Bulk Material Micro-structuring and Surface Modifications

Micro-structuring

- mechanical
- electrical (EDM)
- chemical
- irradiation
- electrochemical

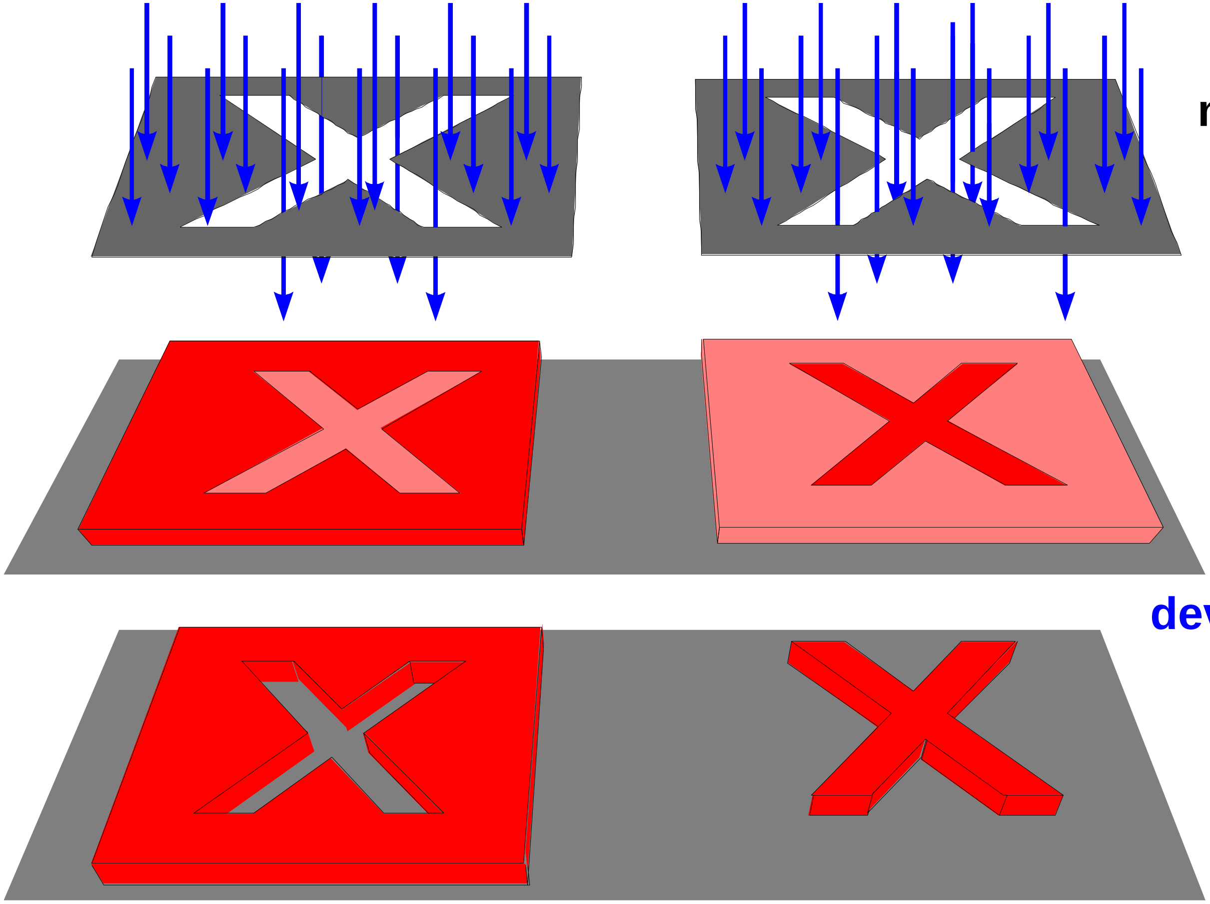
Surface modification

- electrodeposition
- PVD/CVD
- polymer coatings
- chemical
- SAMs

Materials

- metals
- ceramics
- glass
- semiconductors
- polymers

Principle of Optical Lithography



mask

UV-exposure

of resist

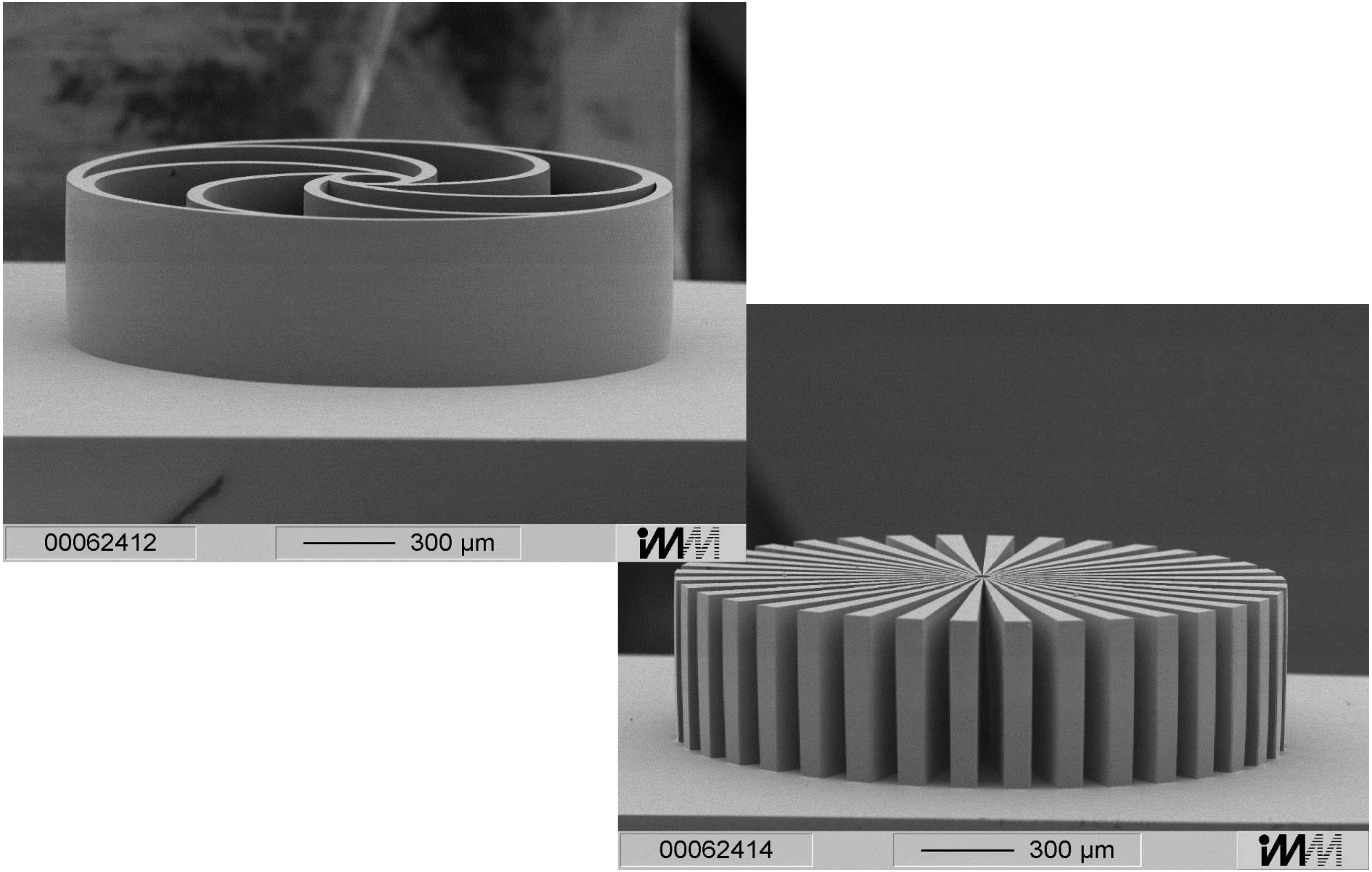
development

result

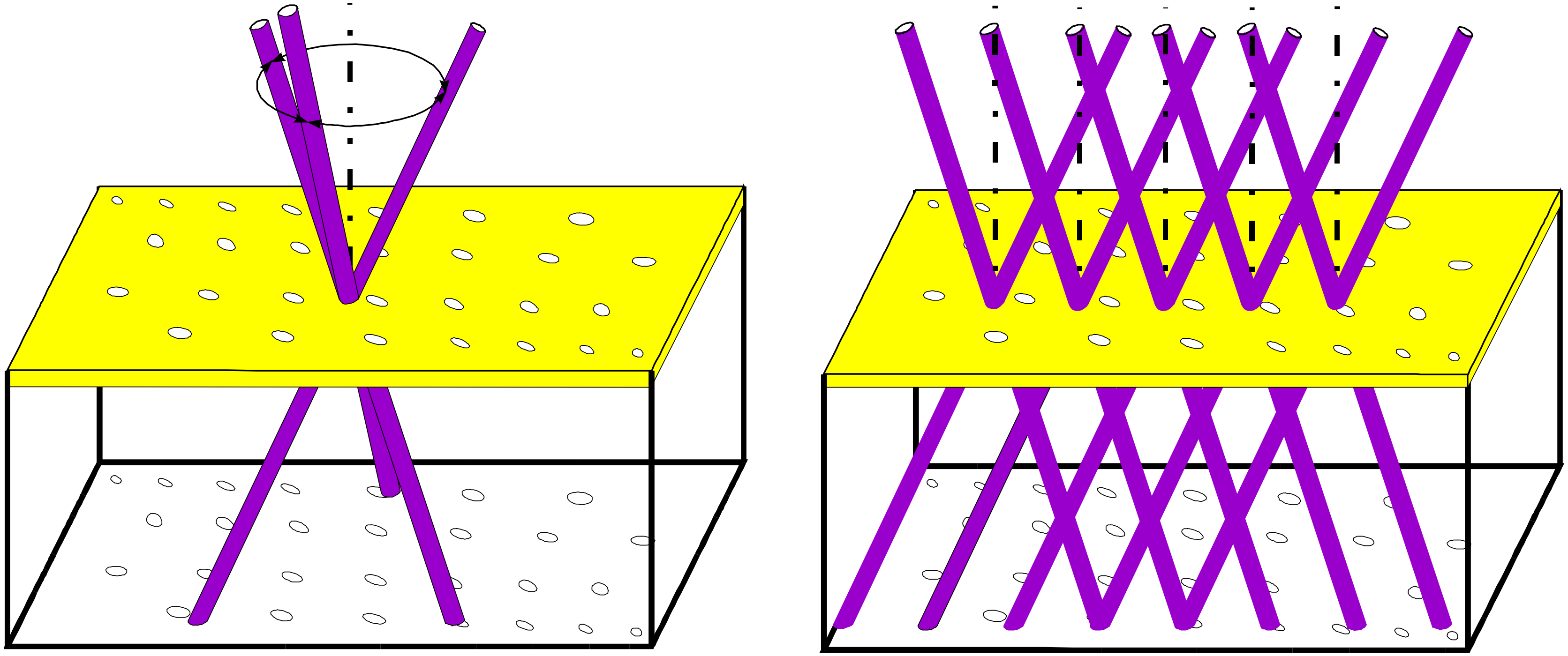
positive

negative

SU-8 Microstructures to be Filled by Electroforming



Fabrication of Photonic Band Gap Structures by X-ray Lithography

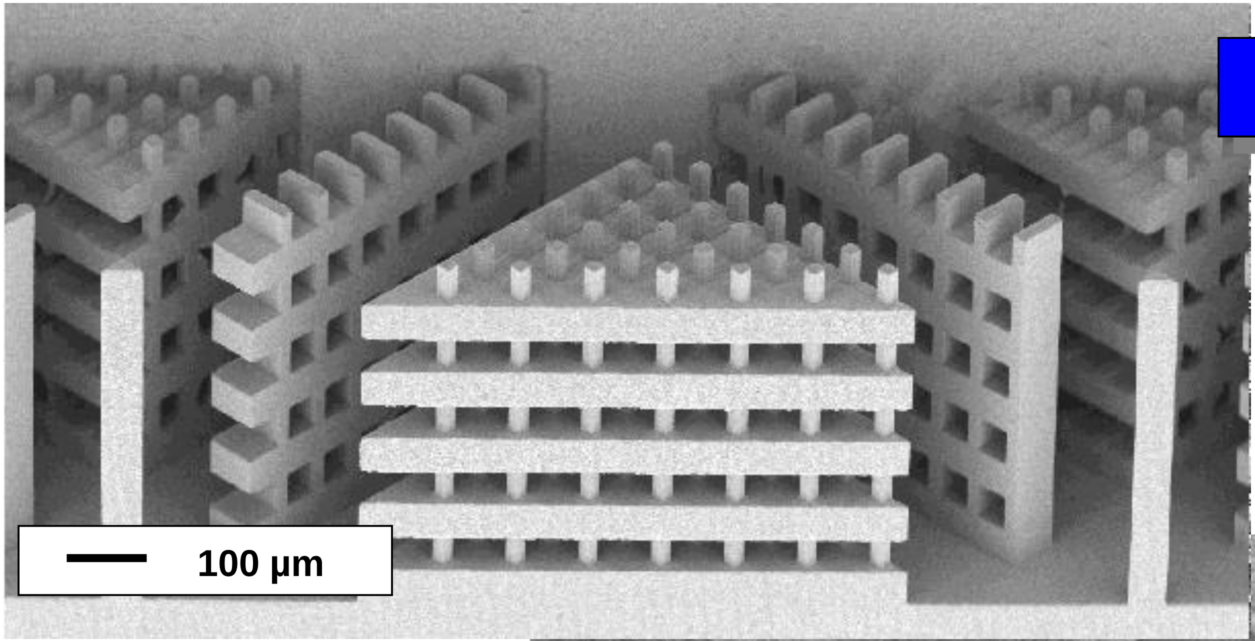


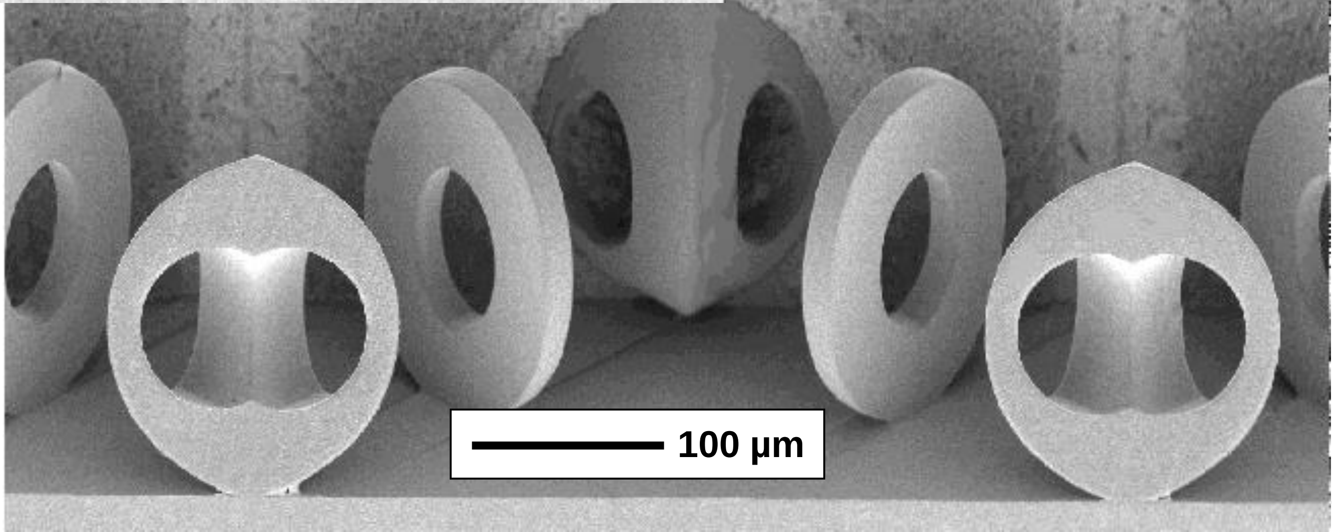
Generation of a fcc type lattice structure

by triple inclined irradiation

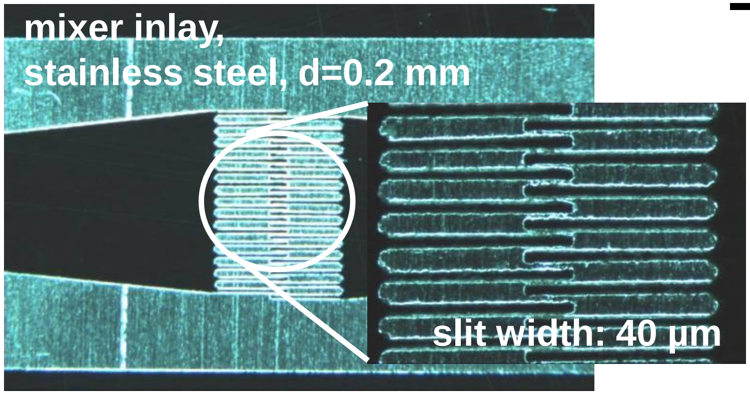
3-D Microstructures in PMMA

Made by LiGA - technique





Nd:YAG Laser Micromachining



mixer inlay,
stainless steel, d=0.2 mm

slit width: 40 µm

Workstations:

Laser: Nd:YAG (doubled)

Wavelength: 1064 (532) nm

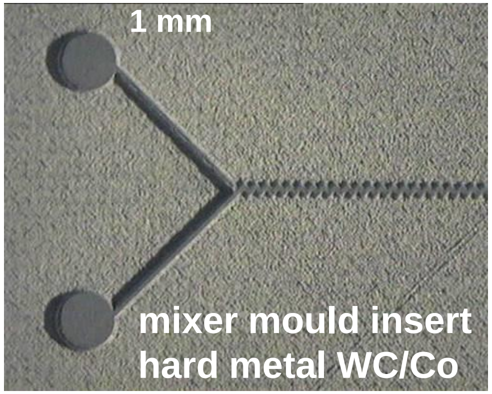
Pulse length: 100 ns

Pulse energy: 10 (1) mJ, max.

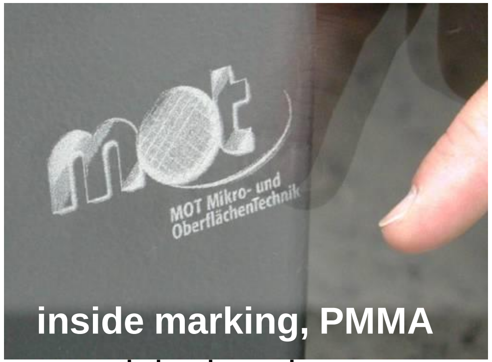
XYZ-table, 10 µm accuracy

Scanner, feed rate up to m/s

Applications:



mixer mould insert
hard metal WC/Co



inside marking, PMMA

Cutting & Drilling:

- sublimation cutting, small kerf width
- material: metals, ceramics silicon, polymers (filled)
- small hole diameters (>10 µm, aspect ratio <100)

Laser Milling:

- rapid tooling/prototyping
- material: metals, ceramics silicon, polymers (filled)
- high resolution (down to 30 µm structure size)

Laser Engraving:

- fast marking
- polymer inside marking
- high processing speed

Eximer Laser Micromachining

EXITEC-Workstation:

Laser: Excimer LPX110i

Wavelength: 193 nm

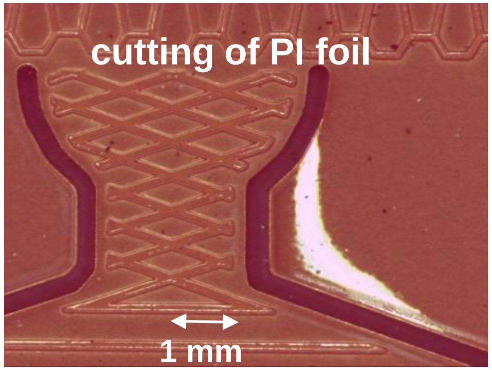
Pulse length: 17 ns

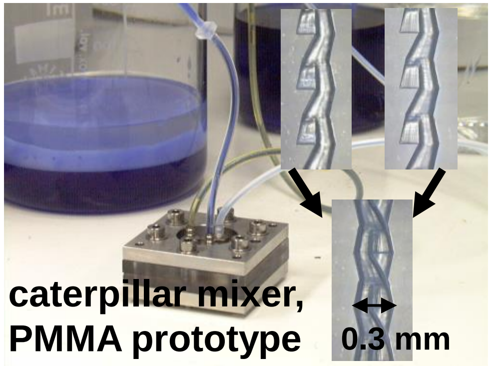
Pulse energy: 200 mJ (max.)

