, DOI: 10.1039/c3k50930c

Bio-mimicking painless microneedles

- Immitates mosquito's proboscis
- 2 mm height
- Conically sharpened tip
- Medical applications: drug delivery and blood collection
- Hollow microneedle sucks blood by capillary force

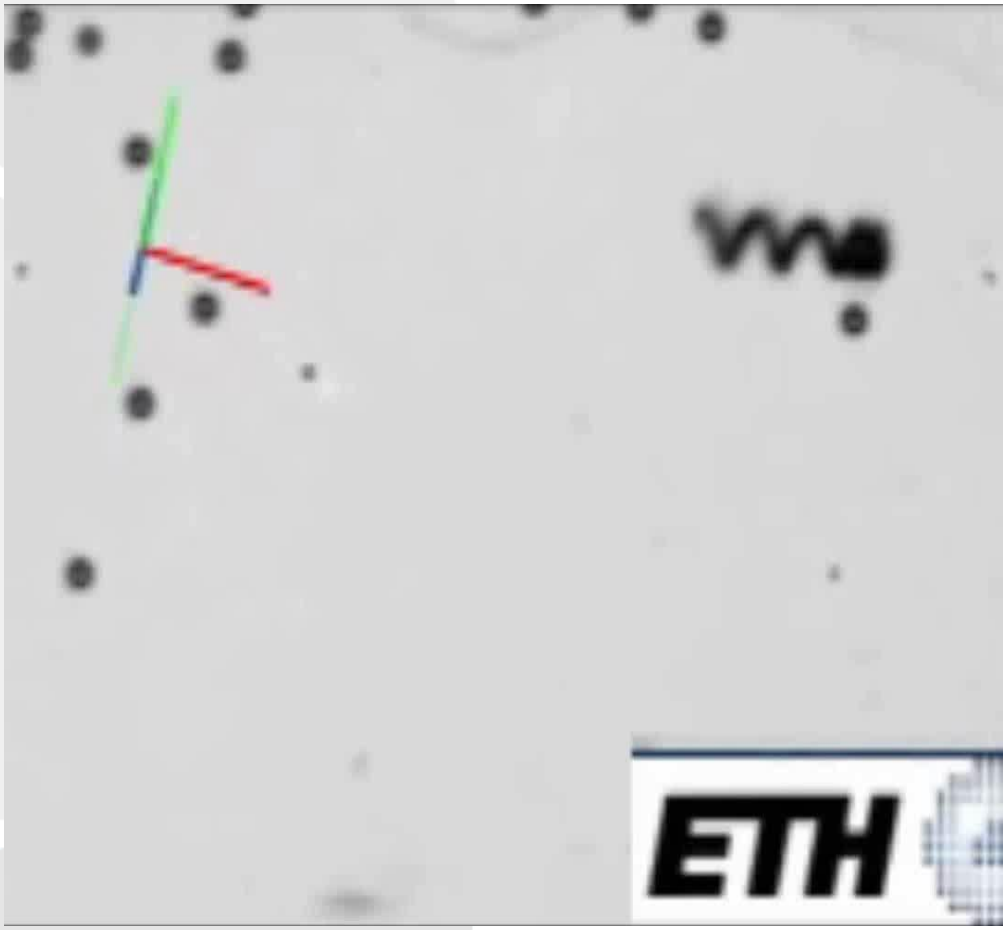


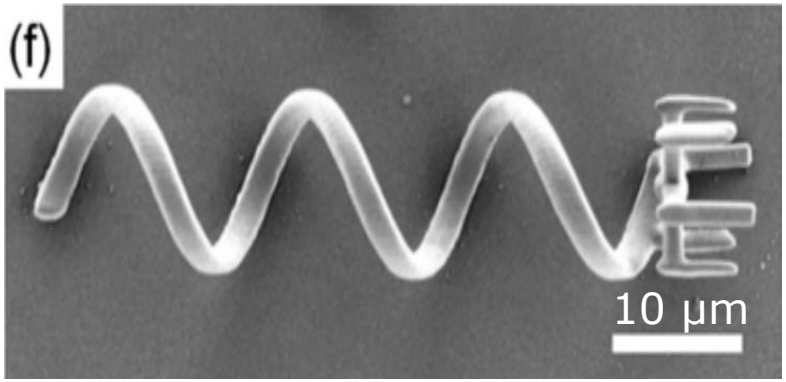
Fabrication of microneedles precisely imitating mosquito's proboscis by nanoscale three dimensional laser lithography and its characterization

