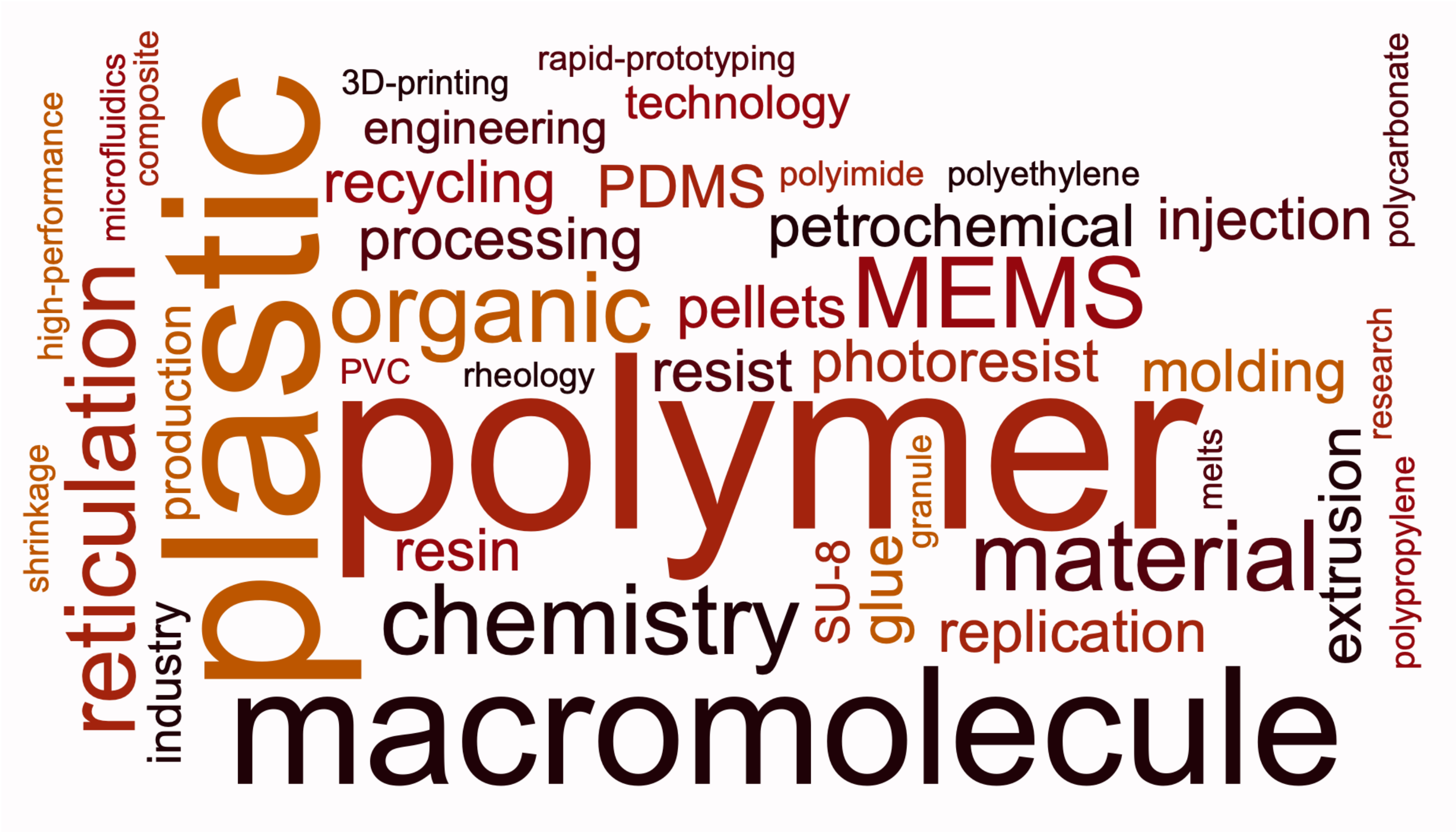


Polymers & MEMS

École
polytechnique
fédérale
de Lausanne

December 2024

Polymers: Definition

Substances composed of very large molecules, called macromolecules, that are multiples of simpler chemical units called monomers. (Encyclop. Britanica)

Natural / Synthetic

Homopolymers / Copolymers

Linear / Branched / Crosslinked / Hyperbranched

Nylon
Nitrile rubber
ABS
DNA
Proteins
PET
Bakelite
Epoxy resin
Vulcanized rubber
Glycogen
Cellulose
PDMS
Etc..

Arnaud Bertsch

Why polymers for MEMS?

MEMS were initially developed to produce micromechanical systems (microphones, accelerometers, gyroscopes, pressure sensors, etc.) using Si, SiO_2, metals

Polymers will not replace Si and traditional MEMS materials, but their characteristics will allow to widen the application domains of MEMS

In the last 15 years, new applications have emerged for MEMS in life science and biomedical domains, where polymers play a key role.

EPFL

Why polymers for MEMS?

The advantages of polymers:

- **Material properties:** not brittle, withstand large strains, low thermal expansion, some are optically transparent, with low fluorescence, chemically inert, biocompatible

- **Can be processed with a wide range of techniques:** Photo-patterning, wet and plasma etching, molding, laser ablation, 3D printing, screen printing, hot embossing, imprinting, plasma and fusion bonding, surface modification, etc..

- **Can be mixed with other materials:** (fibers, nanotubes, particles) to make composite materials and tune their properties.

- **Cost effective, cleanroom not always needed**

Polymers

1- Resists / Photoresists

- Temporary mask in photolithography process
- Direct fabrication of micro-components
- High Aspect Ratio components
- Multi-level components
- 3D printing (stereolithography, micro-stereolithography, TPP, etc..)

Polymers

2- Thermoplastics (plastics that can be melted)

- Injection molding
- Imprinting (nano-imprint)
- Excimer laser fabrication of 3D structures (also with thermosetting polymers)

Polymers

3- Elastomers (plastic material with elastic properties)

- **Rapid prototyping**
- **Molding**
- **Microfluidic applications**

Polymers

4- “Special” polymers

- Vapor phase deposition (CVD)
- Conformal deposition
- Biocompatibility
- Optical films

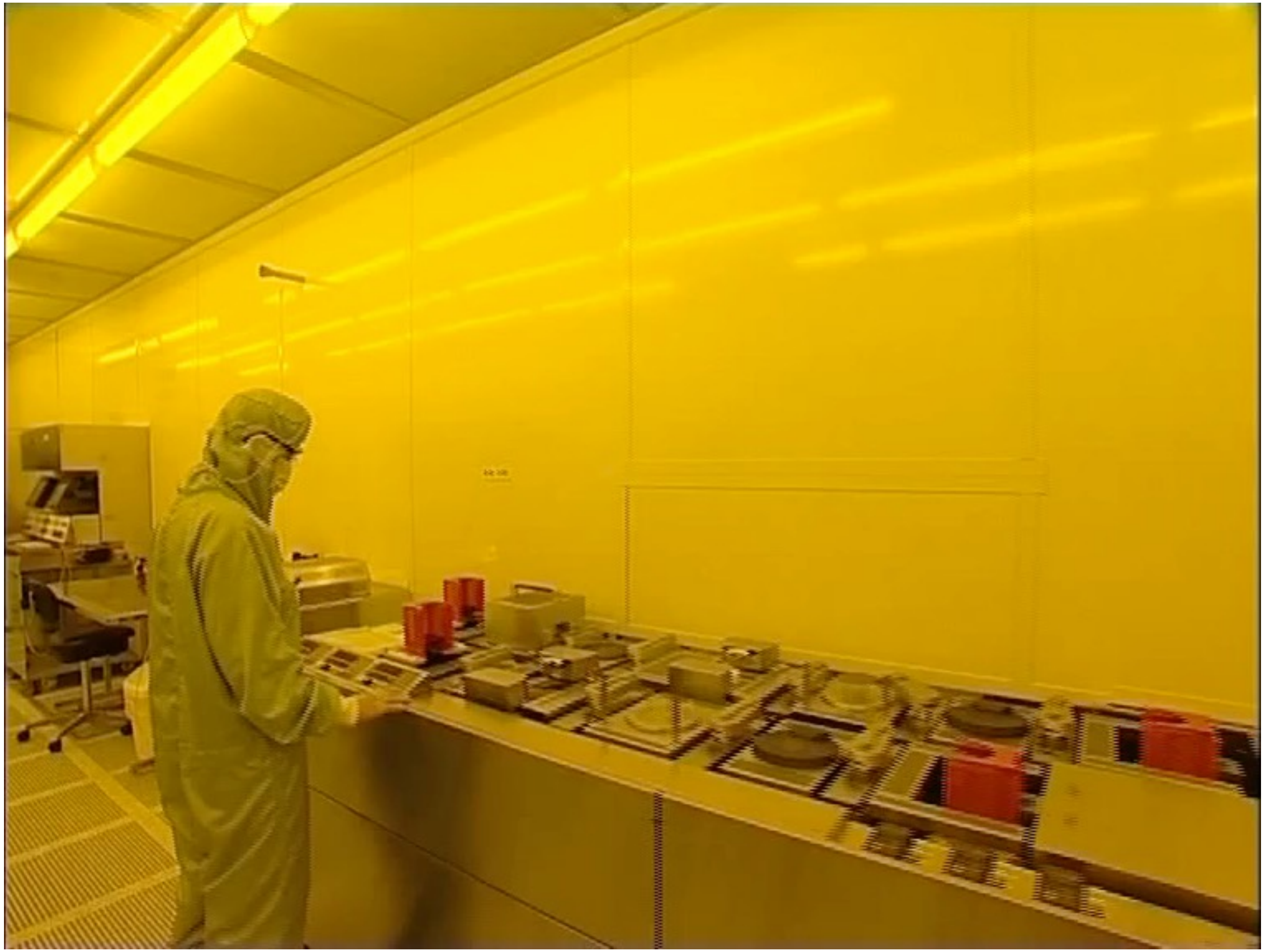
1- Resists / Photoresists

The most used polymers for manufacturing MEMS

Photoresist =

{Polymer + Solvent + Photoinitiator}

Spin coating / Photolithography



EPFL

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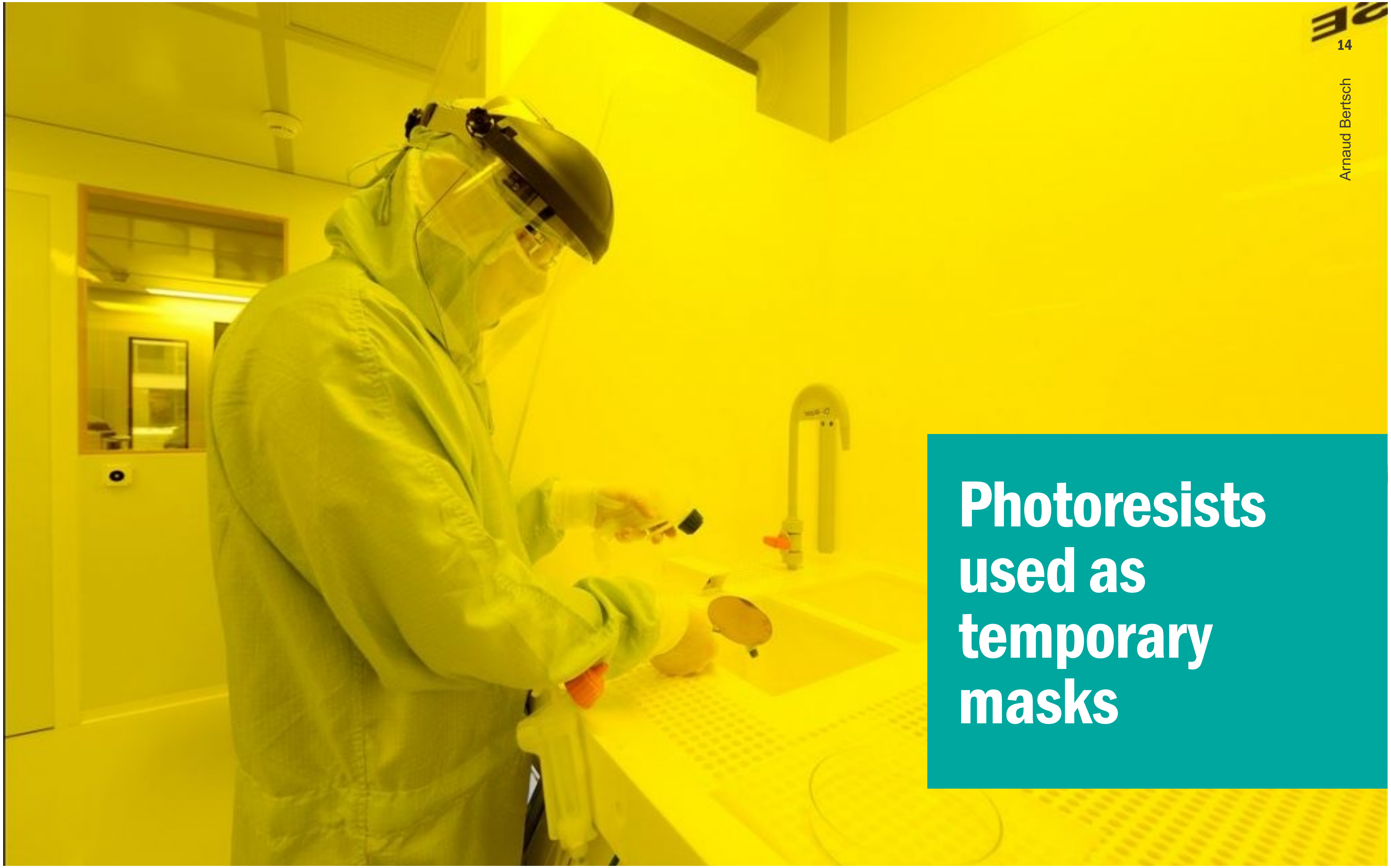


Photoresists used as temporary masks

Photoresists:

Generally used for **masking** during wet chemical or plasma etching, **later removed**.