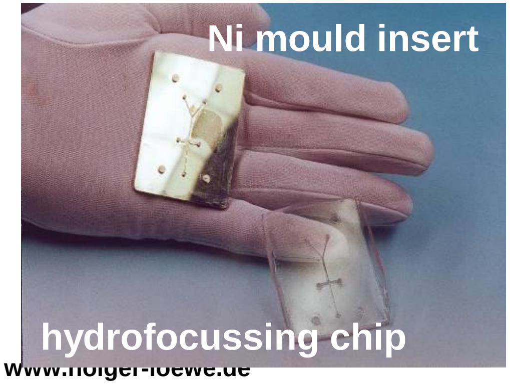
XYZ-table, 1 µm accuracy

Mask projection

Applications:


cutting of PI foil


caterpillar mixer, PMMA prototype


Ni mould insert

hydrofocussing chip

Polymer Machining:

- ablation (depth 5 µm to 1 mm, resolution <5 µm R_a>0.2 µm, quasi 3D)
- fine cutting
- drilling (various hole shapes)

Rapid Prototyping:

- microfluidic channels
- polymer bio chips
- microoptical structures

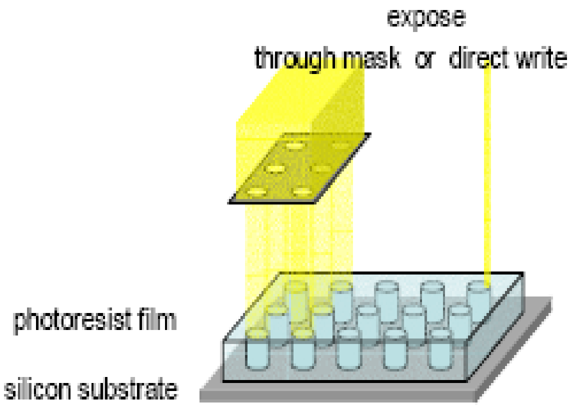
Laser LIGA:

- mould insert fabrication
- material: Ni, Cu
- large number production (hot embossing, injection moulding)

Direct Laser Writing: Introduction

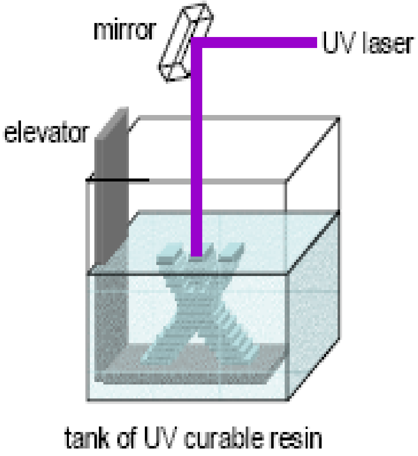
Conventional Lithography

- structures are 3-D representations of 2-D images
- spatial resolution of 20 nm – 1 μm depending on radiation source:



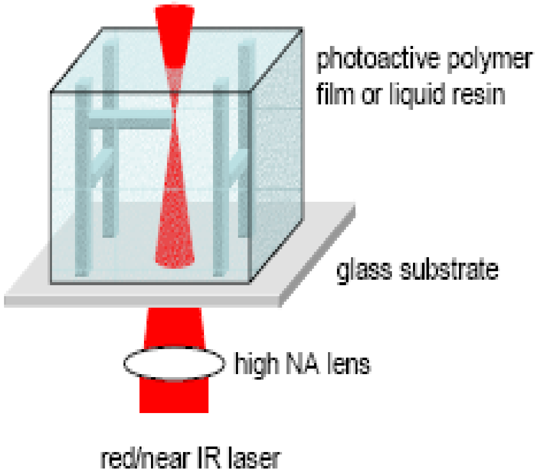
Micro Stereolithography

- one-photon process
- 3-D structures
- layer-by-layer additive process
- spatial resolution of >10 μm

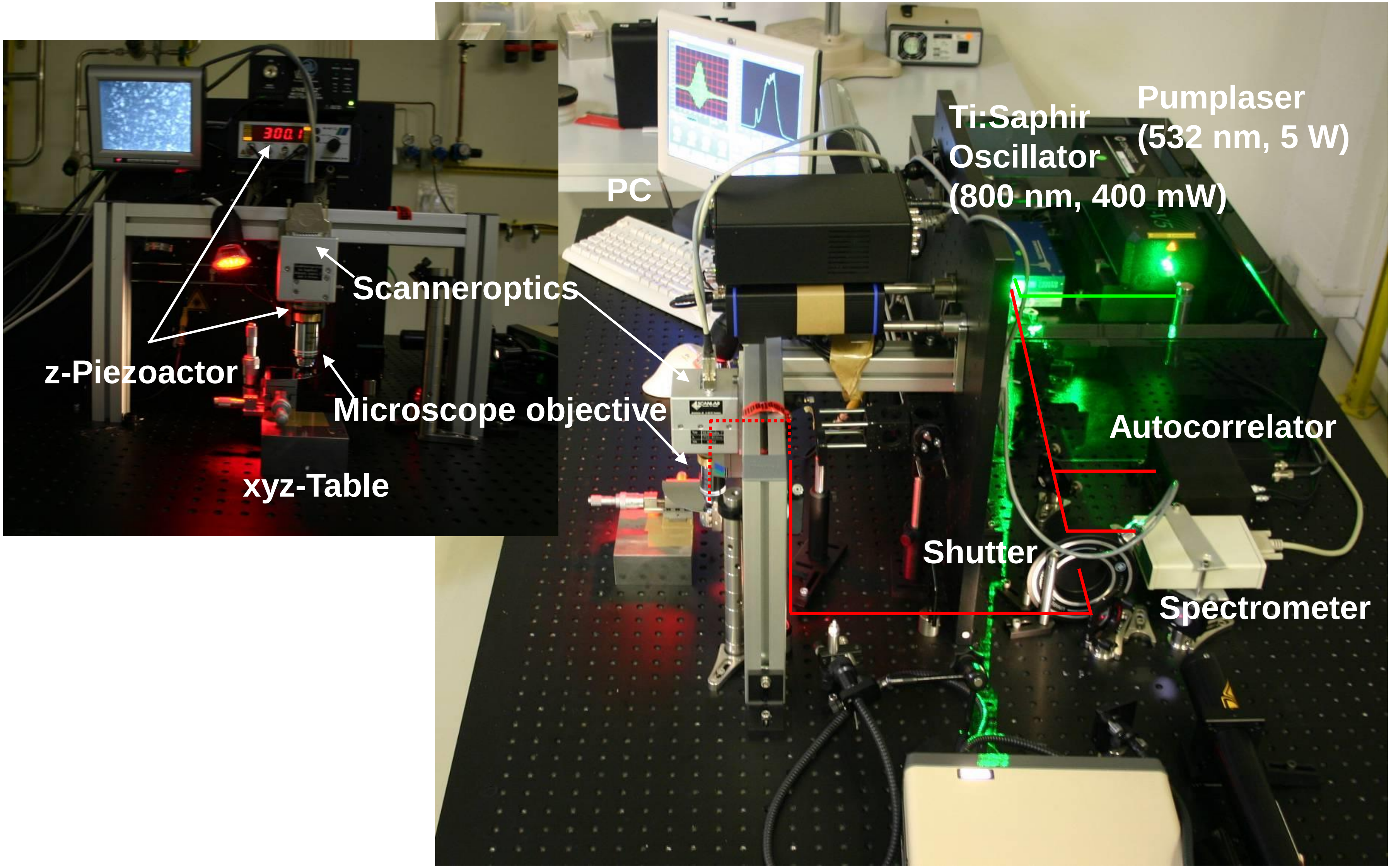


Two-Photon Microfabrication

- a single intuitive step
- 3-D structures
- spatial resolution of < 200 nm



Direct Laser Writing: Experimental Setup

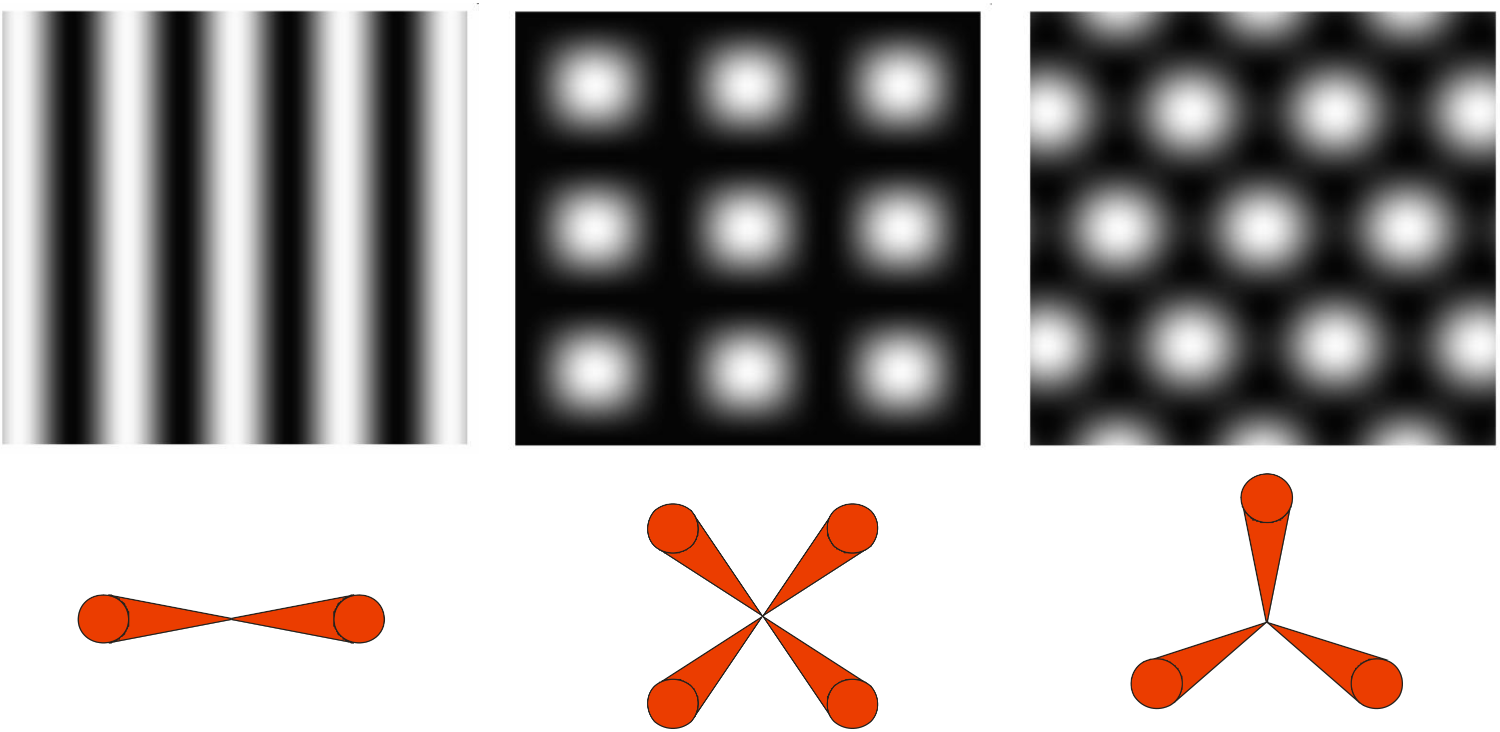


Interference Lithography: Working Principle

If two (or more) coherent laser beams overlap in space, an interference pattern with distinct bright and dark regions is generated.

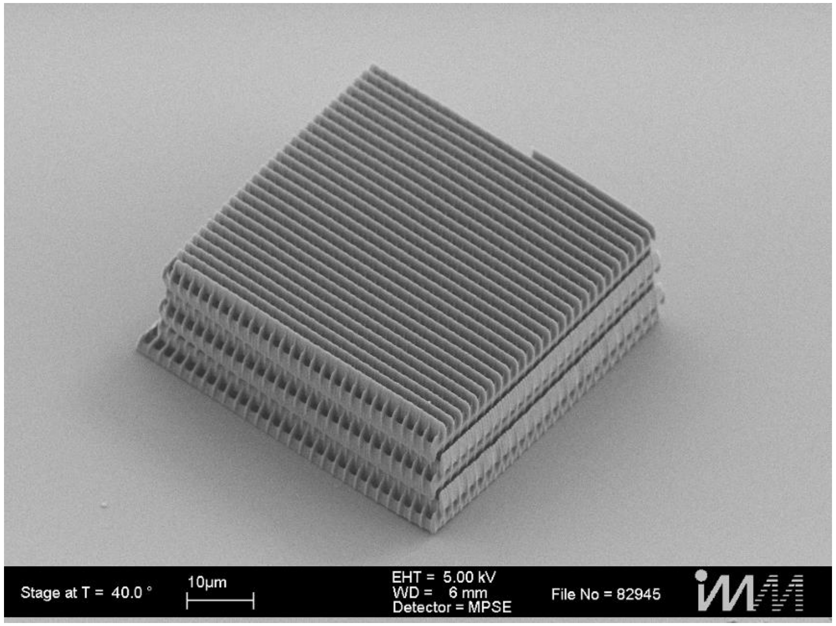
Idea: Expose a photosensitive polymer layer (photoresist) with this pattern.

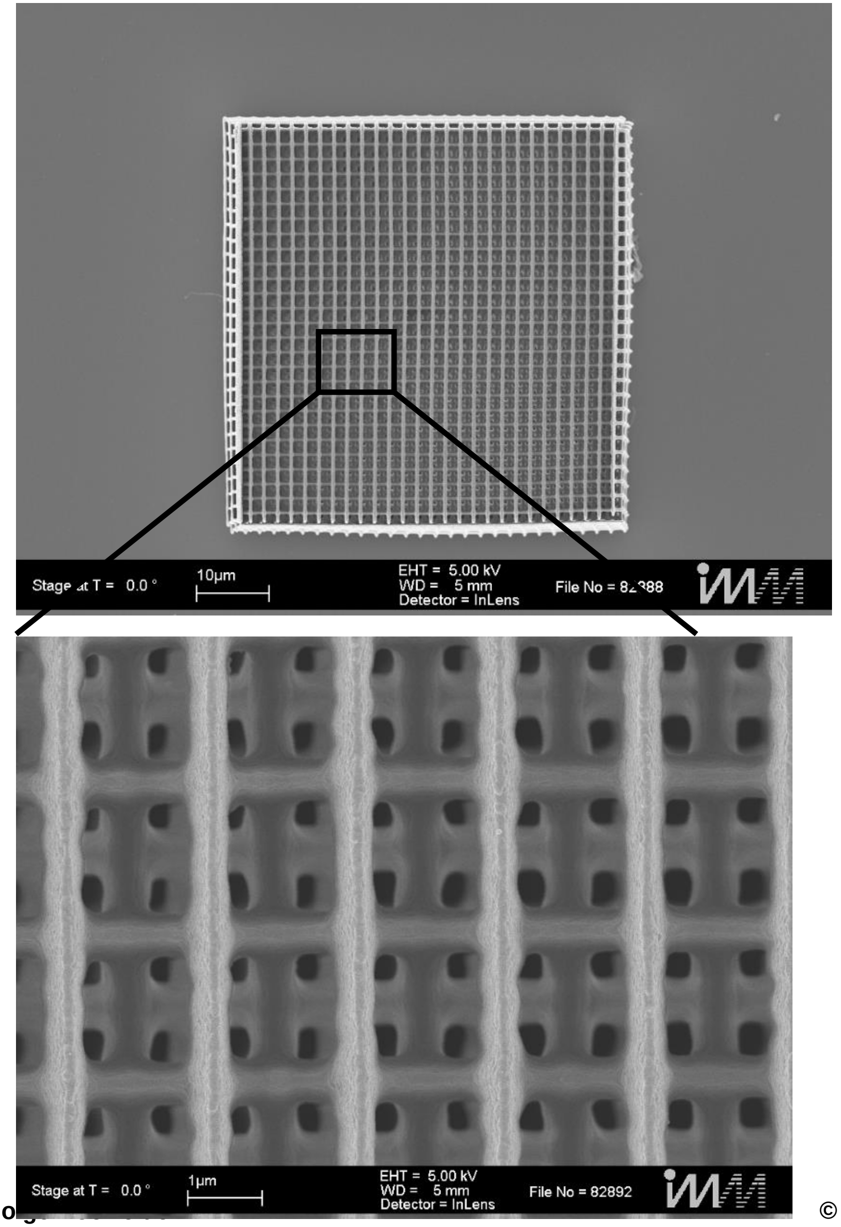
Interference Lithography: Simulation



The pattern geometry is determined by the number of laser beams and their respective intensity, orientation, and polarization.

Direct Laser Writing: Wood-Pile Structures

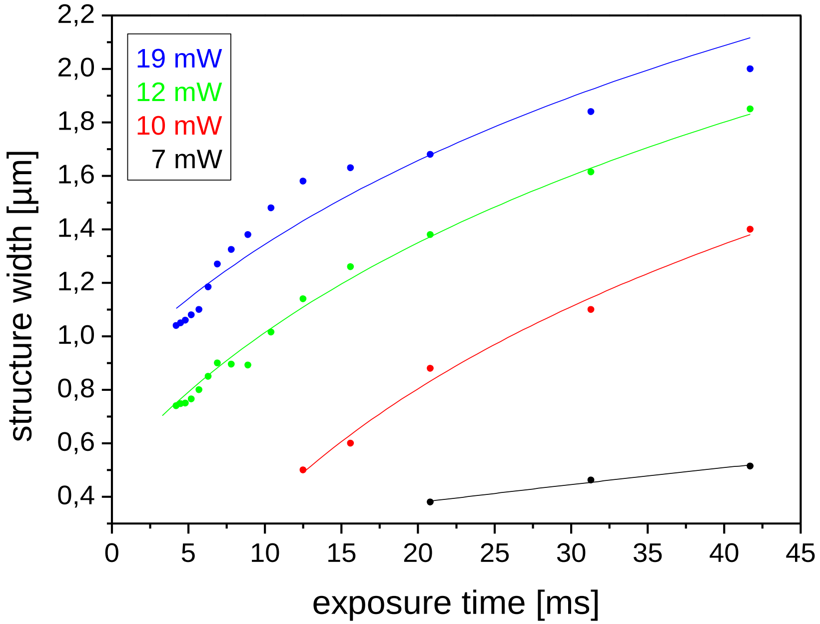


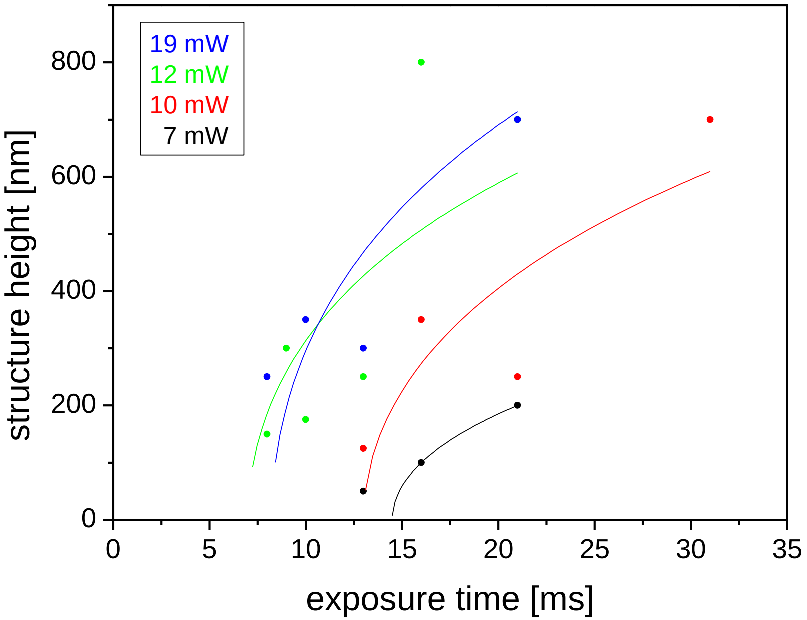


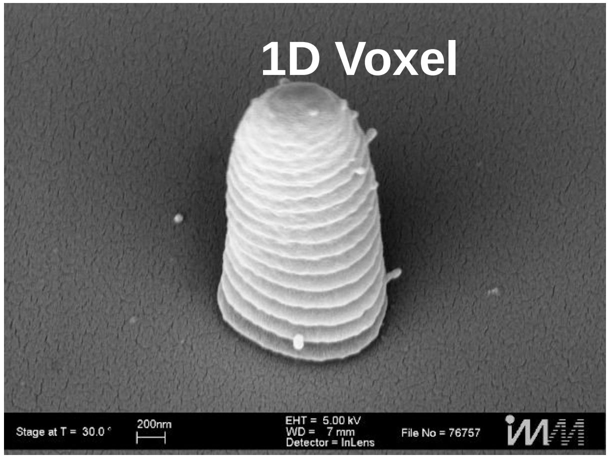
Resist: SU-8

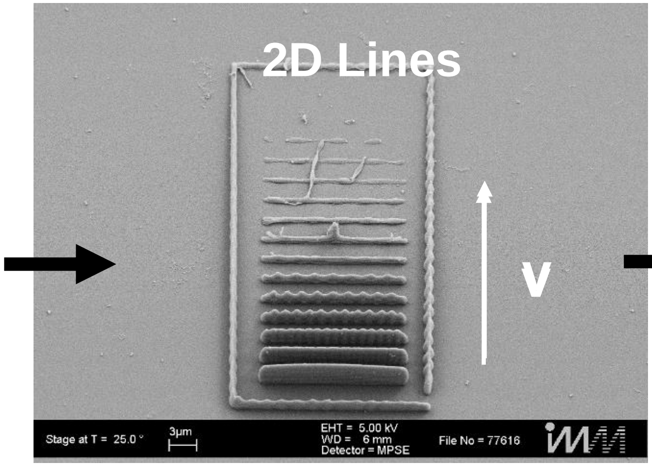
Application: Photonic Crystals with complete band-gap