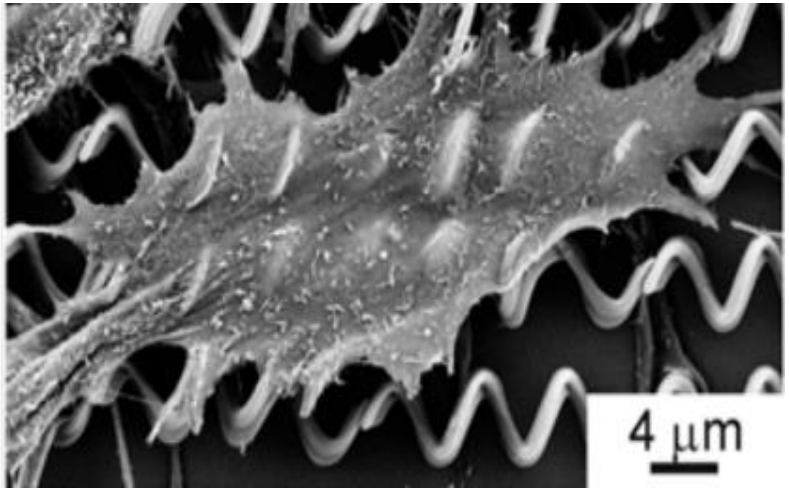
Suzuki, M., Sawa, T., Terada, Y., Takahashi, T., Aoyagi, S.

Solid-State Sensors, Actuators and Microsystems (TRANSDUCERS), 2015, DOI: 10.1109/TRANSDUCERS.2015.7180876

Magnetic Helical Micromachines





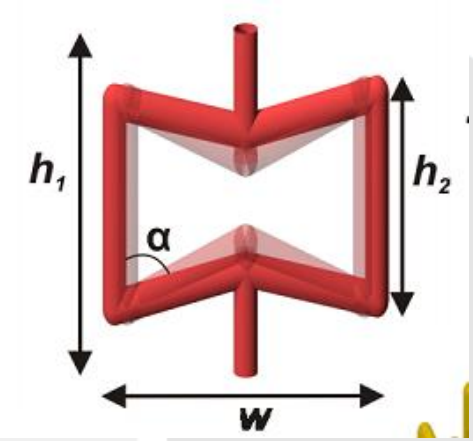


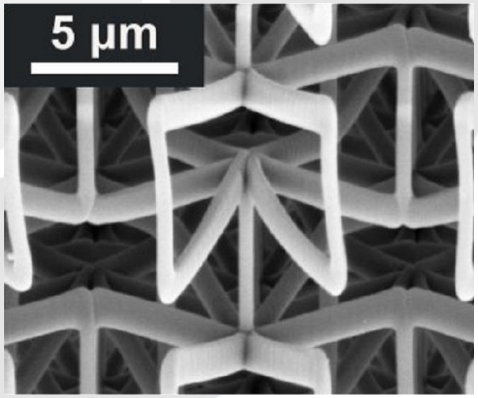
Adv. Mater. **24**, 6, 811–816 (2012)

