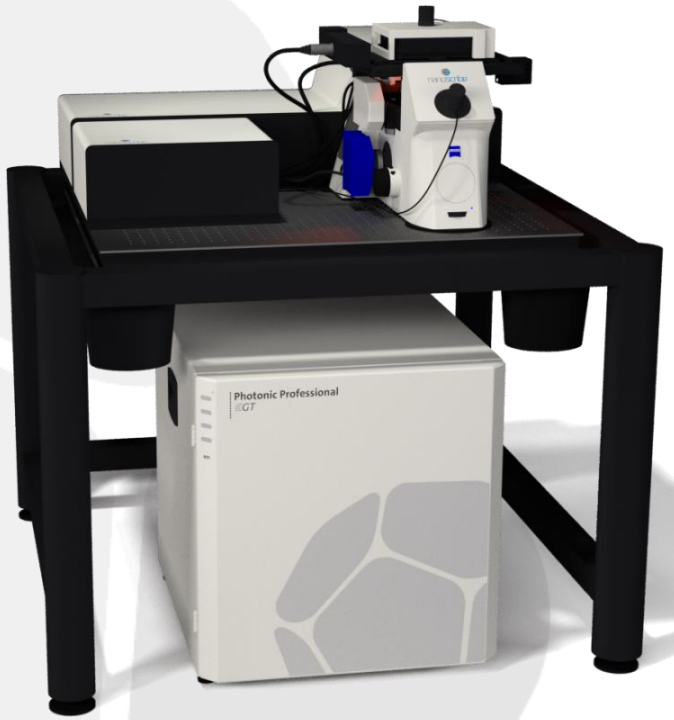
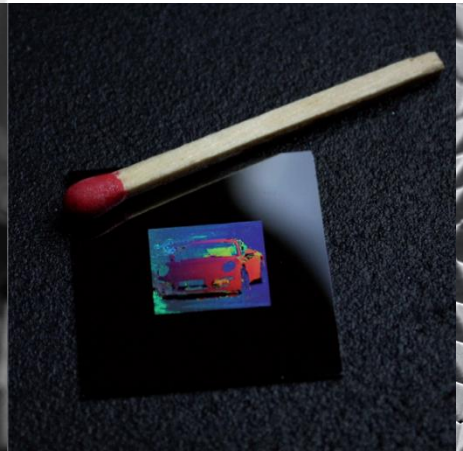
3D µ-Printing by Direct Laser Writing

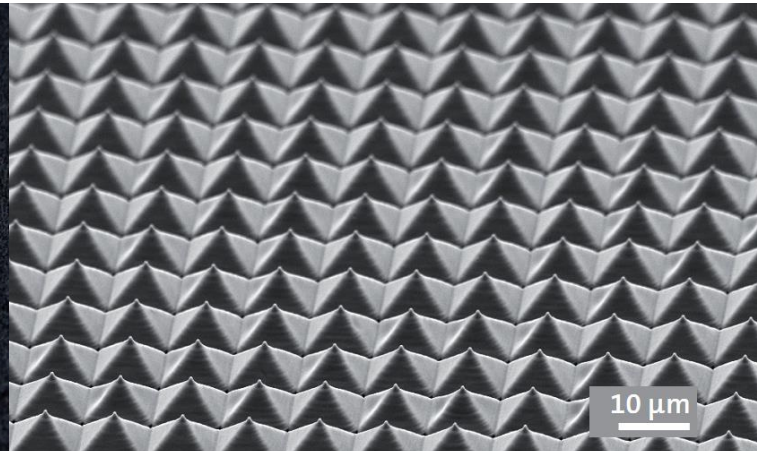
nanoscribe



eu**spen**

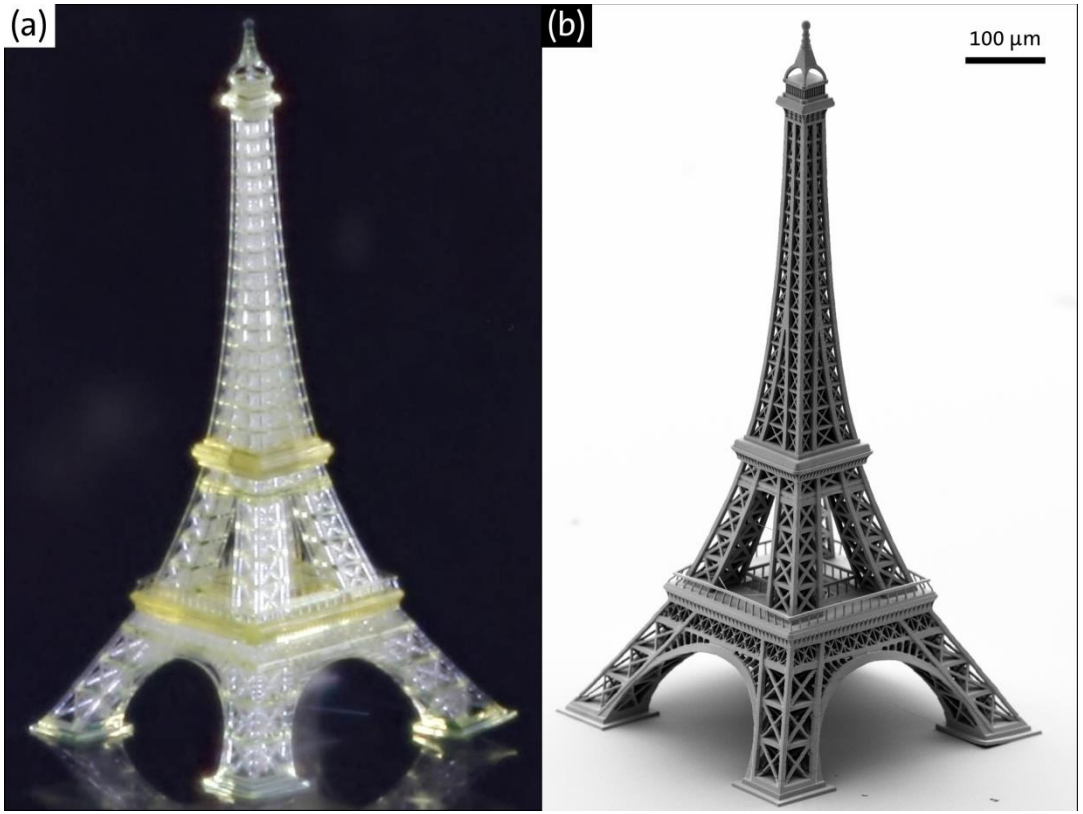
micro/nano manufacturing workshop
Karlsruhe Institute of Technology (KIT)
Nanoscribe GmbH
Martin Hermatschweiler, CEO
November 28th, 2013





Overview

- Introduction: Nanoscribe GmbH
- Technology: Direct Laser Writing
- Materials
  - Photoresists
  - Casting processes
- Applications
  - Photonics
  - Cell Biology
  - Microfluidics
  - Optical Telecom
  - Biomimetics
  - Micromechanics
- Summary



Who We Are …

Karlsruhe Institute of Technology

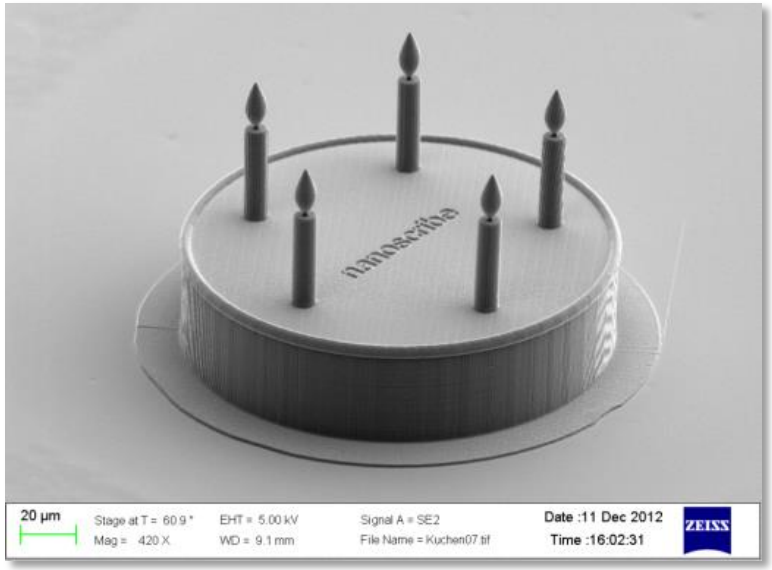
nanoscribe

Company History:

- Spin-off from the Karlsruhe Institute of Technology (KIT) group: Prof. Dr. Martin Wegener
- 2007: Foundation
- >50 systems installed worldwide
- 27 employees + 2 students

Products:

- 3D laser lithography systems
- Photoresists



What We Do …

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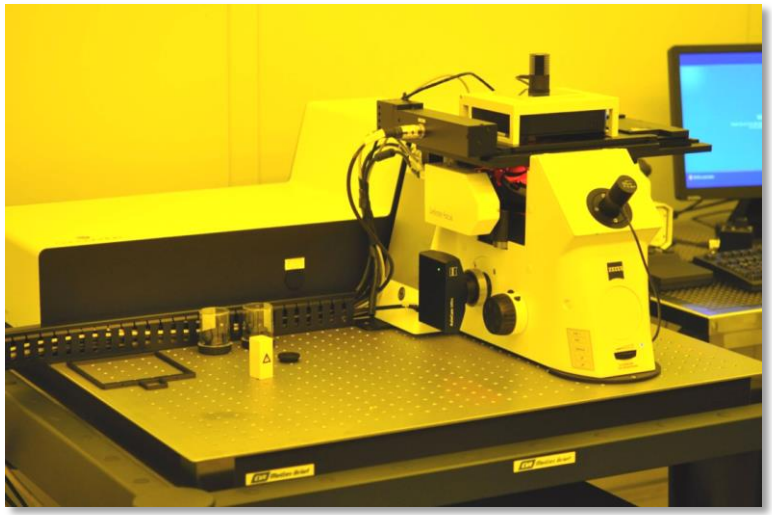

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  - Mechanical Metamaterials
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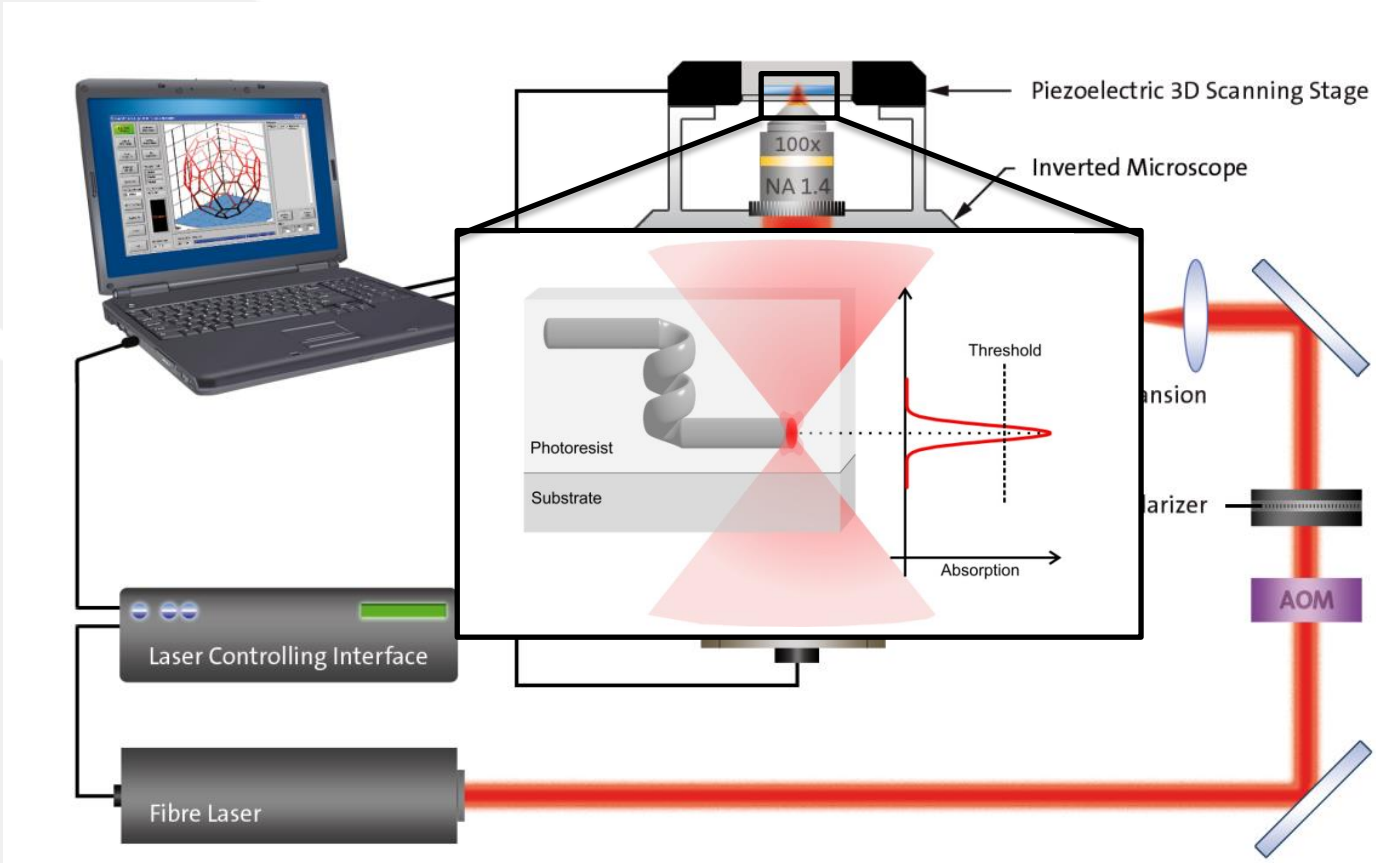
3D Printing by Direct Laser Writing

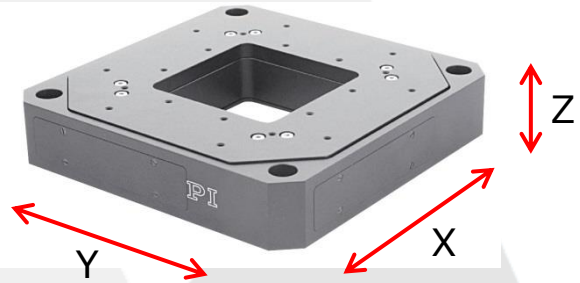


Light source for two-photon polymerization (TPP):

- Er-doped fiber laser @ λ = 780 nm
- Pulse duration < 150 fs / repetition rate: 40-100 MHz
- Power > 45 mW

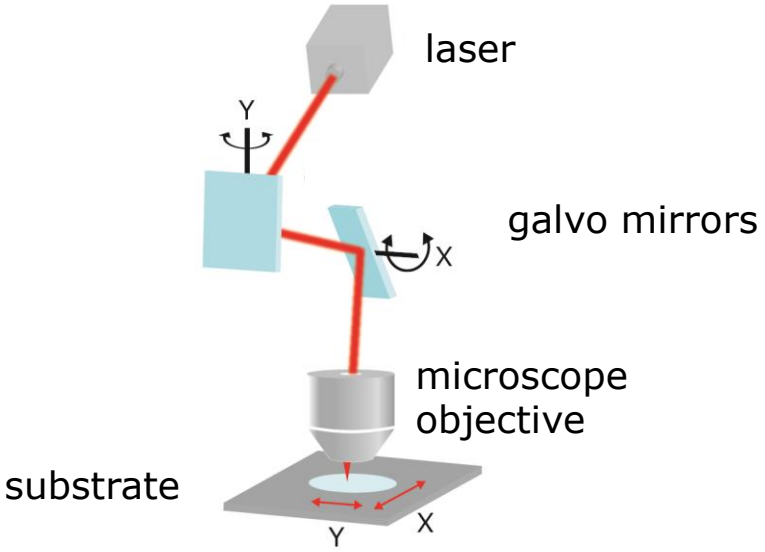
Embedded Writing Modes

Piezo mode



- Fixed laser focus, moving sample by piezoelectric stage
- 3-axes x-y-z-movement
- Arbitrary 3-dimensional trajectories
- Writing field up to 300x300x300 µm³
- PerfectShape®: Optimized speed to accuracy ratio