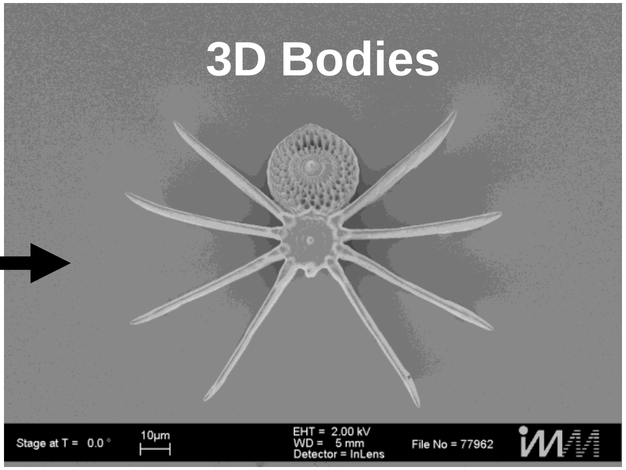
Direct Laser Writing: Results



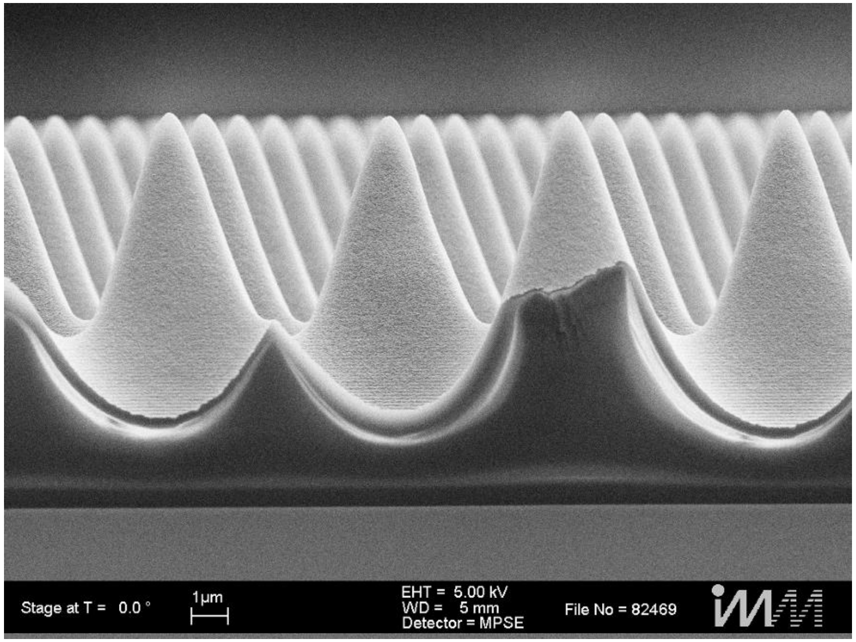


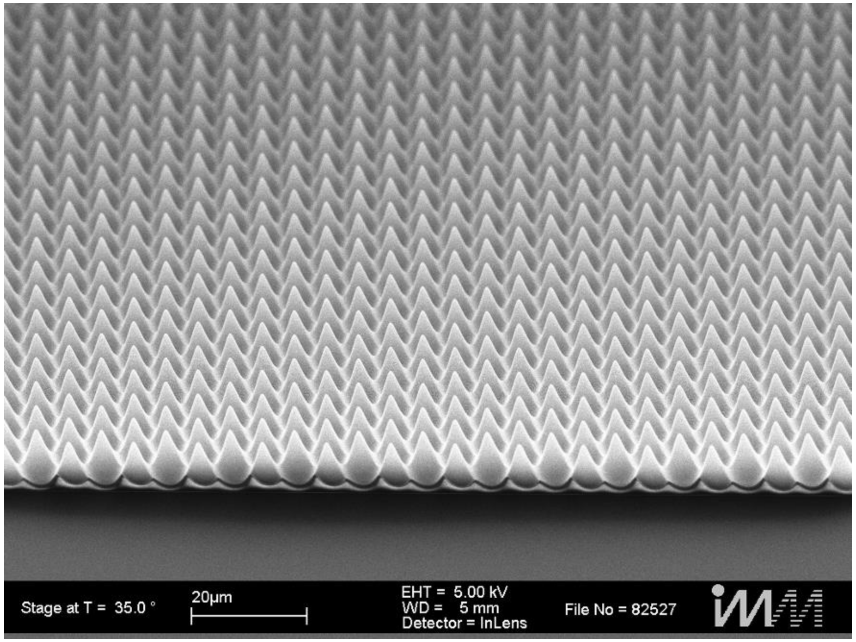




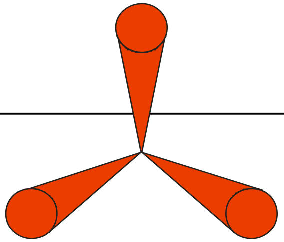


Interference Lithography: 2-D Structures

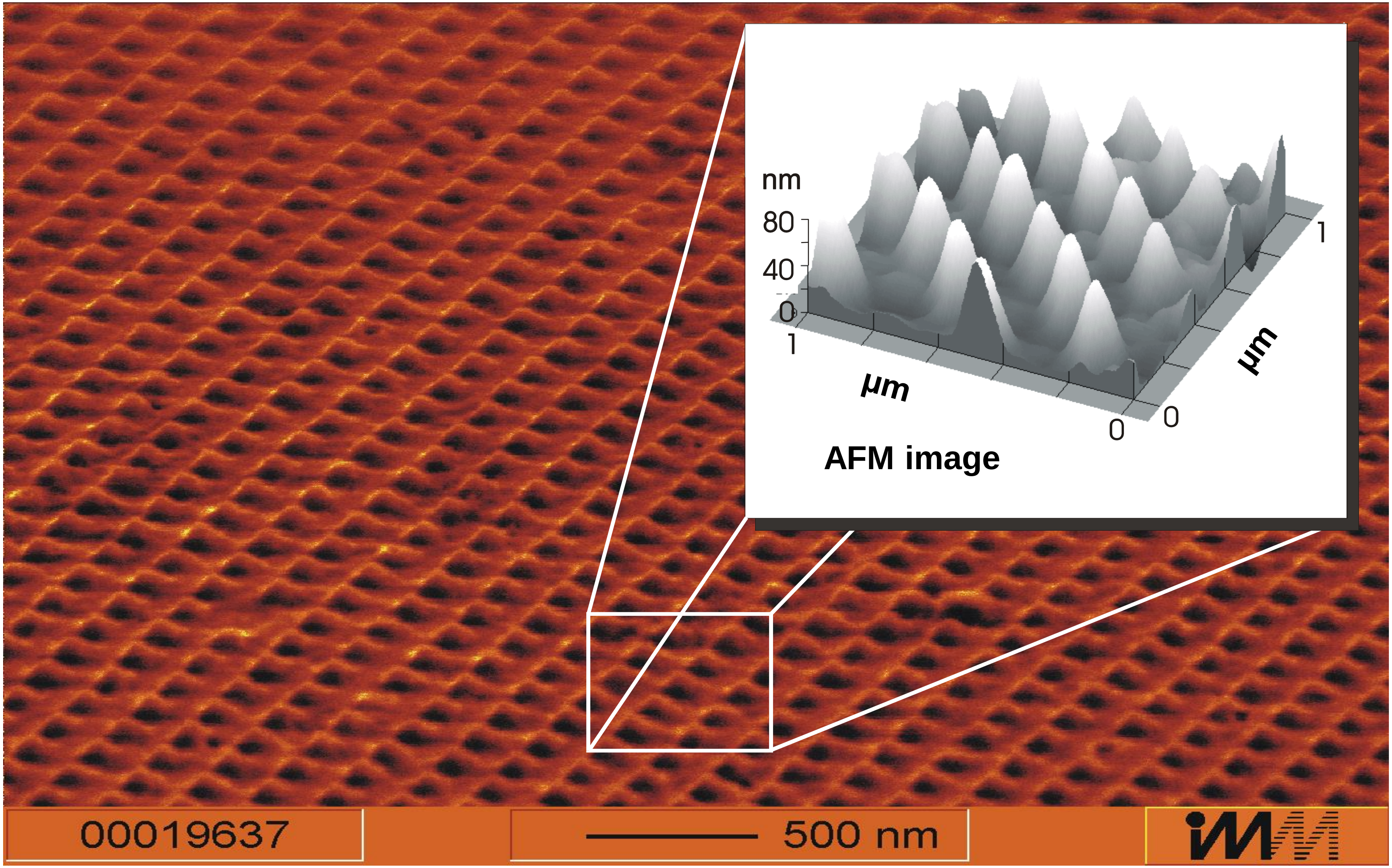




The actual pattern obtained also depends on the properties of the photoresist material.



Electroforming of Nano-tip Arrays with Nickel



Bulk Material Micro-structuring and Surface Modifications (V)

Micro-structuring

mechanical

electrical (EDM)

chemical

irradiation

electrochemical

Surface modification

electrodeposition

PVD/CVD

polymer coatings

chemical

SAMs

Materials

metals

ceramics

glass

semiconductors

polymers

Electrodeposition

General

Gold

Copper

Nickel

Nickel-cobalt

Nickel- iron

Mold iserts

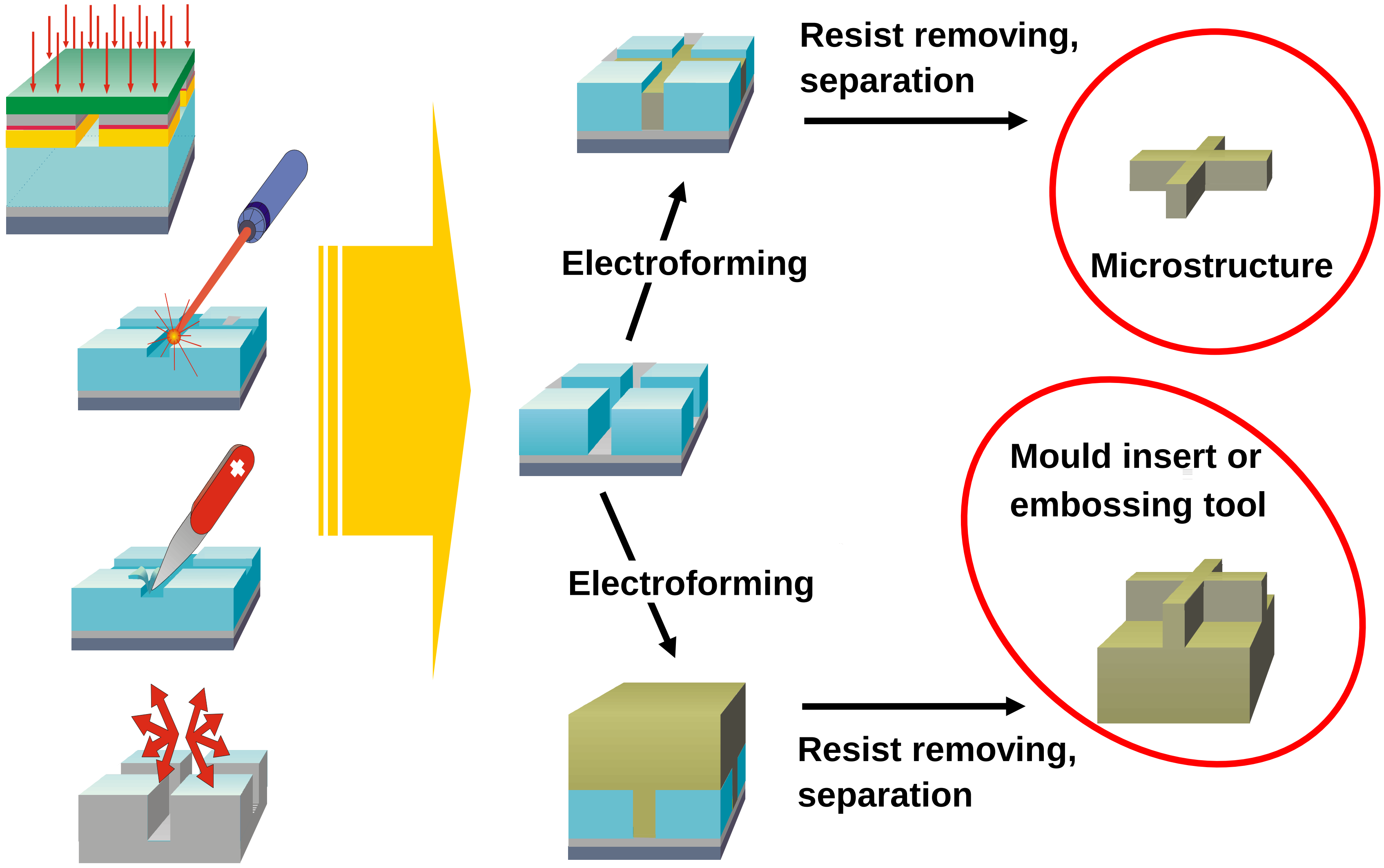
Special types of nickel alloys

Mold inserts from (ASE) silicon masters

Resist

Plating equipment

Principles of Micro Machining Steps



Resist removing, separation

Microstructure

Electroforming

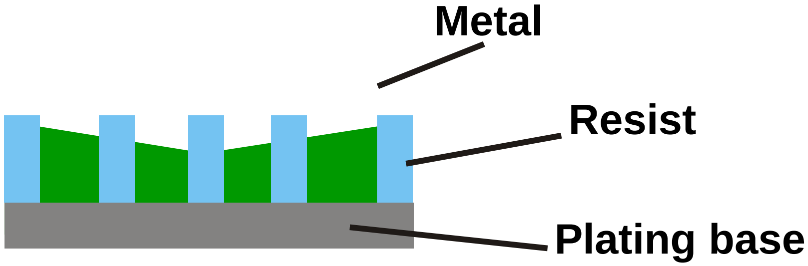
Electroforming

Mould insert or embossing tool

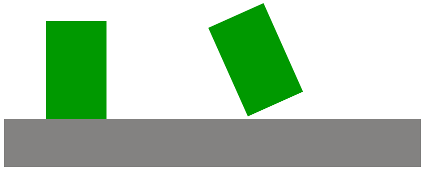
Resist removing, separation

Main Problems in Microelectroforming

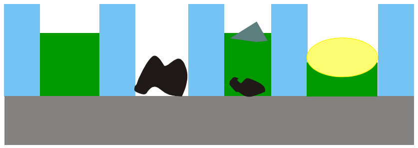
1. Metal distribution



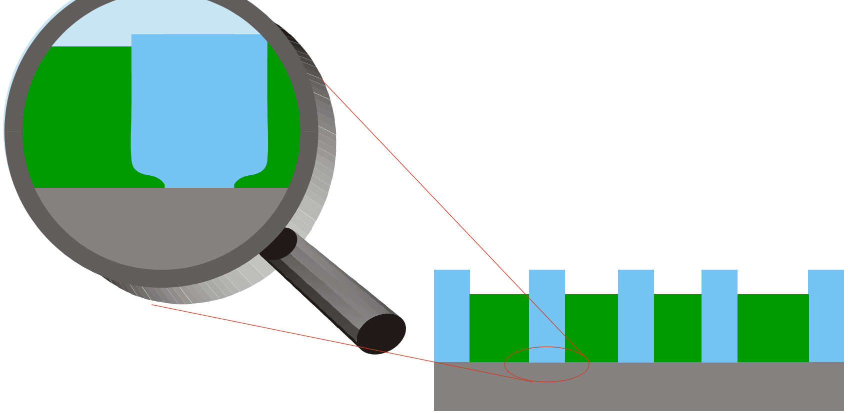
2. Adhesion



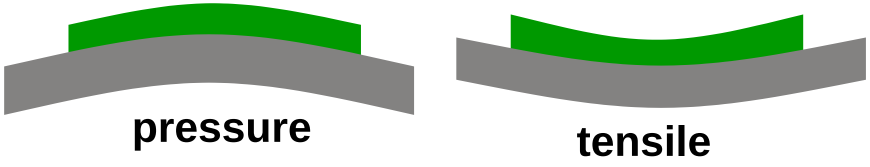
3. Particels and bubbles



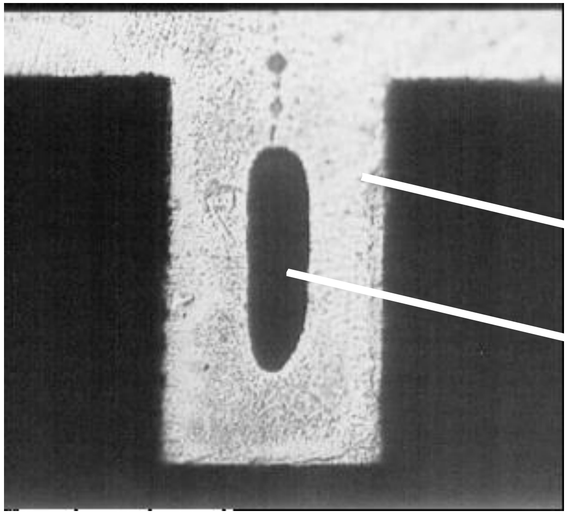
4. Undercutting

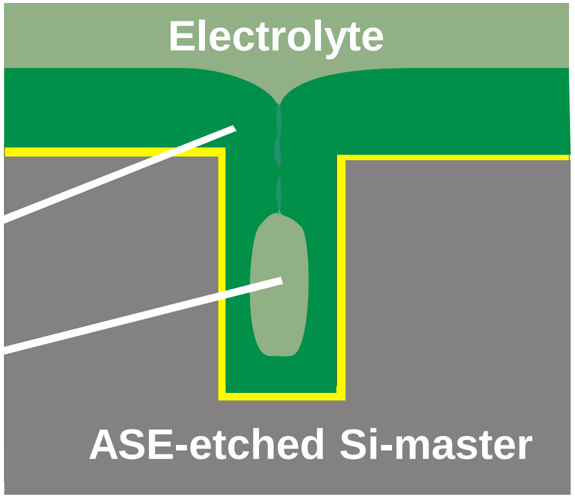


5. Internal stress



Typical Defects Caused by Electroplating of fully metalized ASE-etched Si-surfaces