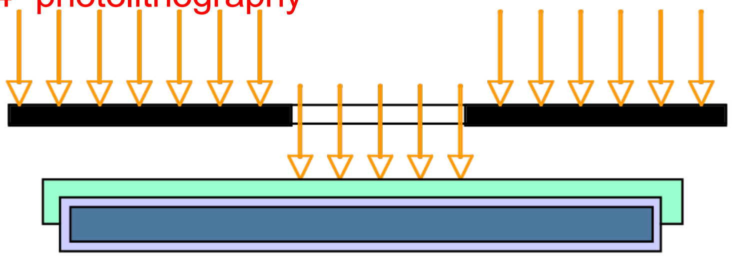
Example: photolithography, SiO_2 as mask for KOH etching

1- Si wafer

2- oxydation (1micron)

3- positive resist

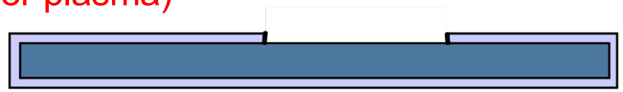
4- photolithography



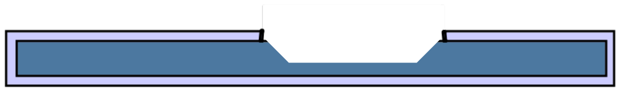
5- development

6- Wet etching of SiO_2 (HF/NH4F)

7- photoresist removal
(solvent or plasma)



8- KOH etching

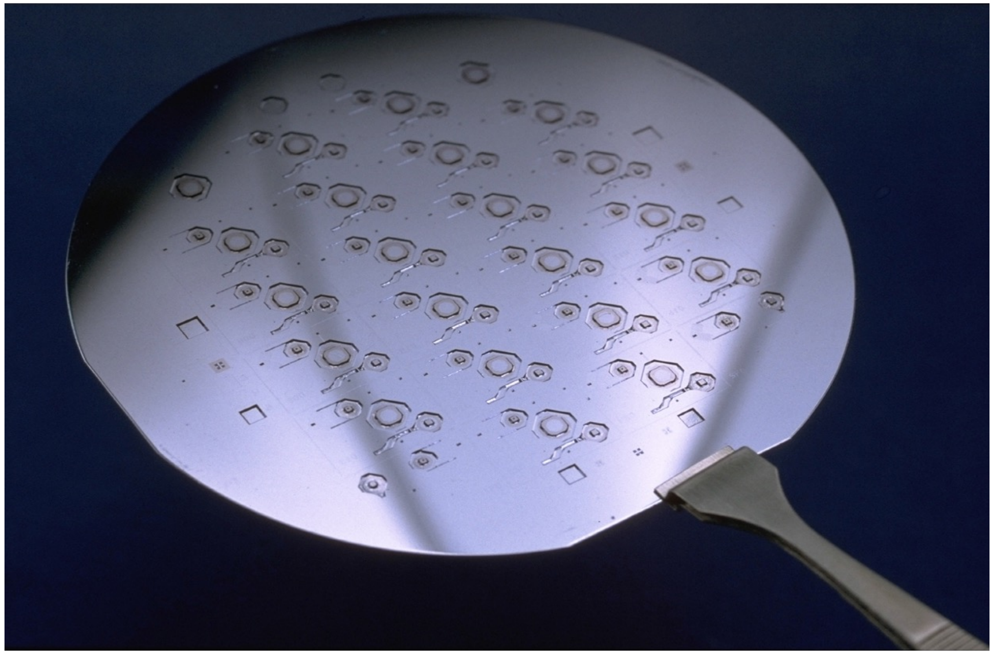


→ KOH etches Si, but not SiO_2

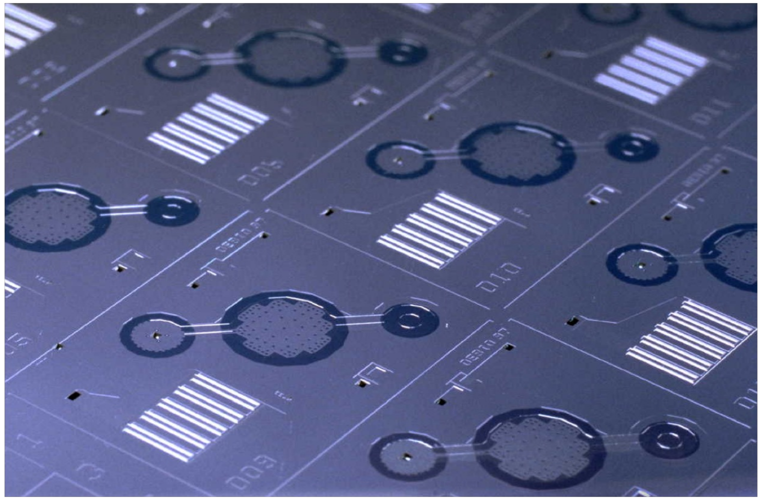
Photoresists:

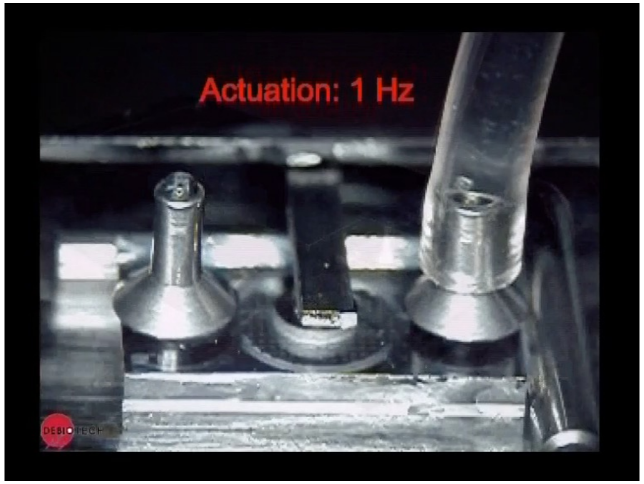
Generally used for masking during wet chemical or plasma etching, later removed.

Example: photolithography of SiO2

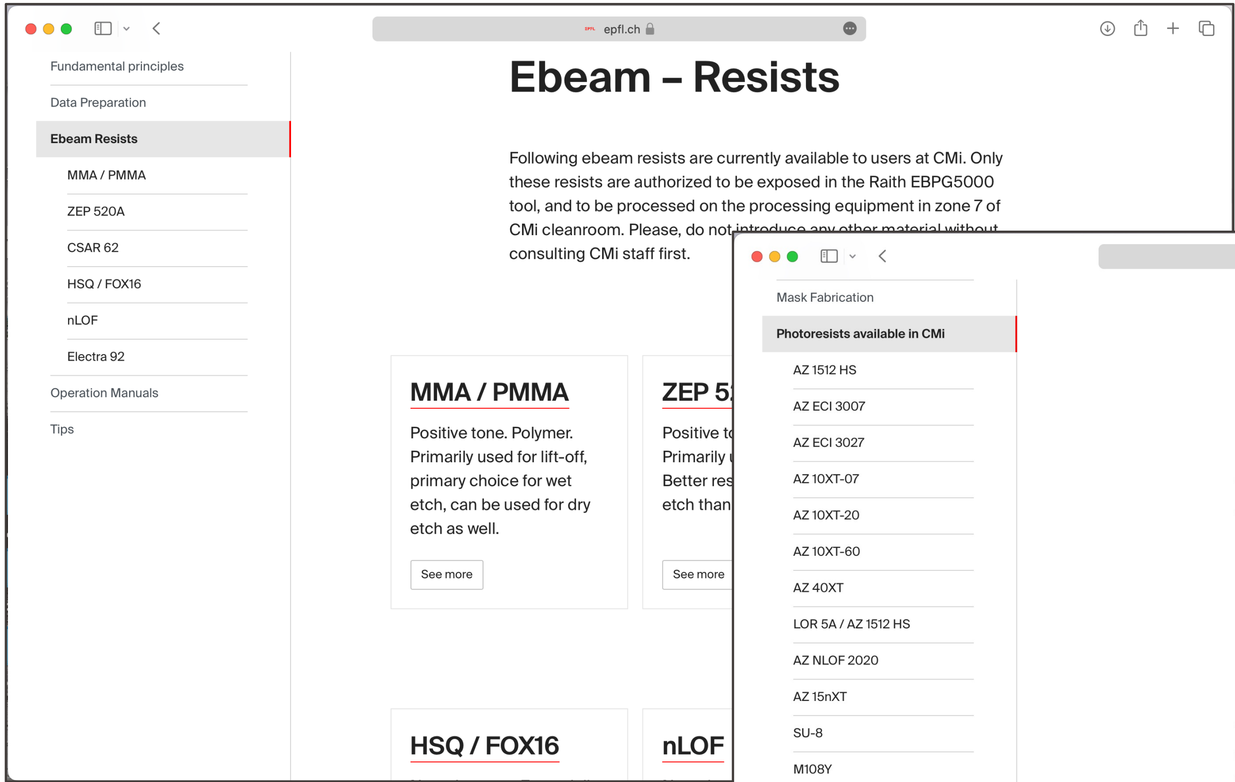


The first micro-pumps were manufactured using this process





More than 20 photoresists are available at CMi


epfl.ch
Fundamental principles
Data Preparation
Ebeam Resists
MMA / PMMA
ZEP 520A
CSAR 62
HSQ / FOX16
nLOF
Electra 92
Operation Manuals
Tips

Ebeam – Resists

Following ebeam resists are currently available to users at CMi. Only these resists are authorized to be exposed in the Raith EBPG5000 tool, and to be processed on the processing equipment in zone 7 of CMi cleanroom. Please, do not introduce any other material without consulting CMi staff first.

MMA / PMMA

Positive tone. Polymer. Primarily used for lift-off, primary choice for wet etch, can be used for dry etch as well.

See more

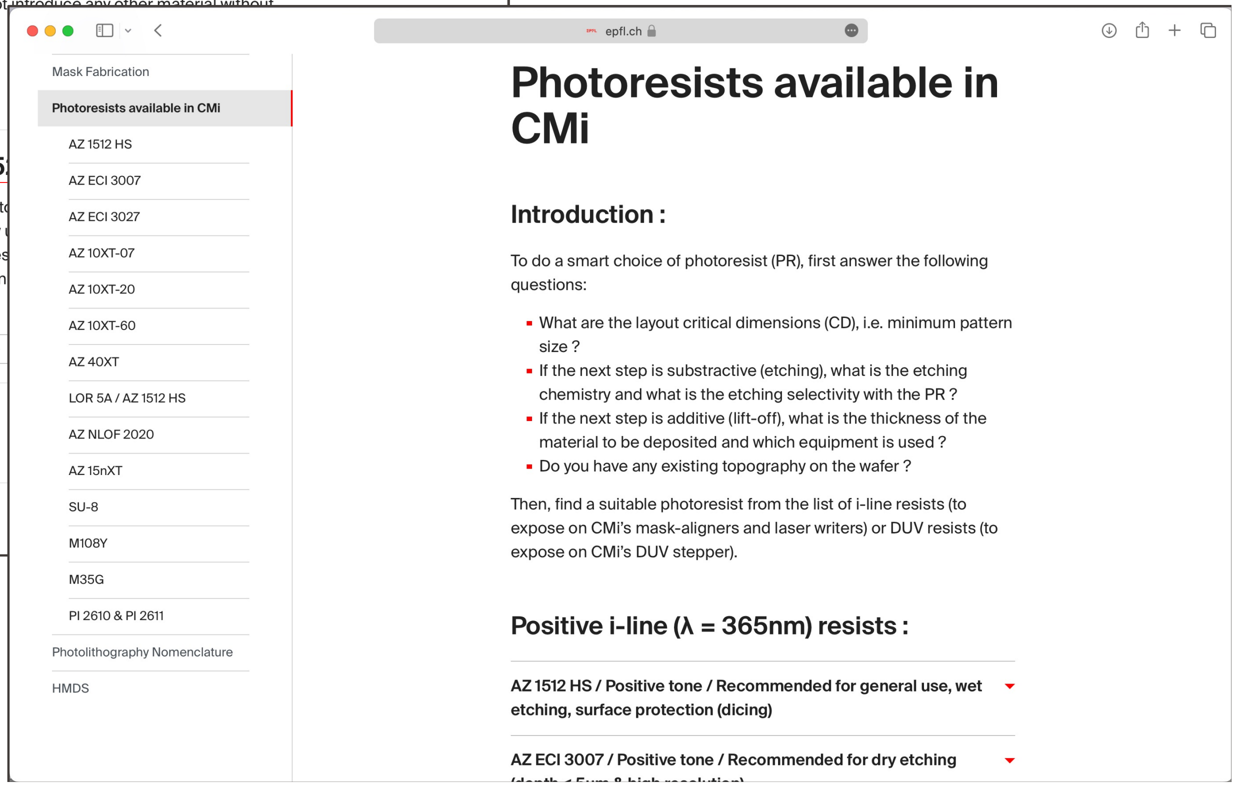
ZEP 5

Positive t
Primarily
Better res
etch than

See more

HSQ / FOX16

nLOF


epfl.ch
Mask Fabrication
Photoresists available in CMi
AZ 1512 HS
AZ ECI 3007
AZ ECI 3027
AZ 10XT-07
AZ 10XT-20
AZ 10XT-60
AZ 40XT
LOR 5A / AZ 1512 HS
AZ NLOF 2020
AZ 15nXT
SU-8
M108Y
M35G
PI 2610 & PI 2611
Photolithography Nomenclature
HMDS

Photoresists available in CMi

Introduction :

To do a smart choice of photoresist (PR), first answer the following questions:

- What are the layout critical dimensions (CD), i.e. minimum pattern size ?
- If the next step is substractive (etching), what is the etching chemistry and what is the etching selectivity with the PR ?
- If the next step is additive (lift-off), what is the thickness of the material to be deposited and which equipment is used ?
- Do you have any existing topography on the wafer ?

Then, find a suitable photoresist from the list of i-line resists (to expose on CMi's mask-aligners and laser writers) or DUV resists (to expose on CMi's DUV stepper).