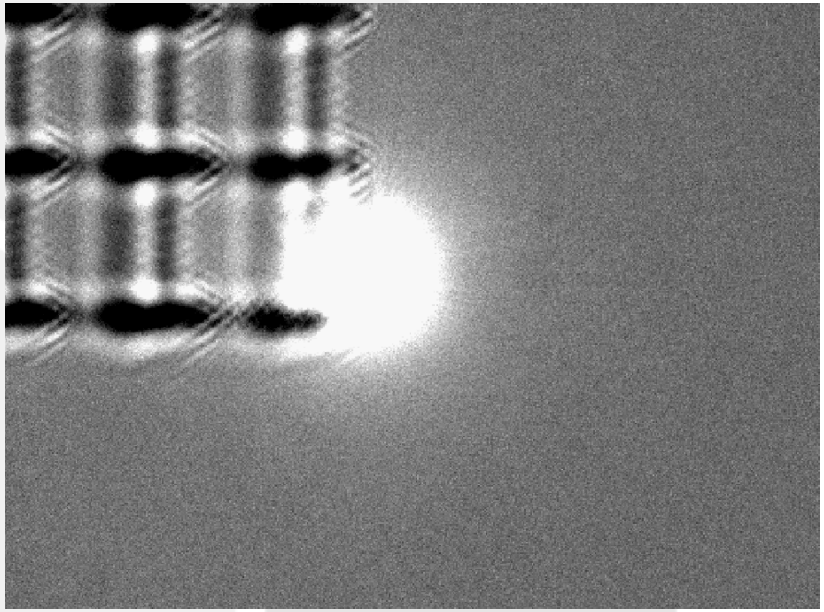
Galvo mode



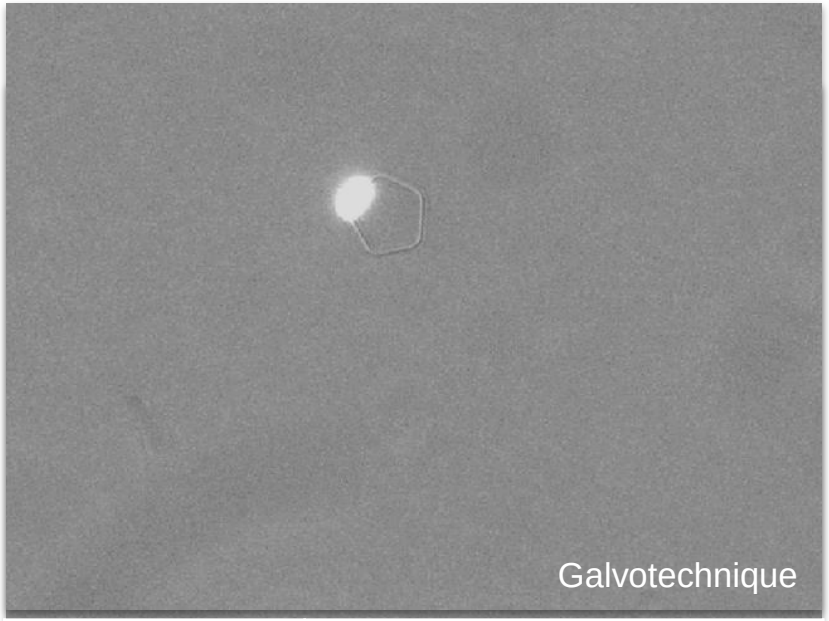
- Deflection of laser focus by galvo mirrors
- Lateral movement in x-y-plane
- Writing field depending on magnification of objective
- High-speed in-plane laser focus movement

Galvo- and Piezo-Scanning

Writing modes



Specs	Piezo Mode
Speed	Up to mm/s
Settling time	>100 ms
Scan rate	<10 lines/s
„Accuracy“	<10 nm
Volume	300 µm x 300 µm x 300 µm
Decription	True 3D scanning along 3D x-y-z trajectories Fixed beam, moving sample



Specs	Galvo Mode
Speed	Up to meters/s
Settling time	<1 ms
Scan rate	>100 lines/s
„Accuracy“	<10 µrad
Area	22 mm/Magnification
Description	Rapid x-y-scanning slice-by-slice Fixed sample, moving beam

Video of Printing Process

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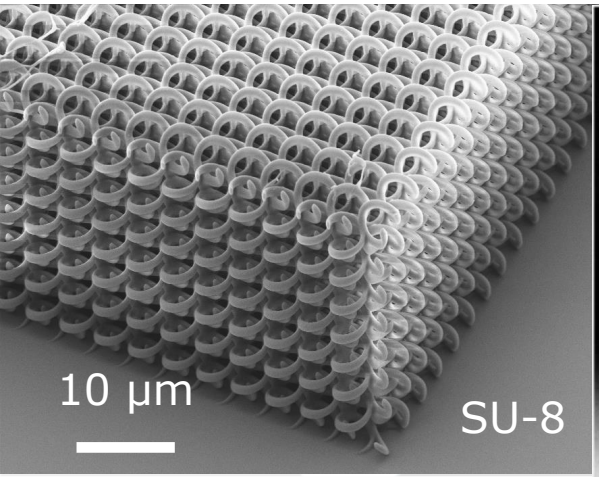
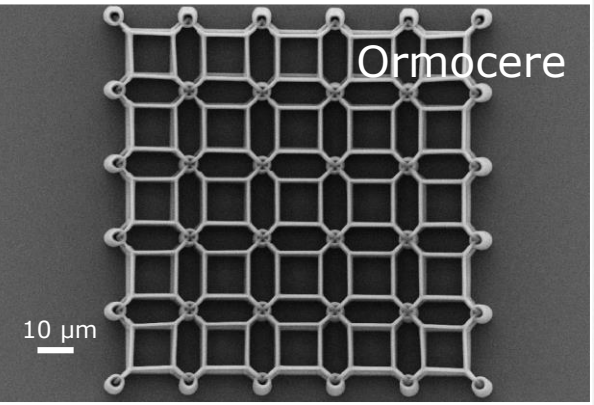
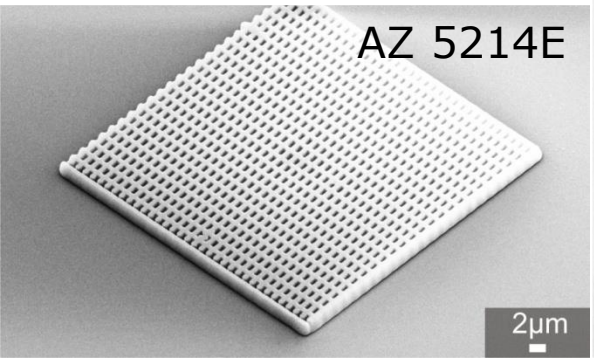
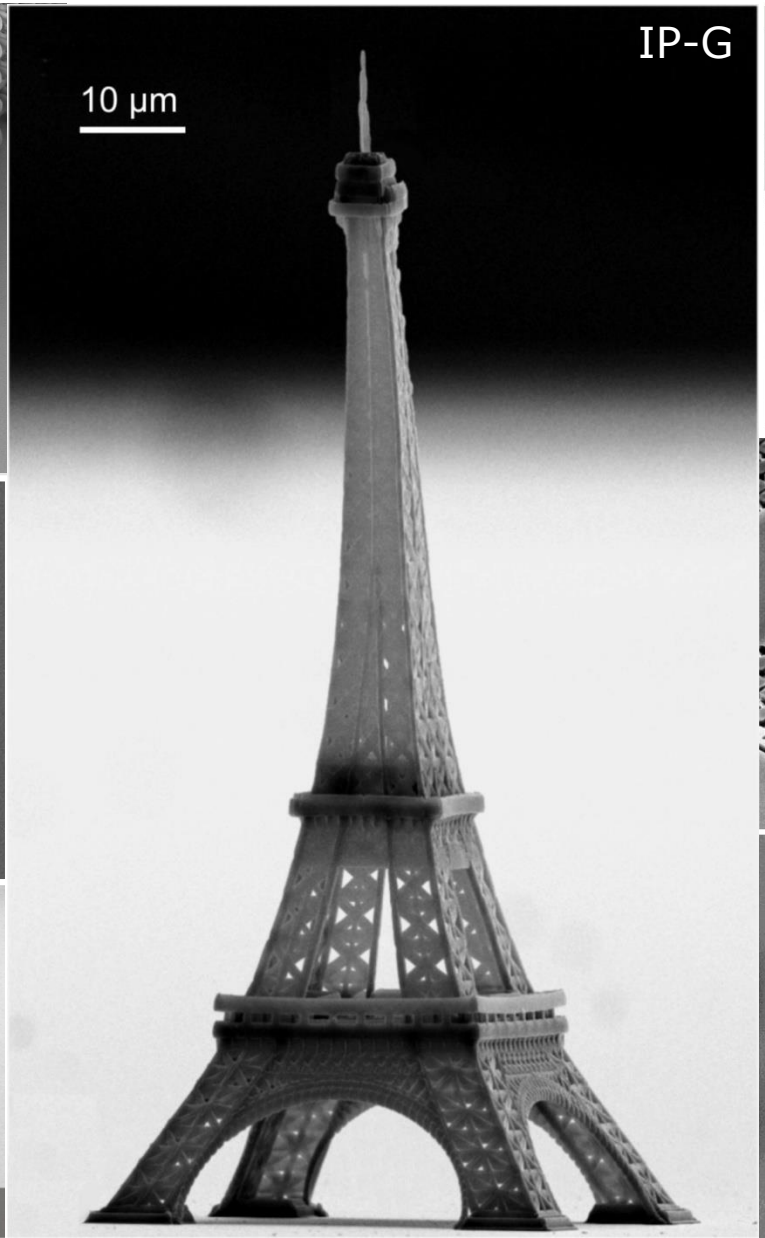
- Company

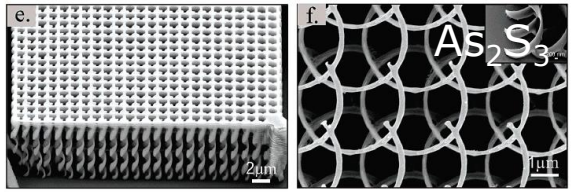
Materials – Printable Resins

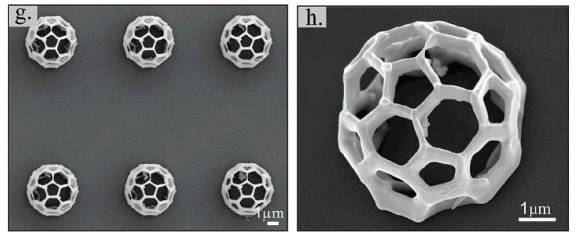


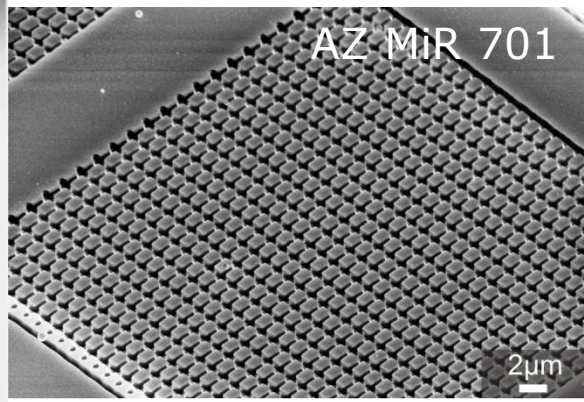


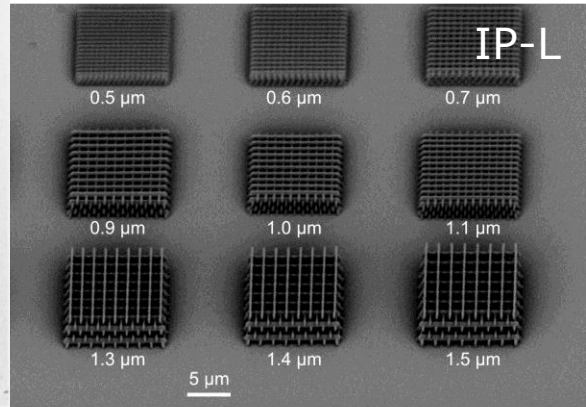








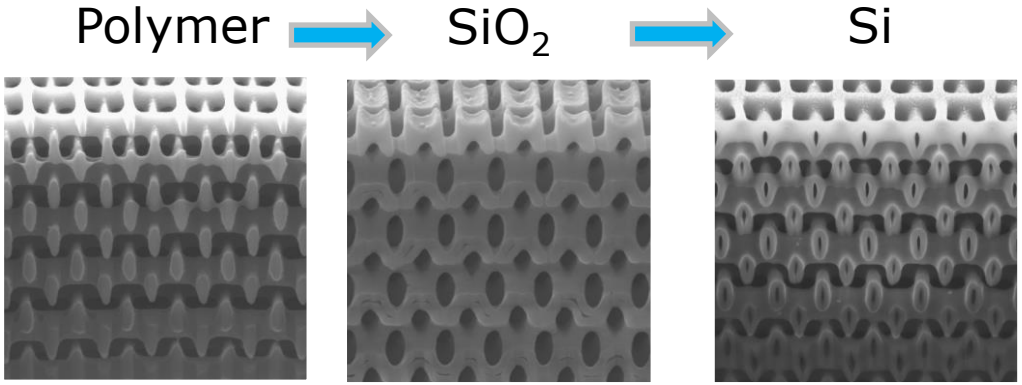




Materials – Casting from Polymers

Dielectrics:

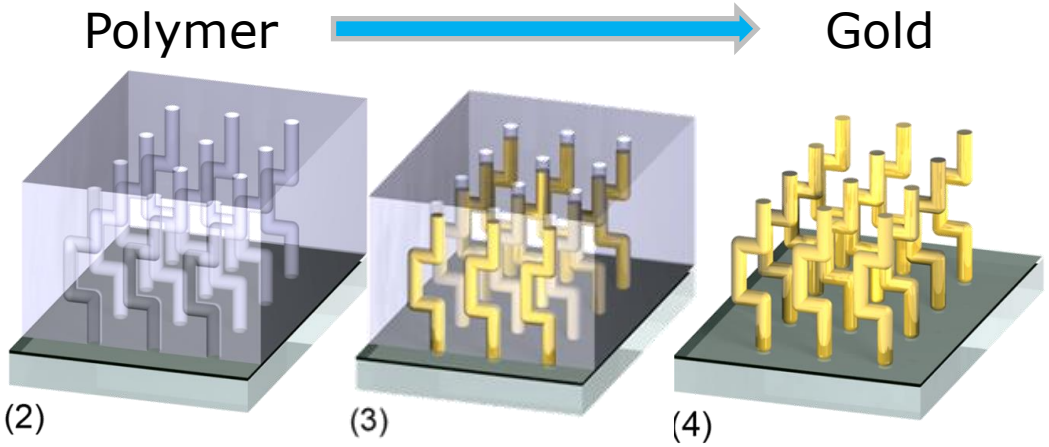
- Silicon Chemical Vapor Deposition (CVD)
- Silica Pulsed Layer Deposition (PLD)
- Titania Atomic Layer Deposition (ALD)