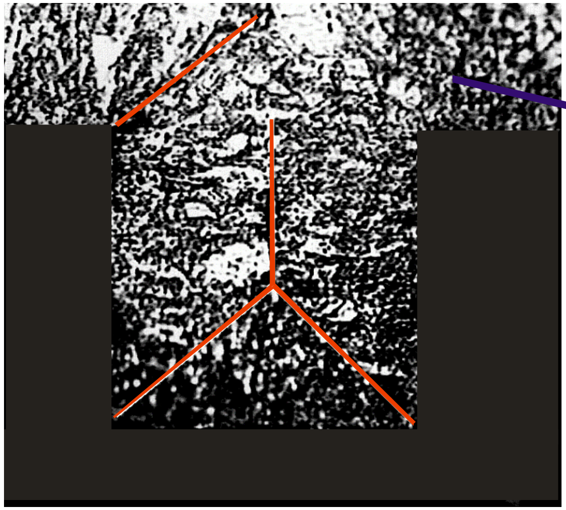


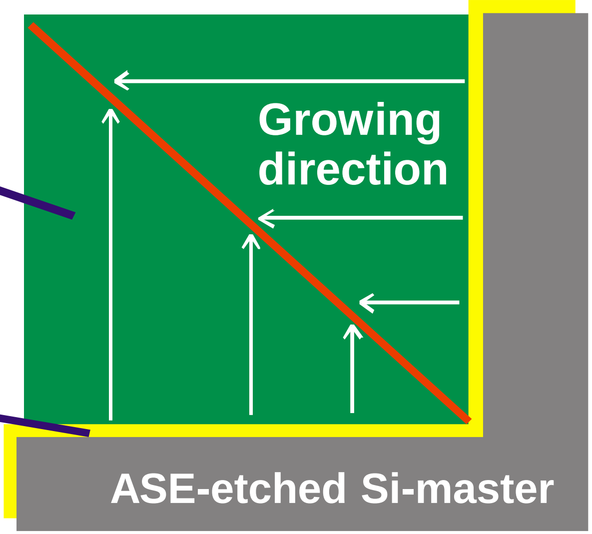
Sputtered adhesion and seed layer

Deposited nickel

Electrolyte entrapment

Aspect ratio 2:1





Deposited nickel

Sputtered adhesion and seed layer

Aspect ratio 1:1

Electrodeposition

General

Gold

Copper

Nickel

Nickel-cobalt

Nickel- iron

Mold iserts

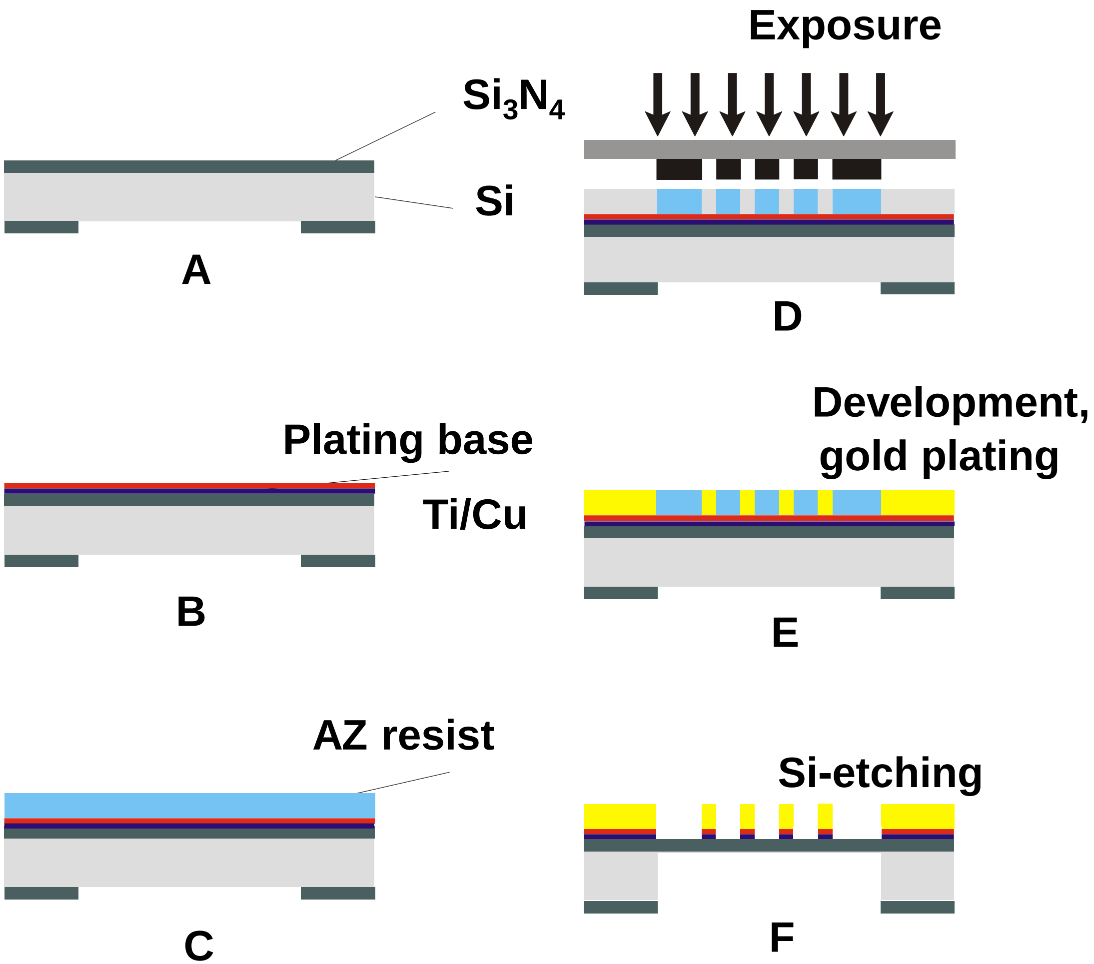
Special types of nickel alloys

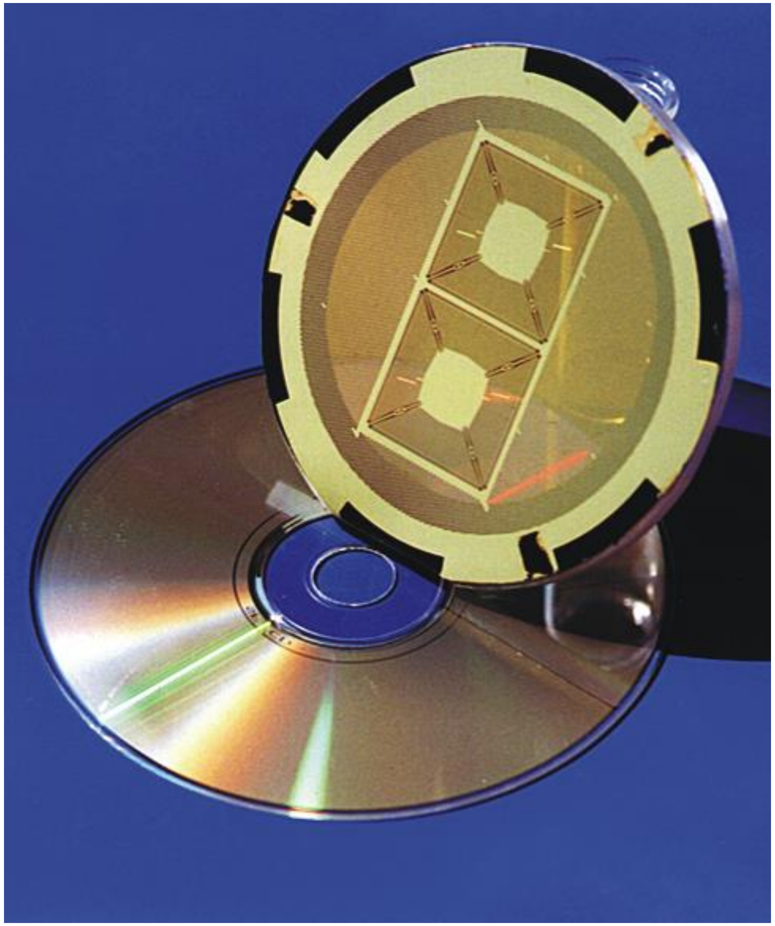
Mold inserts from (ASE) silicon masters

Resist

Plating equipment

X-ray Mask Plating Process



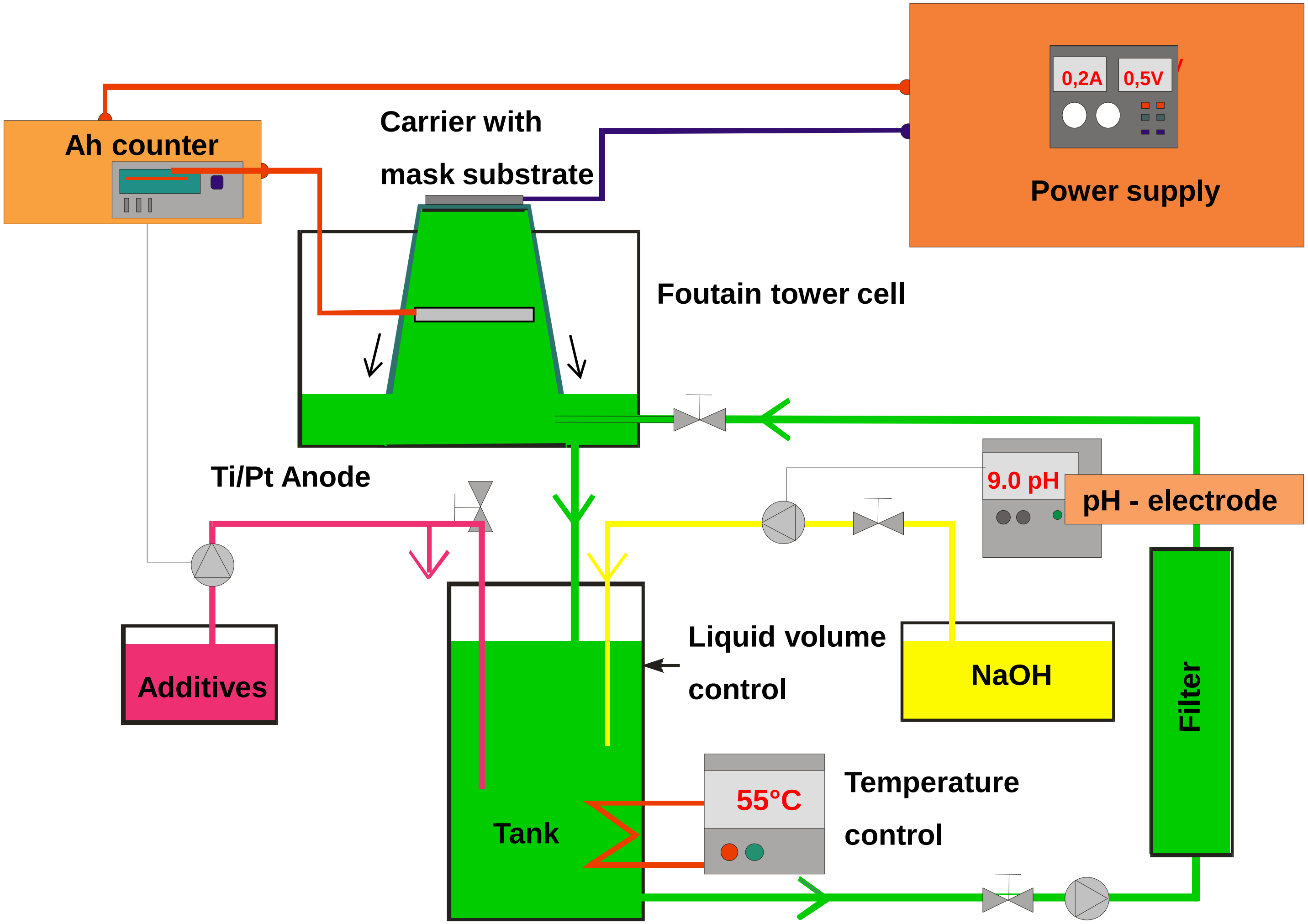


2µm Au-pattern

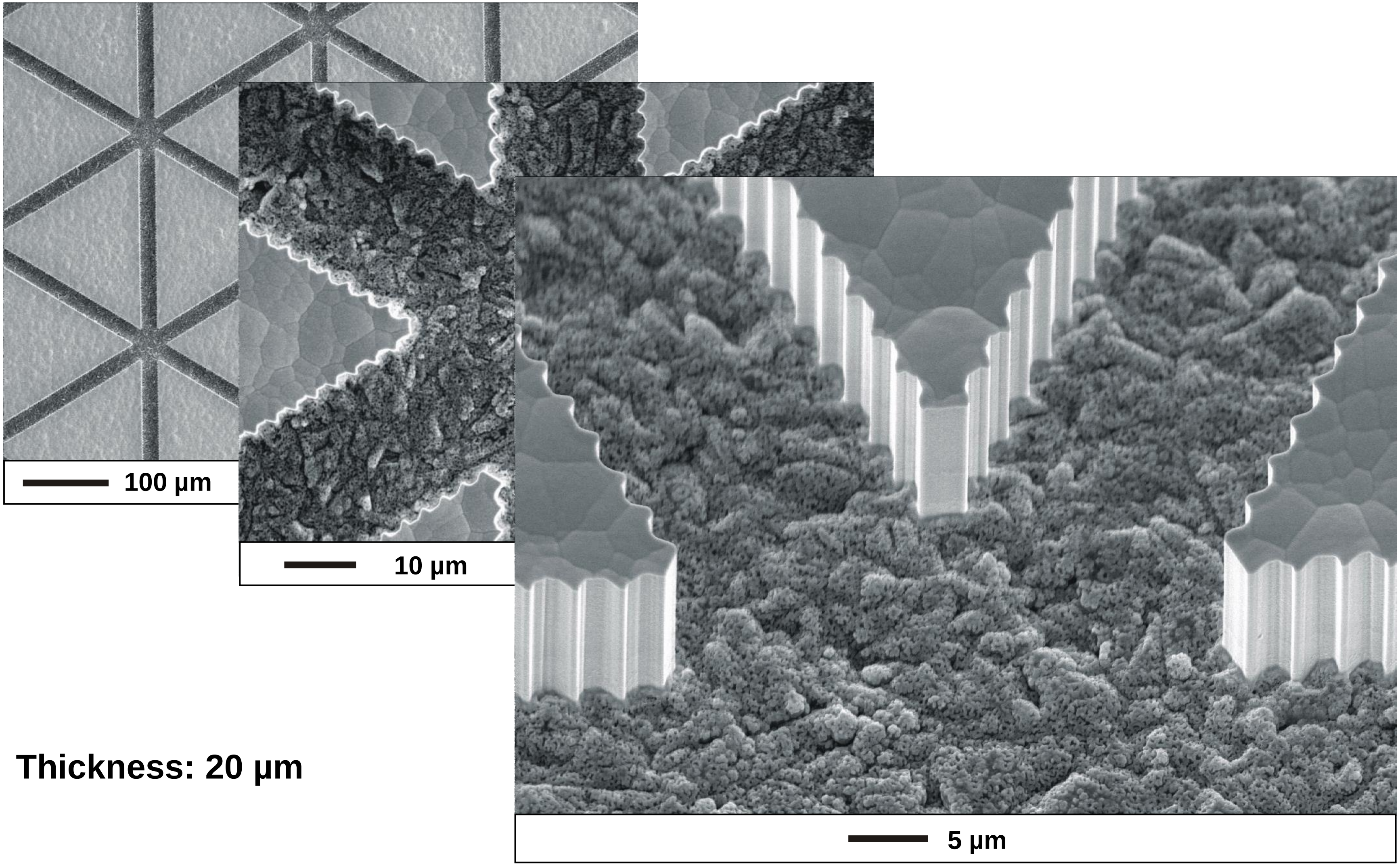
Electrodeposition of Gold: Working Conditions

Gold electrolyte	Modified commercial available gold sulfite electrolyte
Gold content	8 - 12 g/l
Sulfite as sodium sulfite	40 g/l
Leveler	Arsenite / arsenate
pH - value	9.3 - 9.6
Temperature	55° C
Current density	0.2 - 0.4 A/dm²
Anode material	Ti/Pt mesh

Mask Technology:
Gold Electrodeposition in a Fountain Tower Cell

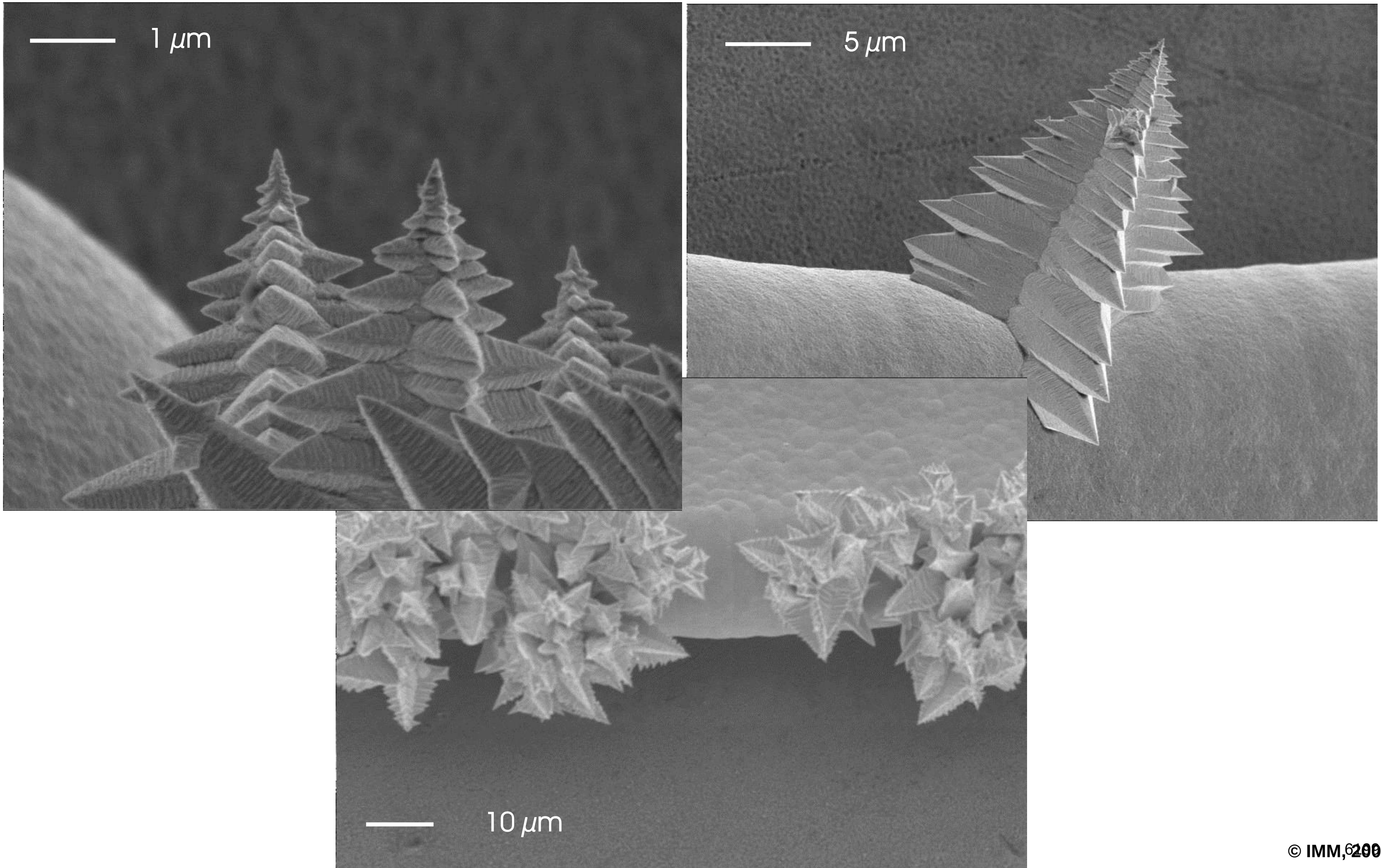


High Leveling Gold Electrodeposition



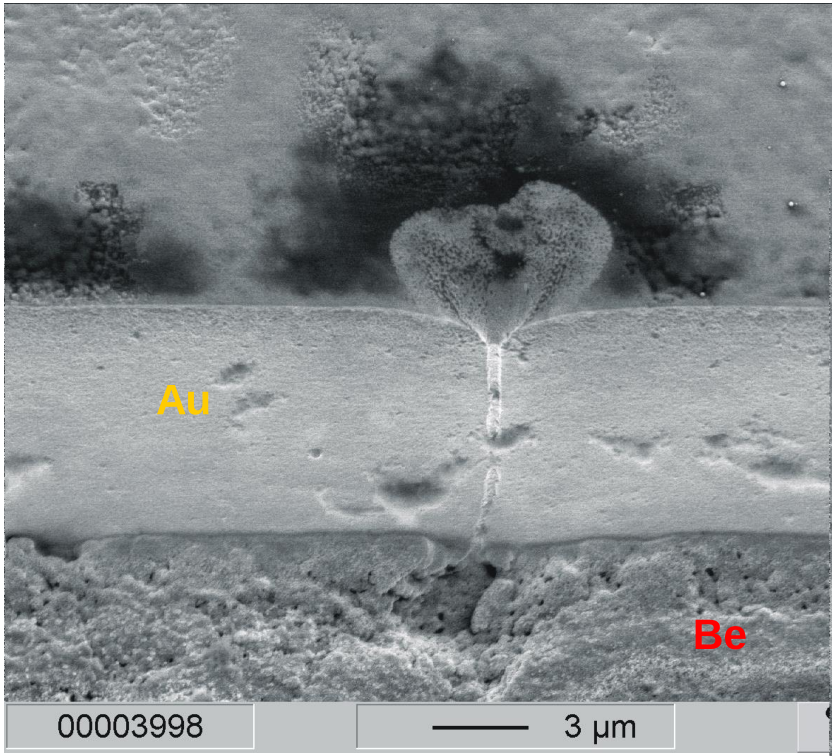
Thickness: 20 µm

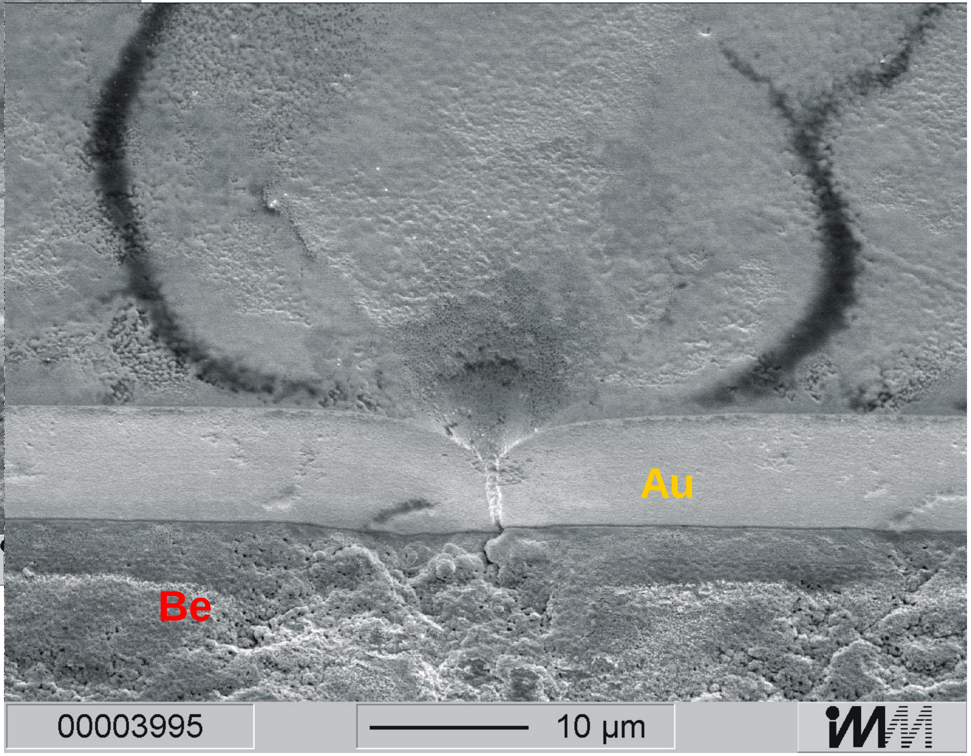
Mistakes in Electroplating of Gold - Leveler Concentration Too Low



Deep X-ray Lithography: Substrate Induced Defects

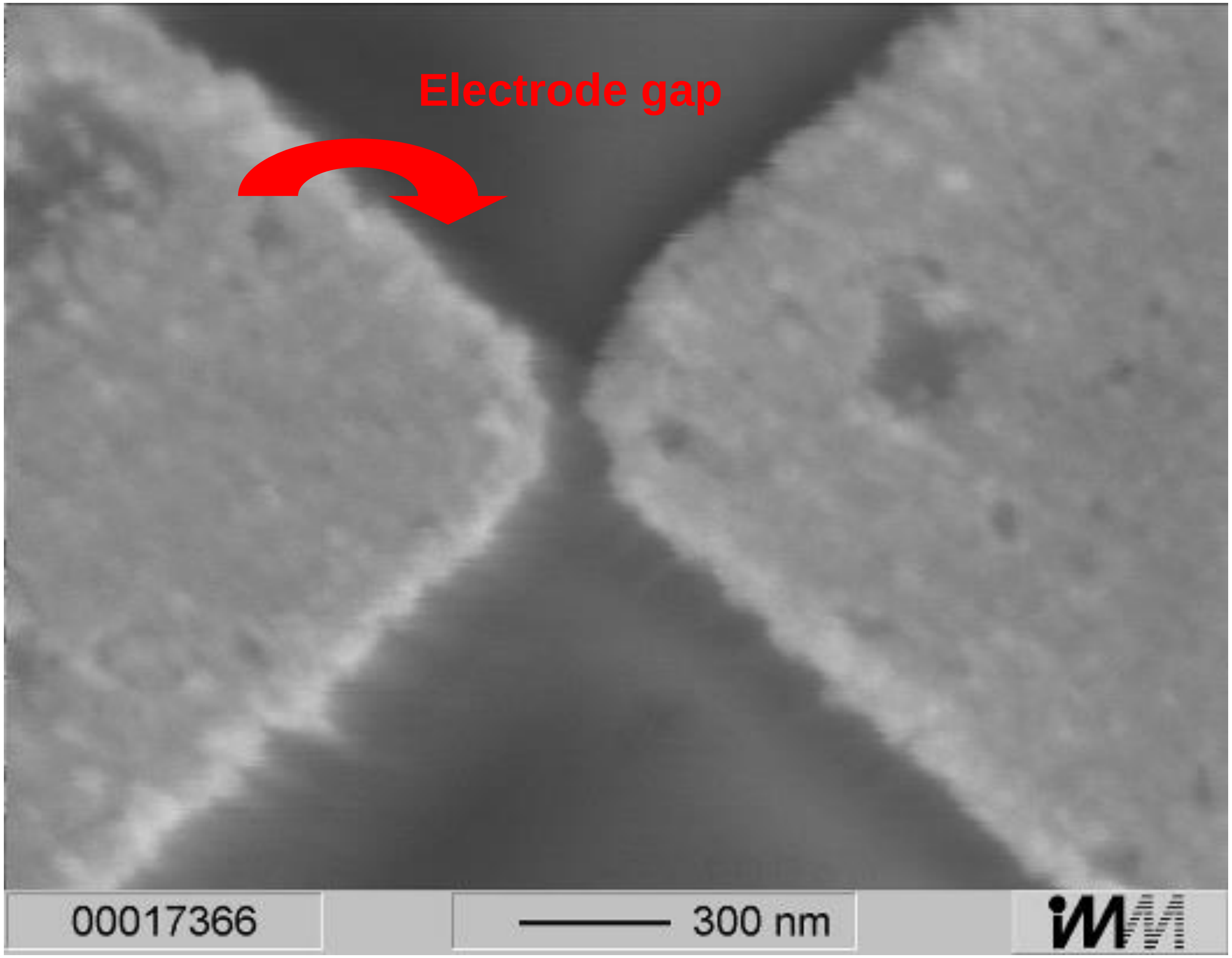
$Be + 2\,H_2O \qquad Be(OH)_2 + H_2$





Formation of gas bubbles by dissolution of the Be-substrate during the electrodeposition process