Positive i-line (λ = 365nm) resists :

AZ 1512 HS / Positive tone / Recommended for general use, wet etching, surface protection (dicing)

AZ ECI 3007 / Positive tone / Recommended for dry etching

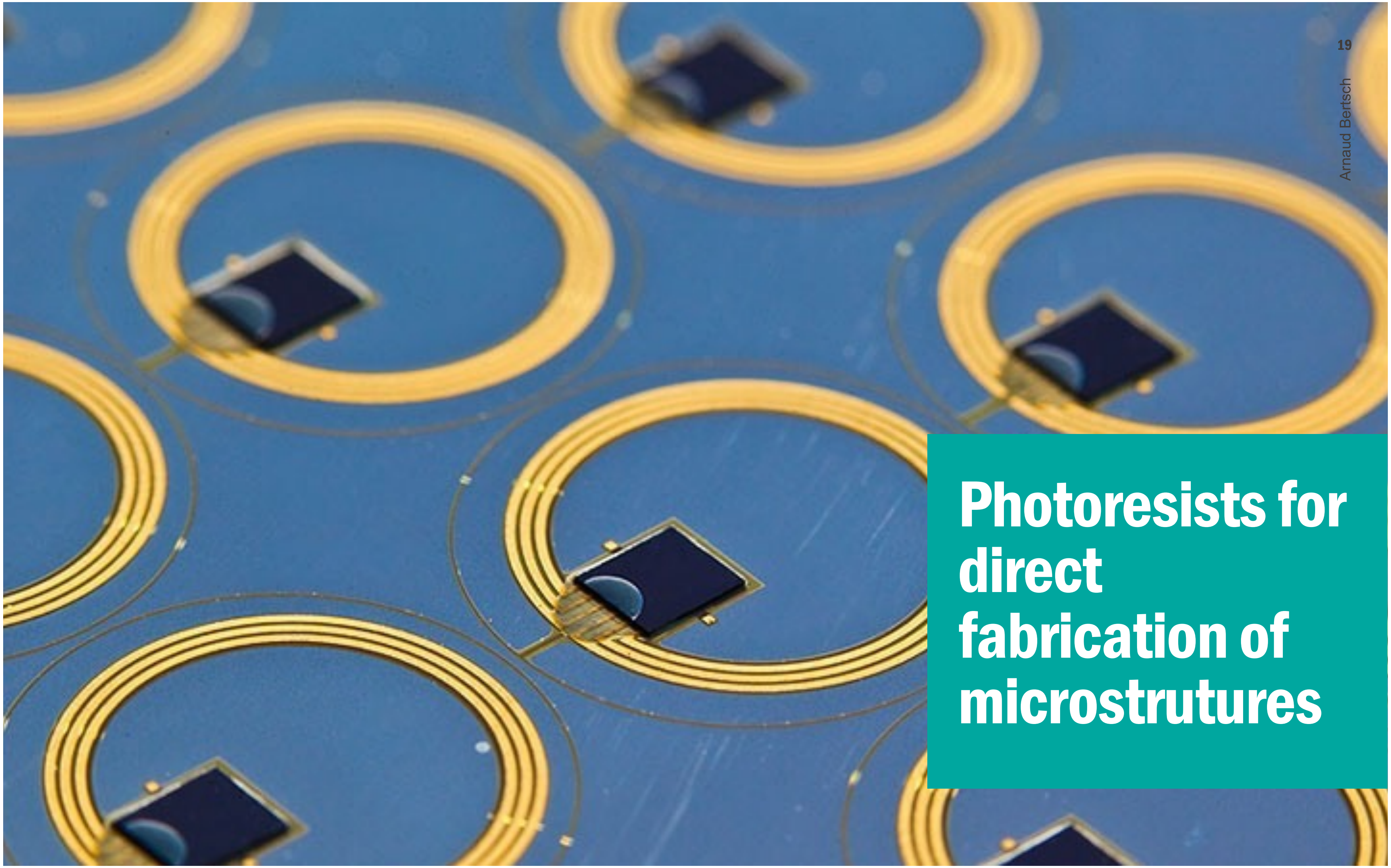
Choose wisely a photoresist for your application

1- Resolution requirements: UV, Deep UV, e-beam ?

2- Resolution requirements: Higher resolutions require thinner photoresist layers

3- Chemical compatibility: Make sure all the previously structured materials are compatible with the chosen photoresist, adhesion promoter, developer, and stripper. If it is used for lift-off, make sure the photoresist is compatible with the subsequent process steps.

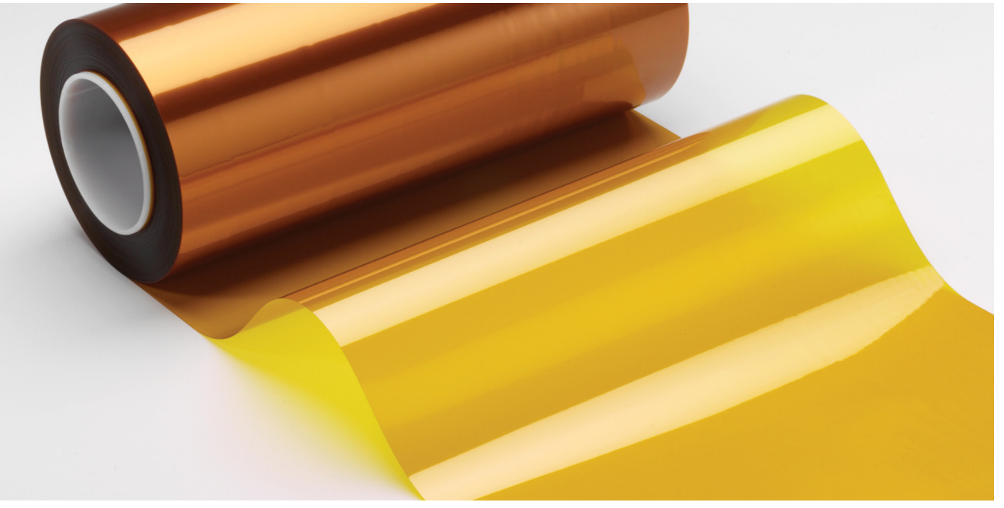
4- Function of the photoresist: Make sure the photoresist is adapted to the application: Thick photoresist layers are generally needed for deep etching processes. Some applications require vertical sidewalls, other do not. Some are etched isotropically in plasmas, others are not.

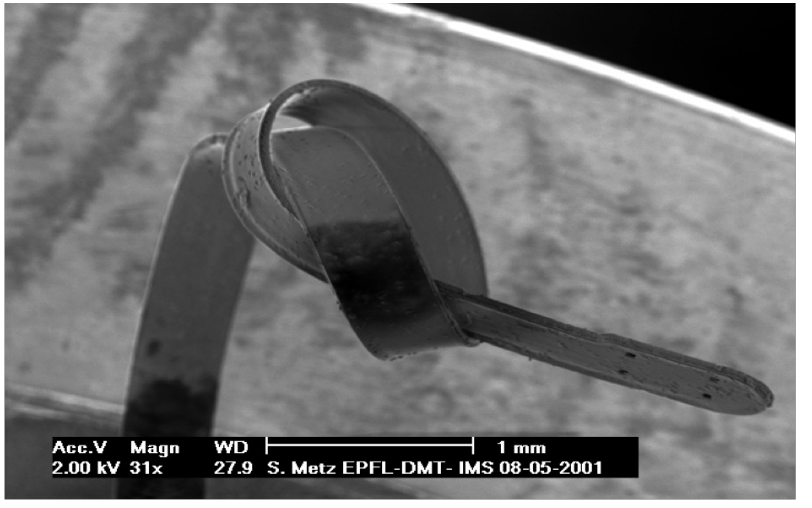


Photoresists for direct fabrication of microstrutures

Photoresists for the direct fabrication of polymer micro-components

Example photosensitive polyimide (PI) (it is a negative photoresist)



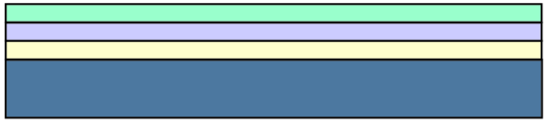


First used as a dielectric material for microelectronics, it is also used as a flexible material for the direct fabrication of MEMS.

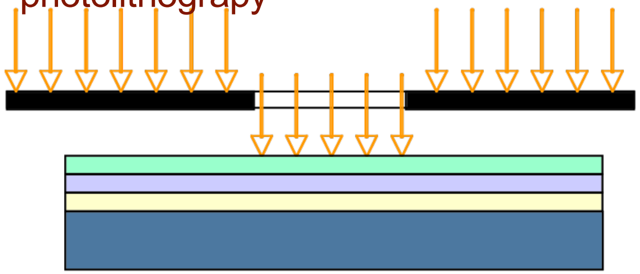
Photoresists for the direct fabrication of polymer micro-components

Example of NON photosensitive polyimide (biocompatible and implantable)

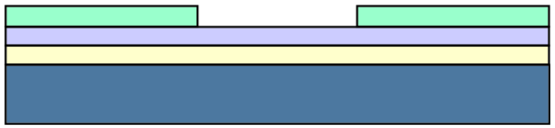
1- Si wafer + PI
+ SiO2 + positive photoresist



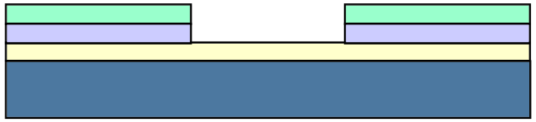
2- photolithograpy



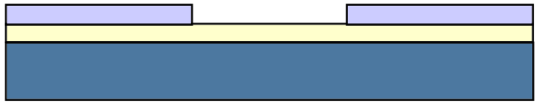
3- development



4- HF etching of SiO2

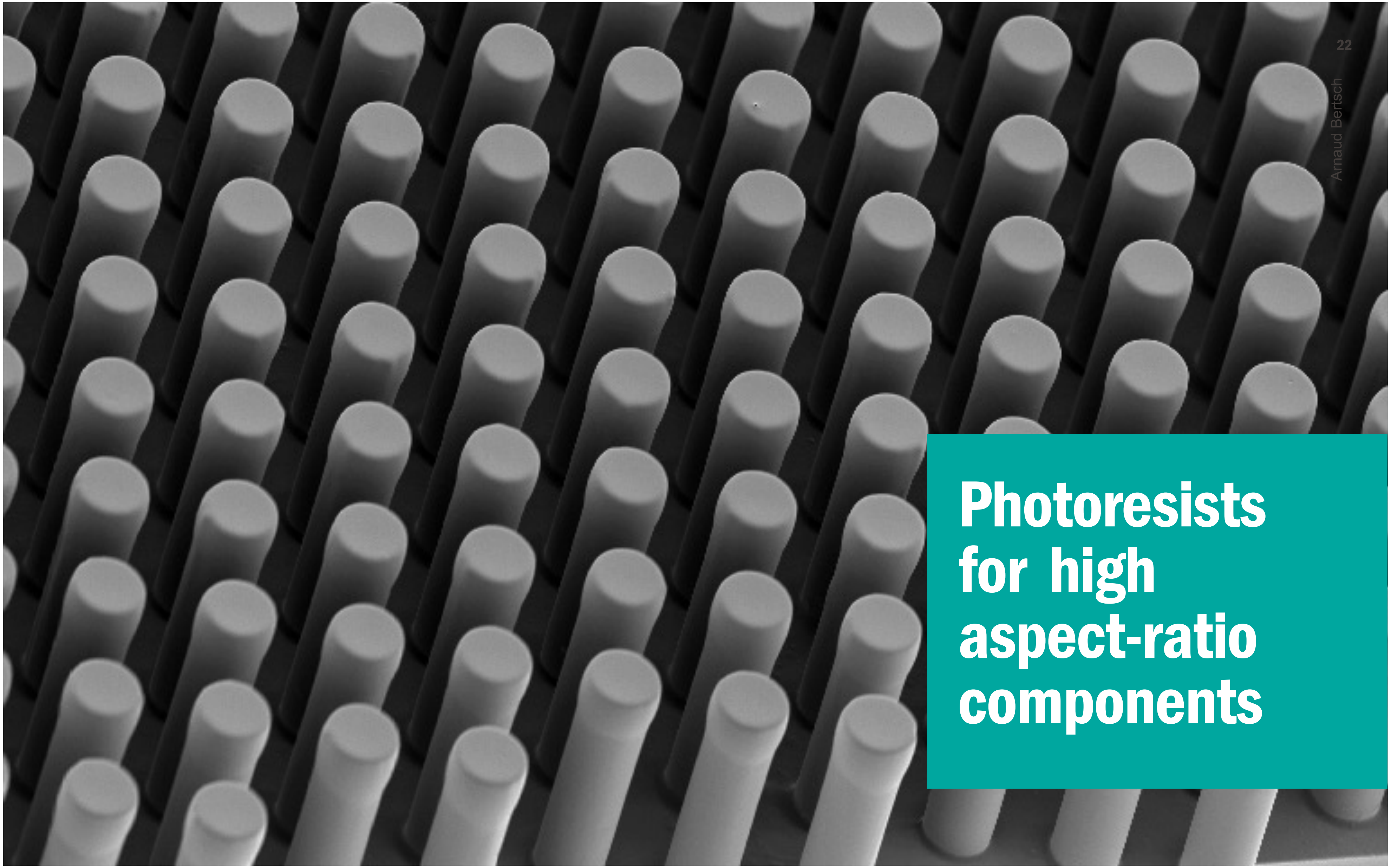


5- photoresist removal



6- O2 plasma etching

7- SiO2 removal (HF)



Photoresists for high aspect-ratio components

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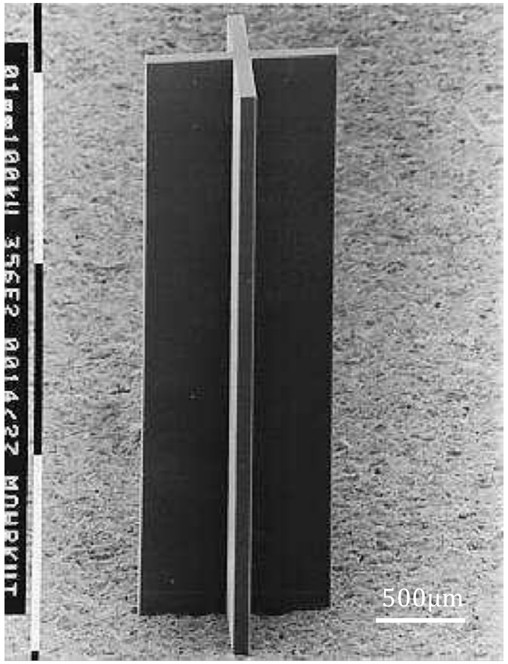
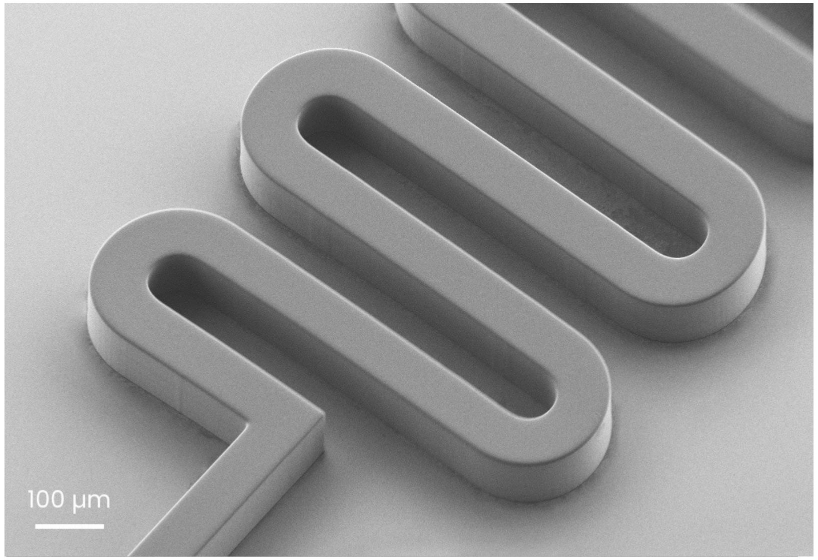
Photoresists for high aspect ratio components