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

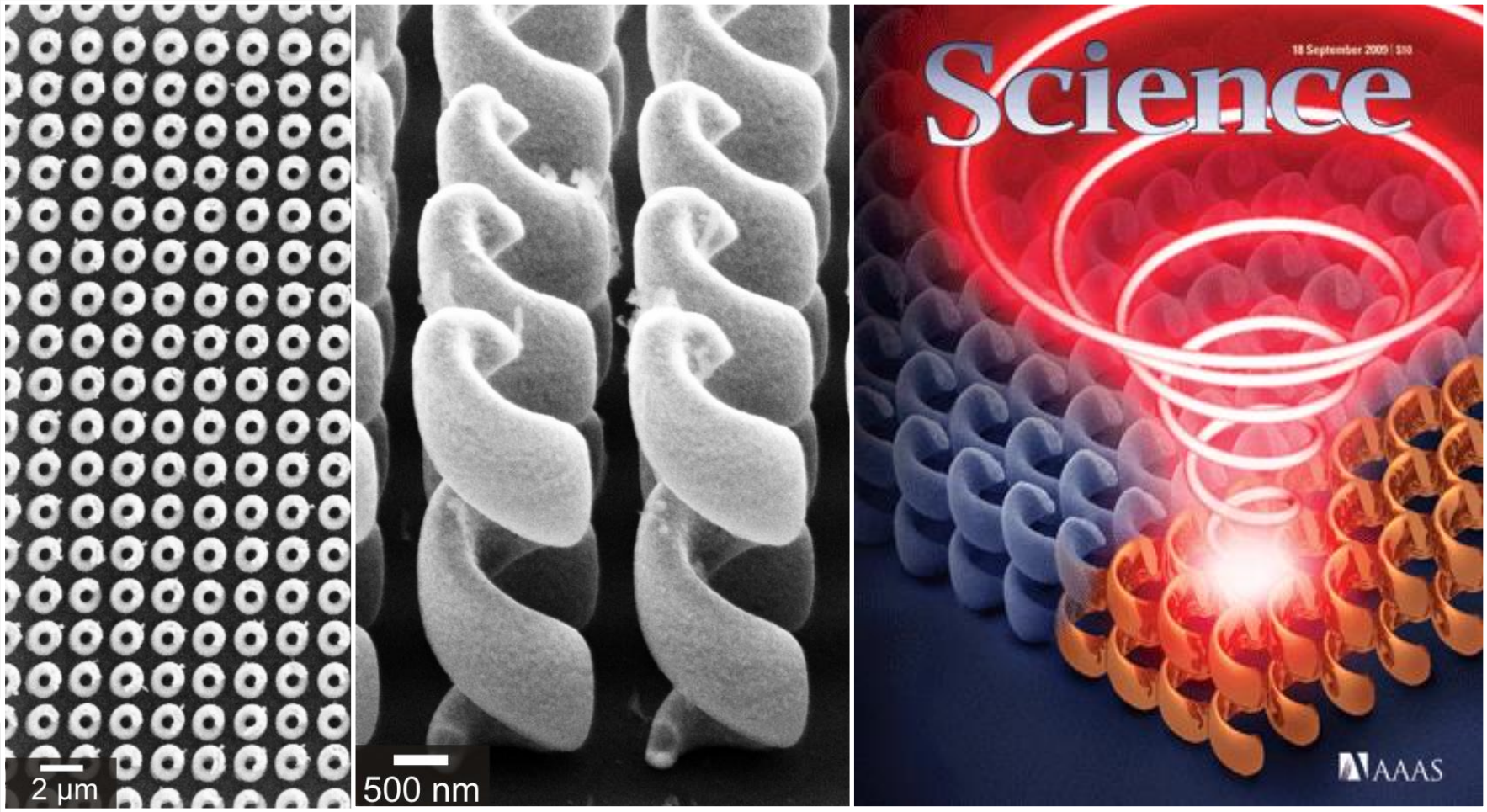
Metals:

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



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

Casting of Metal (Gold)



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

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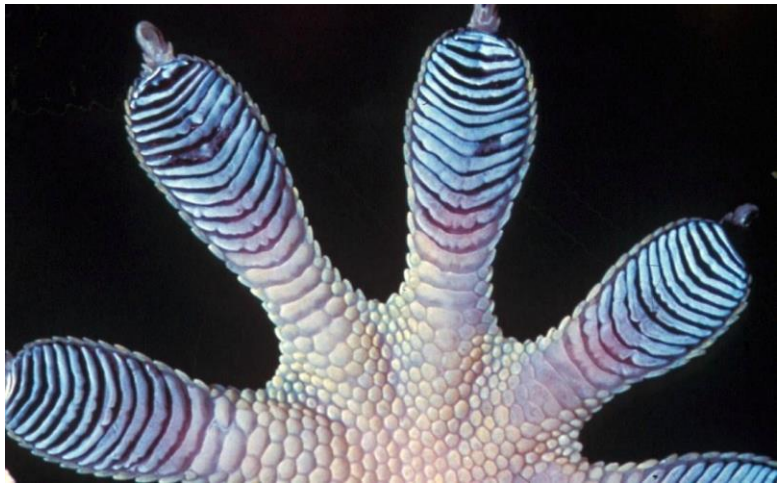
Source and permission: Kurt Wirz, Basel, CH



Source: http://www.nanoqed.org/2009.php

Applications

Photonics

Micro-mechanics

Cell biology

Photonic Professional *GT*

3D µ-Printer

Bio-mimetics

Micro-fluidics

Optical telecom

Applications

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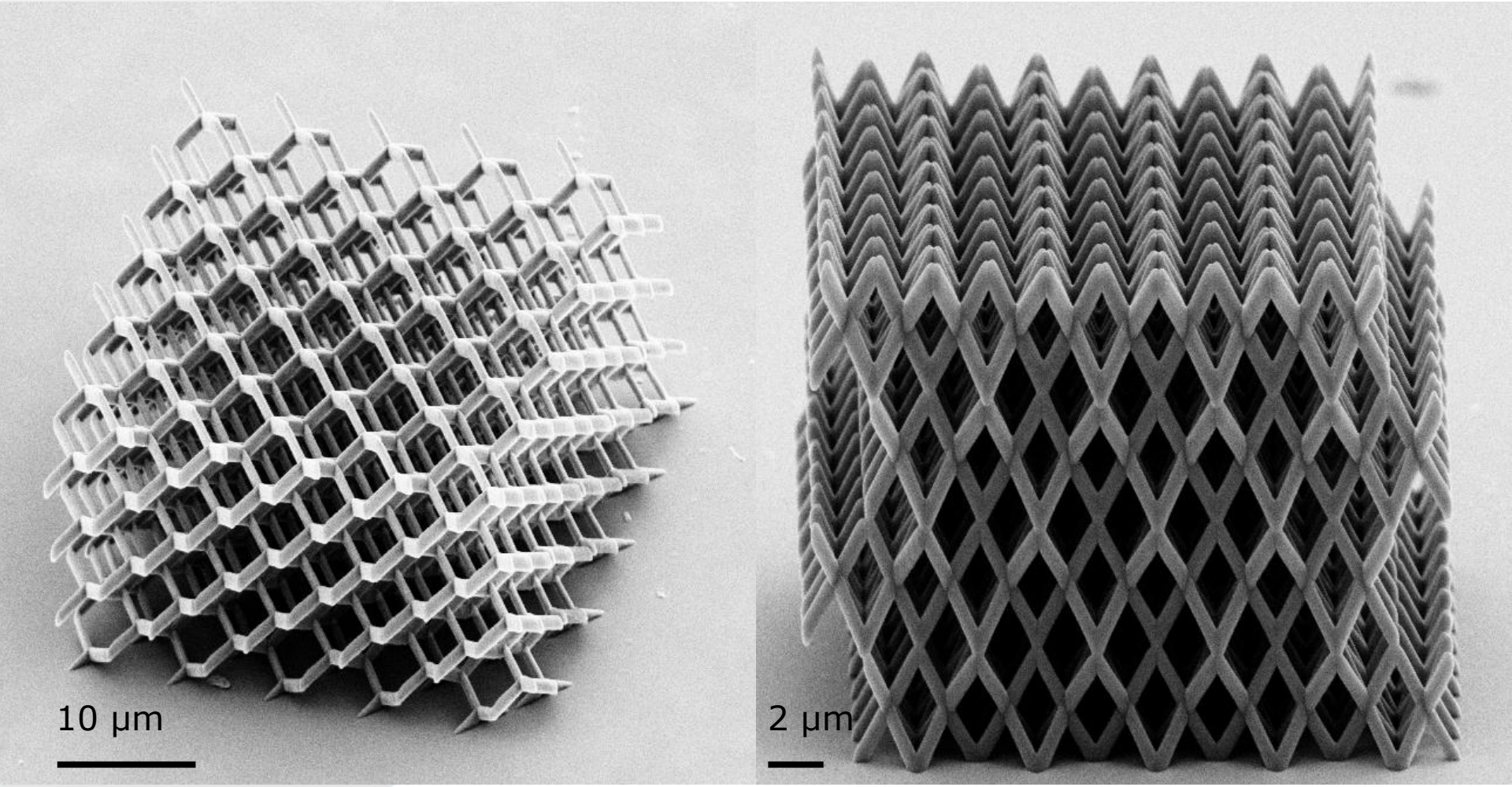
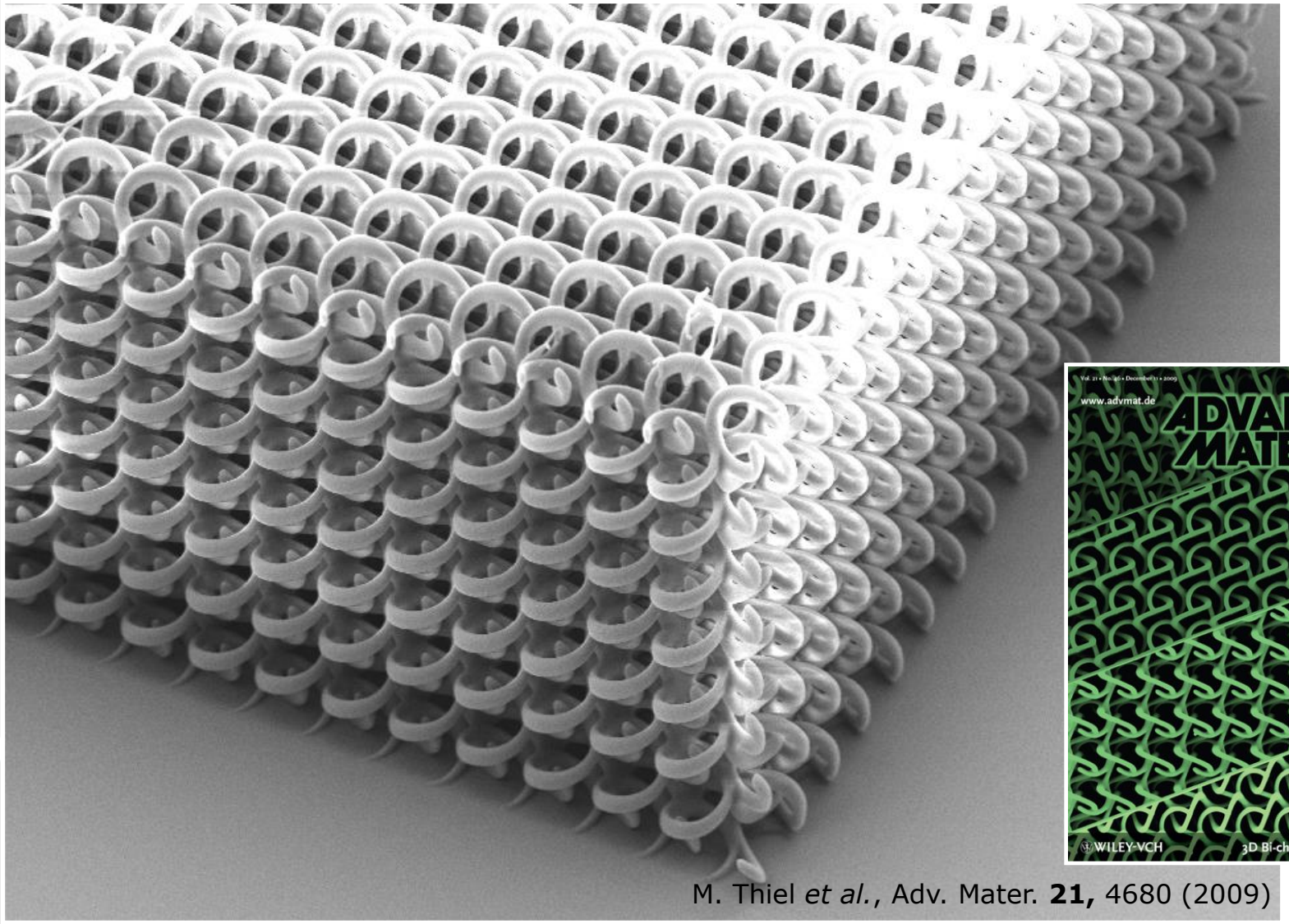
3D Photonic Crystals