Electroplating with AFM Tips: Gold Nanoelectrodes



Electrodeposition

General

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Nickel

Nickel-cobalt

Nickel- iron

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Plating equipment

Nickel Sulfate Electrolyte: Working Conditions

Nickel	100 g/l
Boric acid	40 g/l
Sulfaminic acid	275 g/l
Sulfate	14 g/l
Chloride	5.0 g/l
Saccharin	20 mg
fluorinated wetting agent	20 ml/l (2% solution)
Anode material	Sulfur depolarized nickel
Temperature	55 °C
pH - value	3.8
Current density	1 - 5 A/dm²
Current efficiency	~ 99%
Bath volume	75 l

Anode reaction:

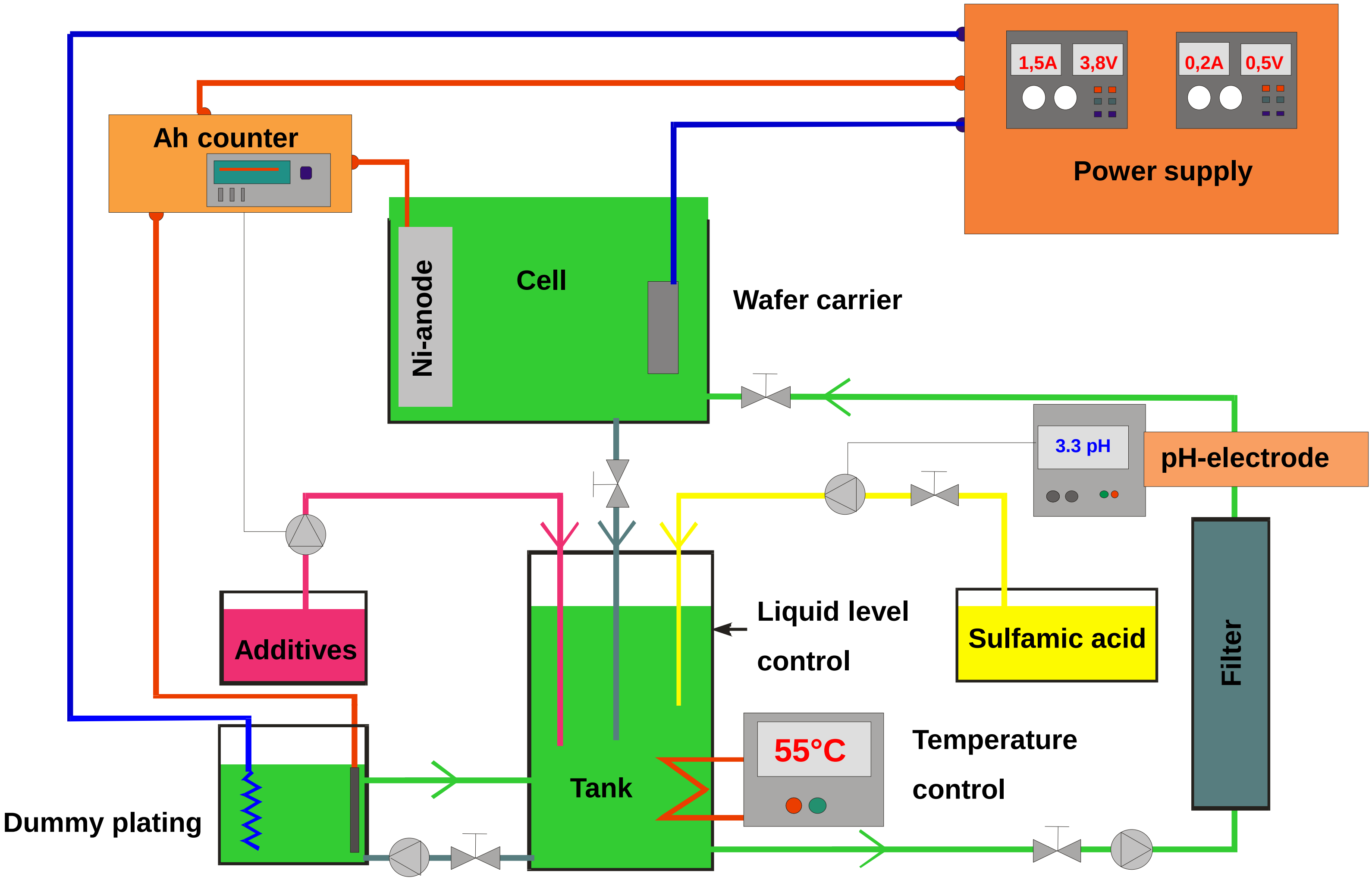
$Ni^{\pm 0} \Longrightarrow Ni^{2+} + 2e$

Cathode reaction:

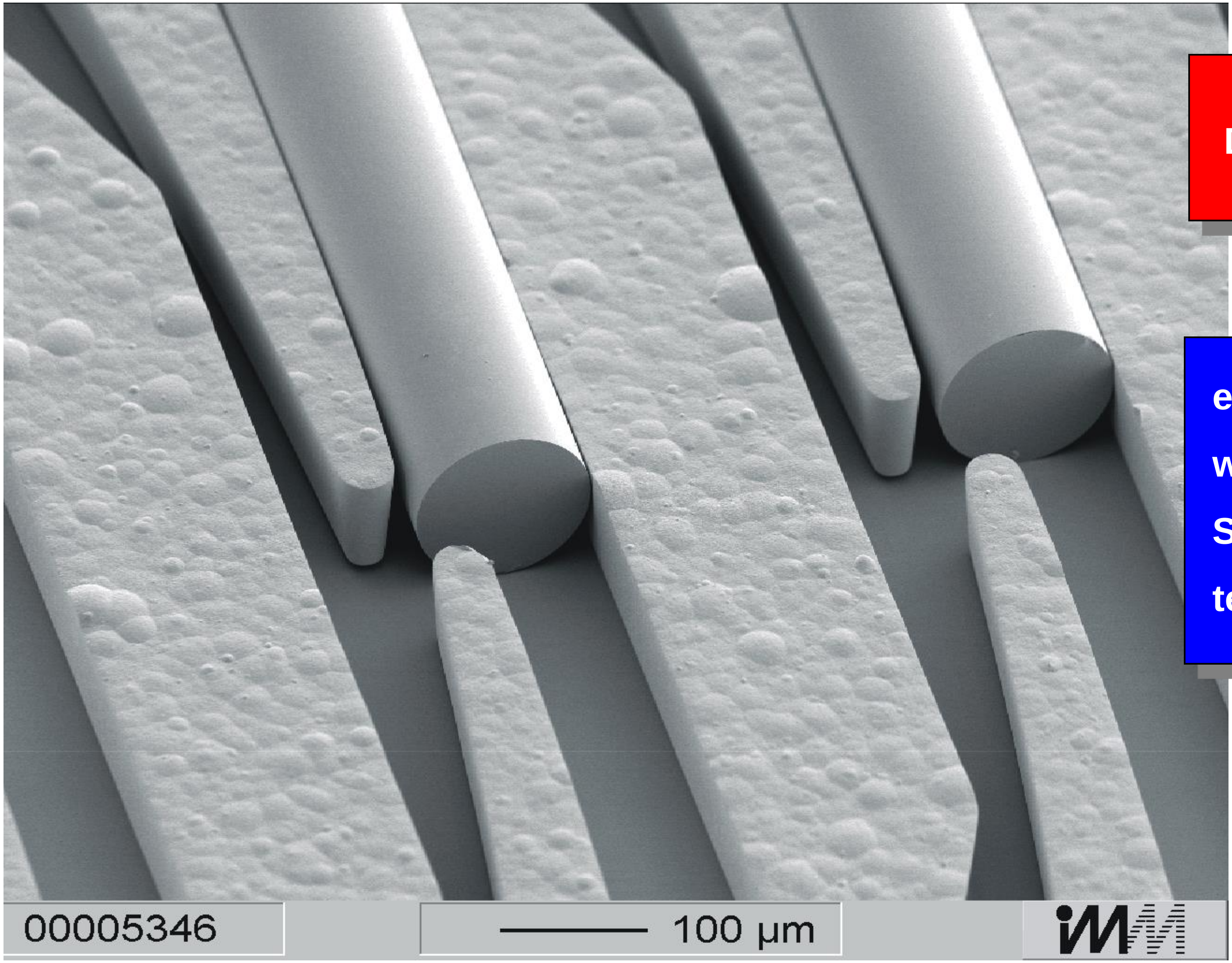
$Ni^{2+} + 2e \Longrightarrow Ni^{\pm 0}$

$2H^{+} + 2e \Longrightarrow H_2$

Nickel Electrodeposition: Flow Chart



Fiber Alignment Device



Deep UV-lithography

electroforming

with nickel

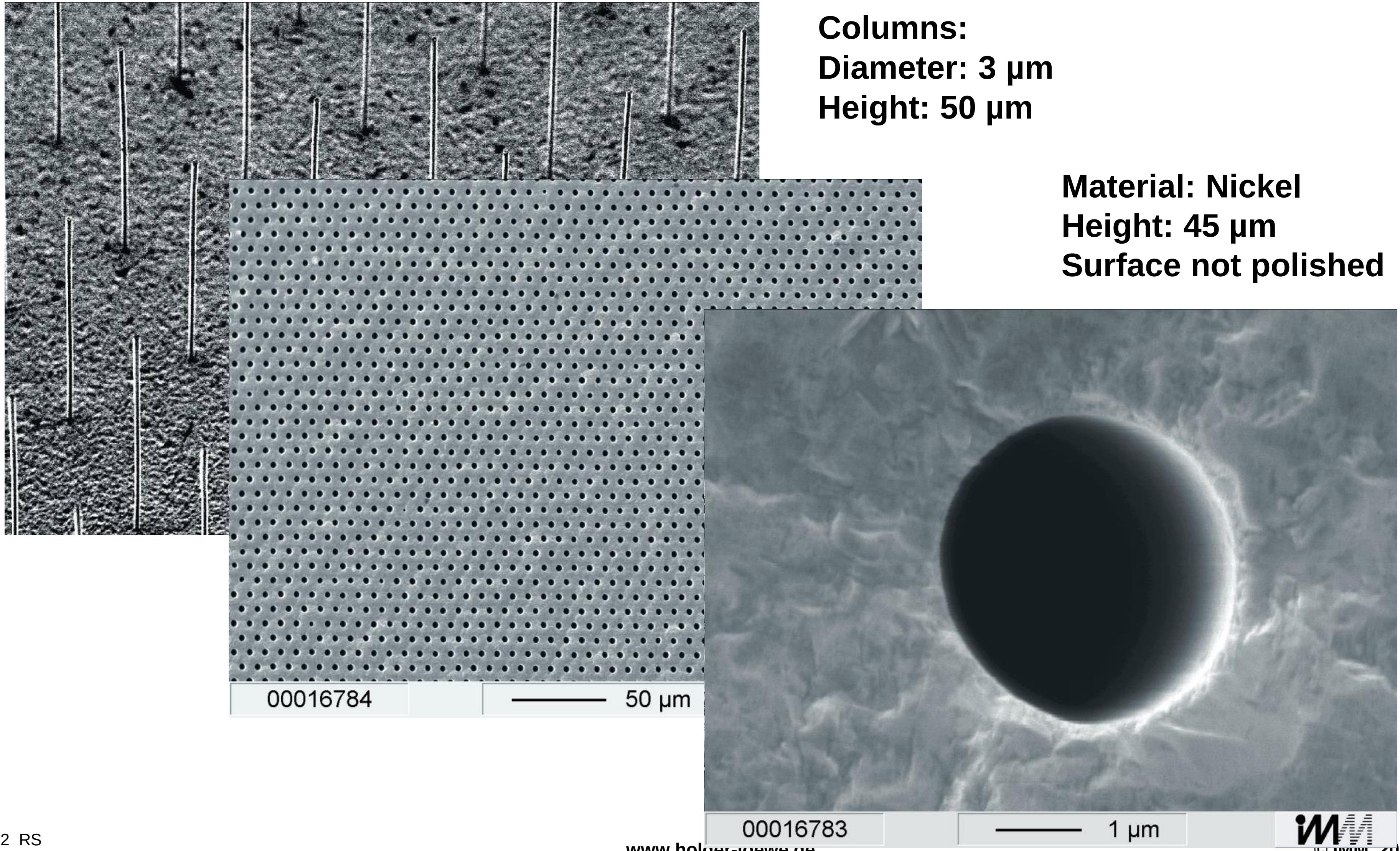
Sacrificial layer

technique

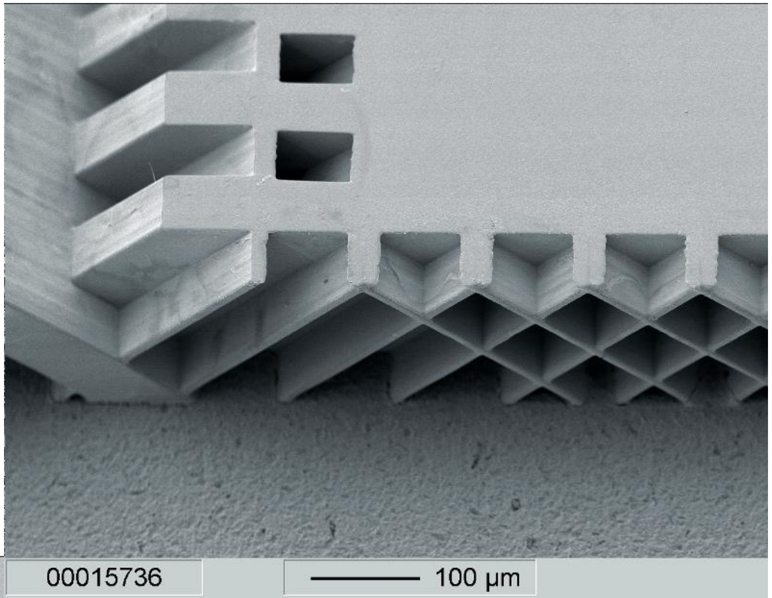
Negative Tone - Resist for Deep X-ray Lithography: Columns Replicated by Electroforming

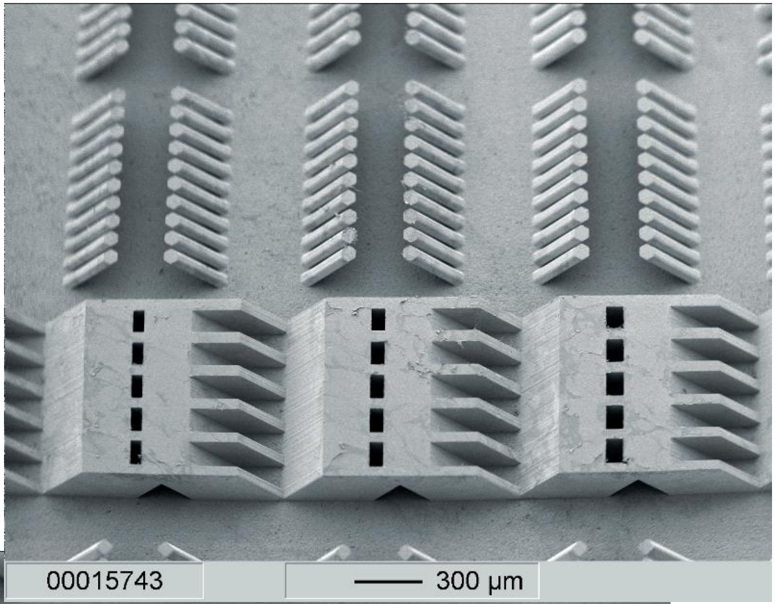
Columns:
Diameter: 3 µm
Height: 50 µm

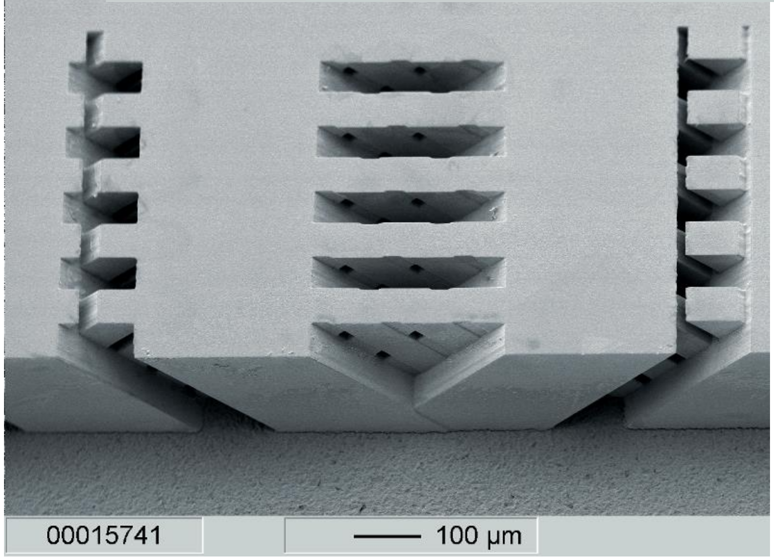
Material: Nickel
Height: 45 µm
Surface not polished

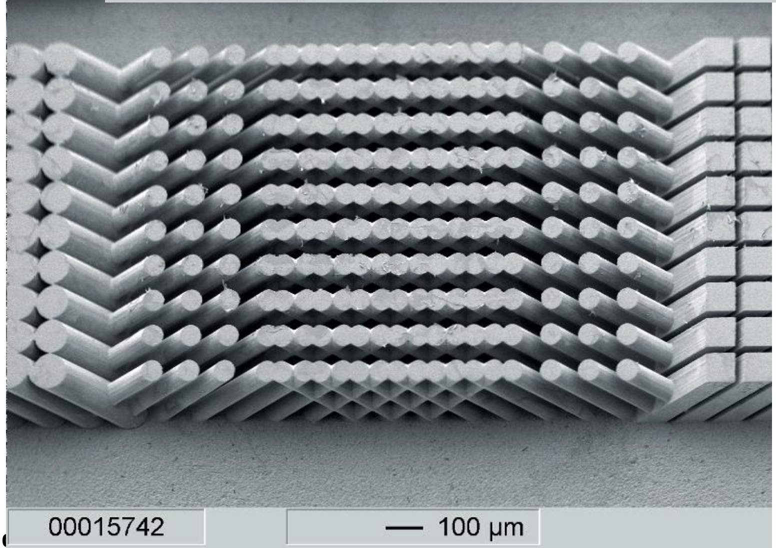


LIGA - Microstructures Made from Nickel: Oblique X-ray Irradiation









3-D Metallic Microstructures

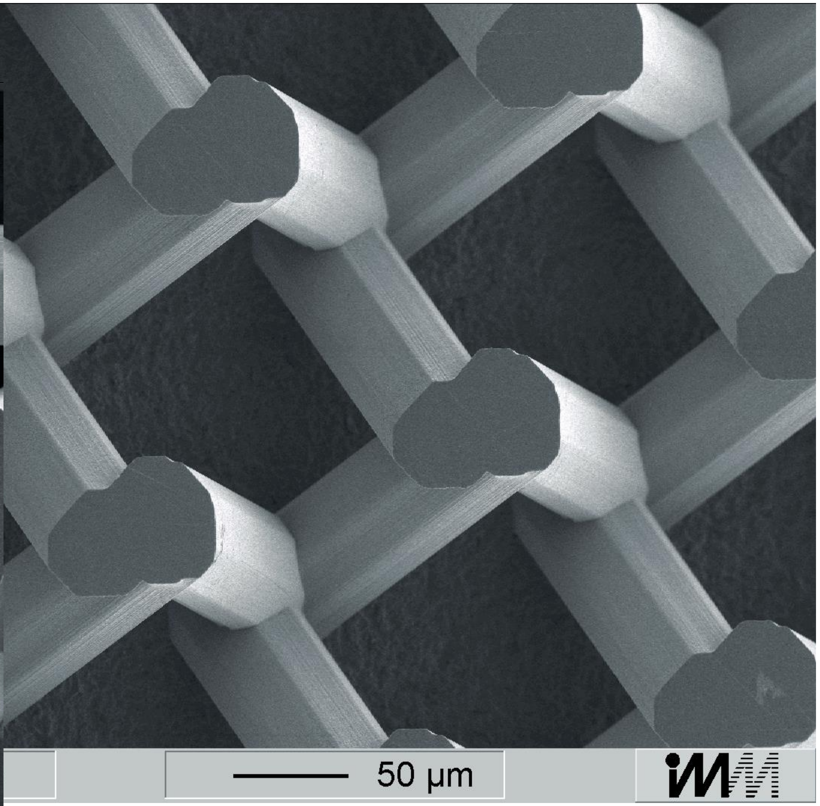
Technology:

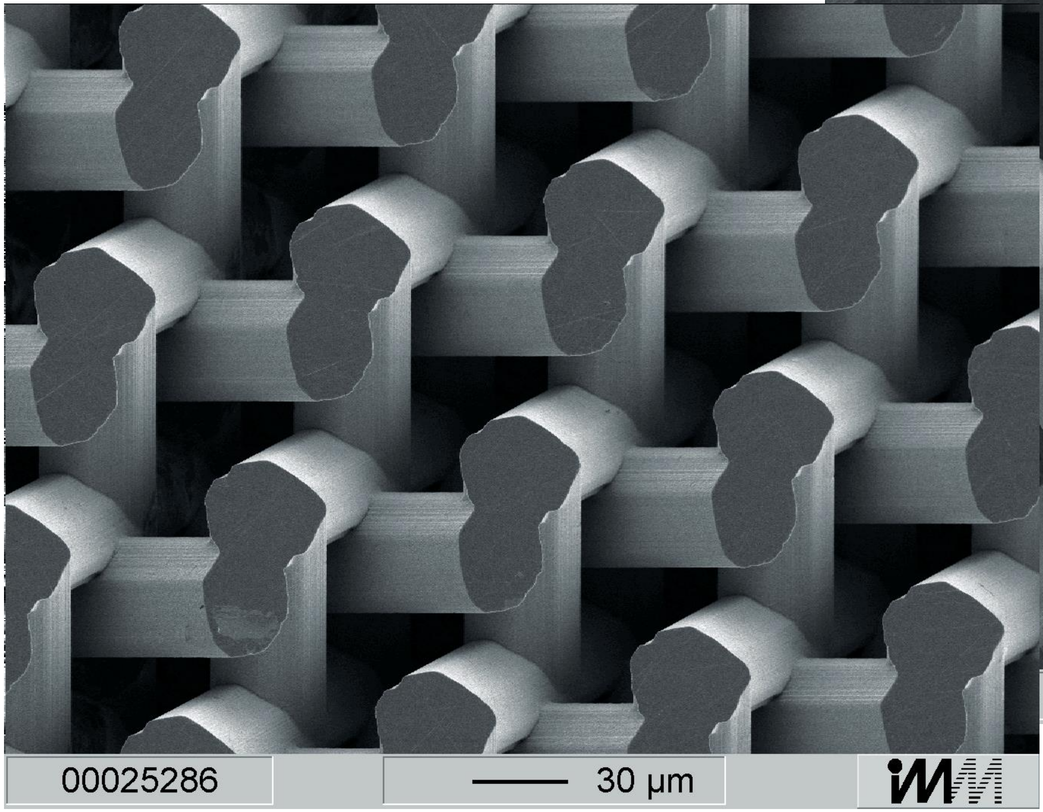
LiGA technique, multiple oblique irradiation with rotation of mask and substrate by angular steps of 120°

Application:

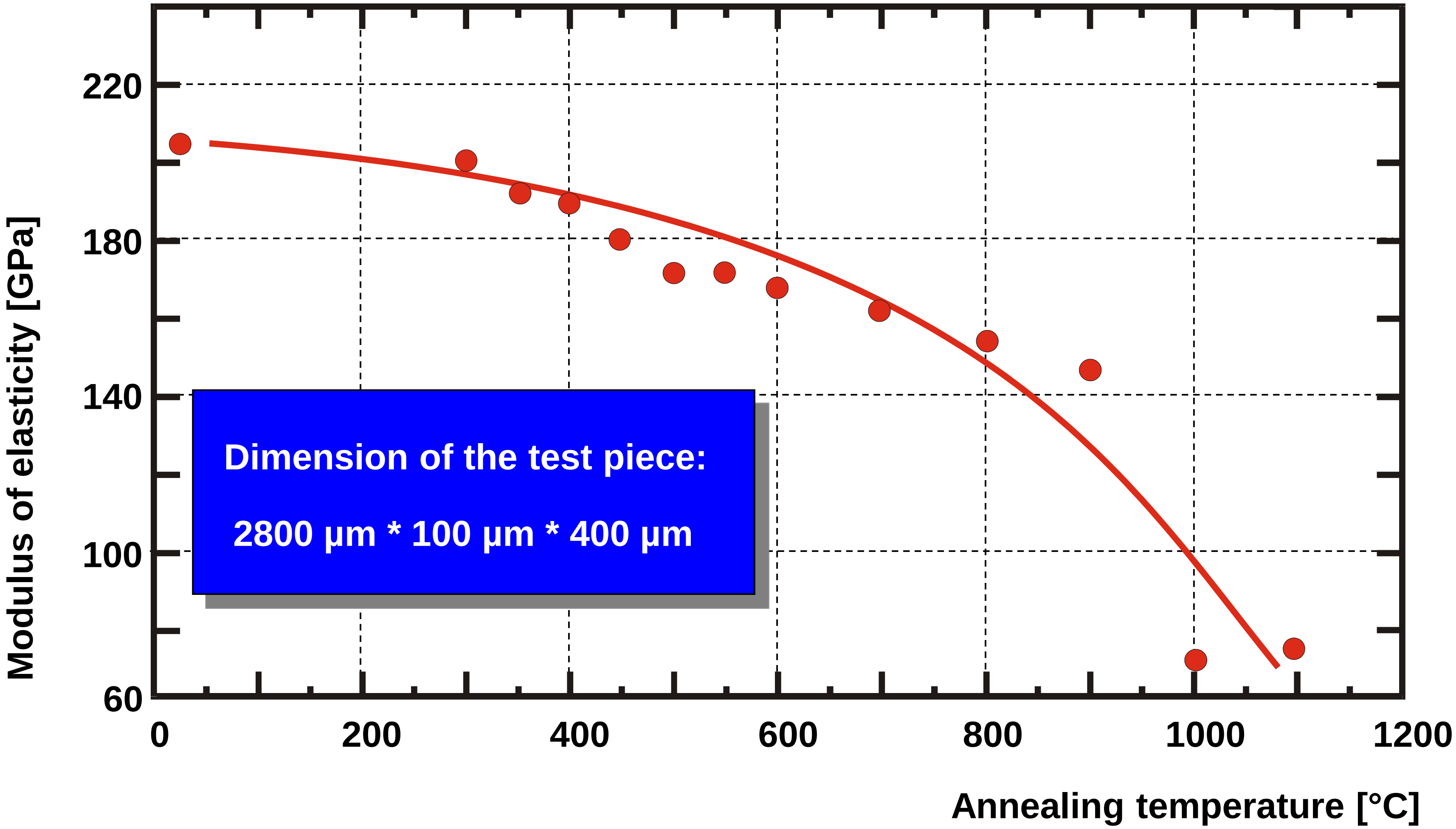
Photonic crystals

Material: nickel





Young´s Modulus of Nickel Microstructures

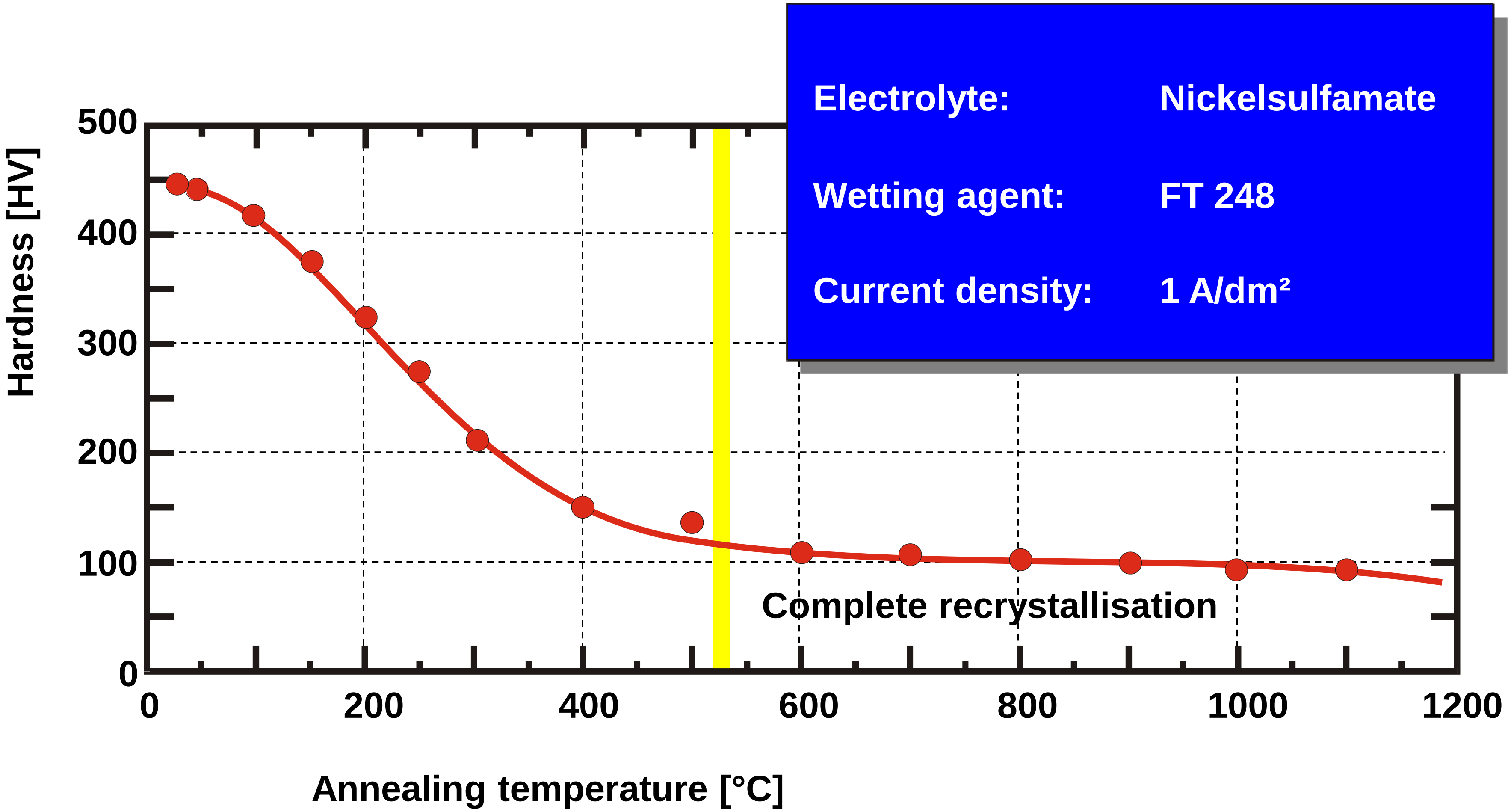


Dimension of the test piece:

2800 µm * 100 µm * 400 µm

(S. Abel; PhD thesis, unpublished results)

Hardness of Ni-microstructures vs. Annealing Temperature



Electrolyte:	**Nickelsulfamate**
Wetting agent:	**FT 248**
Current density:	**1 A/dm²**

Electrodeposition

General

Gold

Copper

Nickel

Nickel-cobalt

Nickel- iron

Mold iserts

Special types of nickel alloys

Mold inserts from (ASE) silicon masters

Resist

Plating equipment

Nickel-Cobalt Sulfate Electrolyte: Working Conditions

Nickel	90 g/l
Cobalt	2.8 g/l
Boric acid	40 g/l
Sulfamic acid	200 g/l
Sulfate	15 g/l
Chloride	1.8 g/l
Saccharin	20 mg
fluoriertes Wetting agent	20 ml/l (2% solution
Temperature	55 °C
pH - value	4.0
Current density	1 - 5 A/dm²
Current efficiency	~ 97%
Bath volume	75 l

Anode reactions:

$Ni^{\pm 0} \Longrightarrow Ni^{2+} + 2e$

$Co^{\pm 0} \Longrightarrow Co^{2+} + 2e$

Cathode reactions:

$Ni^{2+} + 2e \Longrightarrow Ni^{\pm 0}$

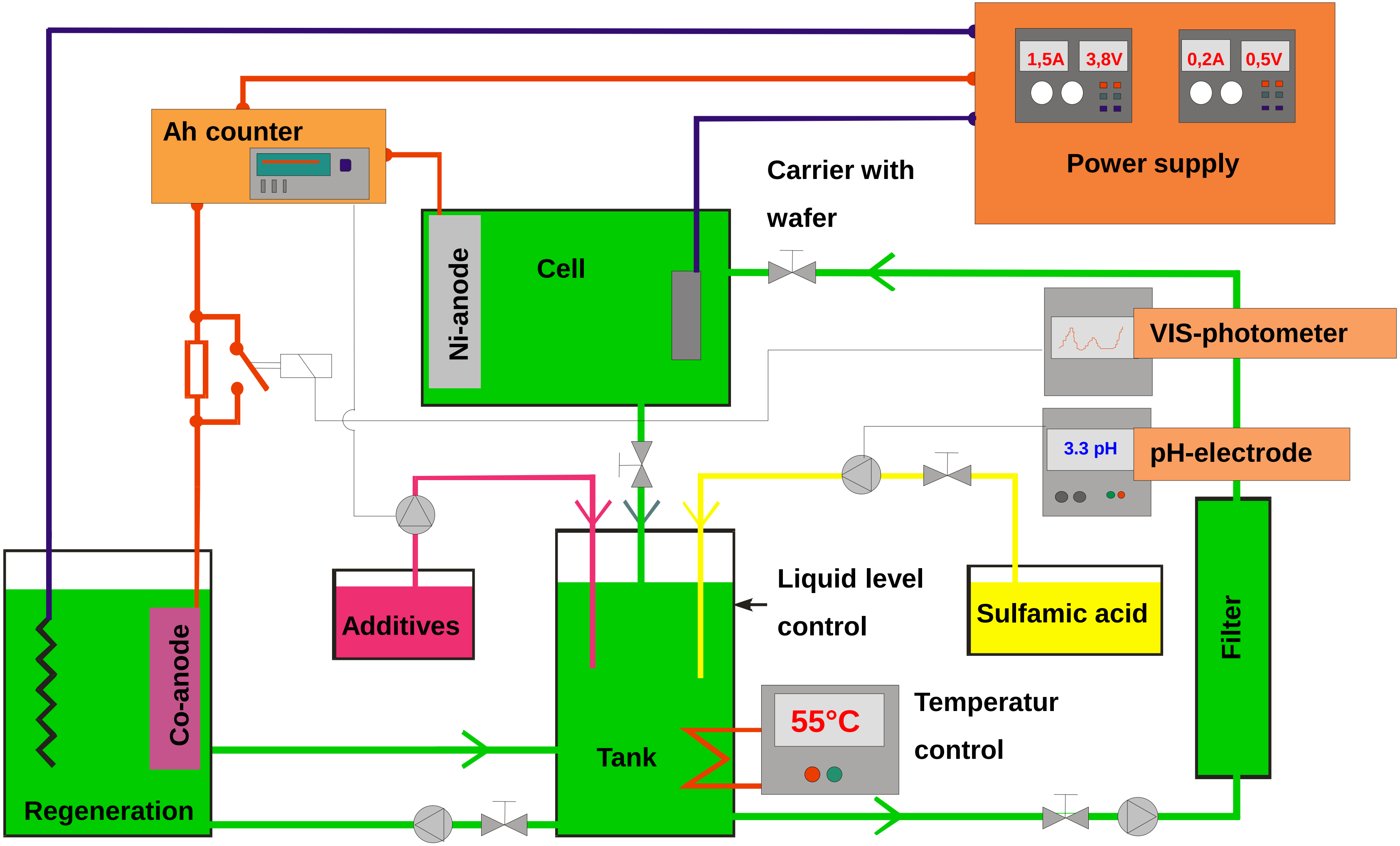
$Co^{2+} + 2e \Longrightarrow Co^{\pm 0}$

$2H^{+} + 2e \Longrightarrow H_2$

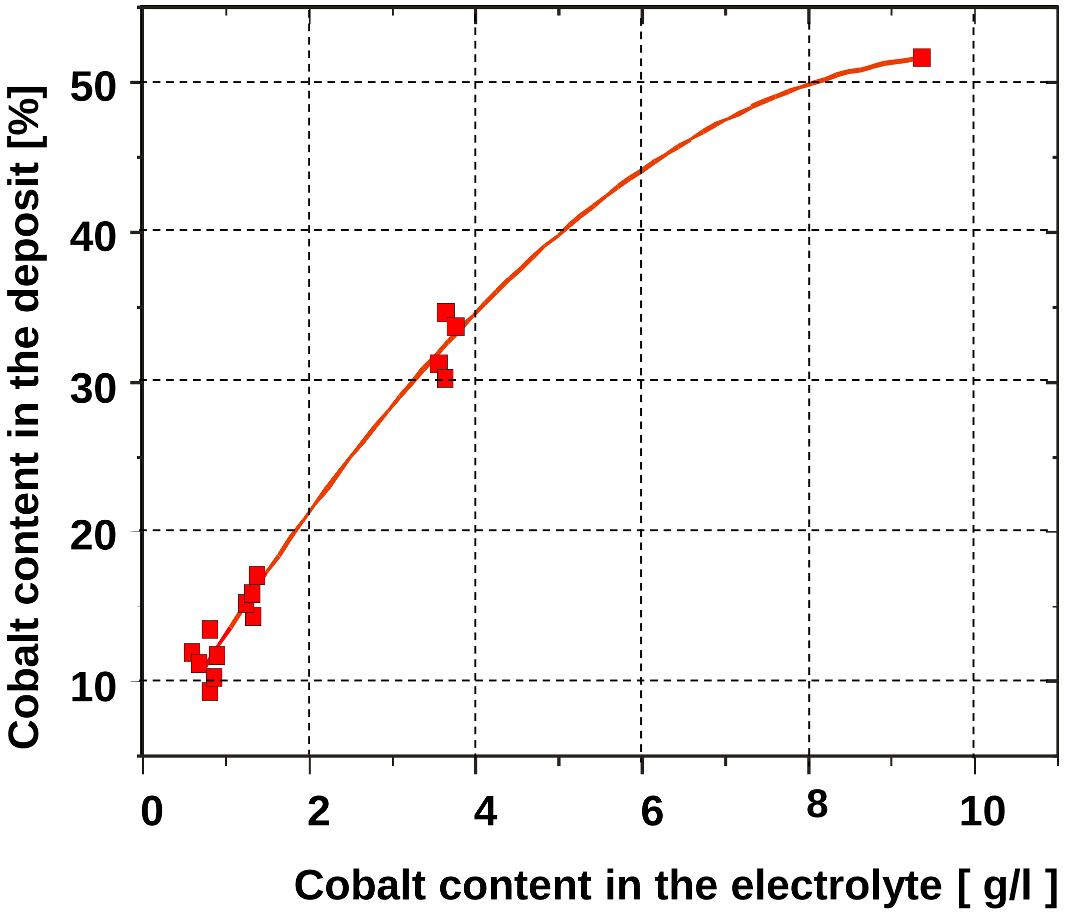
Nickel-cobalt Sulfamate Electrolyte: Mass Balance

Cathode rections:	$Ni^{2+} + 2e \longrightarrow Ni^{\pm 0}$	$Ni^{2+} + 2e \longrightarrow Ni^{\pm 0}$
	$Co^{2+} + 2e \longrightarrow Co^{\pm 0}$	$Co^{2+} + 2e \longrightarrow Co^{\pm 0}$
	$2H^{+} + 2e \longrightarrow H_2$	$2H^{+} + 2e \longrightarrow H_2$
$j =$	$j_{Ni} + j_{Co} + j_{H}$	$j_{Ni} + j_{Co} + j_{H}$
Anode reactions:	$Ni^{\pm 0} \longrightarrow Ni^{2+} + 2e$	$Co^{\pm 0} \longrightarrow Co^{2+} + 2e$
$J_{Ni} =$	$j_{Ni(Cell)}$ +	$j_{Ni(Regeneration)}$
$j_{Co} =$	$j_{Co(Cell)}$ +	$j_{Co(Regeneration)}$