Aspect ratio:

It is the ratio between the vertical and the lateral dimensions of an object



high aspect ratio

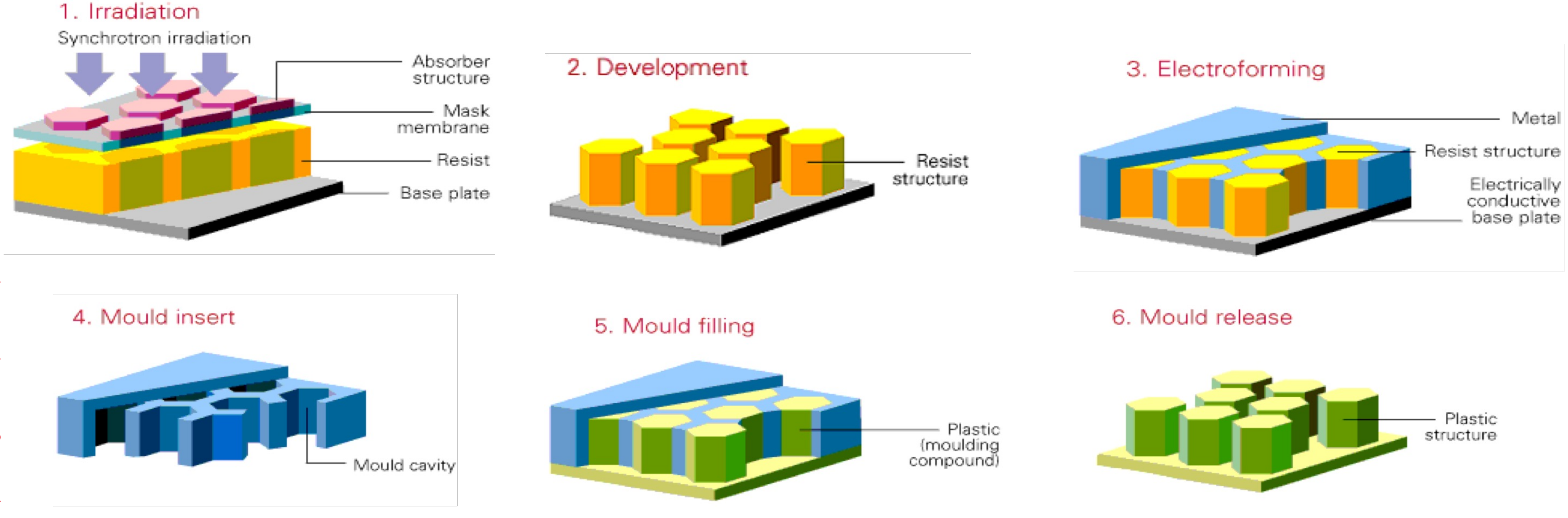


low aspect ratio

LIGA -X

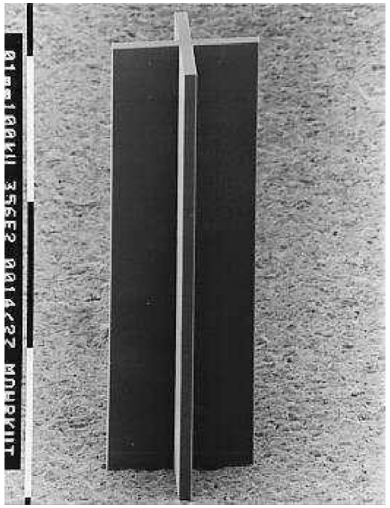
German acronym : *Lithographie, Galvanoformung, Abformung*

Initially, the LIGA process was developped to manufacture microstructures used for uranium enrichment.

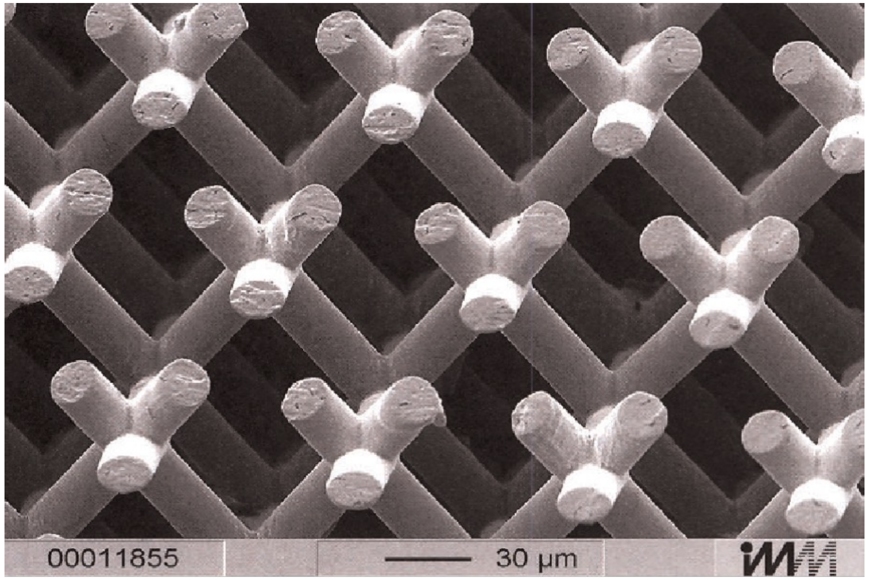


- Resolution better than one micron (200 nm)
- Layer thickness larger than 1 mm
- Very high aspect ratios (up to 500)
- PMMA, SU-8
- After molding: Metals, ceramics, polymers
- But: You need a synchrotron

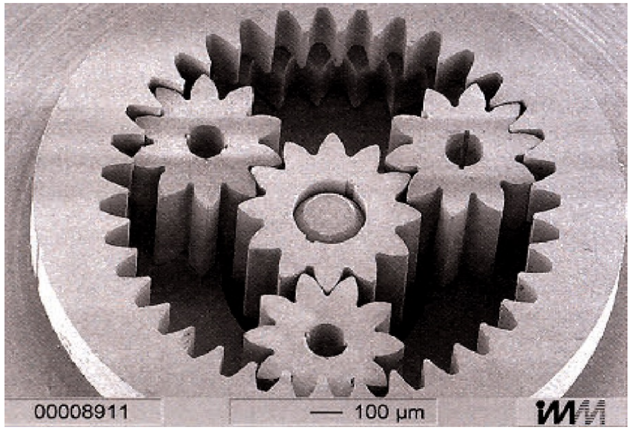
LIGA –X : Examples

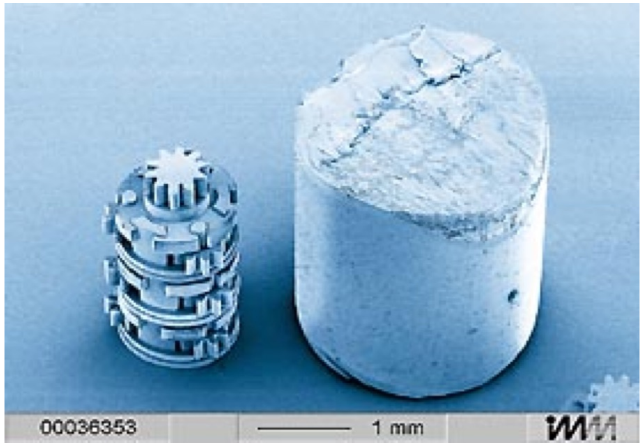


PMMA



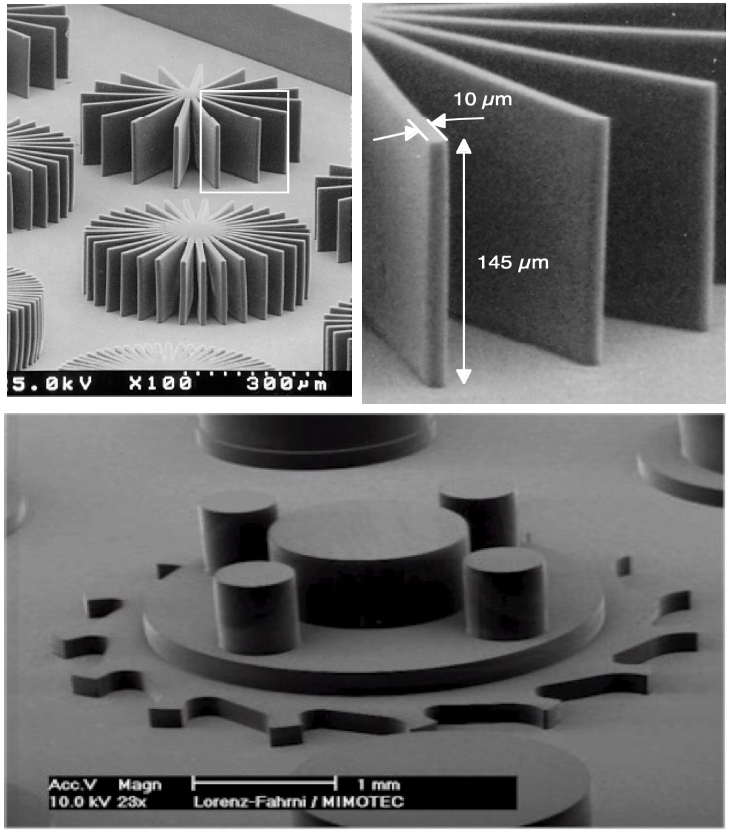
Negative resist
photonic bandgap material

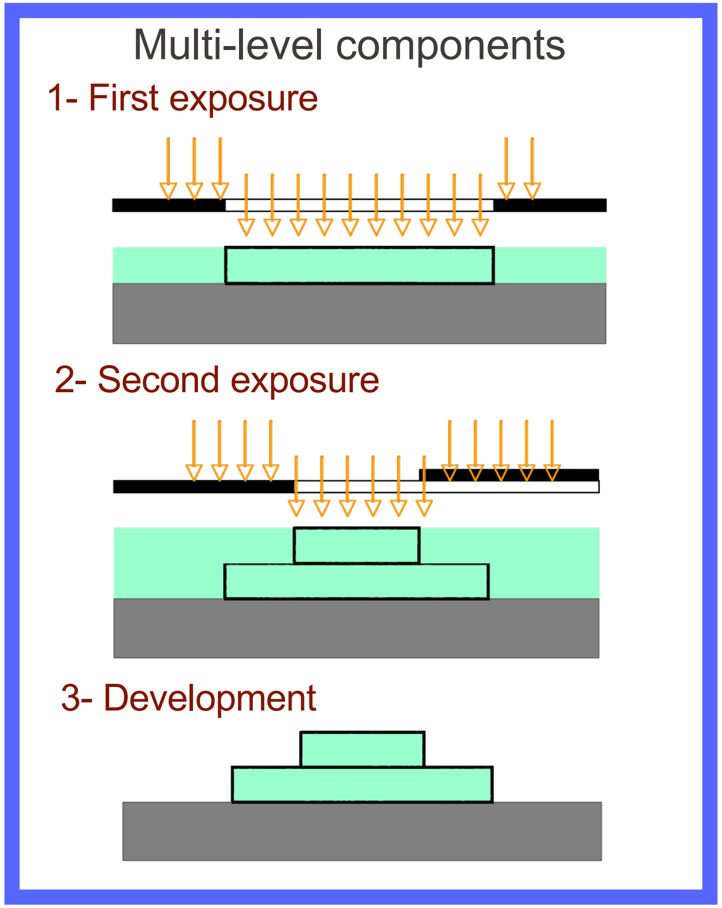




POM (Polyoxymethylene)
Molding

UV - LIGA : The SU-8 resist





- Negative resists (in particular SU-8)
- Resolution: 2 to 3 microns
- Resist thickness: 1 to 500 microns
- Aspect ratio: up to 40