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

Design provided by ITMO, Russia

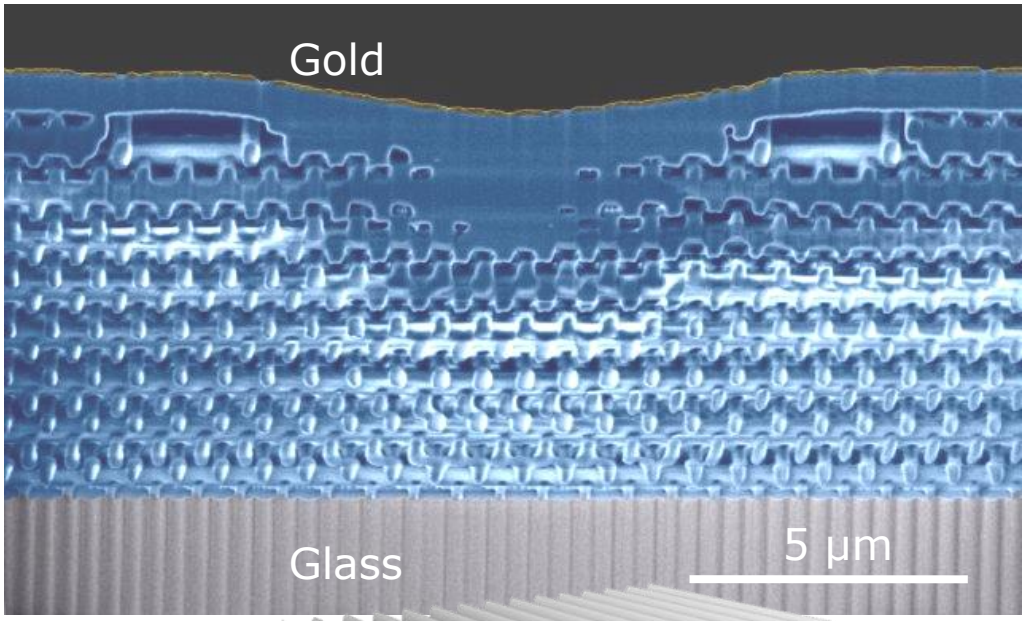
3D Photonic Crystals

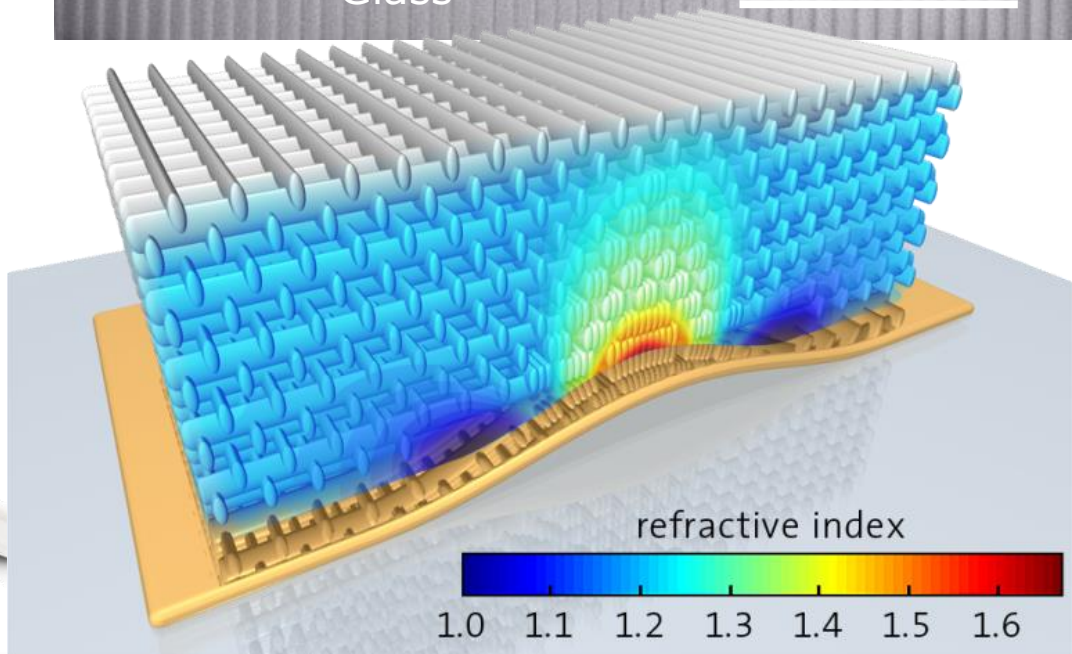


M. Thiel *et al.*, Adv. Mater. **21,** 4680 (2009)

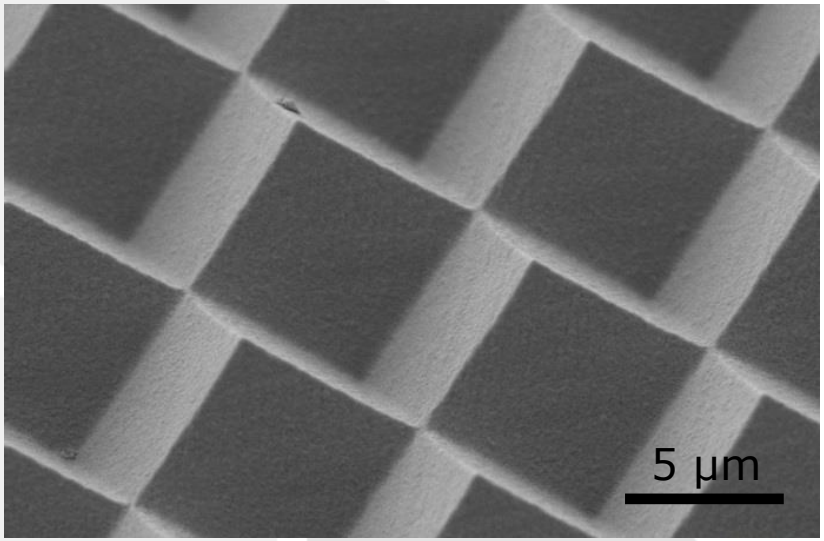
3D Photonics: Cloaking

T. Ergin *et al.*,
Science **328,** 337 (2010)

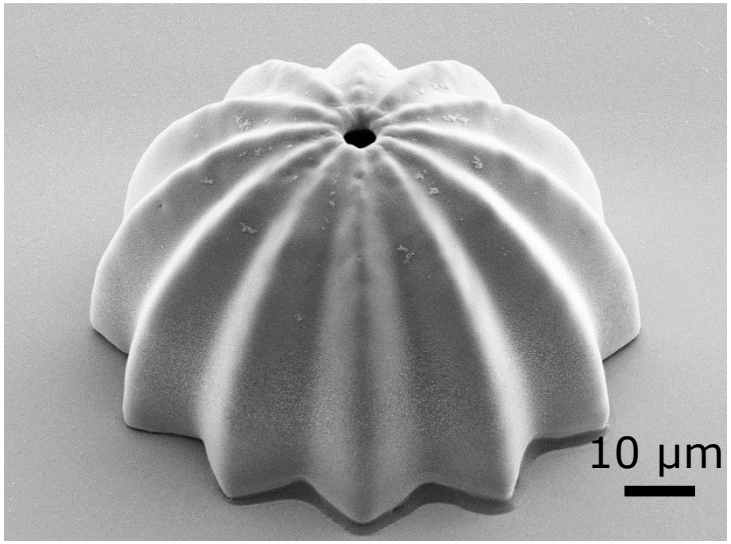




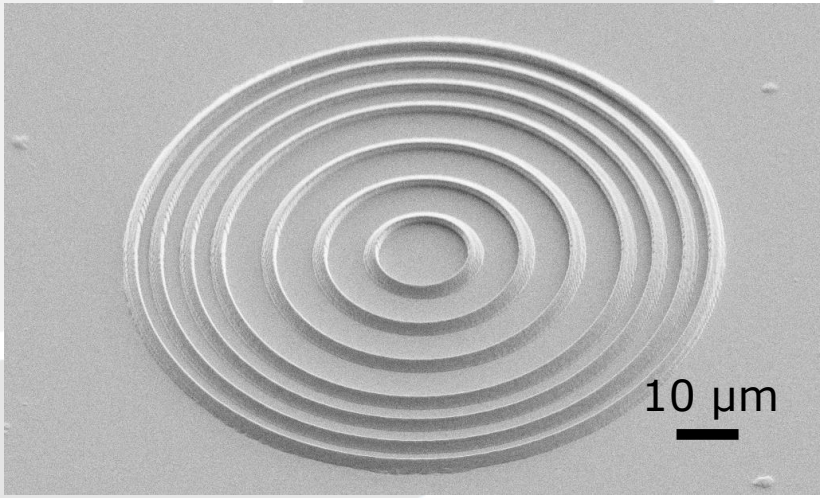
Micro-Optics



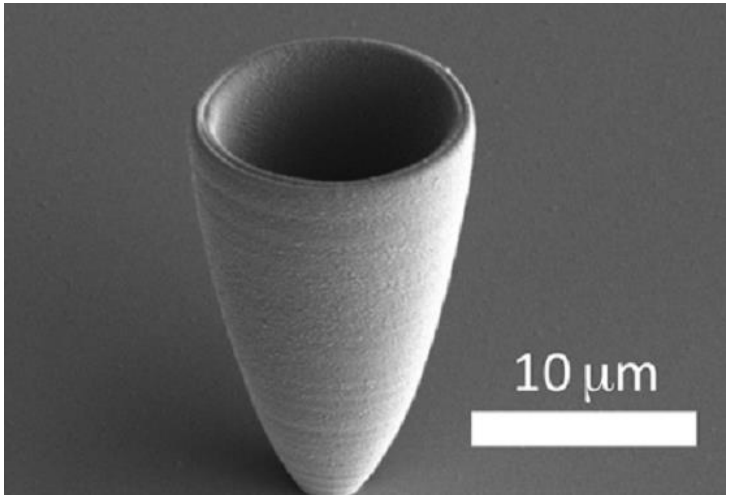
Retroreflector



P. Schmaelzle, PARC, Design APL 45, 2572 (2006)



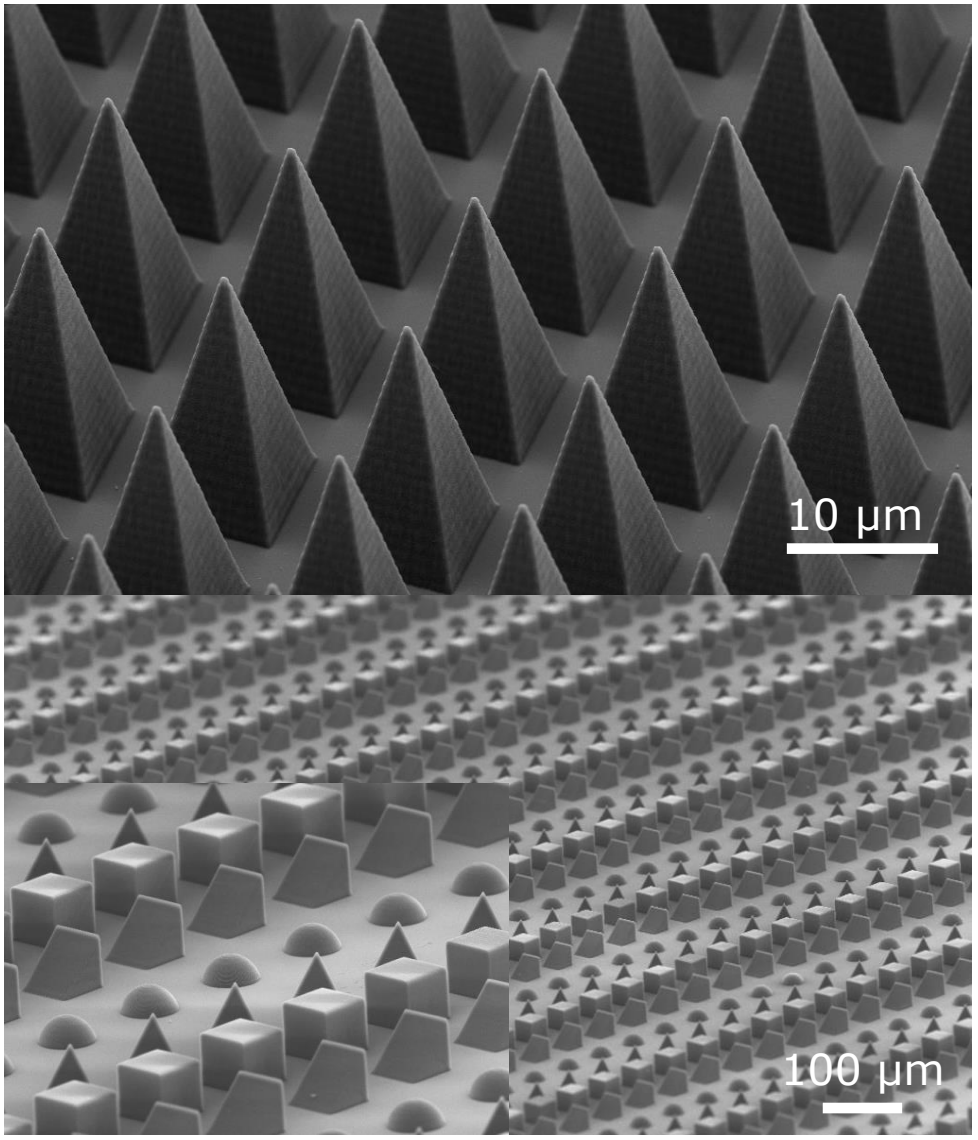
Fresnel Zone Plate



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

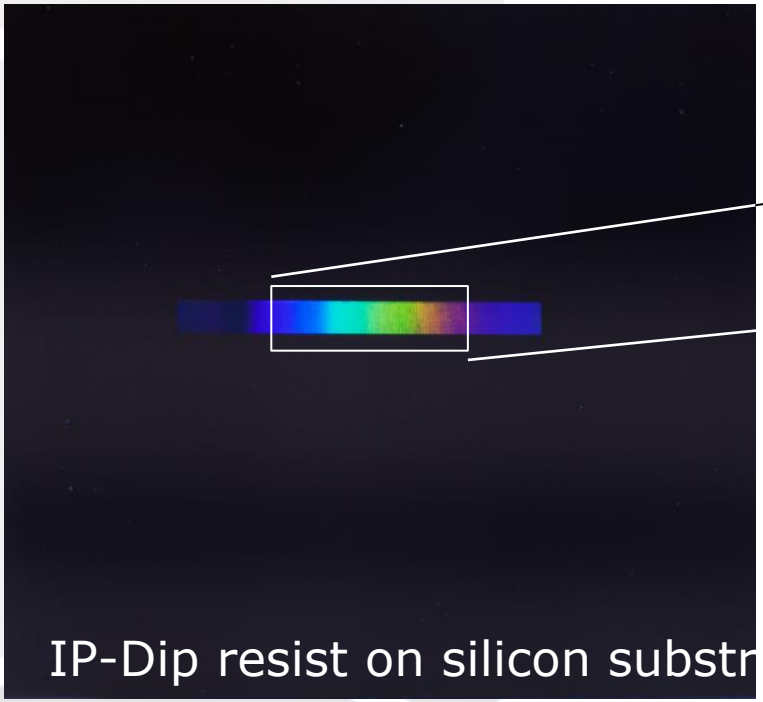
TPP Advantages to Gray Scale Litho

- **High reproducibility:**
  - Negative tone resists (TPP) are very forgiving to fluctuating ambient conditions (temperature, humidity, development time, soft bake, post exposure bake etc.)
  - this is not the case for positive tone resists which are necessary for gray scale lithography when using opaque substrates
- **Height easily tunable:**
  - height independent of resist thickness
  - DiLL (Dip-in Laser Lithography) allows for highest reproducibility and quality independent of structural height
  - different heights on same wafer easy to realize
- **Slender process chain for liquid resists (solvent-free!):**
  - No spin-coating
  - No thickness control necessary
  - No soft bake
  - No post exposure bake
- **Visual feedback:**
  The writing process can directly be observed for multiple photoresists
- **Structural design:**
  - No intelligence needed taking into account Beer's law
  - what you design is what you get
- **Undercuts** are possible and potentially could also be used for lift-off