Ni-Co Alloy Electrodeposition: Flow Chart



Electroplating of Ni-Co Microstructures

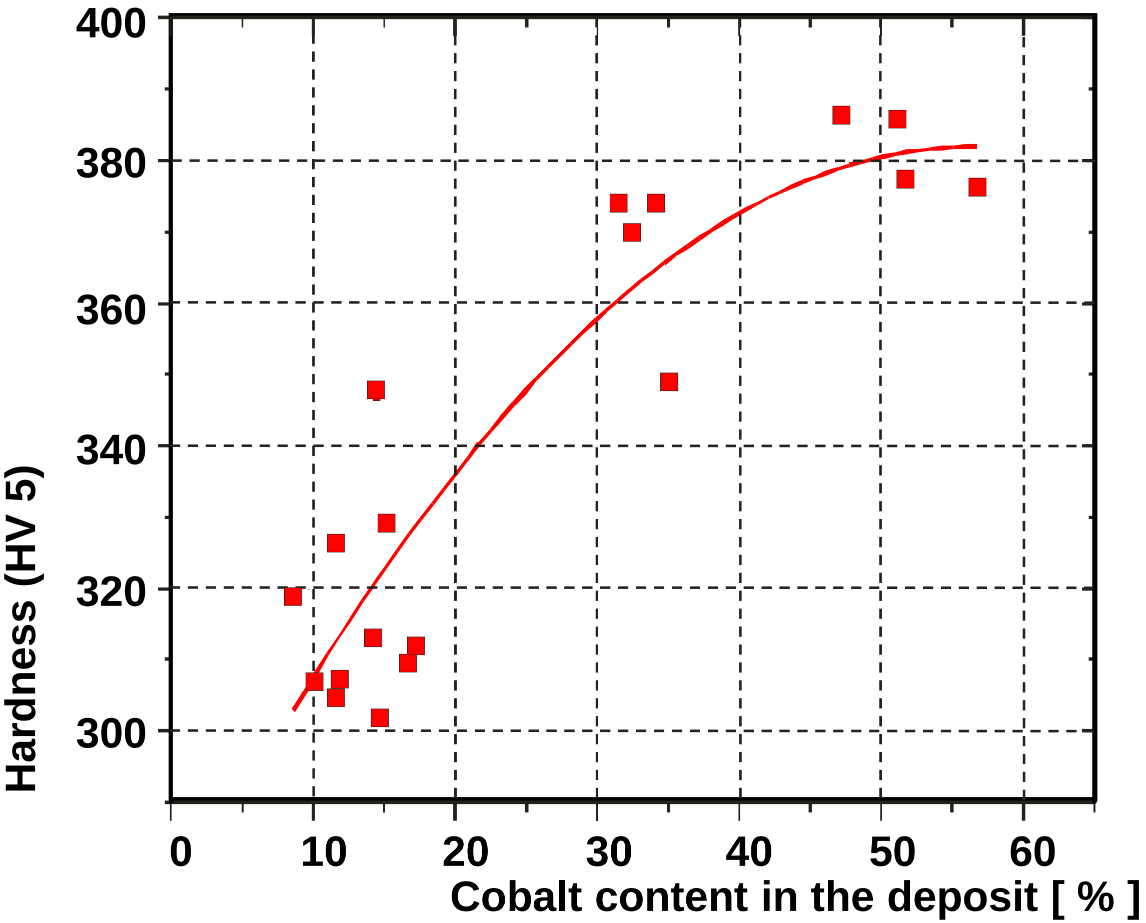


Cobalt content in the deposit versus cobalt concentration in the electrolyte

pH	4.0
T	55°C

Nickel	90 g/l
Sodium sulfamate	40 g/l
Sodium sulfate	15 g/l
Chloride	1.8 g/l

Electroplating of Ni-Co Microstructures

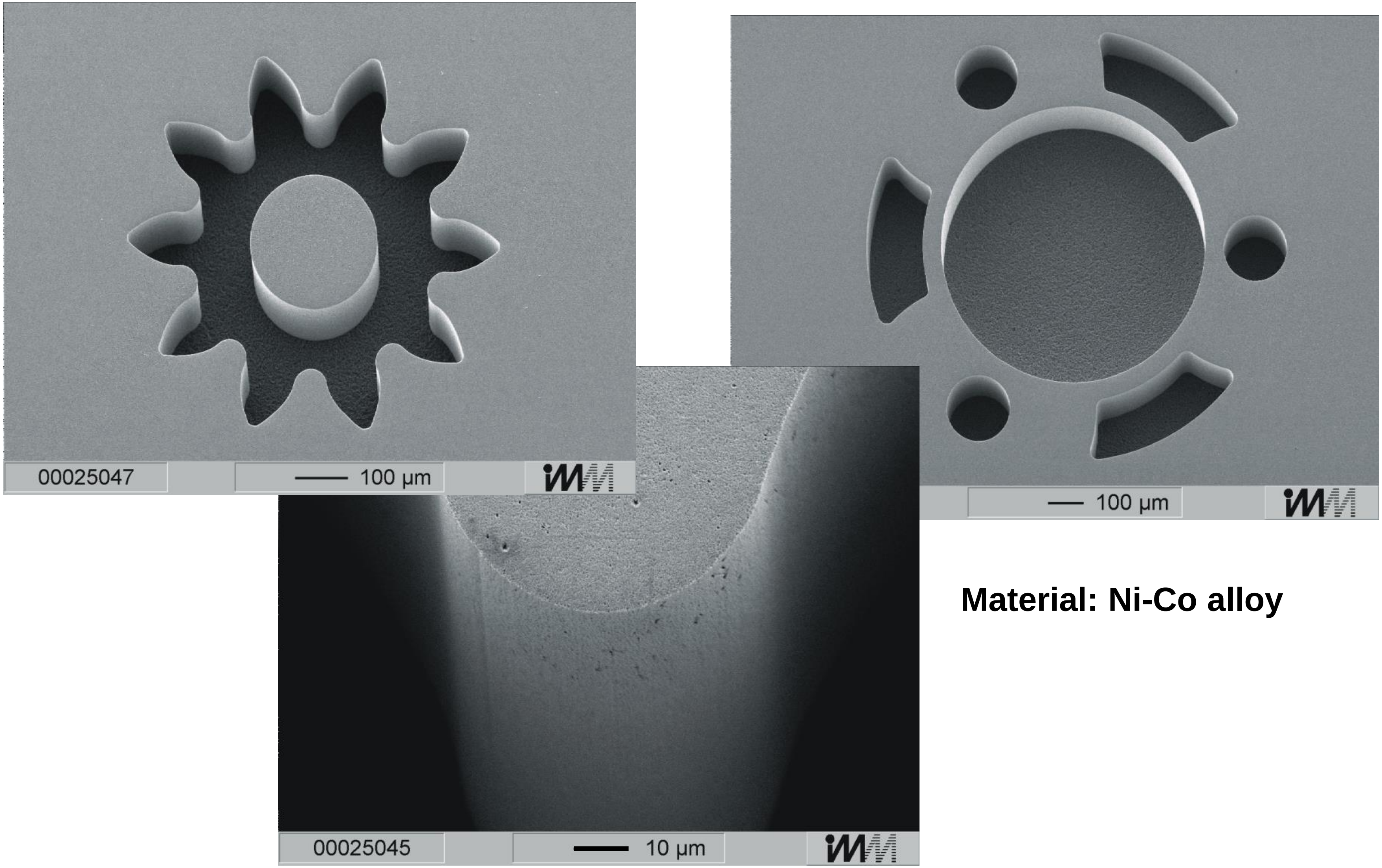


Electrodeposition of Ni-Co micro-structures: micro-hardness versus cobalt content in the deposit

pH	4.0
T	55°C

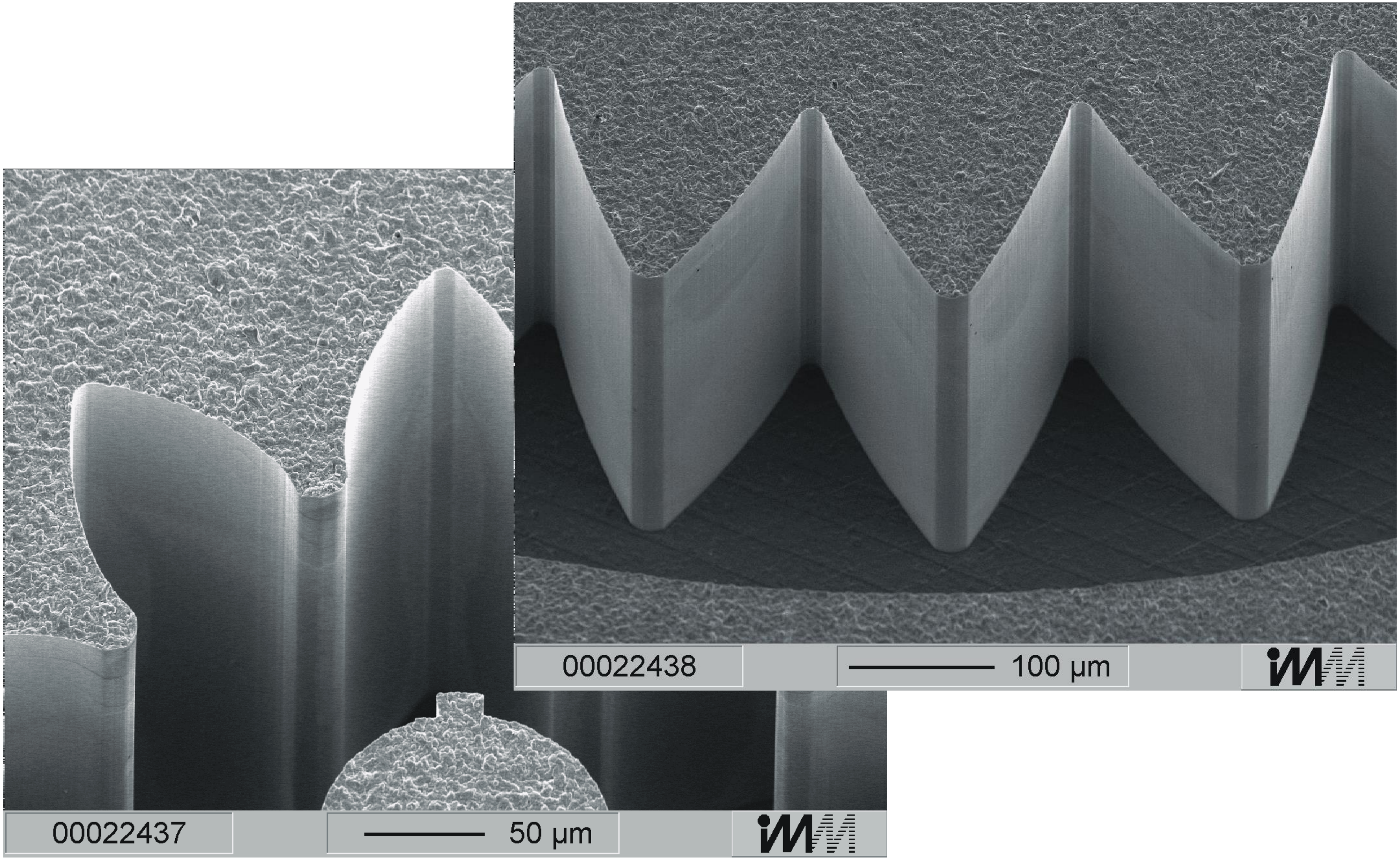
Nickel	90 g/l
Sodium sulfamate	40 g/l
Sodium sulfate	15 g/l
Chloride	1.8 g/l

Electroforming of Mould Inserts



Material: Ni-Co alloy

Electrodeposition of Ni-Co (73/27) Alloy



Electrodeposition

General

Gold

Copper

Nickel

Nickel-cobalt

Nickel- iron

Mold iserts

Special types of nickel alloys

Mold inserts from (ASE) silicon masters

Resist

Plating equipment

Nickel-Iron Alloy Electrodeposition: Working Conditions

Nickel	50 g/l
Iron	1-9 g/l
Boric acid	45 g/l
Sulfate	80 g/l
Complexing agent	15 g/l
Chloride	18 g/l
Saccharin	20 mg
Tenside	5 ml/l (2% Lösung)

Temperature	55 °C
pH - value	3.5
Current density	1 - 5 A/dm²
Current efficiency	~ 98%
Volume	50 l

Anode reaction:

$\mathrm{Ni}^{\pm0} ===> \mathrm{Ni}^{2+} + 2e$

$\mathrm{Fe}^{\pm0} ===> \mathrm{Fe}^{2+} + 2e$

$\mathrm{Fe}^{2+} ===> \mathrm{Fe}^{3+} + 1e$

Cathode reaction:

$\mathrm{Ni}^{2+} + 2e ===> \mathrm{Ni}^{\pm0}$

$\mathrm{Fe}^{2+} + 2e ===> \mathrm{Fe}^{\pm0}$

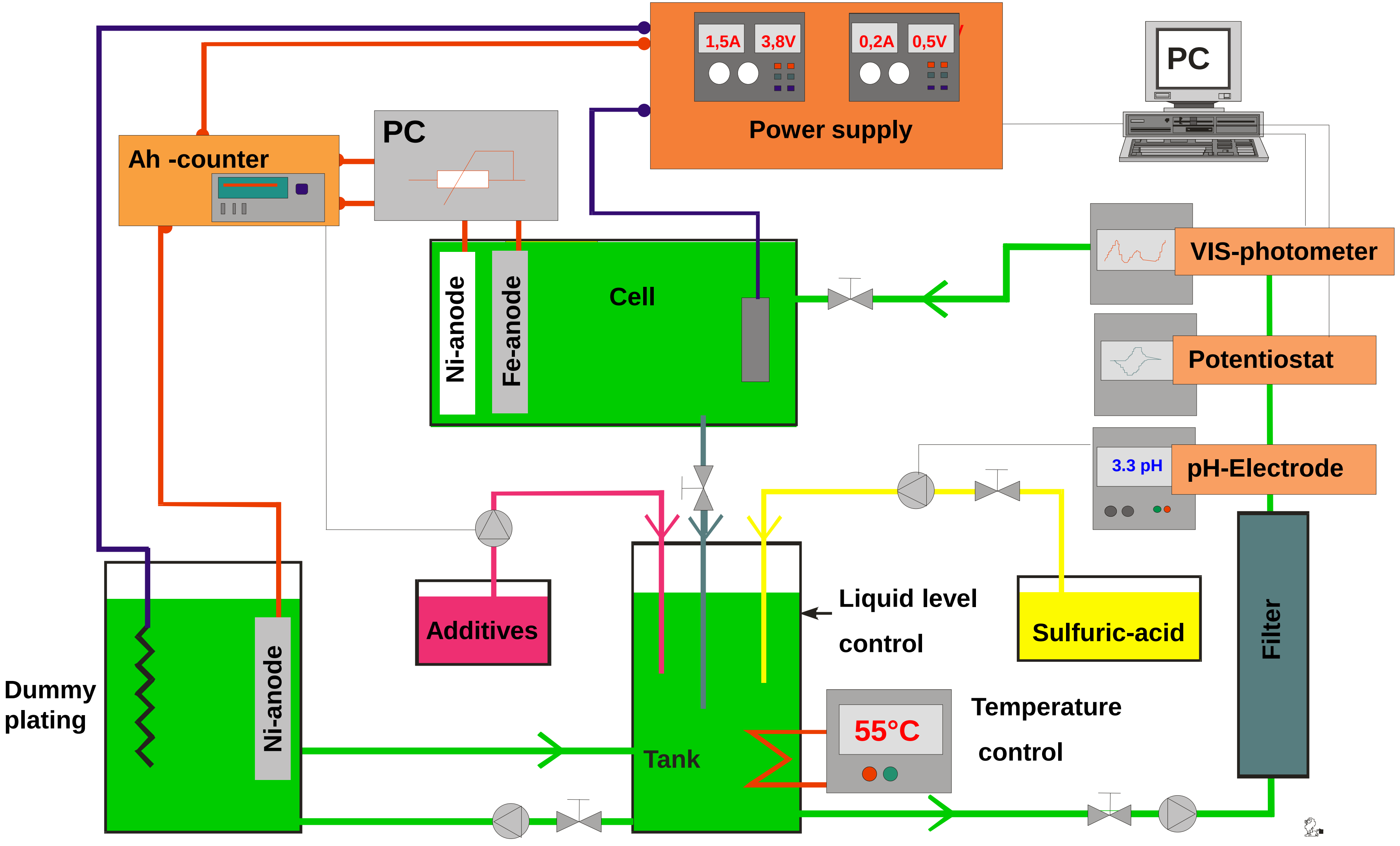
$2\mathrm{H}^{+} + 2e ===> \mathrm{H}_2$

Side reaction:

Fe^{2+} + Oxygen in air ===> Fe^{3+}

$2\mathrm{Fe}^{3+} + \mathrm{Fe}^{\pm0} ===> 3\mathrm{Fe}^{2+}$

Nickel-Iron Alloy Electrodeposition: Flow Chart



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Nickel-iron Sulfamate Electrolyte: Mass Balance

Cell

Cathodic reactions:

$Ni^{2+} + 2e \longrightarrow Ni^{\pm 0}$

$Fe^{2+} + 2e \longrightarrow Fe^{\pm 0}$

$2H^{+} + 2e \longrightarrow H_2$

$j = j_{Ni} + j_{Fe} + j_{H}$

Anodic reactions

$Ni^{\pm 0} \longrightarrow Ni^{2+} + 2e$

$Fe^{\pm 0} \longrightarrow Fe^{2+} + 2e$

Regeneration cell

$Ni^{2+} + 2e \longrightarrow Ni^{\pm 0}$

$Fe^{2+} + 2e \longrightarrow Fe^{\pm 0}$

$2H^{+} + 2e \longrightarrow H_2$

$j_{Ni} + j_{Fe} + j_{H}$

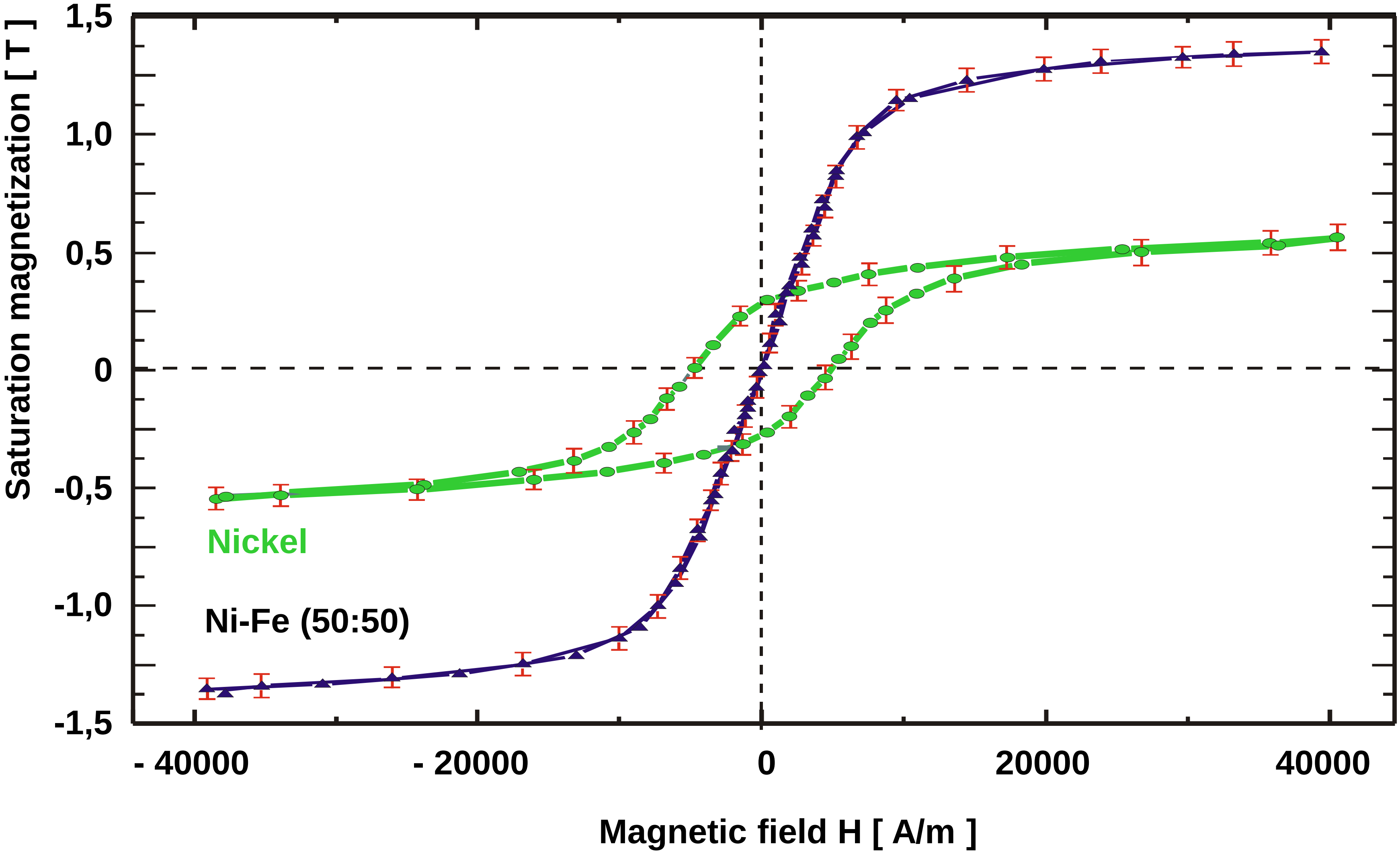
$Ni^{\pm 0} \longrightarrow Ni^{2+} + 2e$

Side reactions:

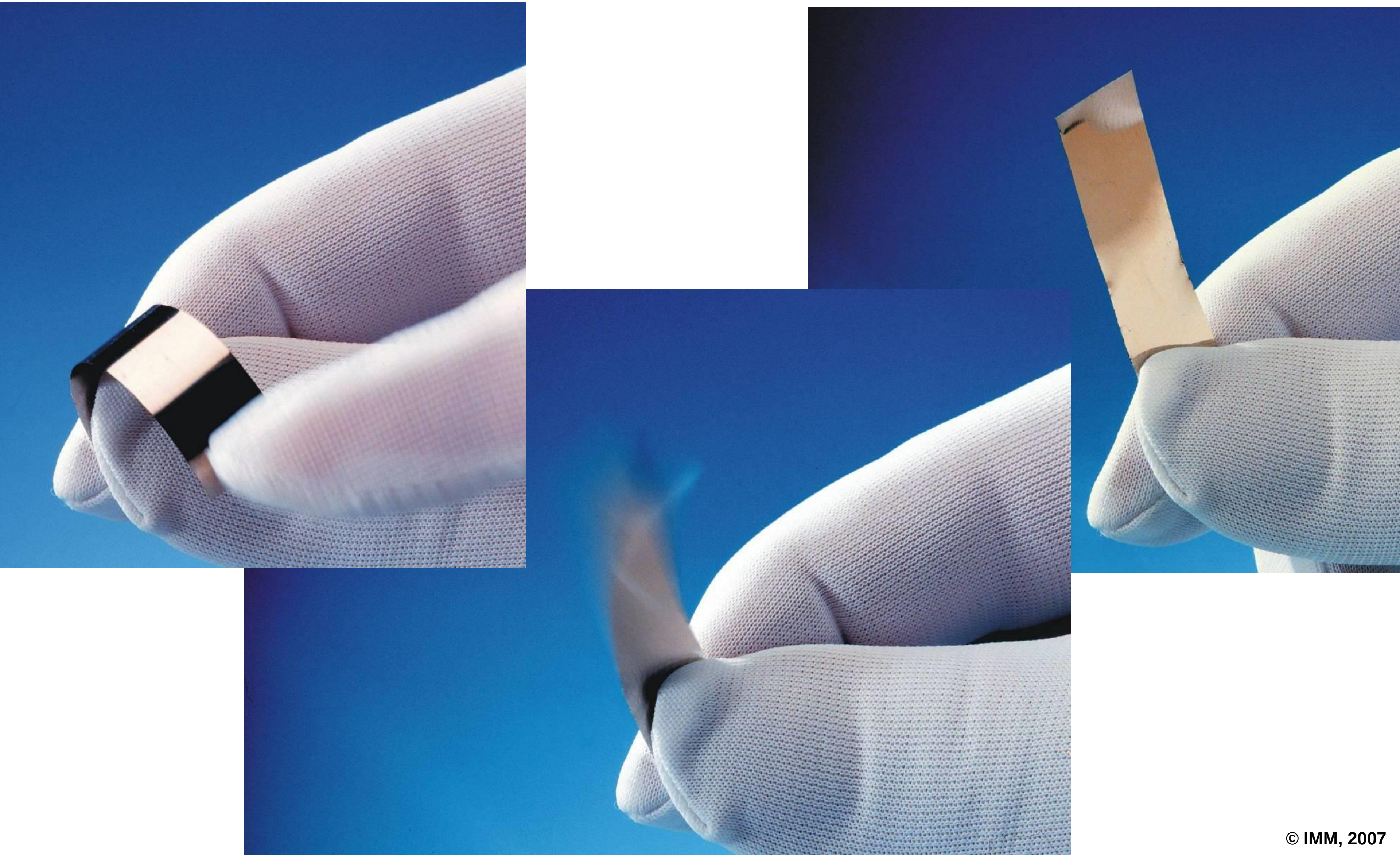
Fe^{2+} + oxygen in air $\longrightarrow Fe^{3+}$