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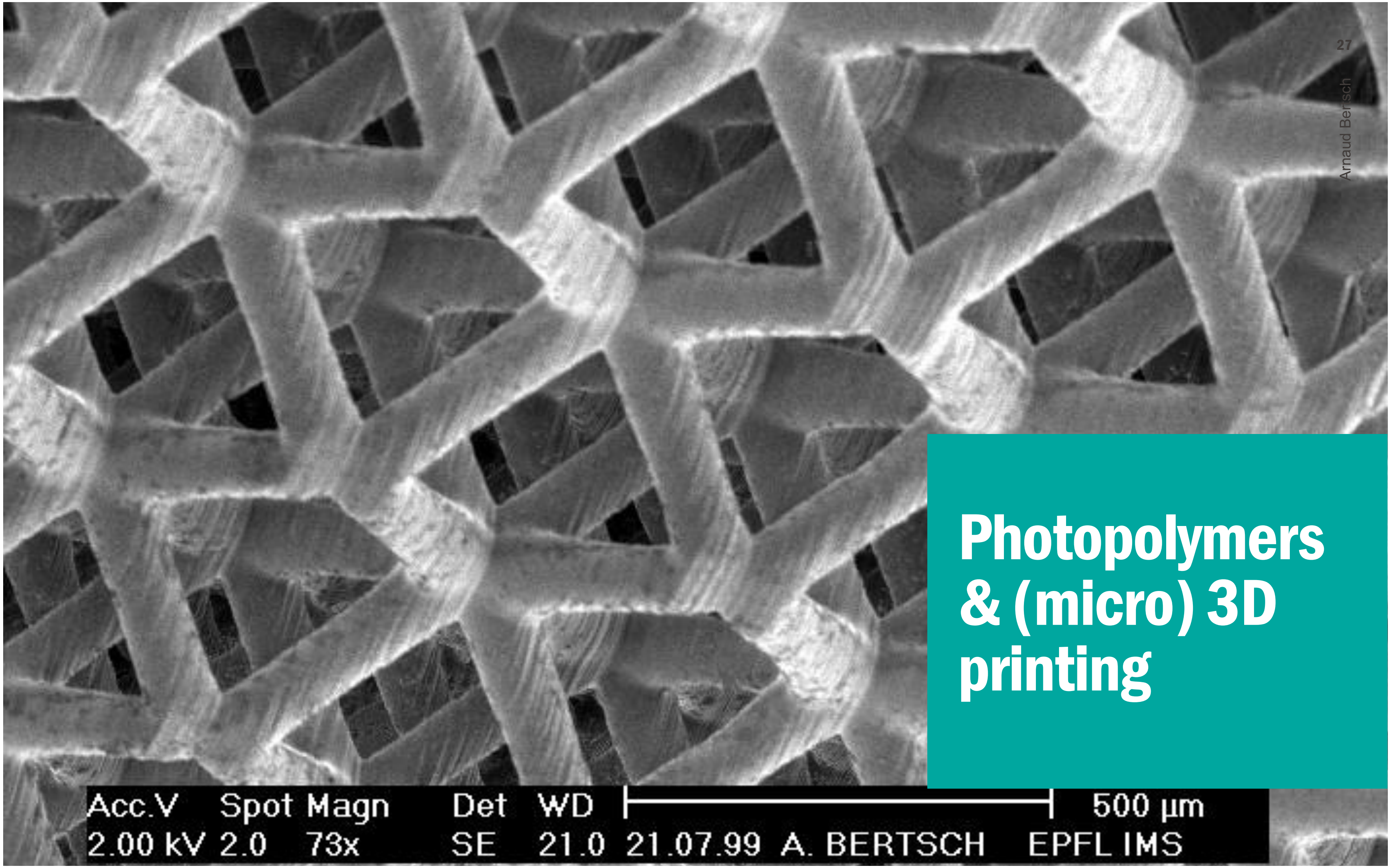

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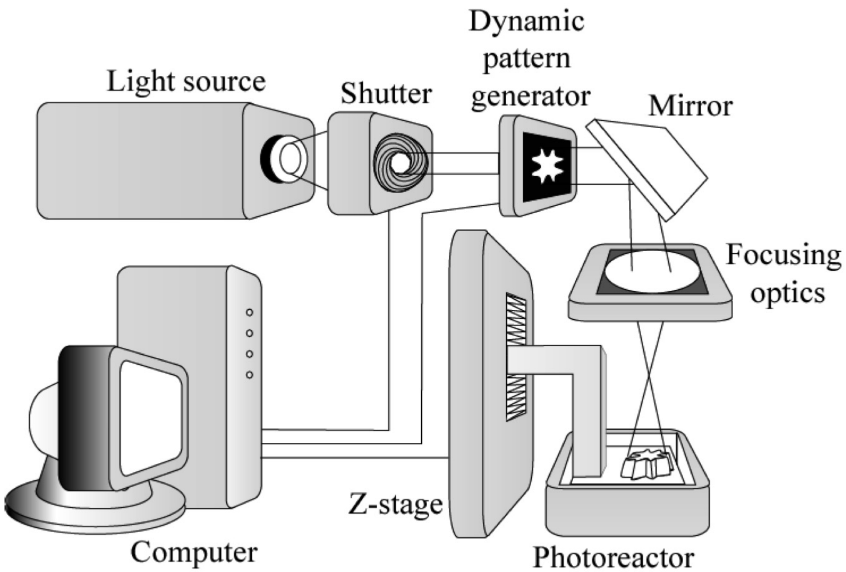
Photopolymers & (micro) 3D printing

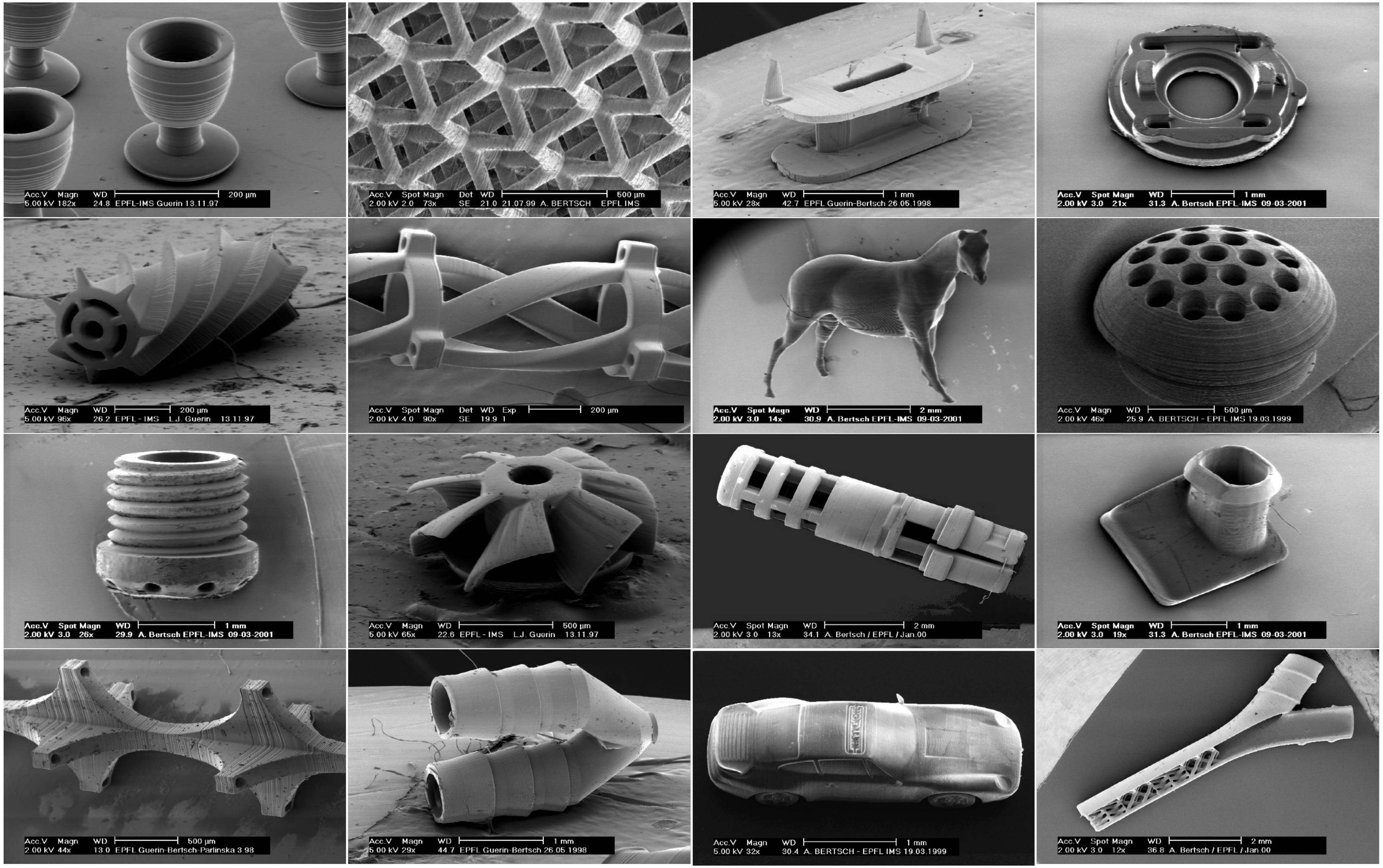
Photopolymers for stereolithography



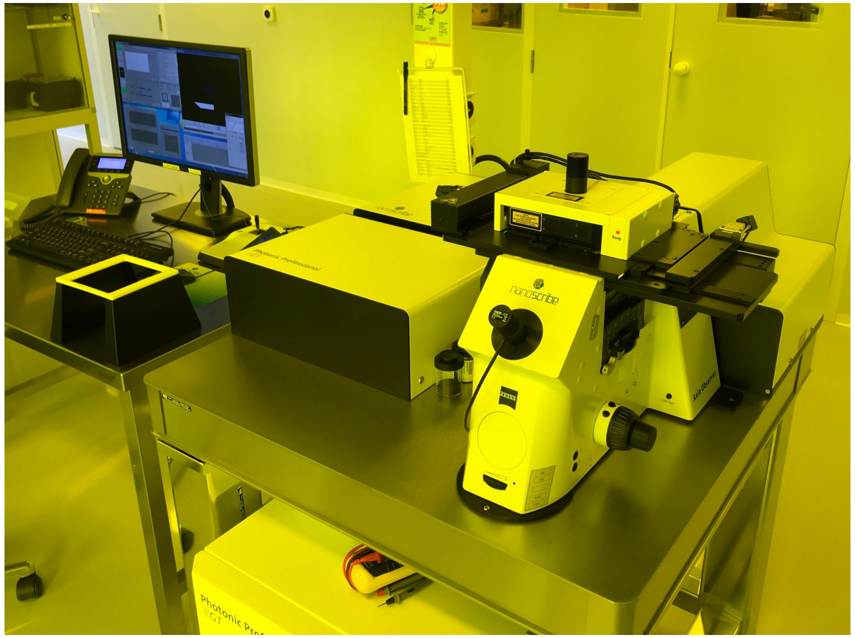
- Layer by layer fabrication
- The image of the layer being manufactured is projected on the liquid resin surface, which induces local polymerization.
- Once the irradiation of one layer is done, the object is moved vertically in the photoreactor, and a layer of liquid resin is spread on the last fabricated layer.
- The fabrication process is repeated until all layers are manufactured.

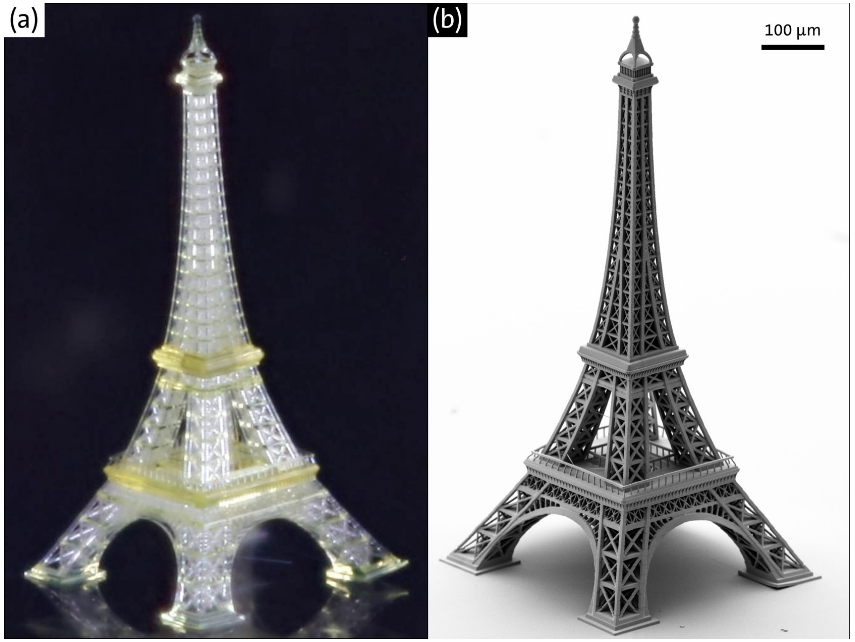
- 3D objects (really)
- Resolution: 200nm to 10 microns, depending on the process
- Limited choice of materials
- 3D components are unlikely to be used for molding
- Not wafer-compatible

Microstereolithography



TPP: Two-photon stereolithography (nanoscribe)

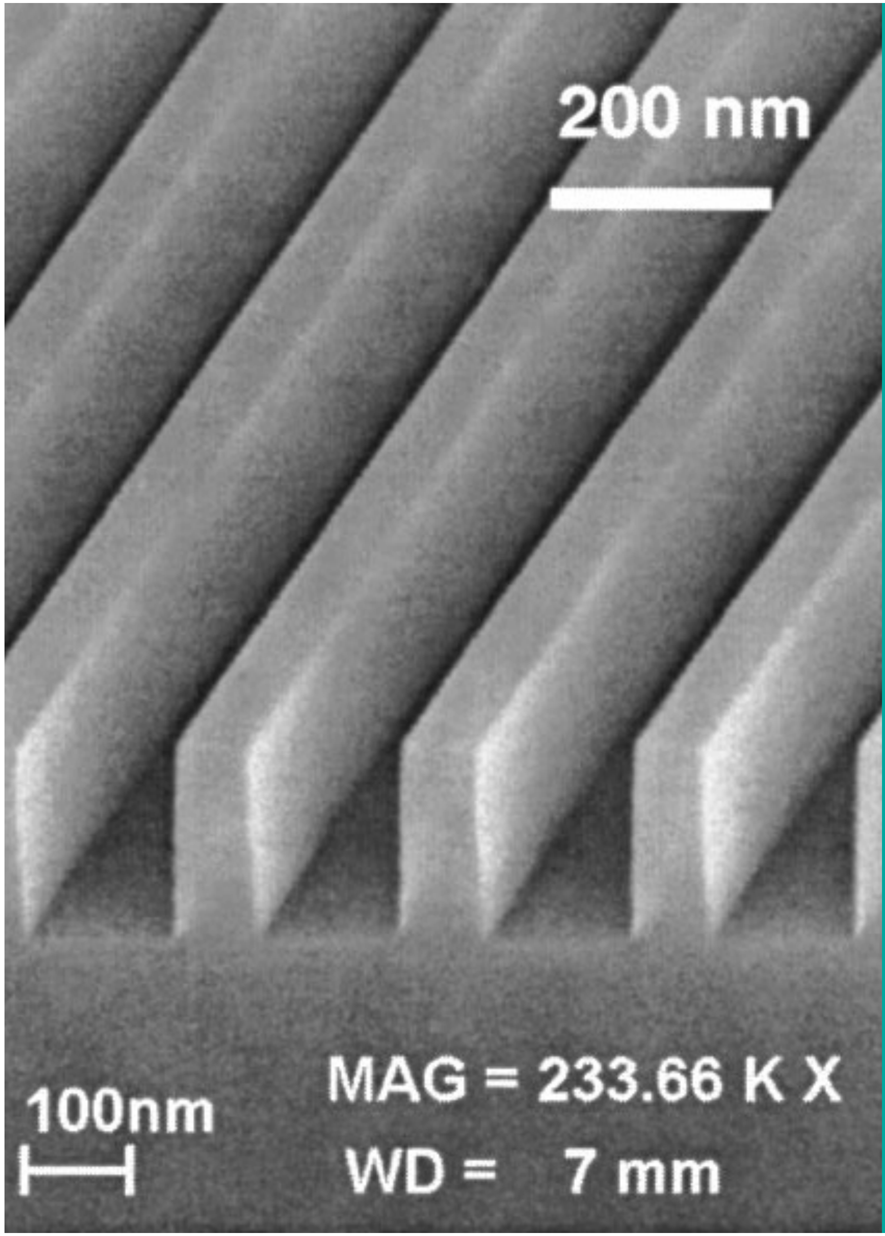




Fabricated CAD model

- The two-photon absorption requires that the combined energy of two photons matches the transition energy between the ground and excited states of the photoinitiator, it has a quadratic dependence on the light intensity, which confines this phenomenon to the area of the focal point, and allows to obtain polymerized volume elements of sub-micron resolutions.