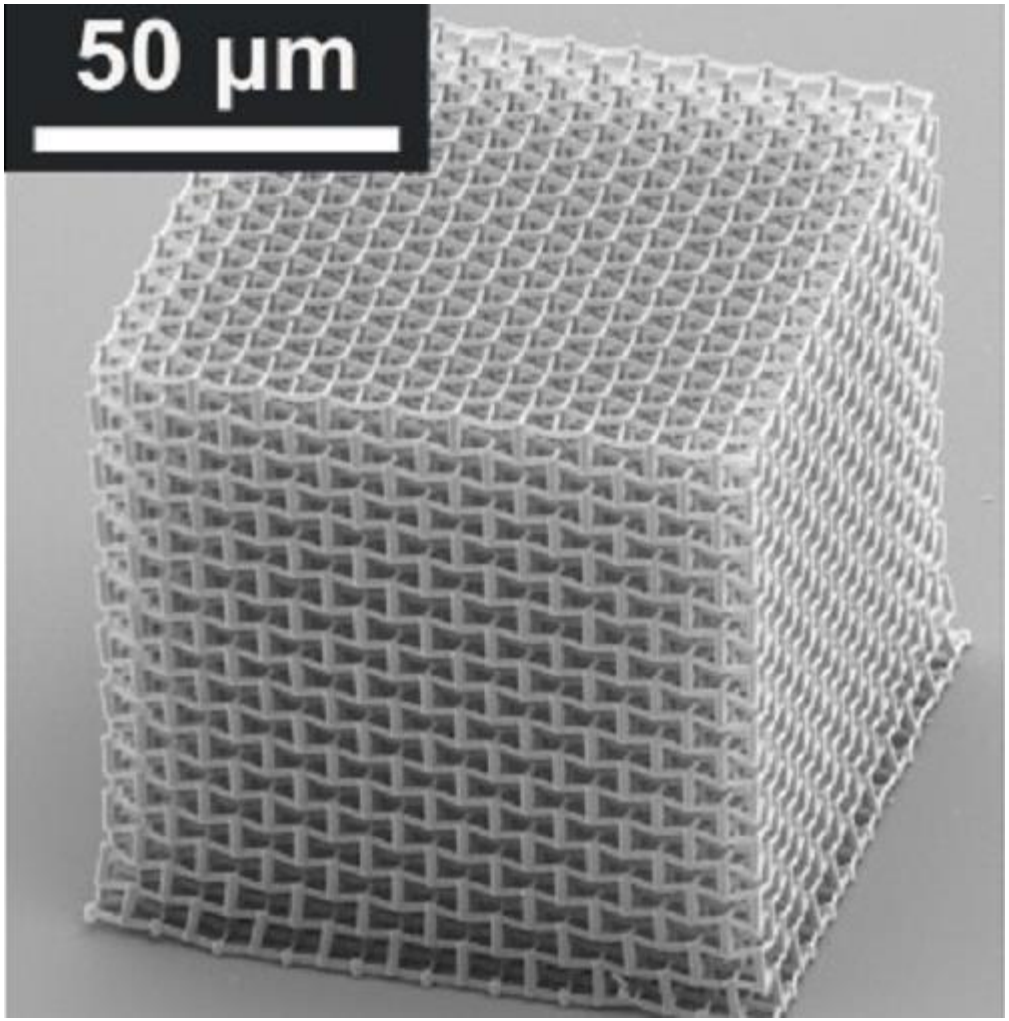
Mechanical Metamaterials

Auxetics:

- Tunable Poisson's ratio ν
- $-0.12 < \nu < +0.13$





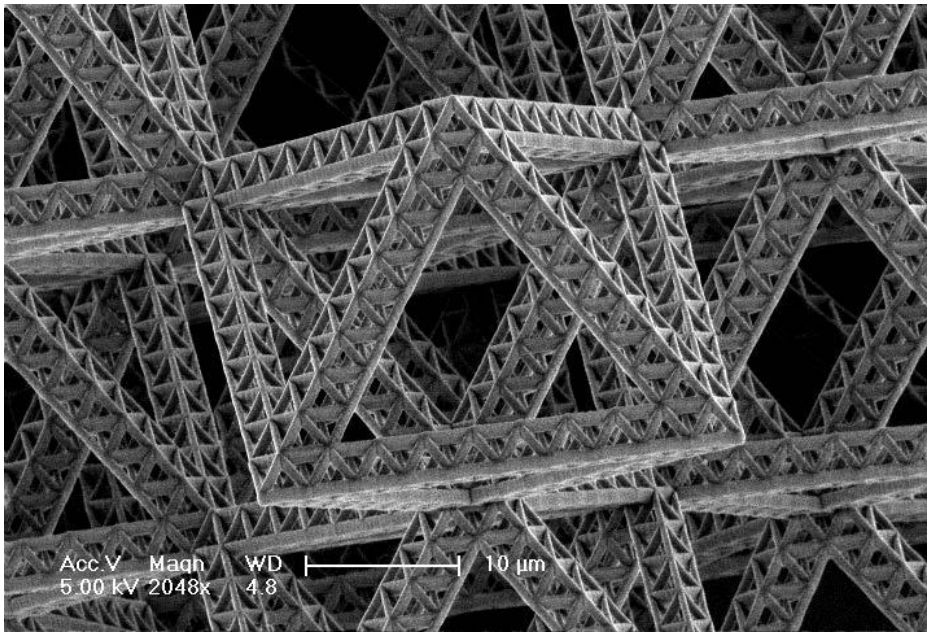


T. Bueckmann et al., Advanced Materials 24, 2710 (2012)

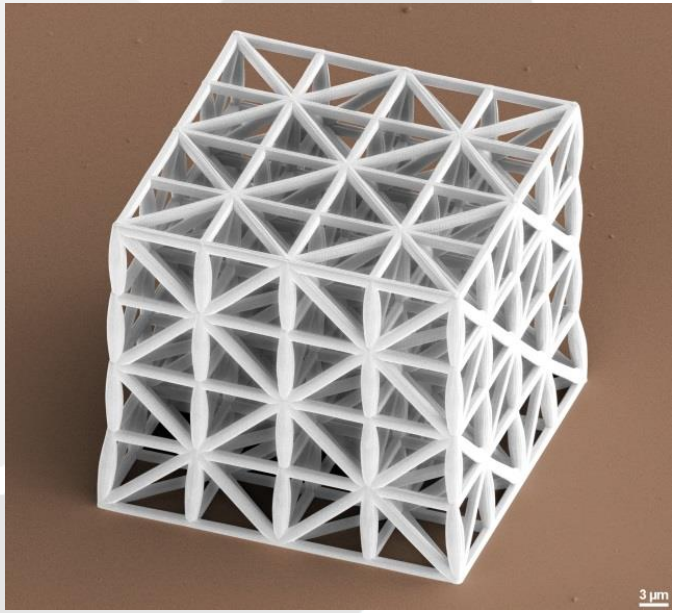
Ultralight Microlattices

Applications:

- Thermal insulation
- Battery electrodes
- Acoustic/vibration/shock damping

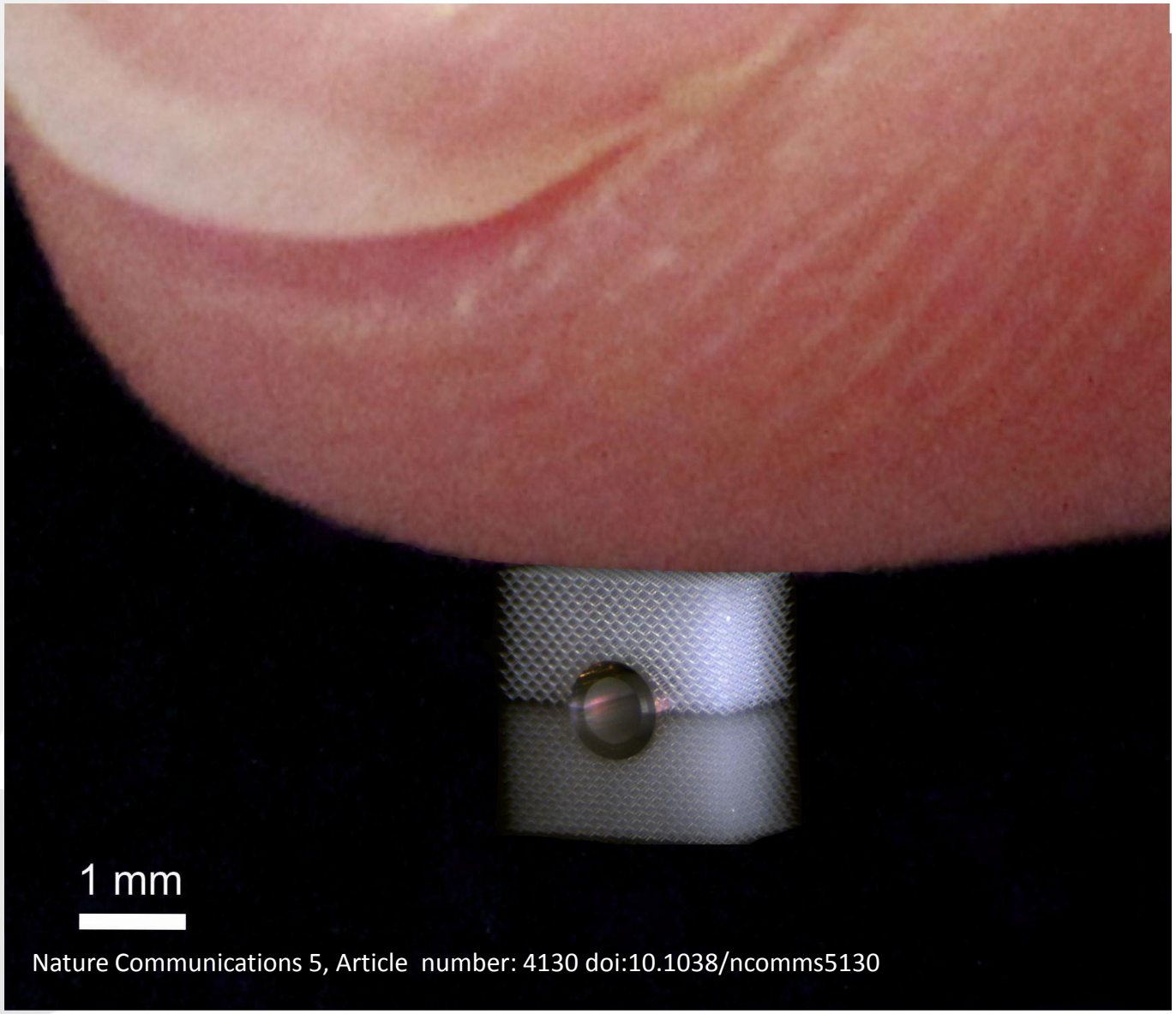


J. R. Greer et al., Science 345, 1322 (2014)
http://www.caltech.edu/content/miniature-truss-work



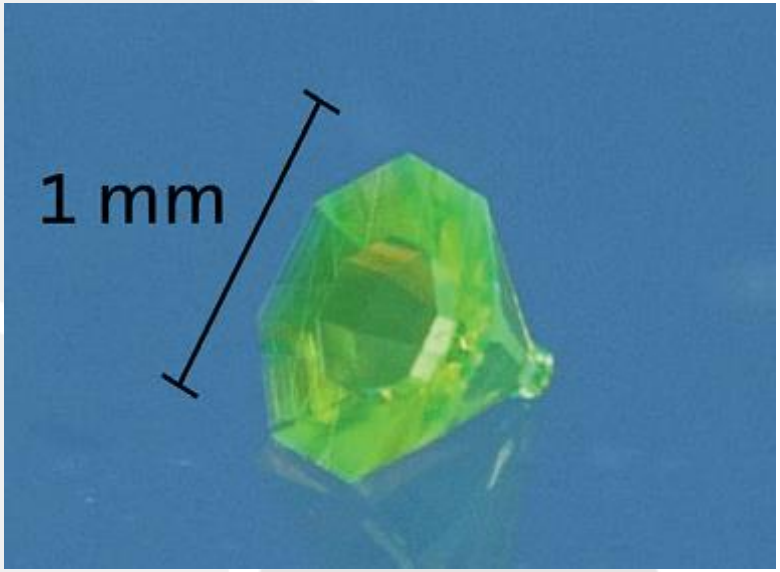
Ultra-lightweight designer mechanical material
J. Bauer et al., PNAS, doi: 10.1073/pnas.1315147111 (2014)