$2Fe^{2+} + Fe^{\pm 0} \longrightarrow 3Fe^{2+}$

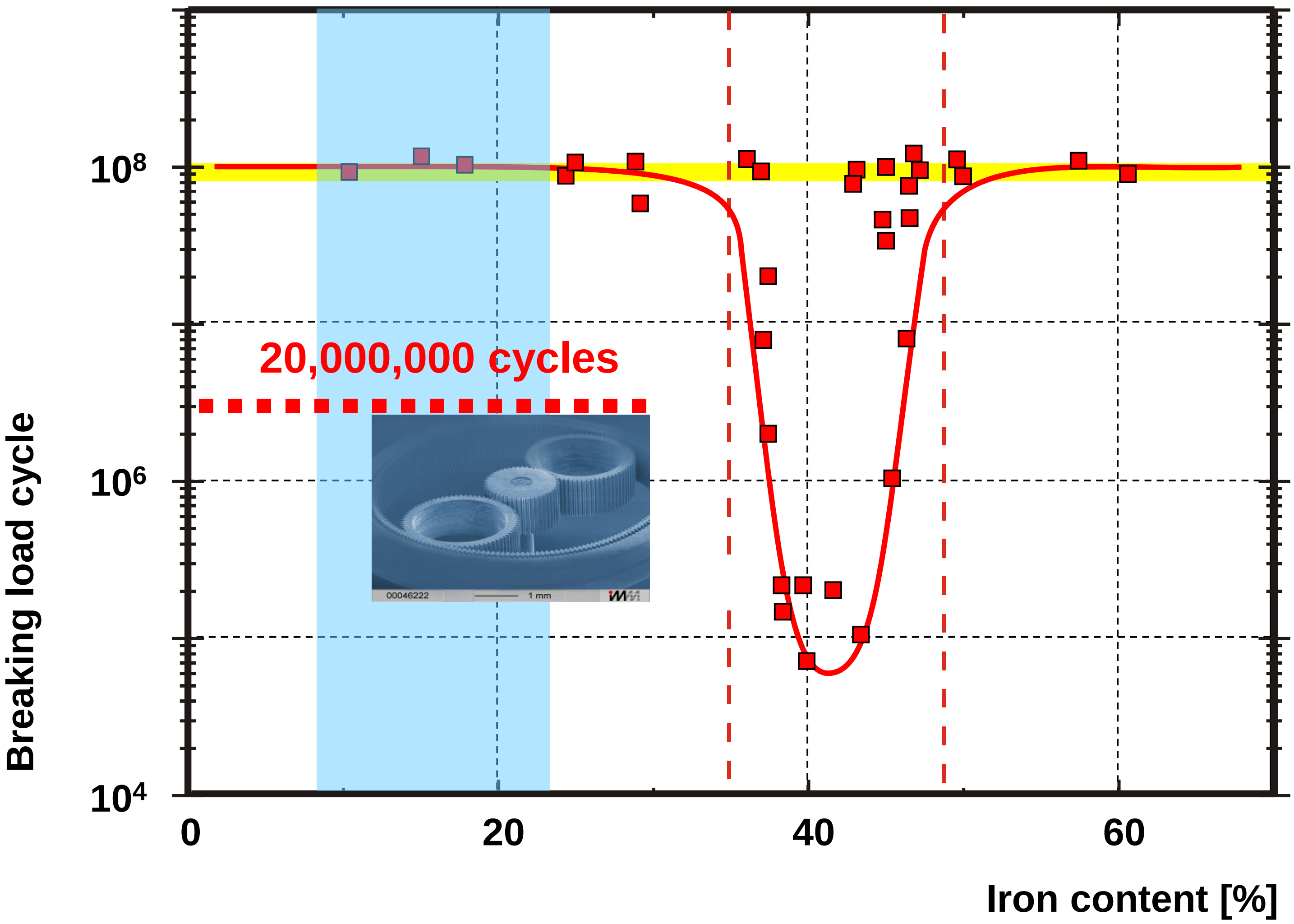
Comparison of Nickel and Nickel-Iron Microstructures: Hysteresis Curves



Material For Leaf-Springs; Electroplated Ni-Fe (90/10) Alloy

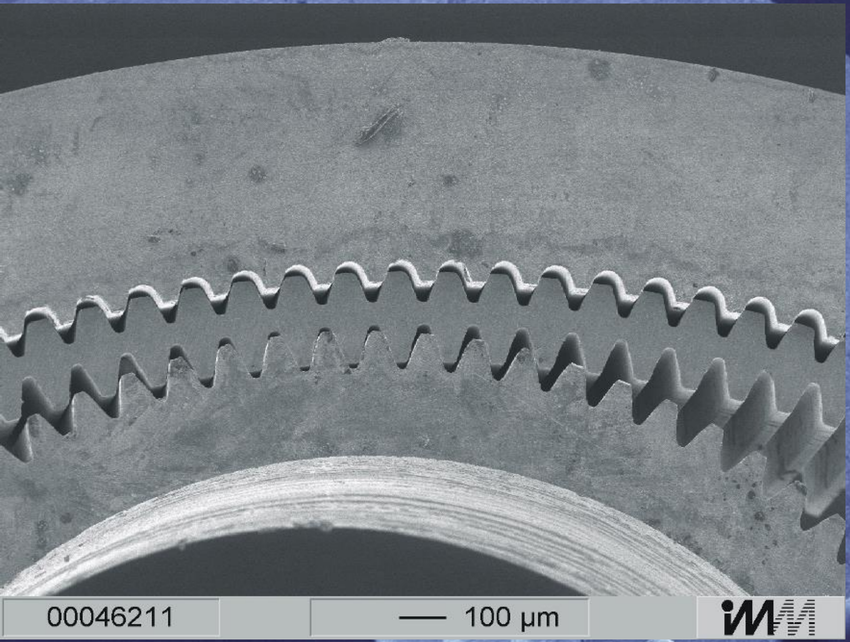


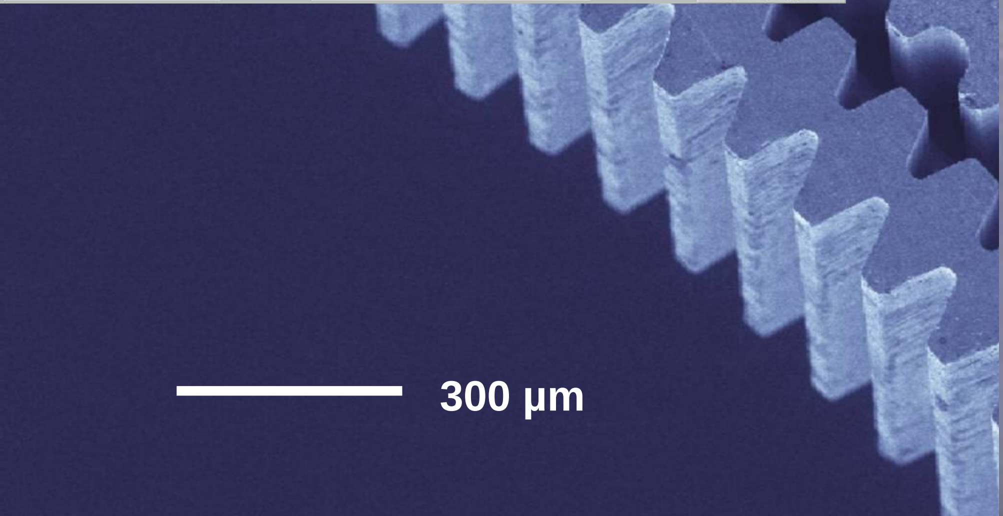
Endurance Strength of Ni-Fe Alloy Microstructures



Micro Harmonic Drive™: Flex Spline

- Gear ratio 500
- Torque 15 mNm
- Up to 50 000 rpm





Electrodeposition

Gold

Copper

Nickel

Nickel-cobalt

Nickel- iron

Mold iserts

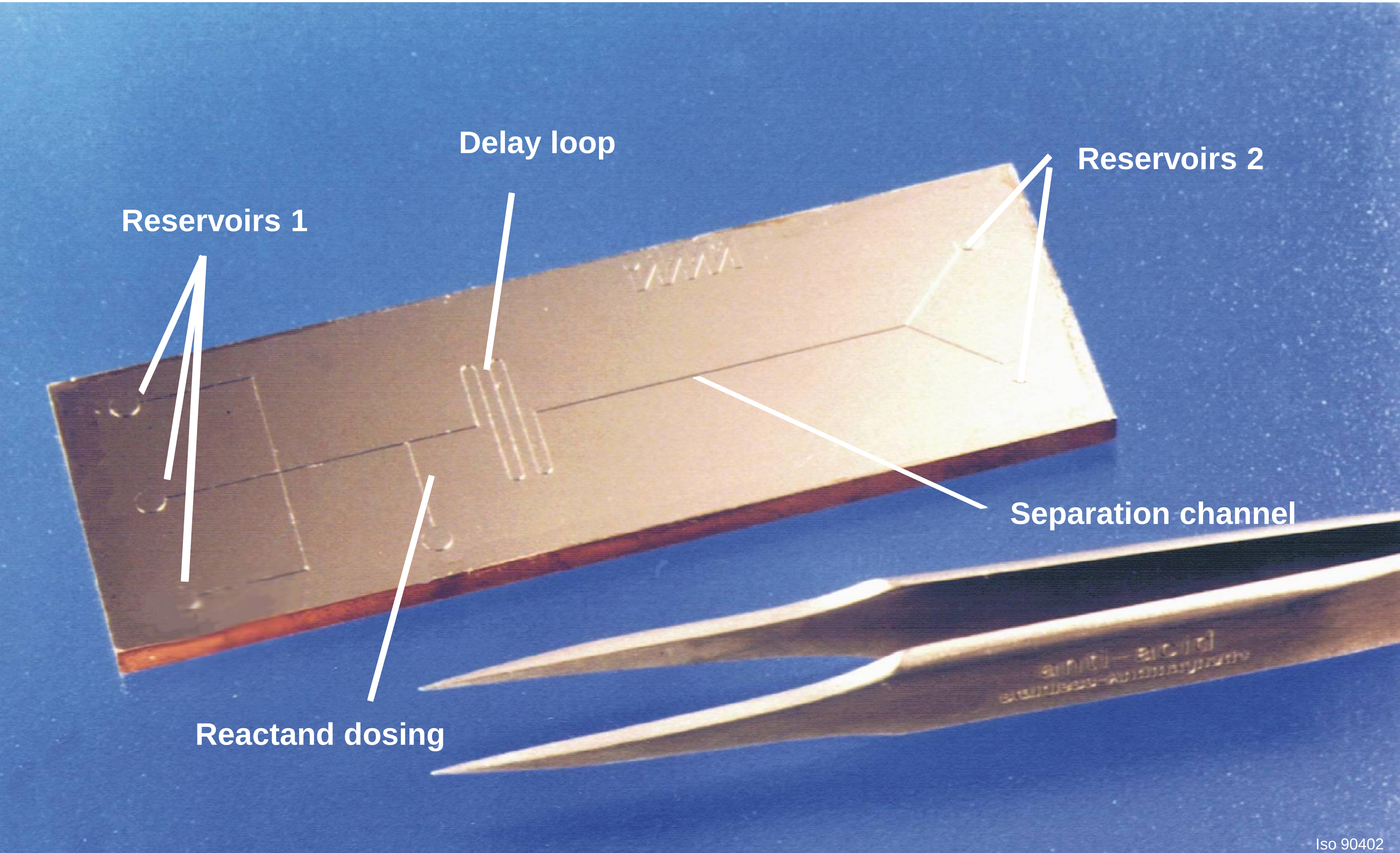
Special types of nickel alloys

Mold inserts from (ASE) silicon masters

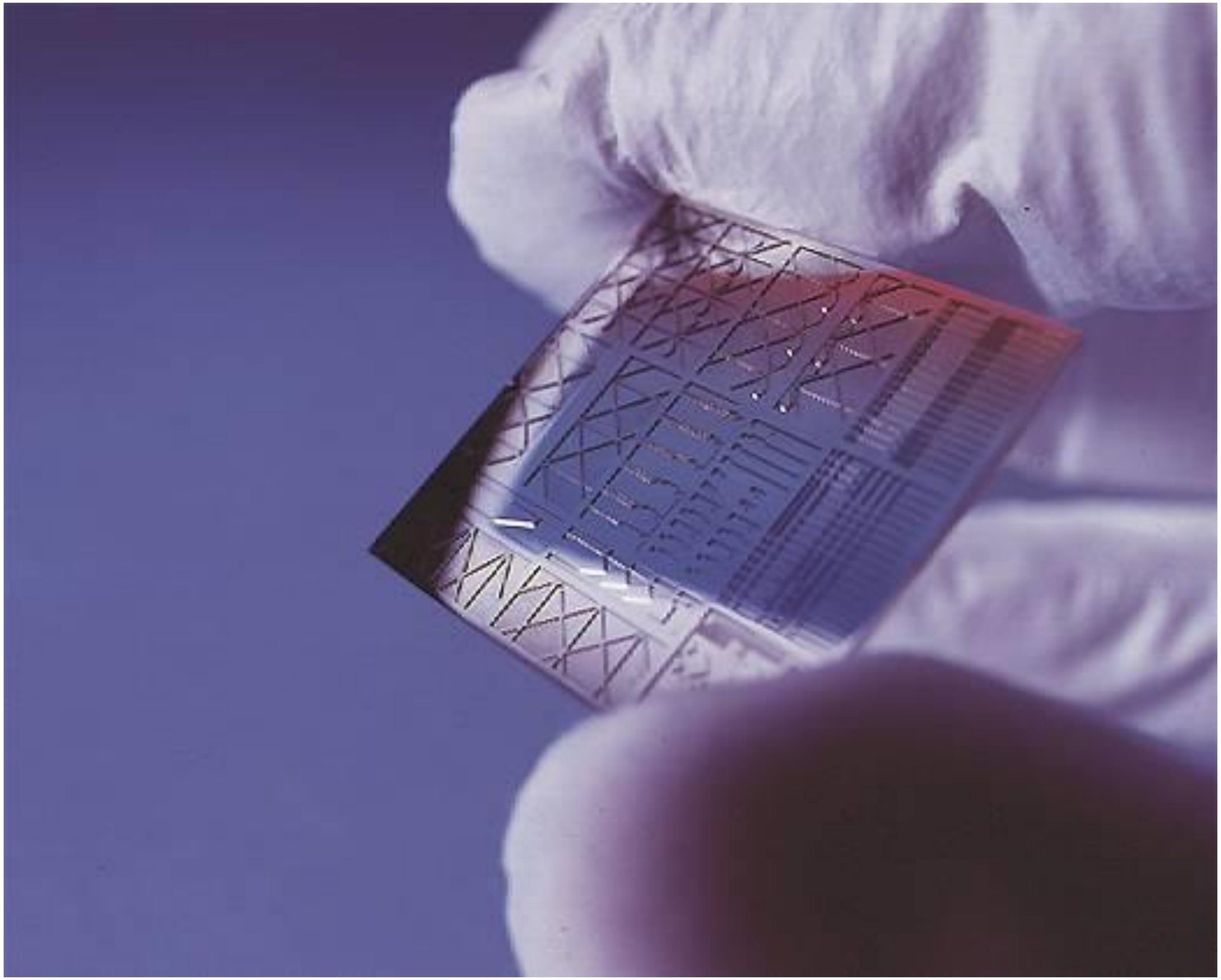
Resist

Plating equipment

Nickel Mold Insert for Lab-On-A-Chip Fabrication



Mold Insert for Micro-optical Structures



LIGA - technique

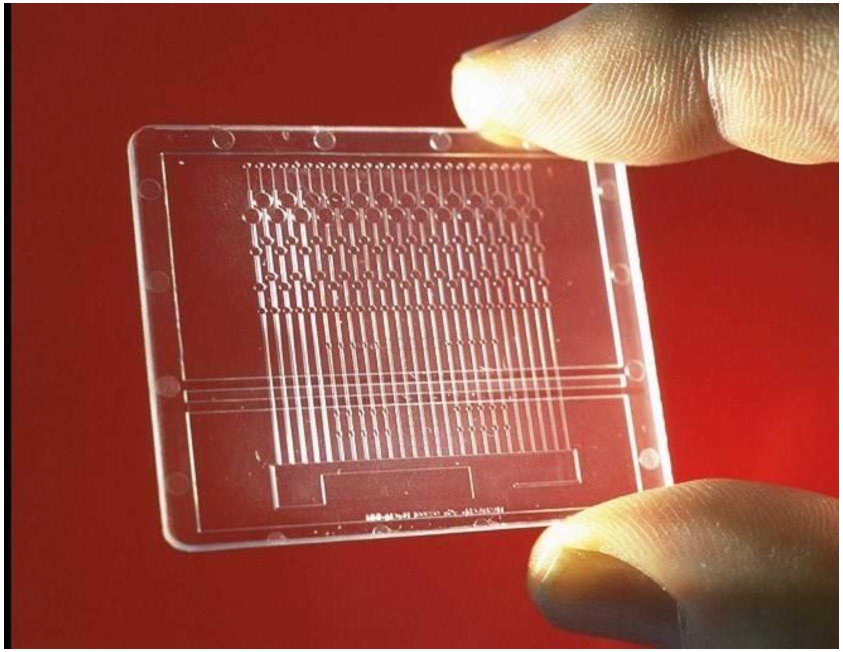
Material: Nickel

Dimensions:

25mm x 25mm

Fiber Grooves for 125 µm single-module fibers, microcuvettes and lens systems for beam shaping

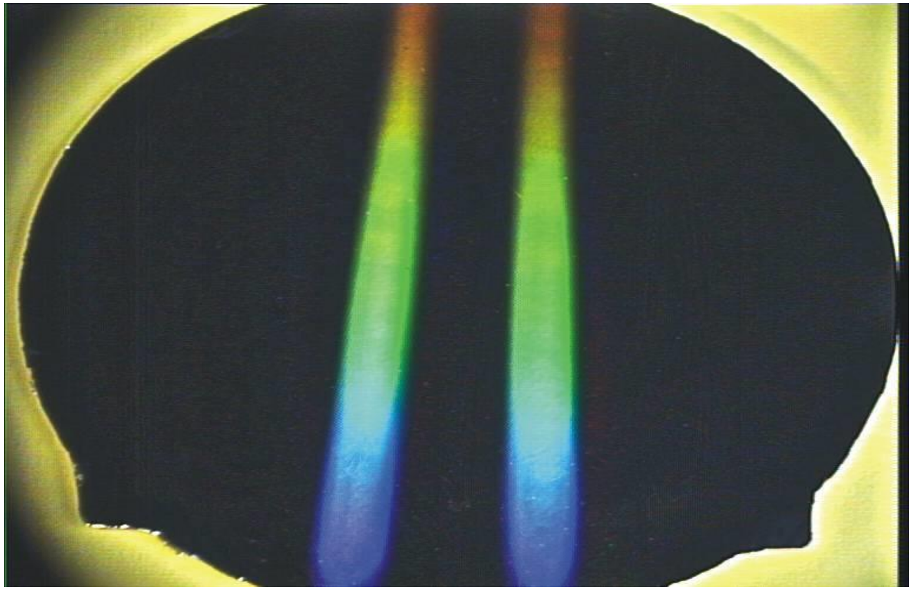
Polymer Chip Design and Fabrication



- Fabrication of master by Advanced Silicon Etching (ASE)
- Electroforming of mold insert by using NiFe electrolyte
- Plastic chip manufacturing
- Surface functionalization of microchannels via wet chemical process

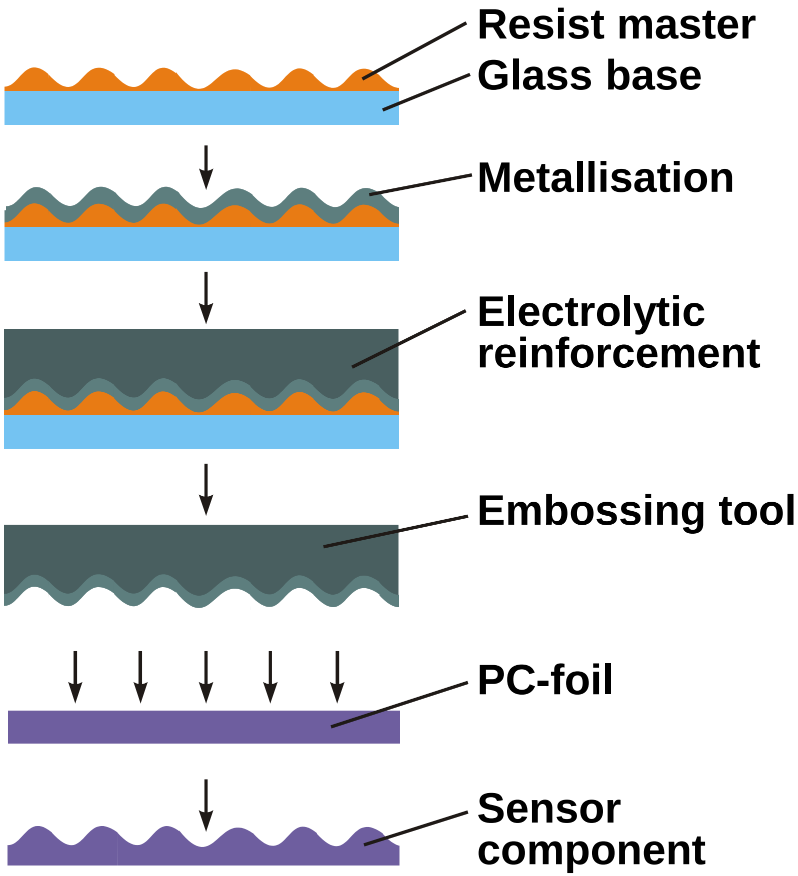
- 25 reaction chambers supplied by microfluidic channels
- Reaction volume 20 nl
- Liquid transport by combination of capillary forces and membrane actuators

Ultraprecision Hot Embossing



Minimum feature size: <3nm

Reproducibility: <1nm



Resist master

Glass base

Metallisation

Electrolytic reinforcement

Embossing tool

PC-foil

Sensor component