- Printing speed: 1 to 10mm^3 per hour.



2- Thermoplastics

Used in industrial production of MEMS, with replication techniques

Generally used thermoplastics:

PMMA, PC, POM, PEEK

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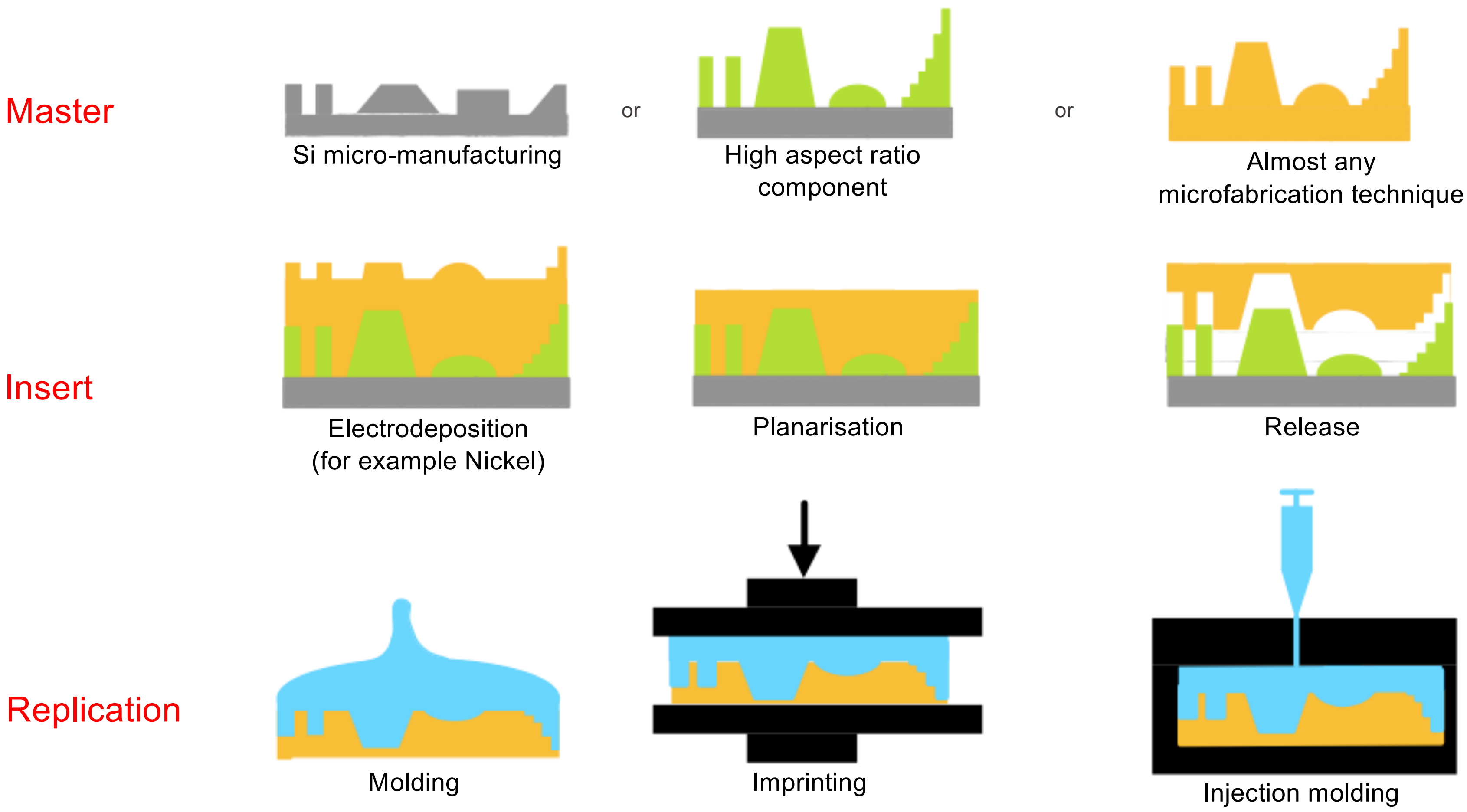
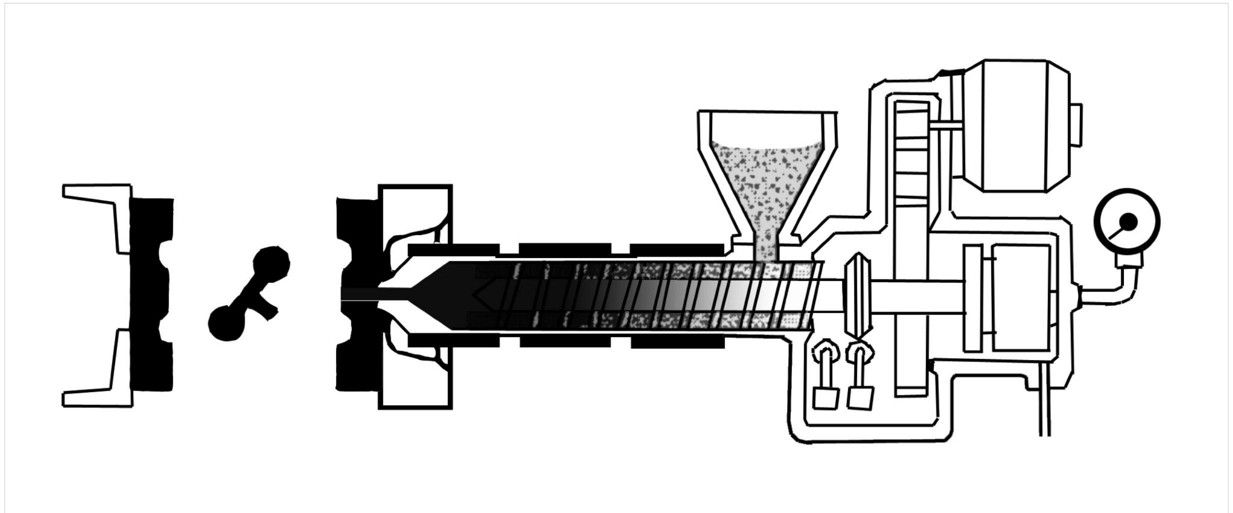
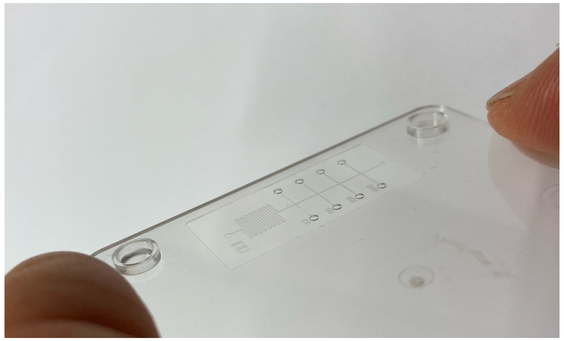
Micro replication



Thermoplastics Injection molding

Micro Injection Molding





- Micro Injection Molding uses the same machine as standard injection molding
- BUT mold inserts are adapted for microcomponents (adapted mold design, systematic use of molds with multiple cavities, shorter cycle durations, etc.)
- Molds can be manufactured by diverse micromanufacturing methods (Si micro-manufacturing, RIE X-LIGA, UV-LIGA, laser ablation, micro EDM, etc.)
- Generally used thermoplastics: PMMA, PC, POM, PA12, PSU, PEEK, LCP, etc.
- Aspect ratios: up to 30 / Details down to 0.9 microns / walls down to 20 microns

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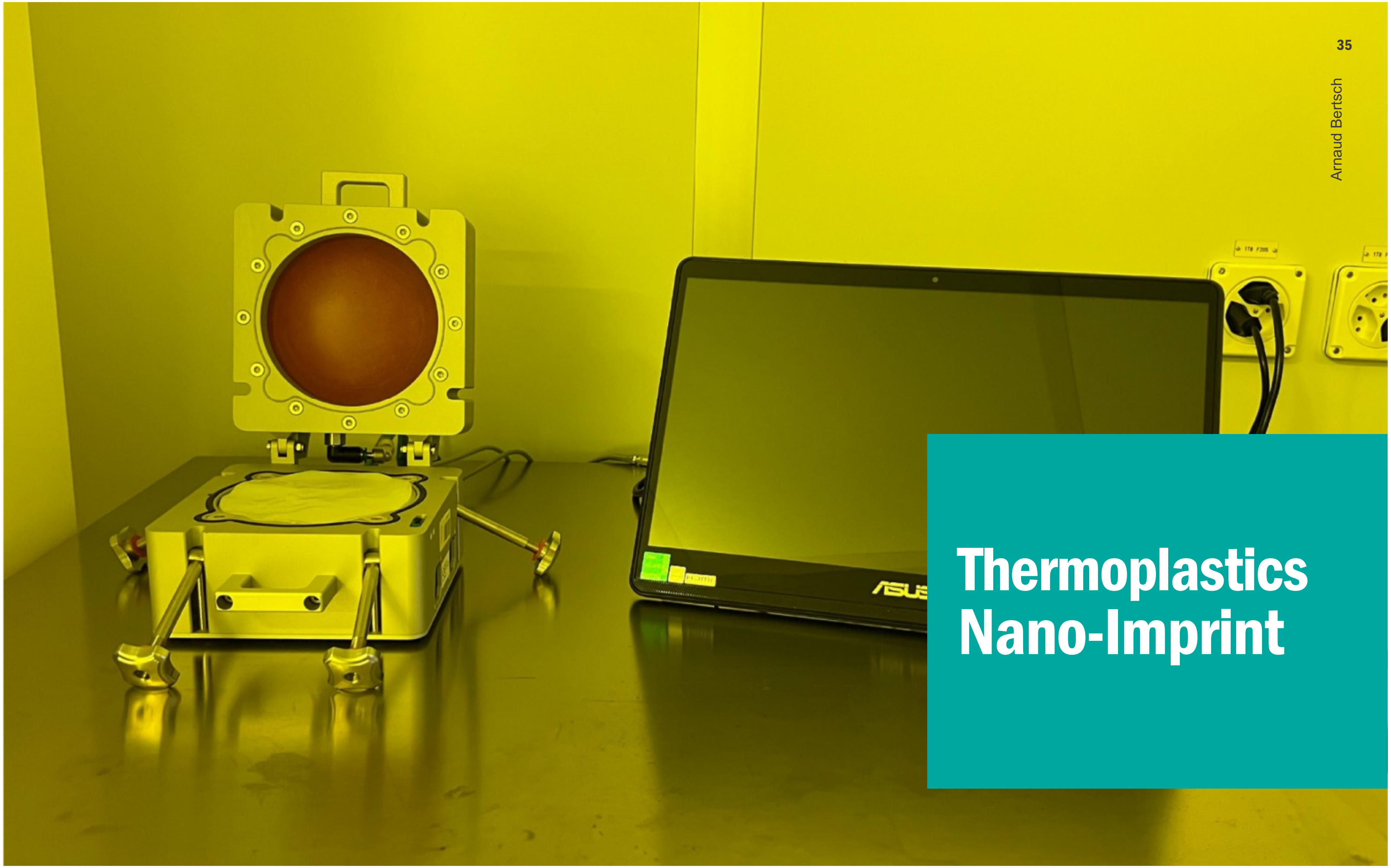

Thermoplastics Nano-Imprint

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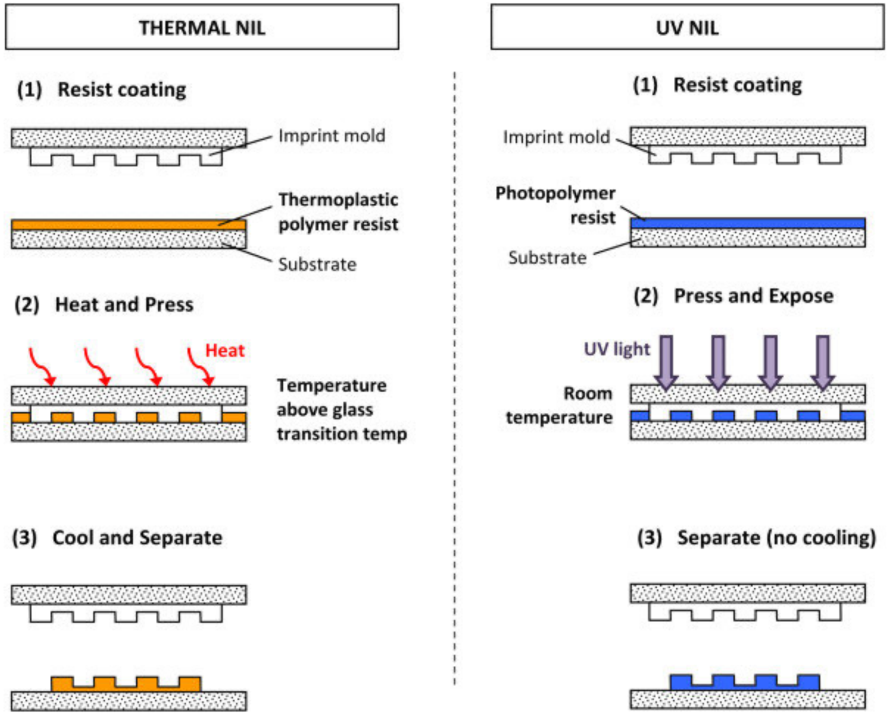
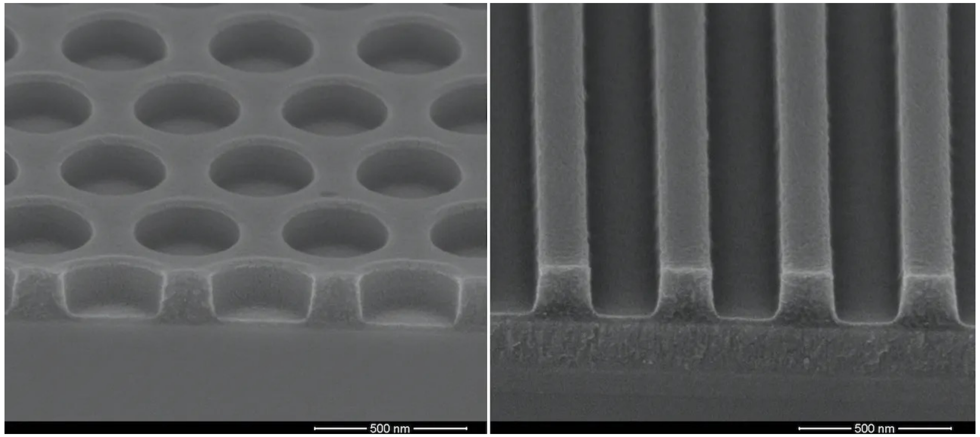
Nano-Imprint (hot embossing)





www.imec-int.com

- Replication of very fine details (resolution of a few nanometers)
- Large choice of materials (all thermoplastics)
- Molds can be fabricated by many microfabrication methods (Si micromachining, RIE, X-LIGA, UV-LIGA, laser ablation, micro EDM, etc.)
- Many applications (micro-optics, displays, high-density nanopatterns for DNA analysis, genomics,…)