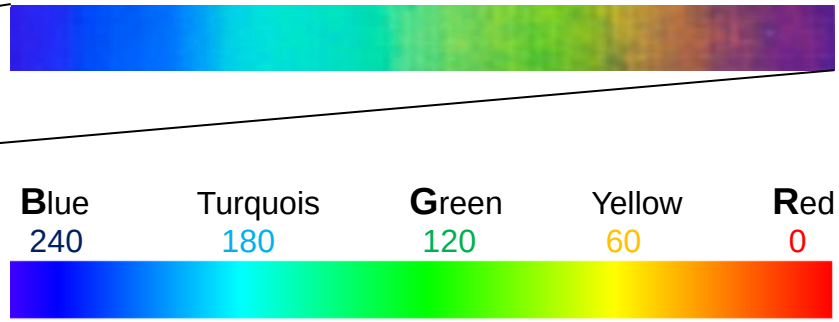


Photonic Colors / Security Labels

Color mapping - 10 mm x 1 mm rainbow



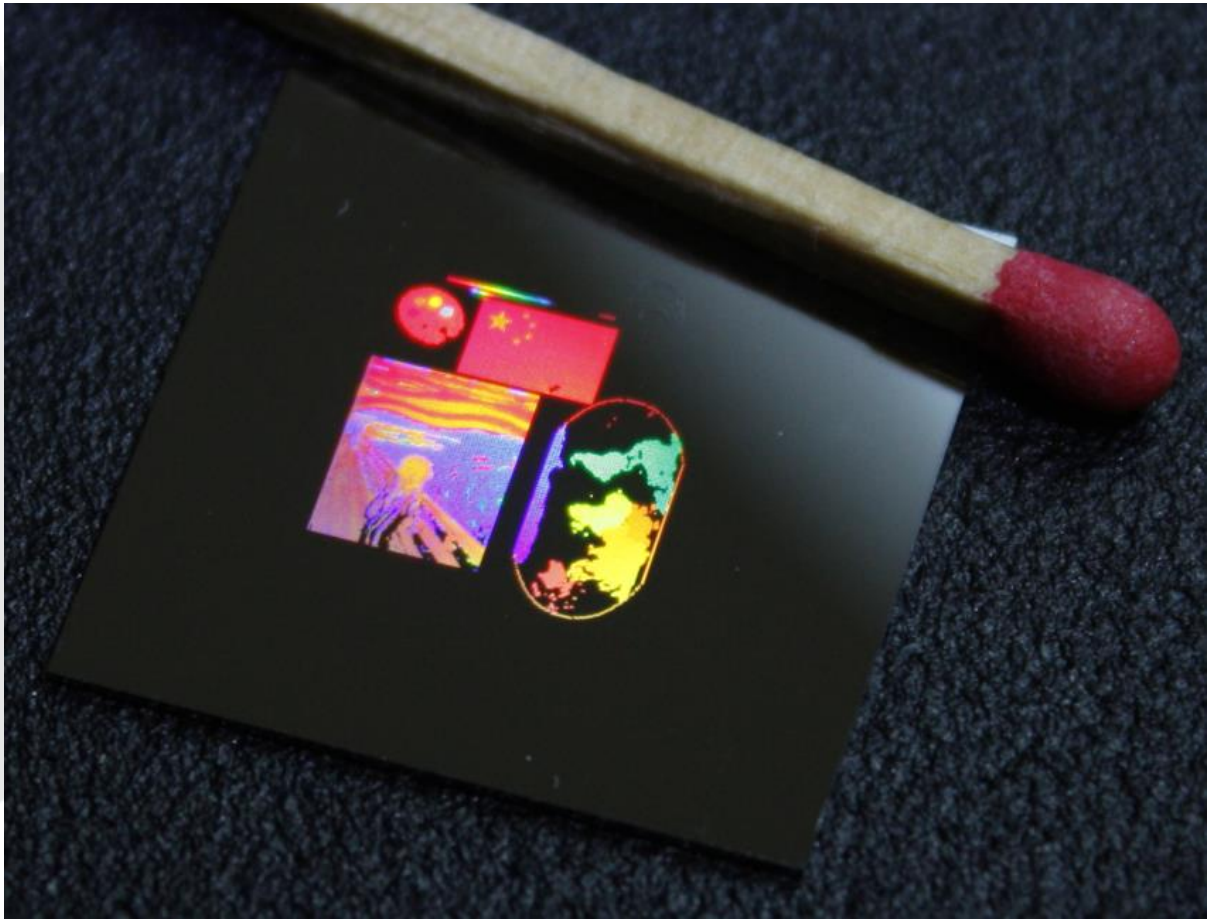
We use the *hue of* HSV color model



exposure time = 0.05 ms, settling time =0.5 ms; 40x, NA=1.3, 50µm x 50µm field size, 201 dot array pixel with periods of 600 nm to 1600 nm (5nm increment)

Photonic Colors / Security Labels

Graphical Input (png, jpg,…)



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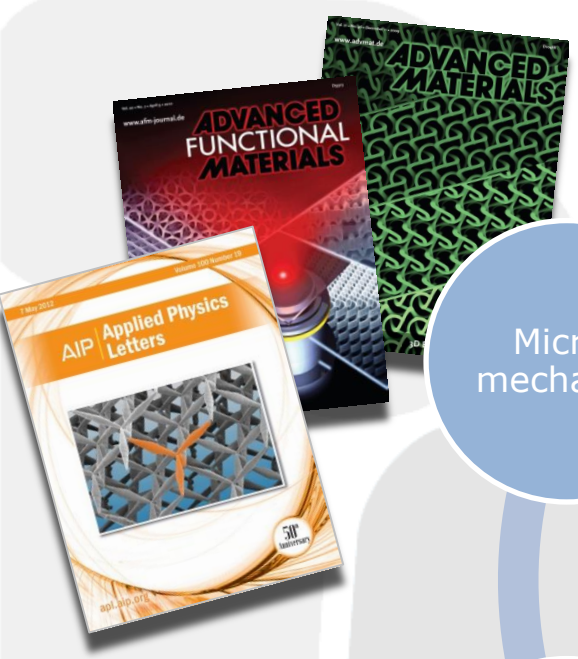
Applications



Photonics

Micro-mechanics

Cell biology

Photonic Professional *GT*

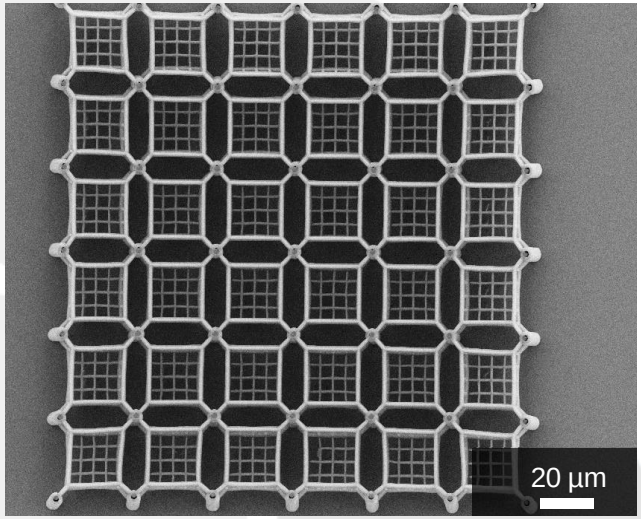
3D µ-Printer

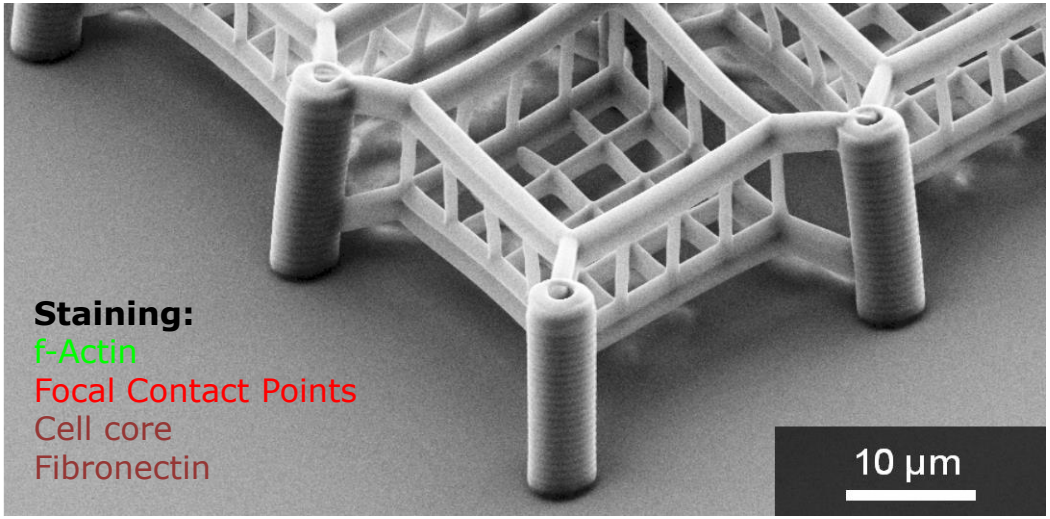
Bio-mimetics

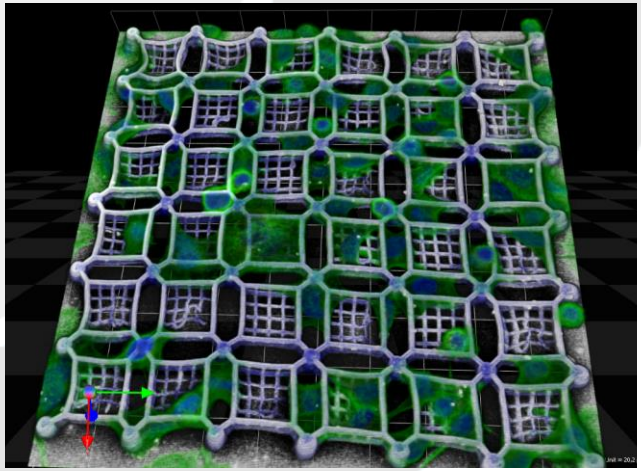
Micro-fluidics

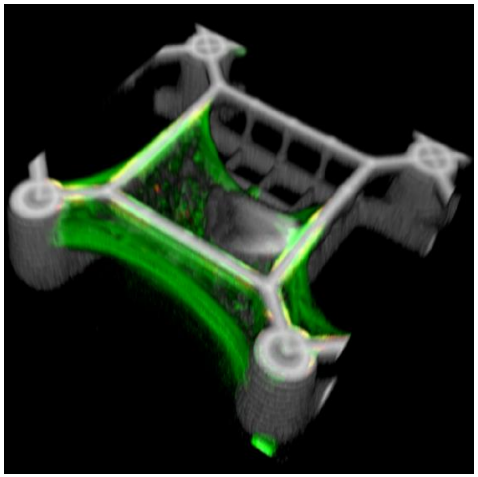
Optical telecom

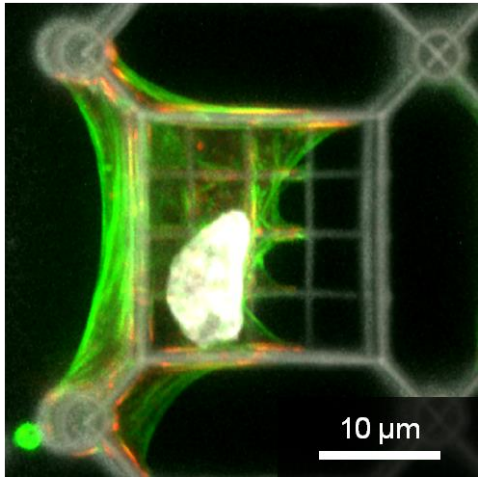
Fabricated Structures & Cell Culture







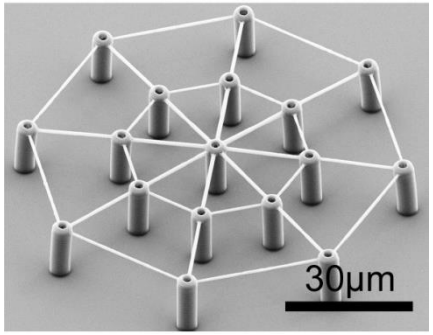


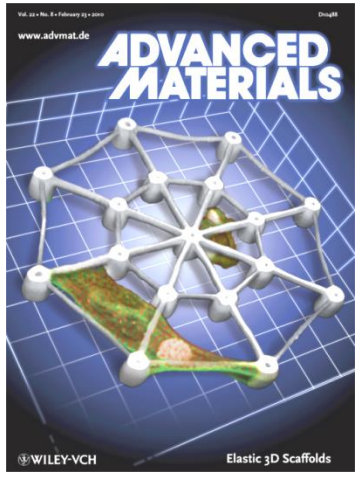


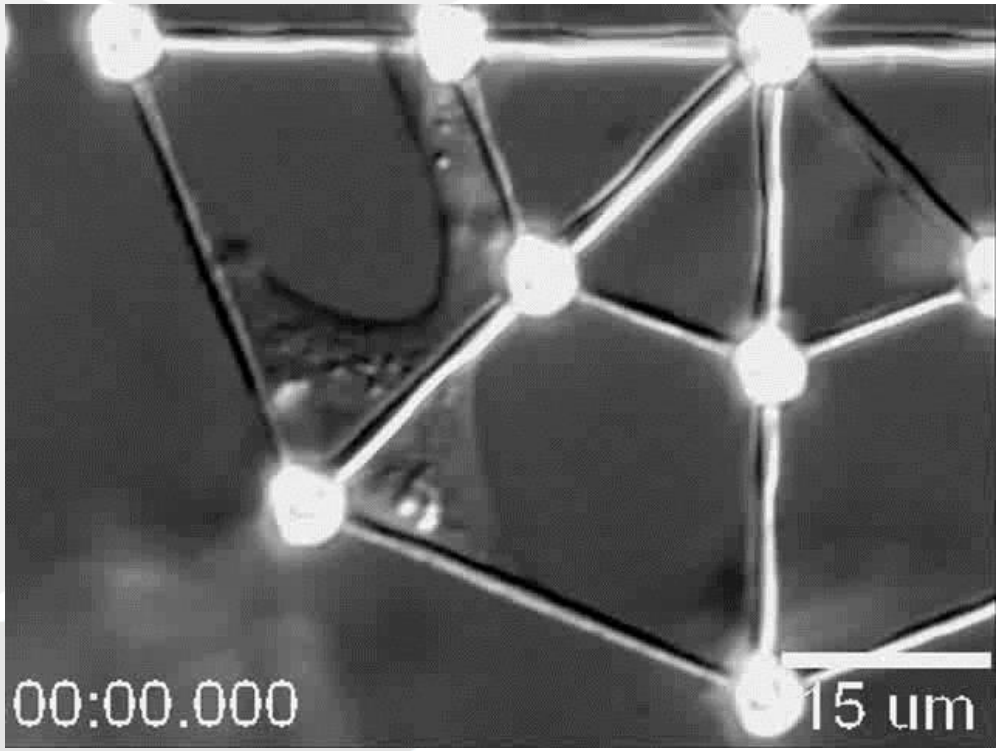
ORMOCERE, J. Fischer, F. Klein, T. Striebel, M. Bastmeyer, Karlsruher Institut für Technology (KIT)