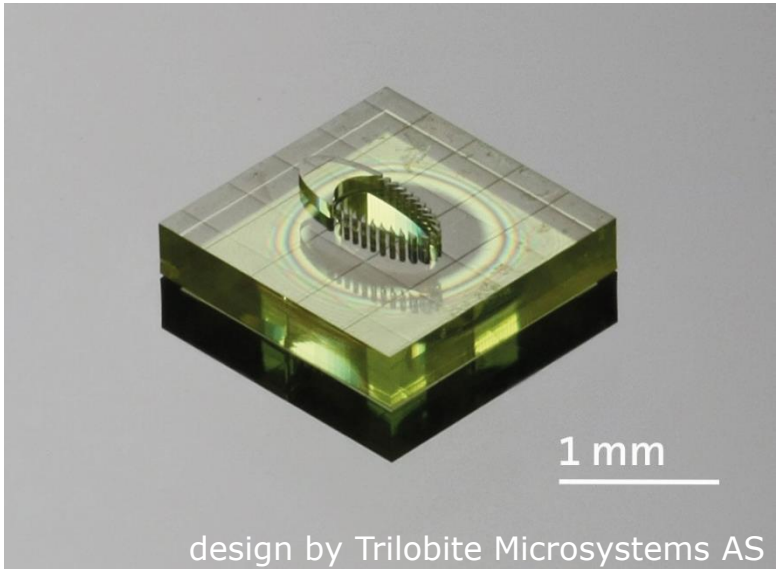
Unfeelability cloak



Nature Communications 5, Article number: 4130 doi:10.1038/ncomms5130

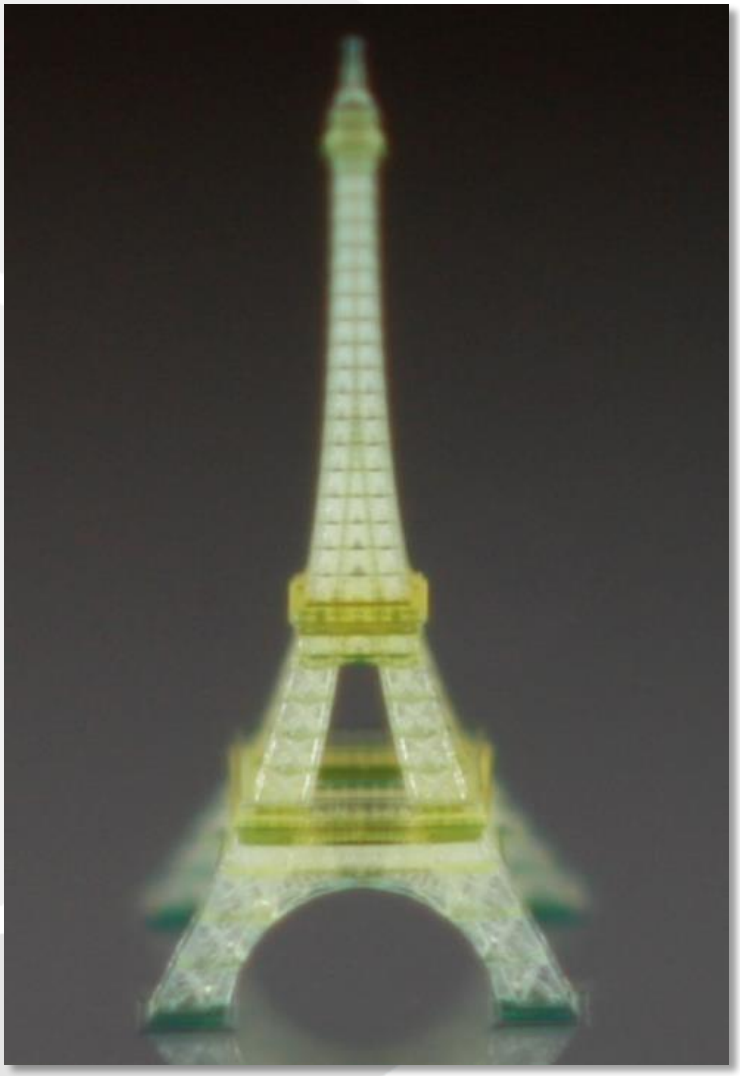
Meso-scale objects