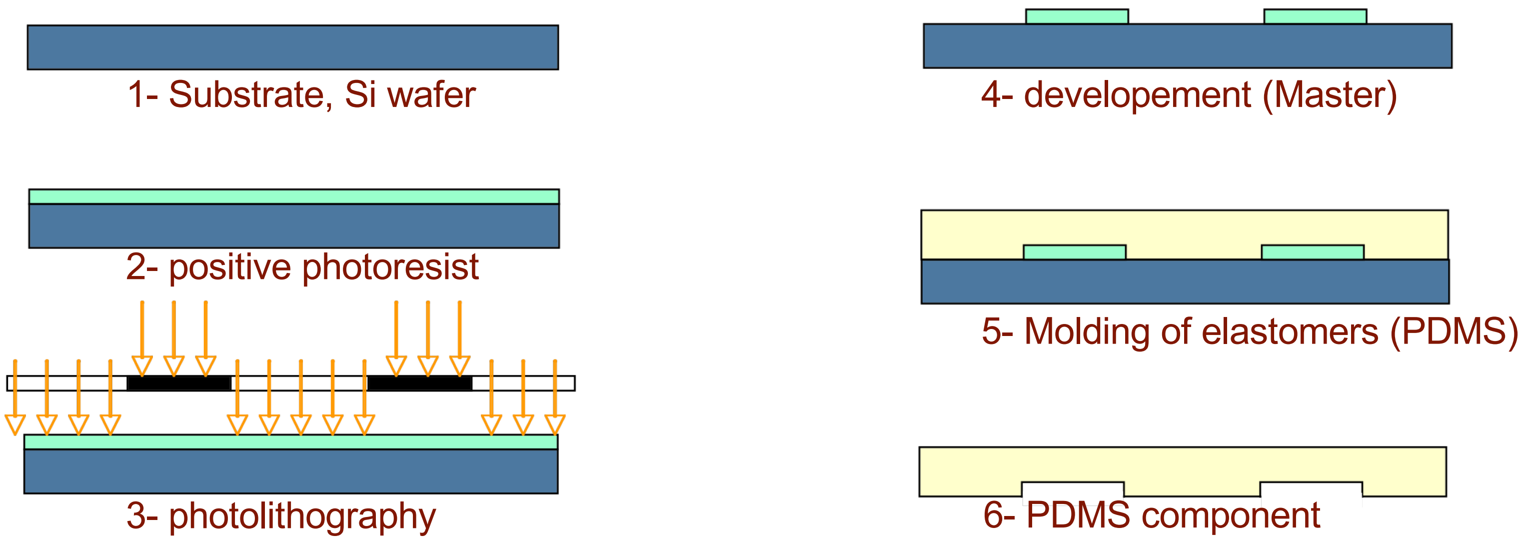
3- Elastomers

Molding

Polydimethylsiloxane (PDMS)

Rapid prototyping of Microfluidic devices

Molding of elastomers (PDMS)



- PDMS molding can be performed on a large variety of microstructured masters.
- PDMS can be irreversibly bonded to glass or pyrex by simple O2 plasma activation
- PDMS is very flexible and transparent
- Used for microfluidic prototyping (almost always)
- Often used for making wearable devices

PDMS, the advantages

- Easy molding of fluidic channels down to details of microns in dimensions
- Rapid fabrication, easy and low cost
- Very flexible material, but mechanically strong
- Optically transparent (from 240nm to 1100nm), which is valuable for optical microscopy
- Very permeable to gases

PDMS, the limitations

- Very permeable to water (evaporation), and to many gases.
- Highly hydrophobic (which is a problem for cell culture)
- Permeable to a large number of organic molecules. Swells when exposed to a large number of solvents.
- Chemically inert surface

Multilayer PDMS

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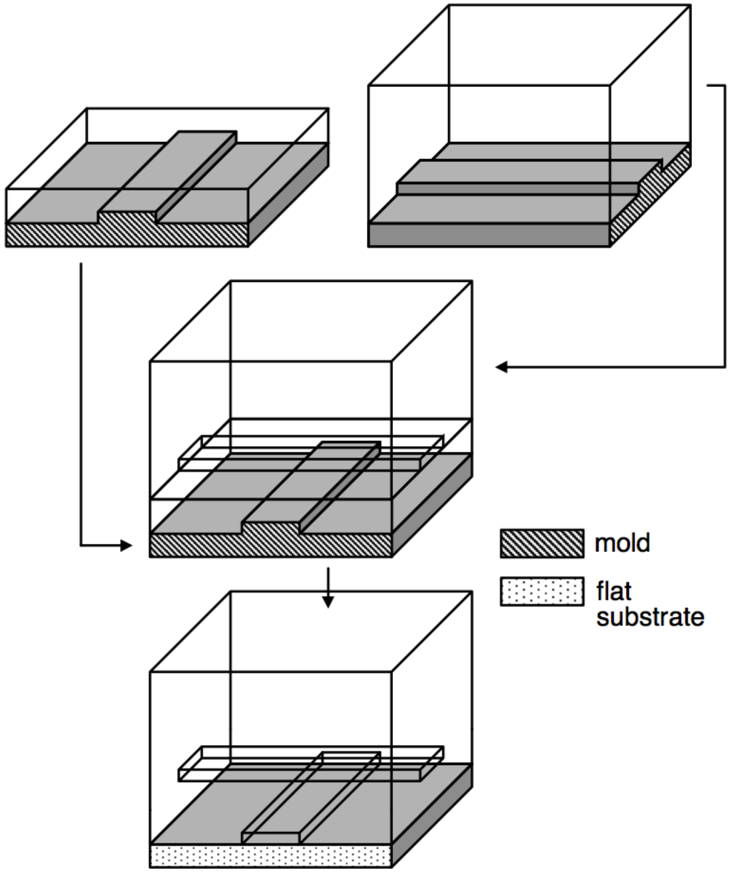

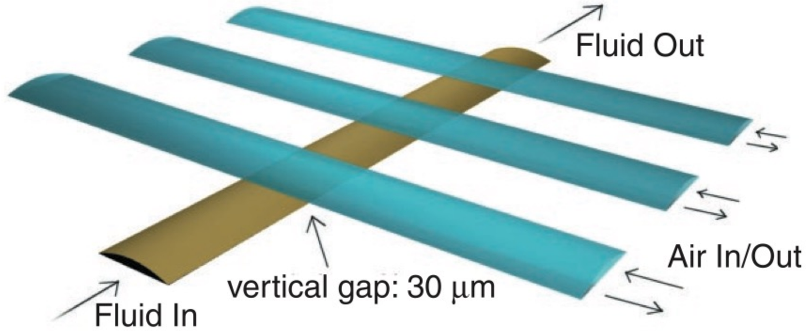

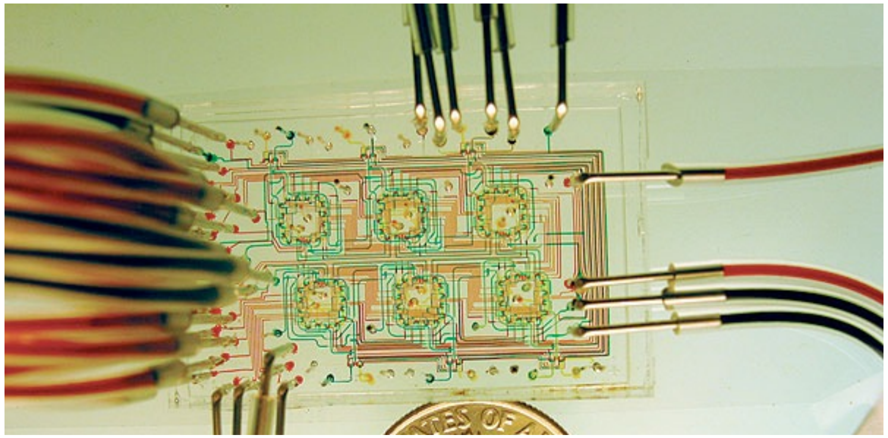

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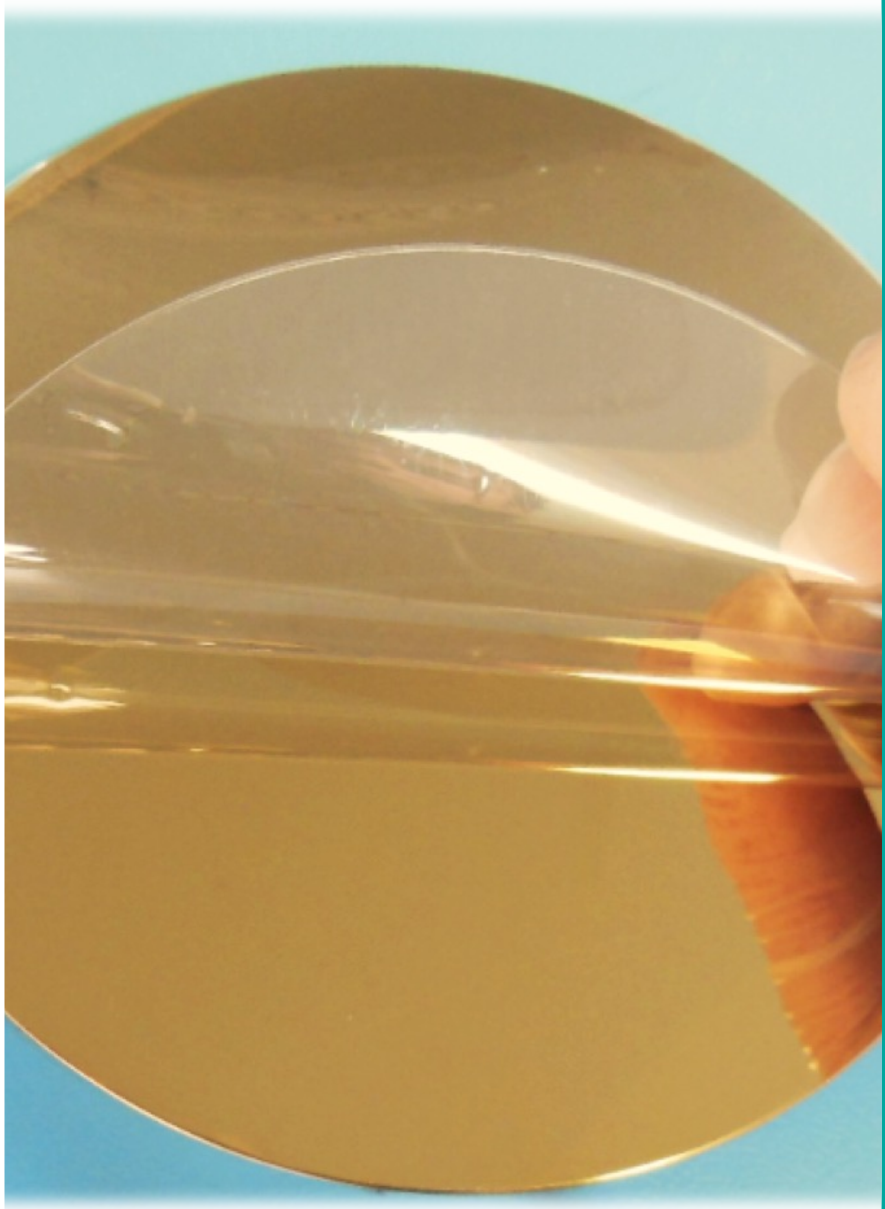