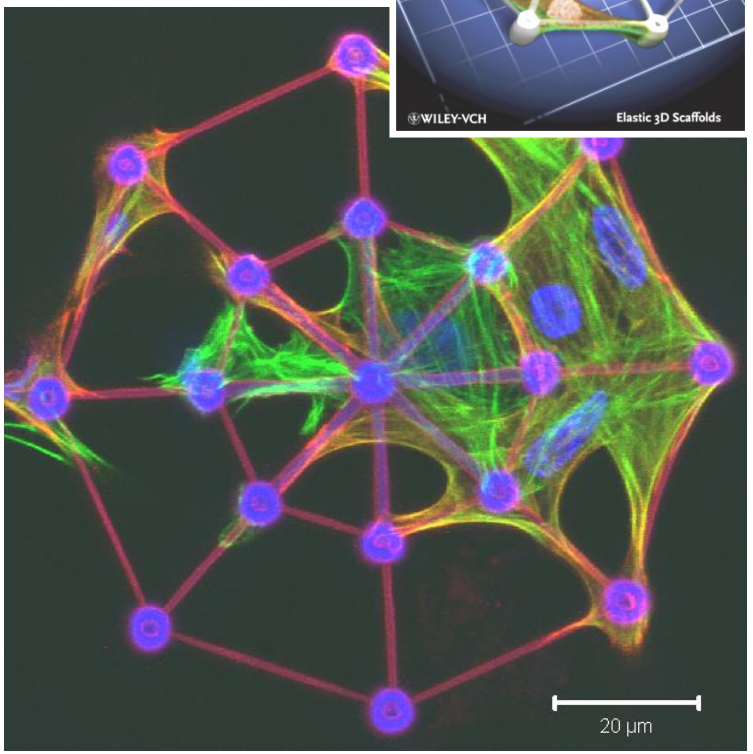
A Gym for Cells

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

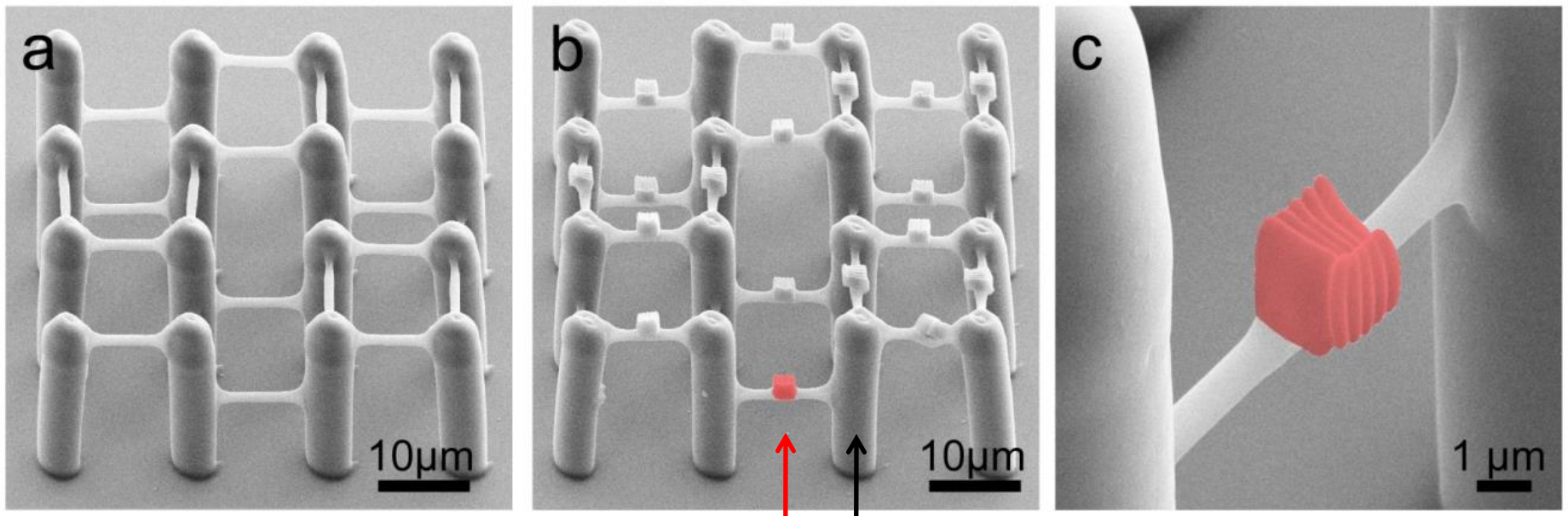








Multiple Exposure – Realignment to Markers

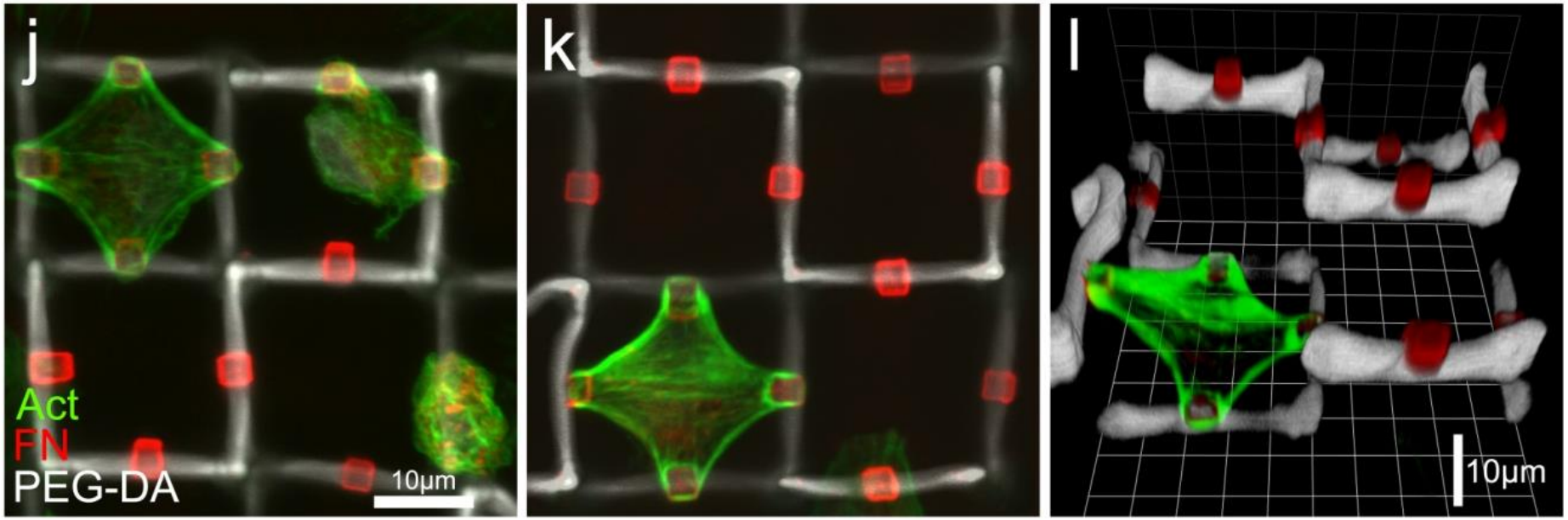


Protein repellant
Protein binding

PEG-DA/PETA
ORMOCERE

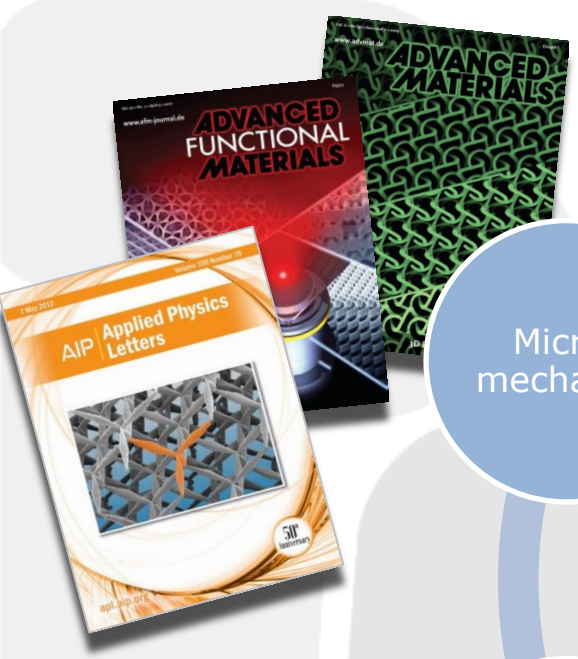
F. Klein & B. Richter *et al.,* Adv. Mater. 23, 1341-1345 (2011)

Multiple Exposure – Realignment to Markers



F. Klein & B. Richter *et al.,* Adv. Mater. 23, 1341-1345 (2011)

Applications



Photonics

Micro-mechanics

Cell biology

Photonic Professional *GT*

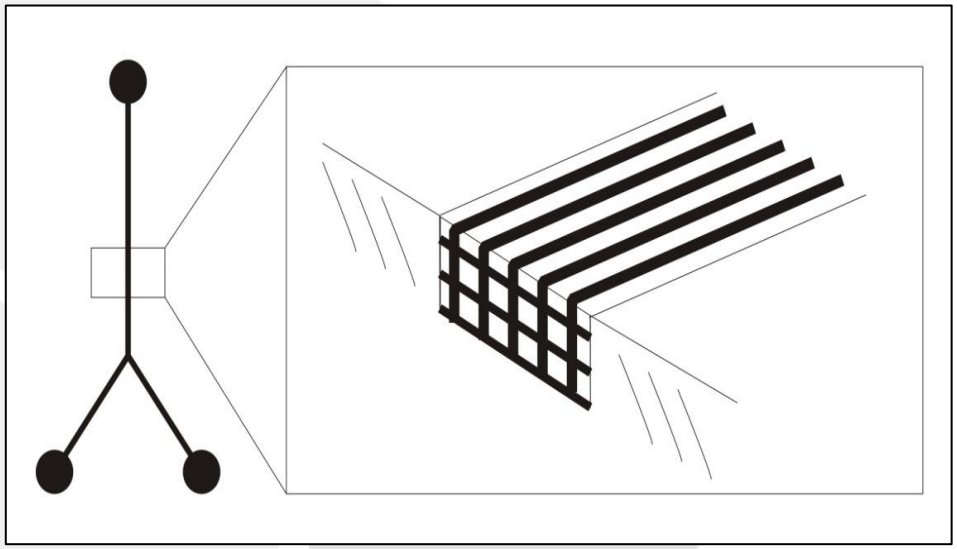
3D µ-Printer

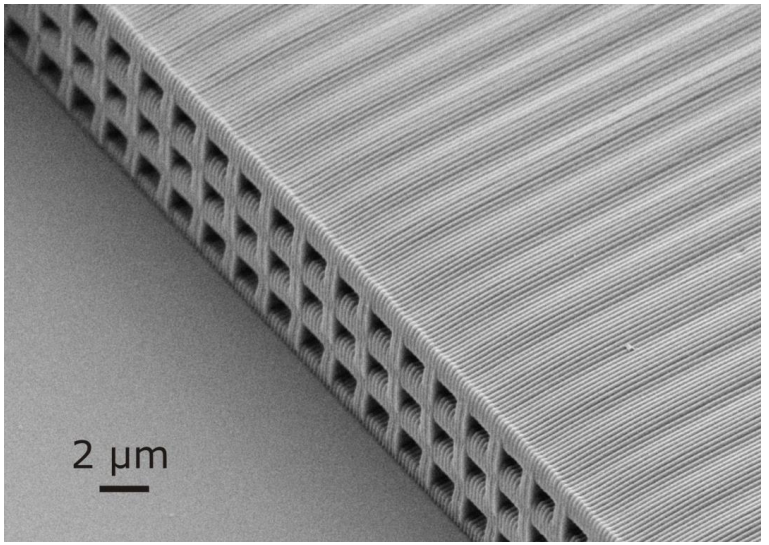
Bio-mimetics

Micro-fluidics

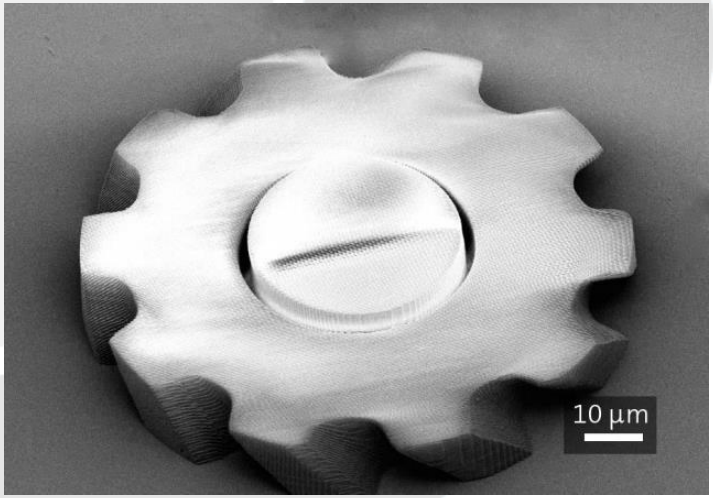
Optical telecom

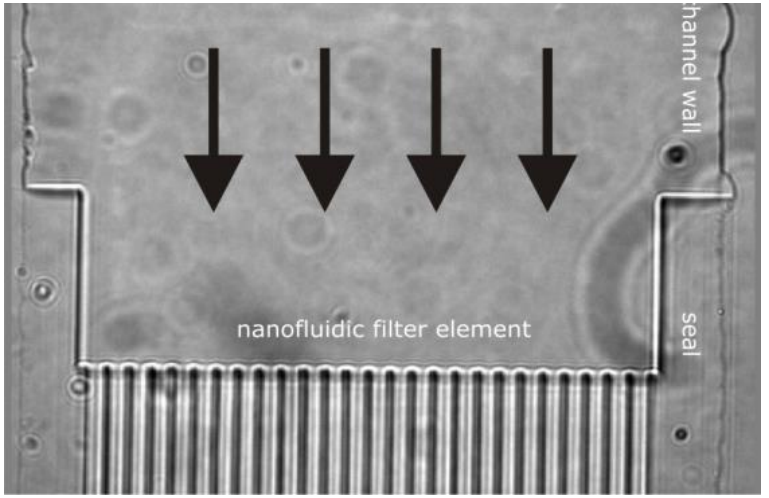
Writing of Microfluidic Elements



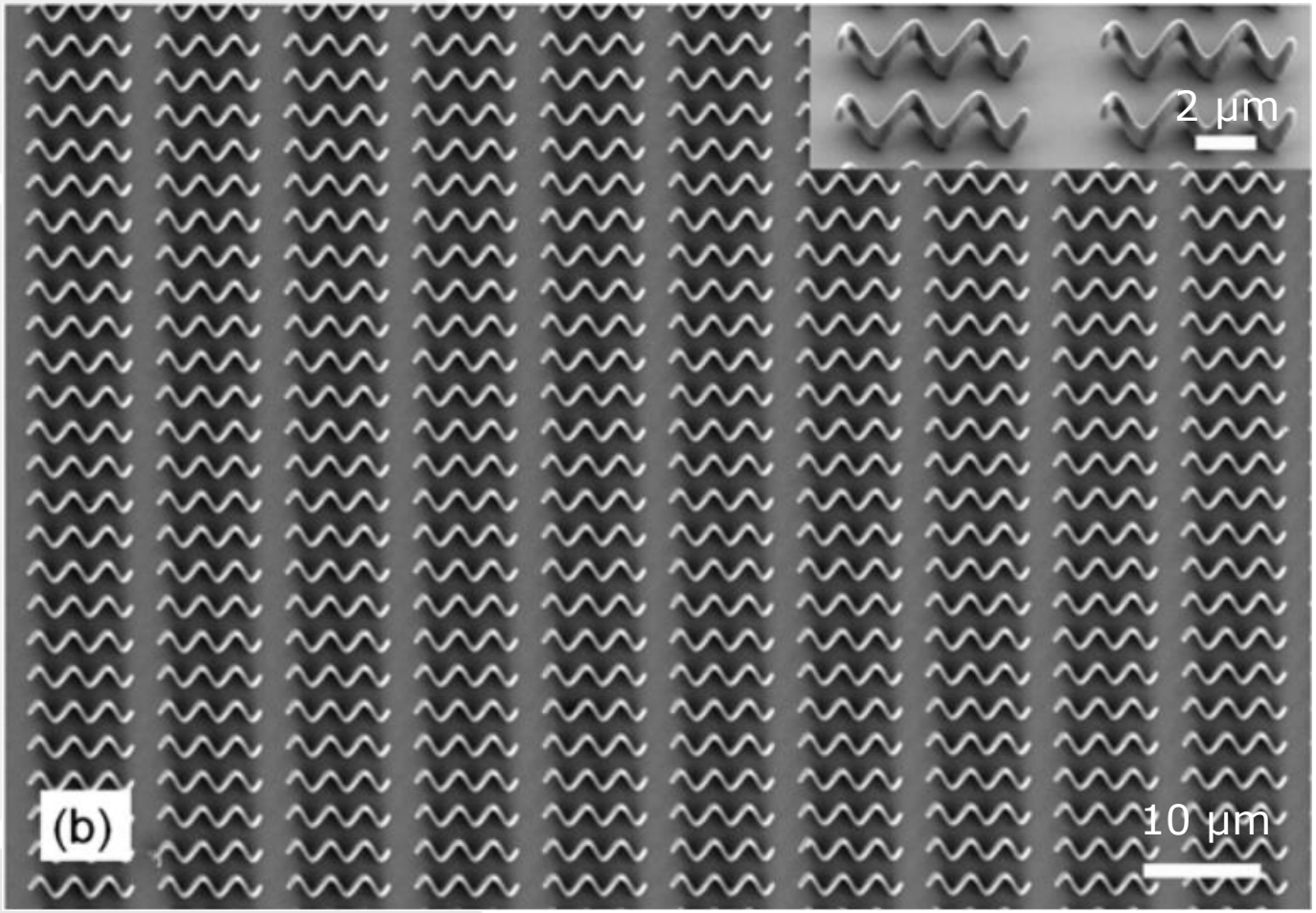


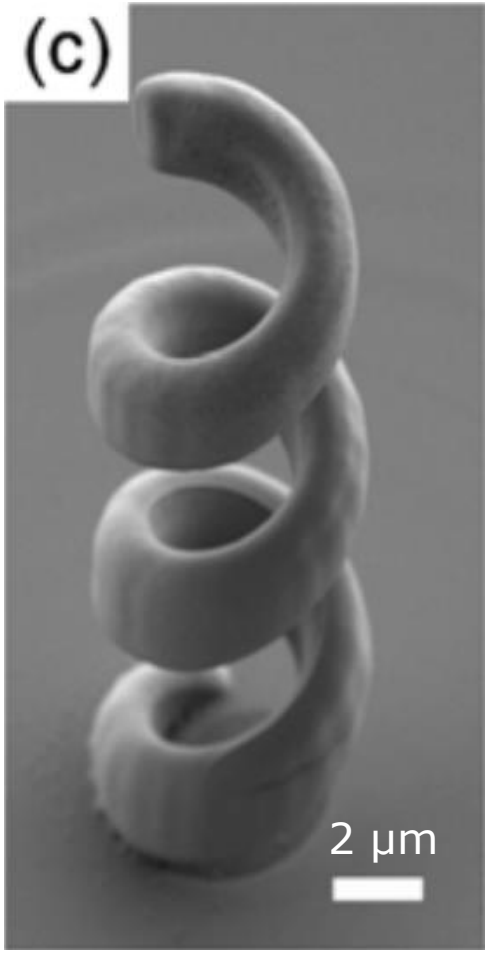
Design by A.-M. Haghiri-Gosnet, LPN-CNRS, France