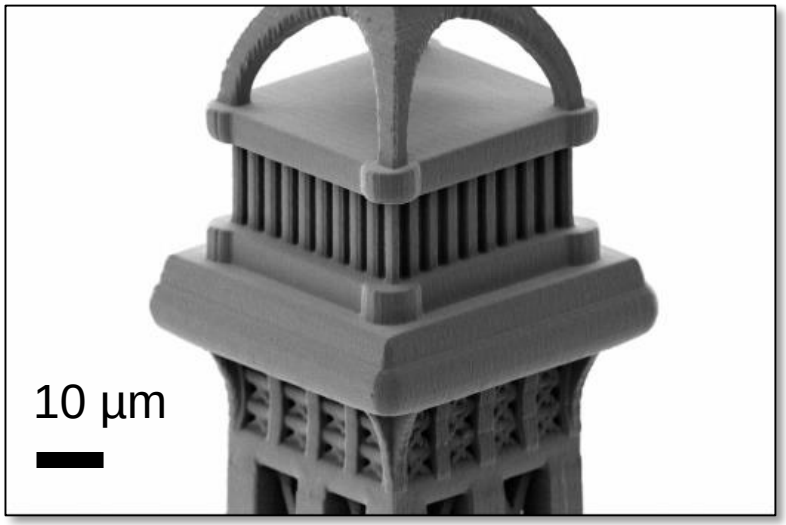


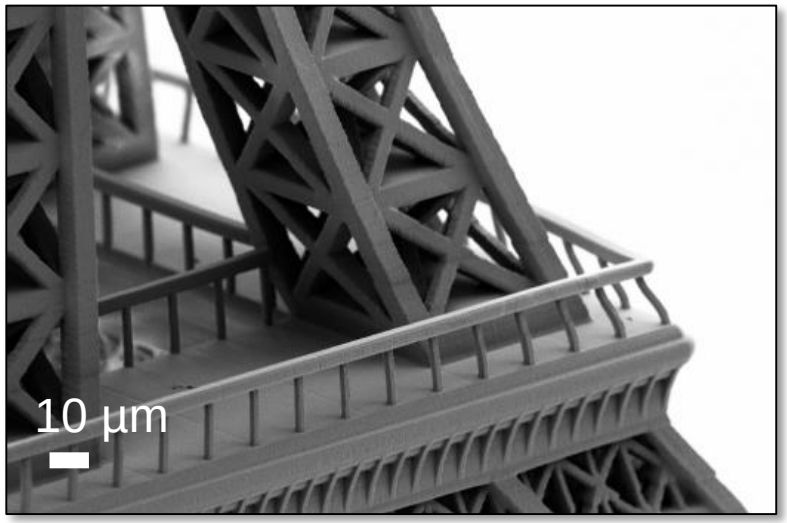


3D Micro-Printing

nanoscribe



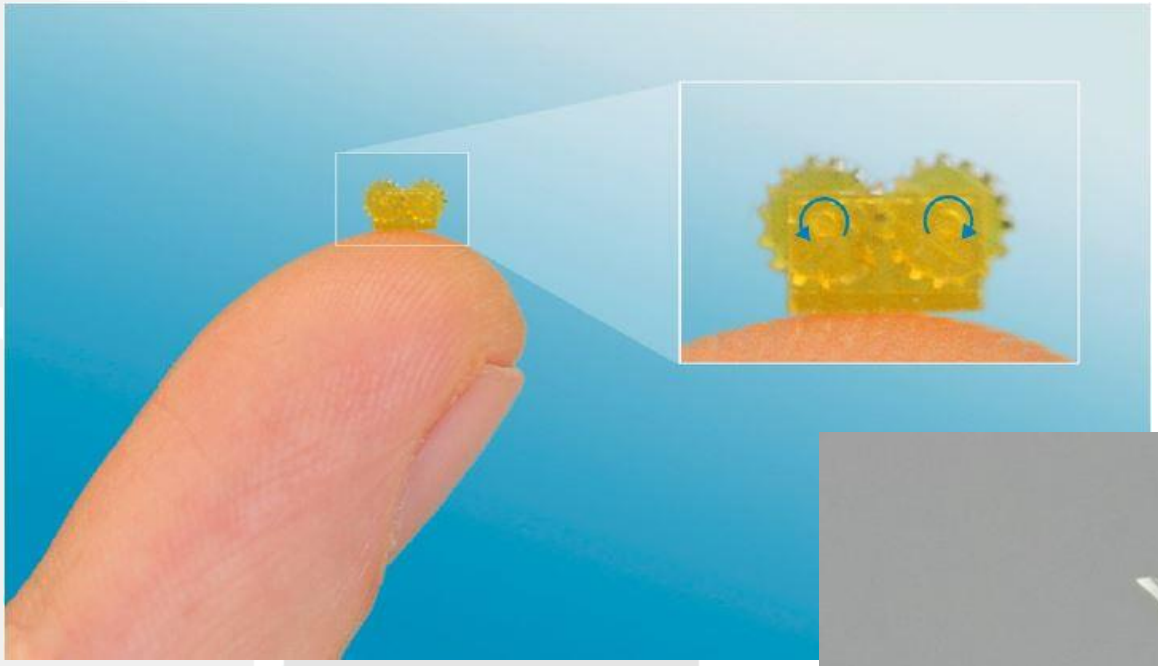


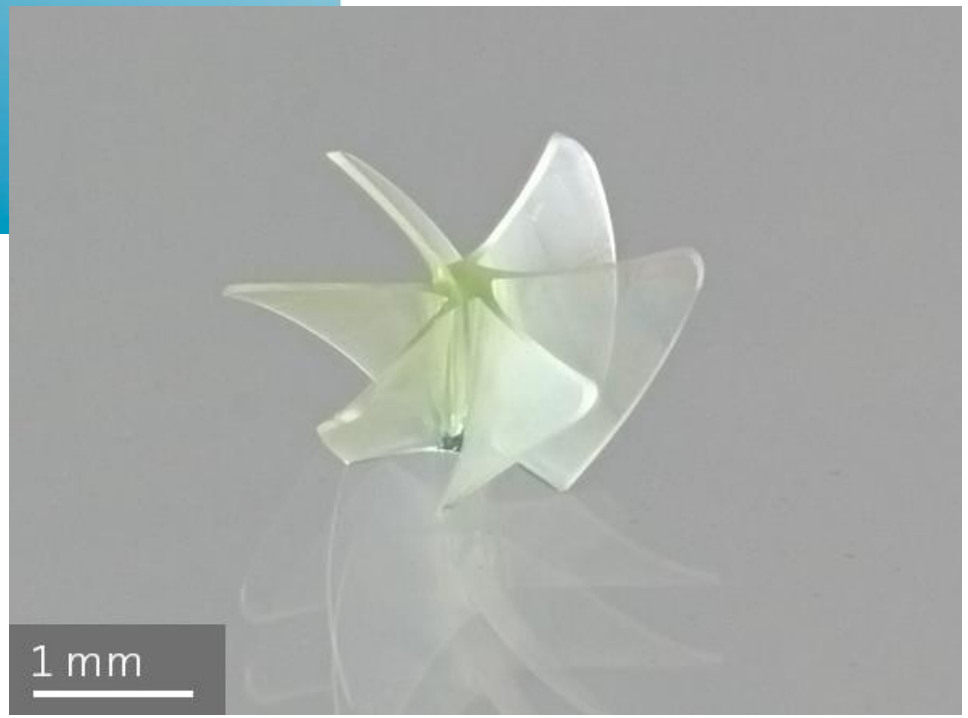


3D Micro-Printing

nanoscribe

µ-3D Printing in mm





10 mm

Castle of Karlsruhe for its 300th anniversary

Thank you for your attention

10 mm

Castle of Karlsruhe for its 300th anniversary