4- Special polymers

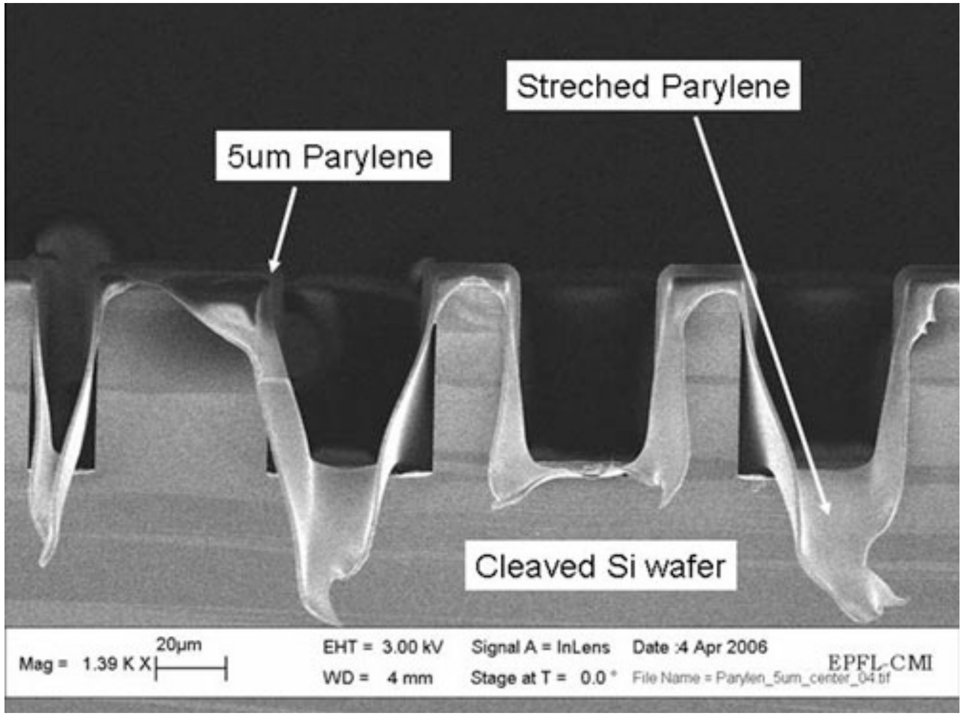
Thin films

Biocompatibility

Optical films

Parylene

- Gas-phase deposition (CVD)
- Conformal deposition
- Low dielectric constant
- Optically clear
- Bio-compatible
- Moisture barrier
- Does not induce constraints
- Electrical insulation
- Room temperature deposition

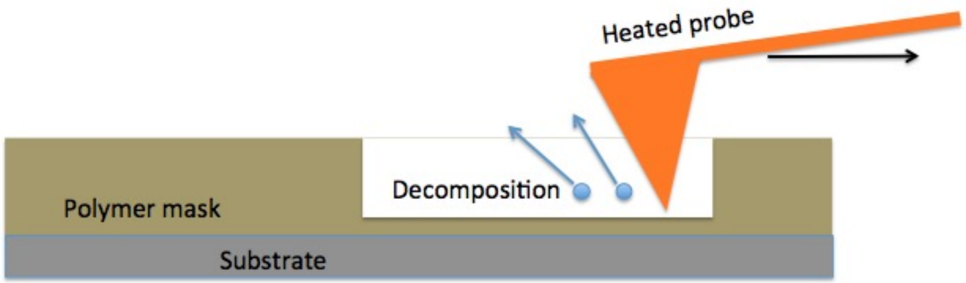


Used in an increasing number of applications (electronics, medical, aerospace, defense, automotive, telecom, etc..)

Polymers for Thermal Scanning Probe (t-SPL)

Arnaud Bertsch

- Sublimation of polymers
- No residues after polymer degradation
- Nano-meter thick structures
- Non planar substrates
- Printing in 2.5D



- PAA (Phthalaldehyde)
- Polycarbonates (for ex. Polyethylenecarbonate)
- PETN (Pentaerythritol tetranitrate, explosive)

In the future, which new trends in polymers for microfabrication?

- Bioresponsive Polymers (Change with pH or in the presence of specific bio-molecules, useful for bio-sensing or drug delivery systems)
- Stimuli-Responsive Polymers and shape-memory polymers (Change of properties when subjected to an external stimuli, such as light, heat, electric field gradient. Can be used as actuators or valves)
- Self-healing polymers (Self heal in case of cracks or dammage)
- Biodegradable polymers (For medical applications and environmental use)
- Conductive polymers (For example PEDOT:PSS can be used in soft electronics systems, for wearable electronics)
- Bioactive polymers (For example polymers which favor or inhibit cell adhesion, antiviral, anticancer, and antimicrobial activities etc.)
- Multifunctional polymers (both functional and structural material)
- Sustainable polymers (sustainably sourced, recyclable, etc.)

5- Applications

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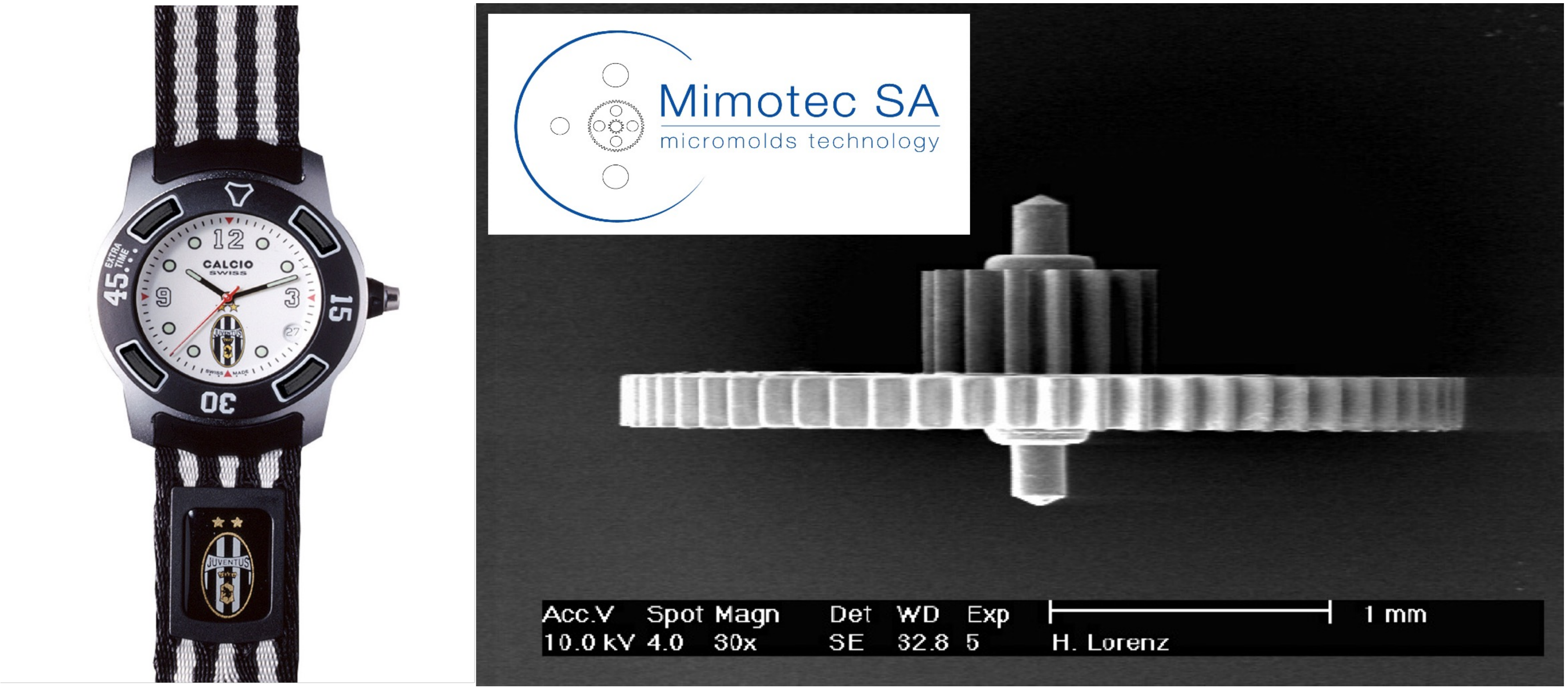
Directional deep brain stimulation electrode

- Non-photosensitive polyimide
- Biocompatible elastomers

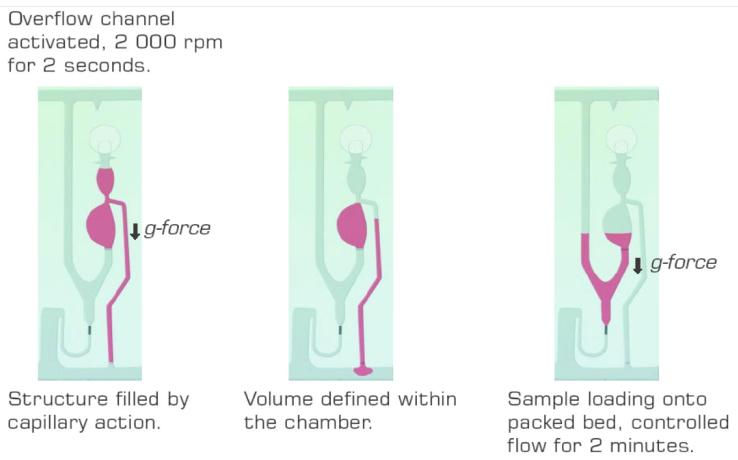
Watch components

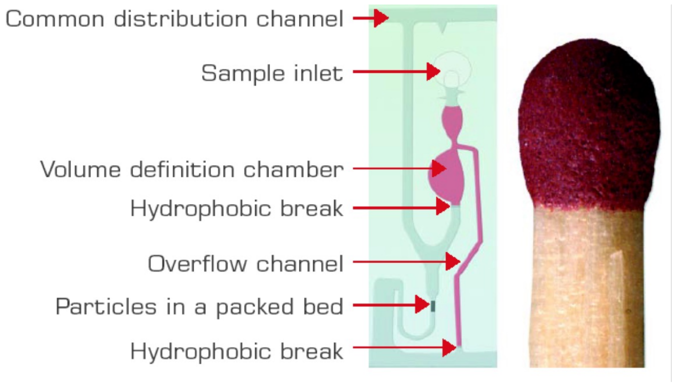


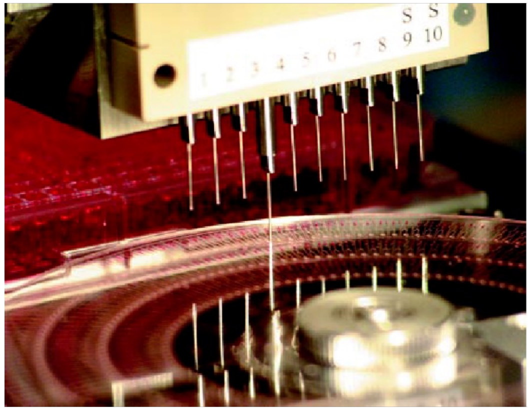
- UV-LIGA
- Injection molded for components production

Micro Fluidics: Centrifugal microfluidics on a disk

- Injection molded disk
- Capillarity to enter fluids
- Centrifugal forces

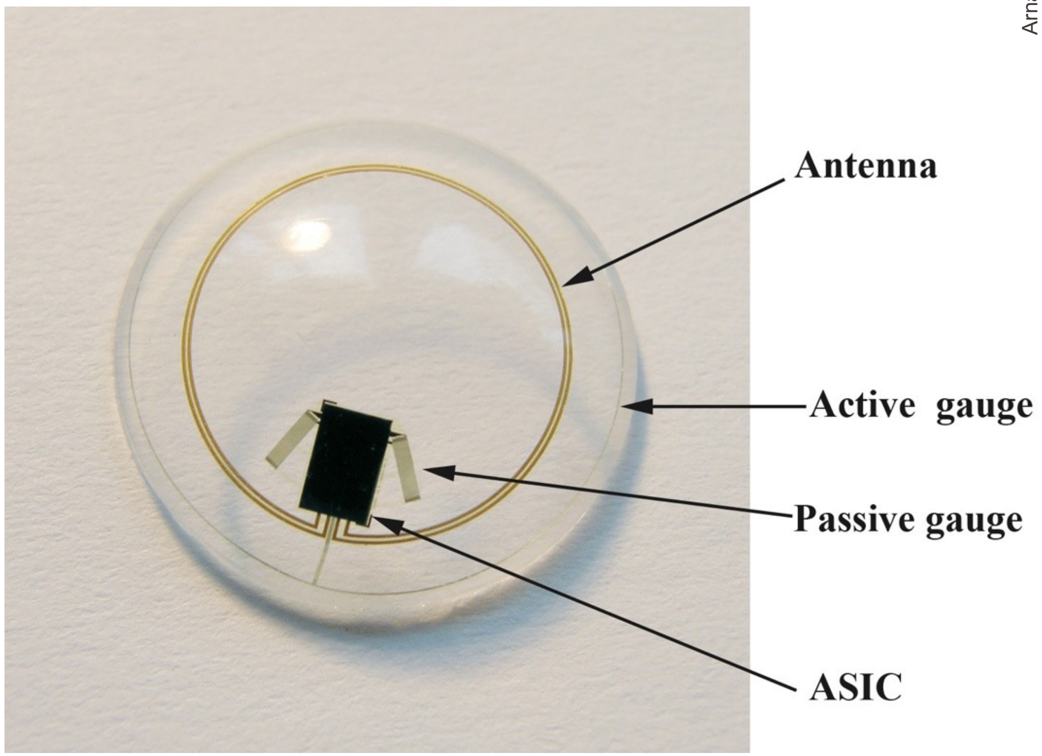


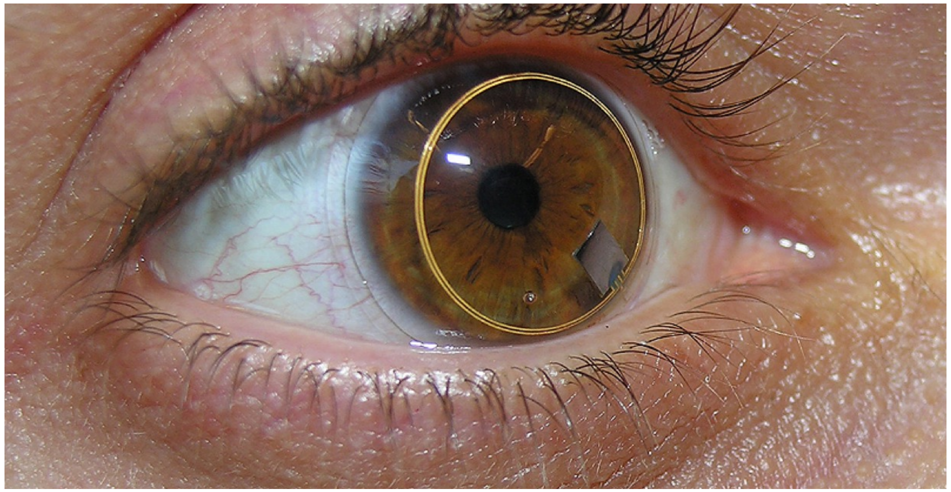




A soft contact lens for Glaucoma detection

- Non photosensitive Polyimide
- Molding of biocompatible elastomers
- Two-step molding





Conclusion

- Polymers will not replace silicon.
- They open the way for new applications fields of MEMs.
- High volume production of MEMS by replication
- Biomedical applications
- Cell-based applications
- Microfluidics

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Thank you

École
polytechnique
fédérale
de Lausanne