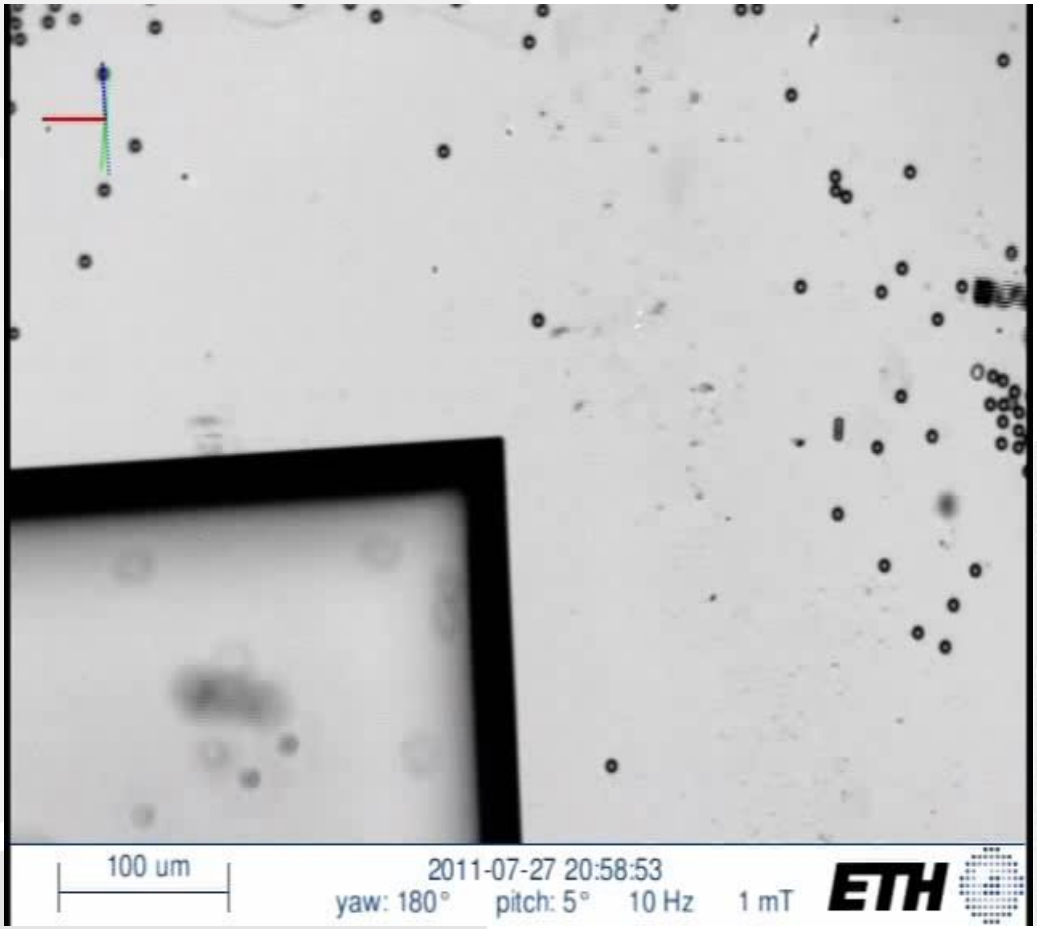
Magnetic Helical Micromachines

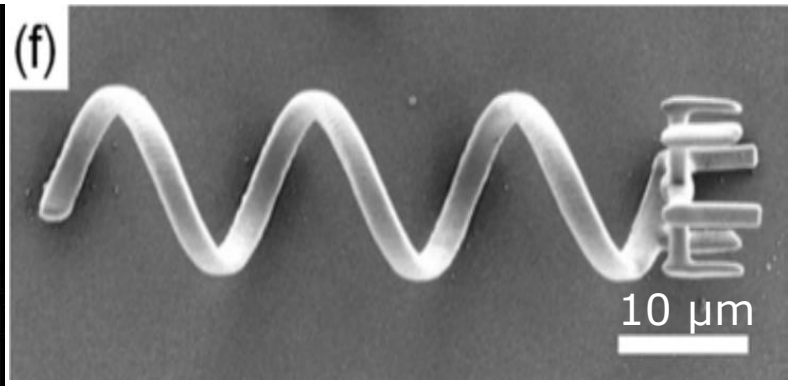


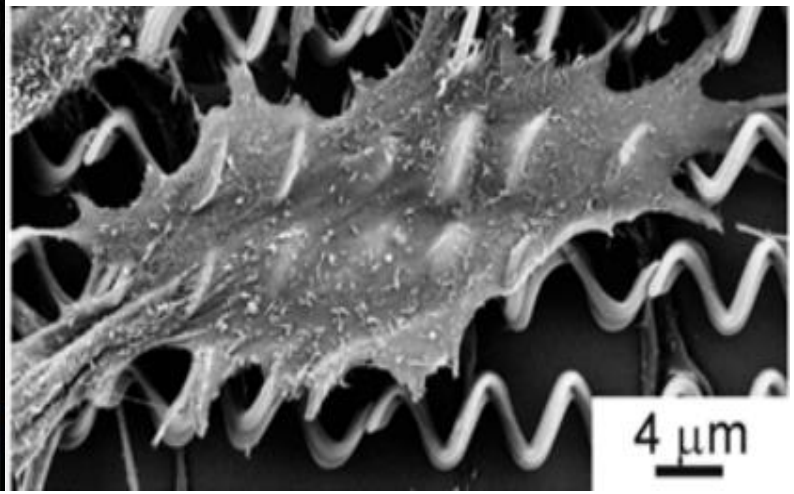


Adv. Mater. **24**, 6, 811–816 (2012)

Magnetic Helical Micromachines





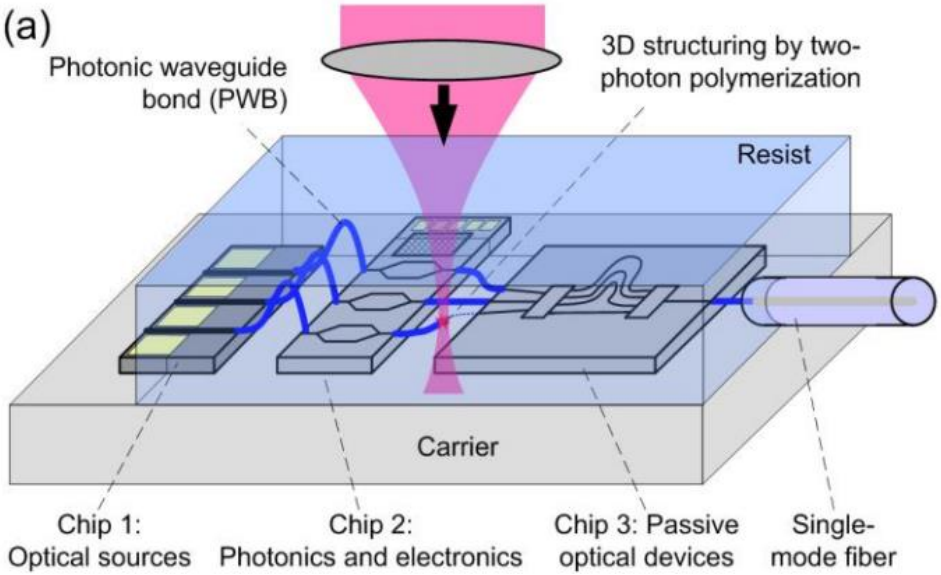


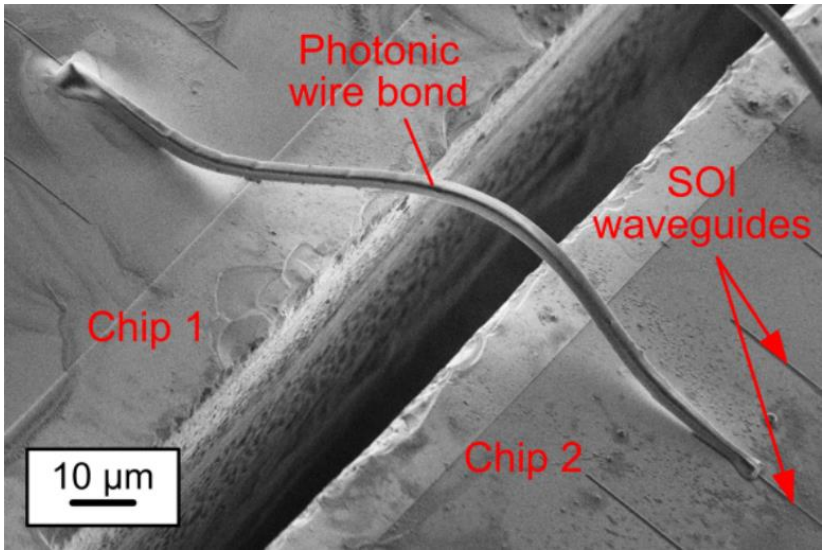
Adv. Mater. **24**, 6, 811–816 (2012)

Photonic Waveguide Bonds – Chip-to-Chip Int.

Optical Interconnects:

- Novel concept of chip-to-chip optical interconnect
- Optical analog to electrical wire bonds of electrically integrated circuits (IC)
- Experimental results on data rates in information processing:
  5.25 Tbit/sec
- BMBF funds project „Phoibos“ with ~2.9 Mio Euros





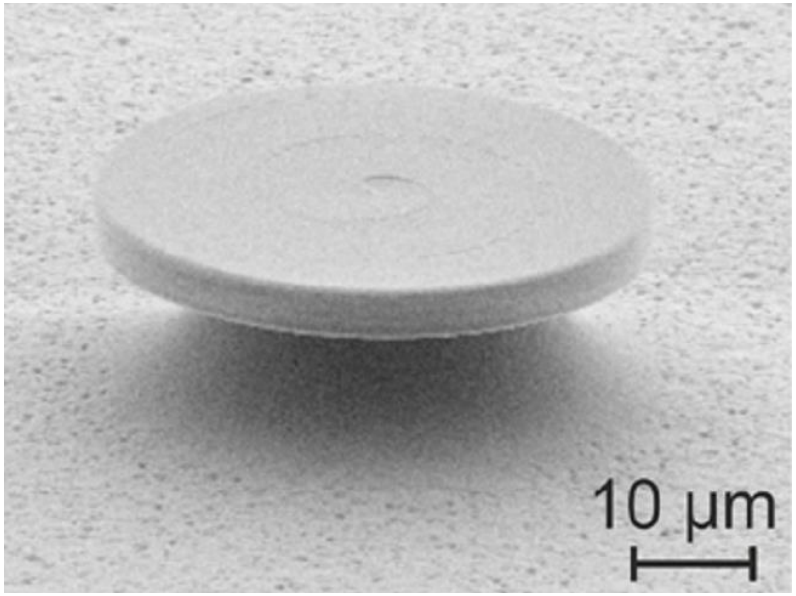
N. Lindenmann *et al.,* Proc. OFC'11, Los Angeles (CA), USA, Paper PDPC1 (2011)
Optics Express, Vol. 20, 17667 (2012)

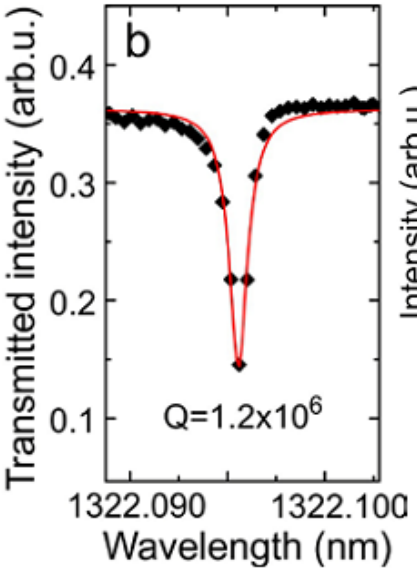
High-Q-Polymer Microdisks: Active & Passive

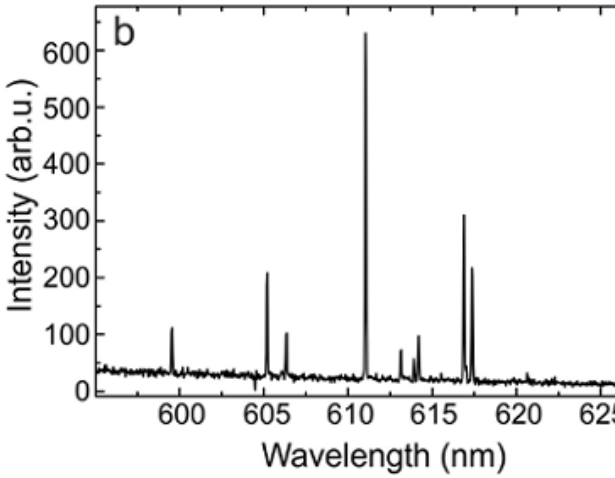
- High-Q passive microdisks for sensing applications with $Q=1.2x10^6$
- Dye-doped microdisk laser

- Material: ORMOCOMP®
- Laser dye: Pyrromethene 597

Complete flexibility in cavity design







T. Grossmann, *et al.*, OPTICS EXPRESS Vol. 19, 11451 (2011)

Applications

Photonics

Micro-mechanics

Cell biology

Photonic Professional *GT*

3D µ-Printer

Bio-mimetics

Micro-fluidics

Optical telecom

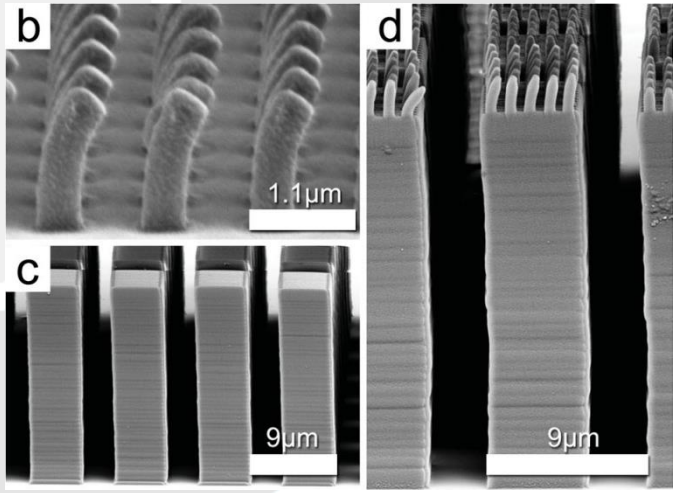
New fields – Biomimetics

Salvinia effect:

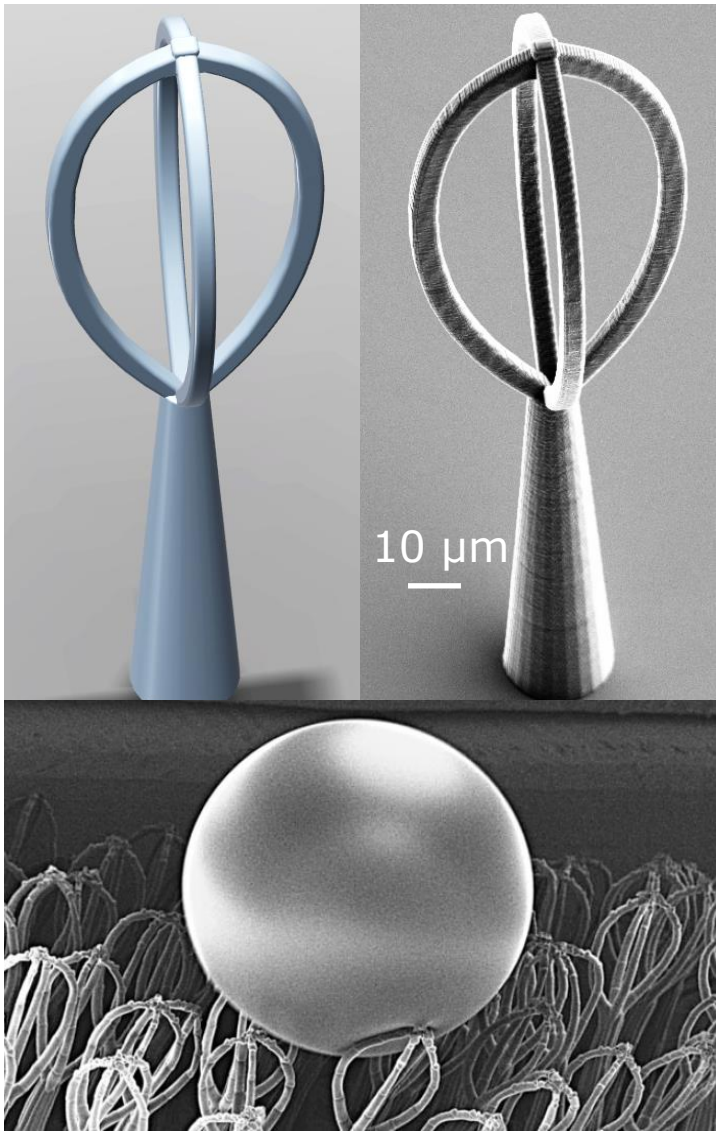
- Floating fern
- Air retention prevents getting moldy when drowned under water
- Application: Friction reduction of ships

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)

Applications

Photonics

Micro-mechanics

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3D µ-Printer

Bio-mimetics

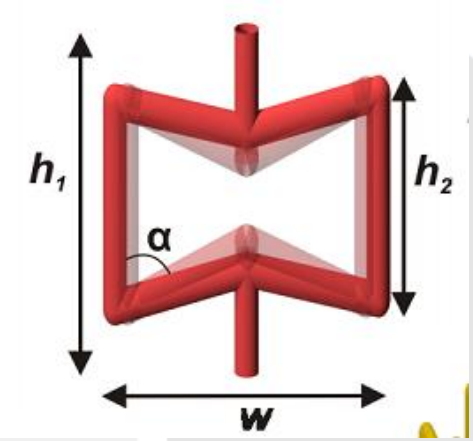
Micro-fluidics

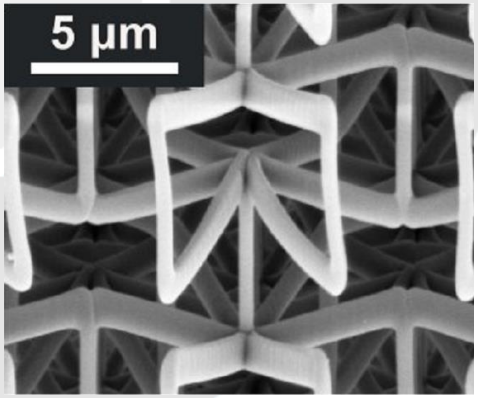
Optical telecom

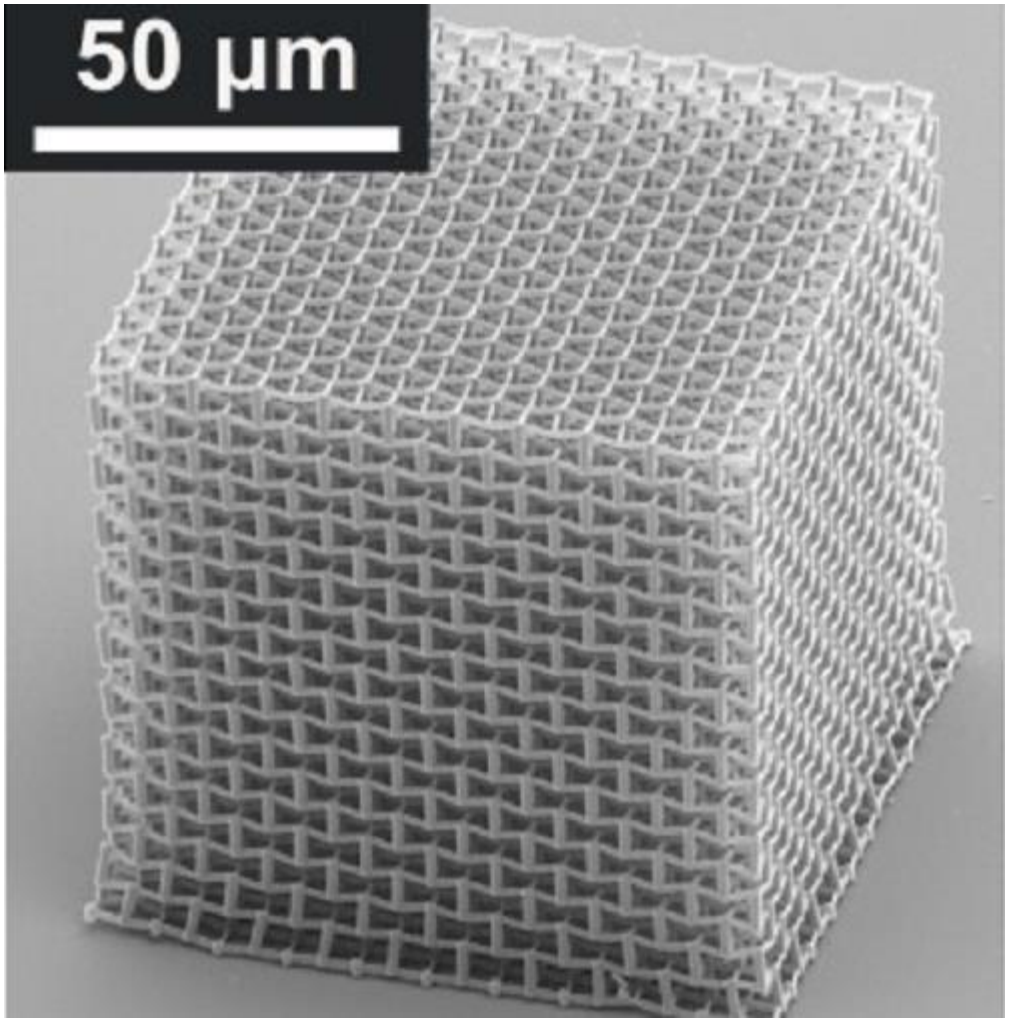
Mechanical Metamaterials

Auxetics:

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





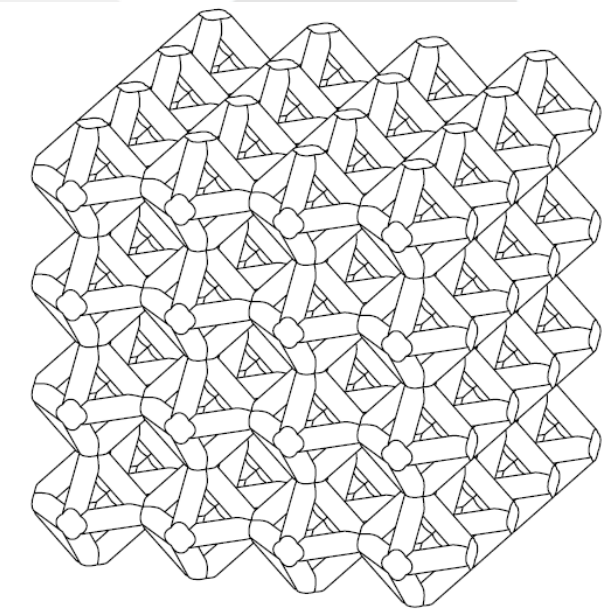


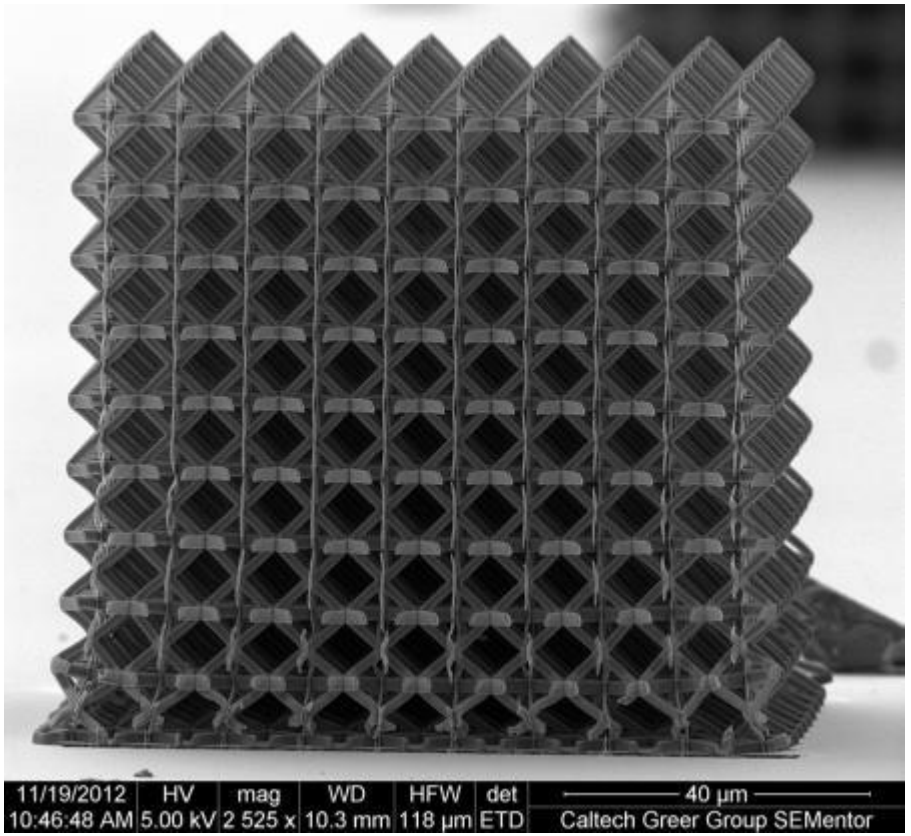
T. Bueckmann et al., Advanced Materials 24, 2710 (2012)

Ultralight Microlattices

Applications:

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

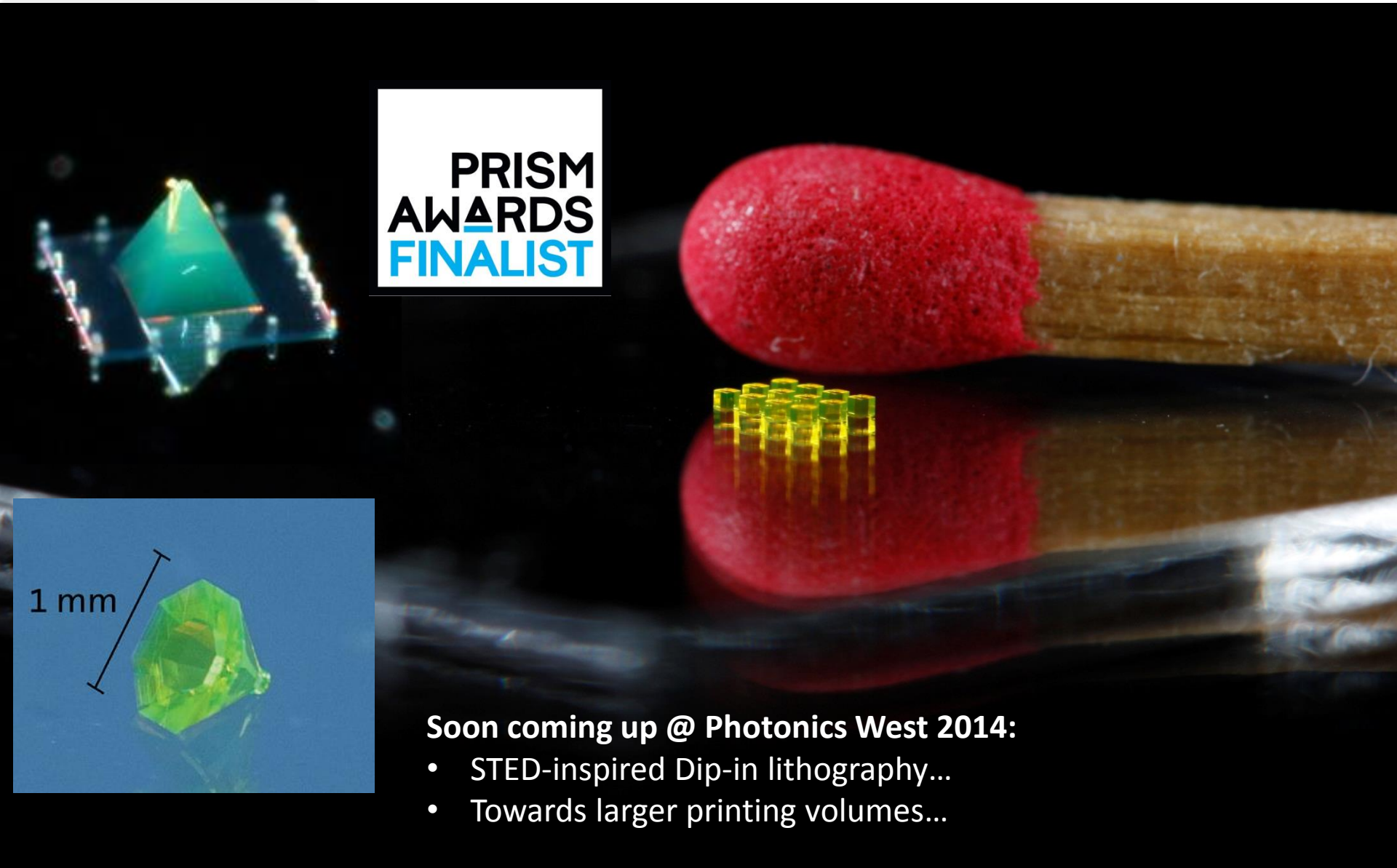




J. R. Greer et al., Nature Materials, DOI: 10.1038/NMAT3738 (2013)

Macro Scale Objects for MEMS

nanoscribe



Soon coming up @ Photonics West 2014:

- STED-inspired Dip-in lithography…
- Towards larger printing volumes…

Our Team

Summary – 3D µ-Printing

nanoscribe