Micro Precision Manufacturing by Electroforming

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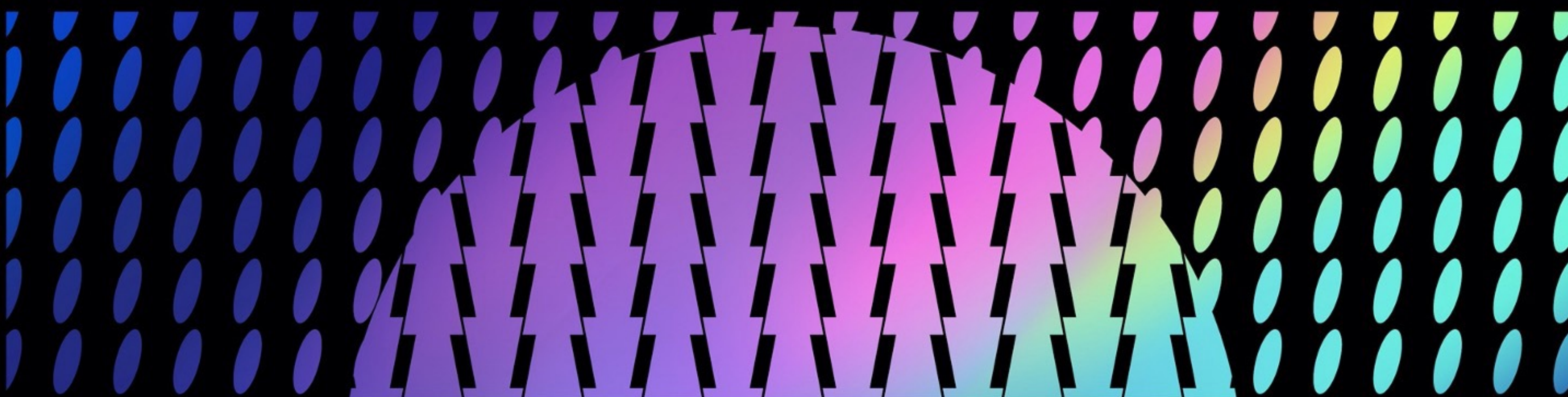
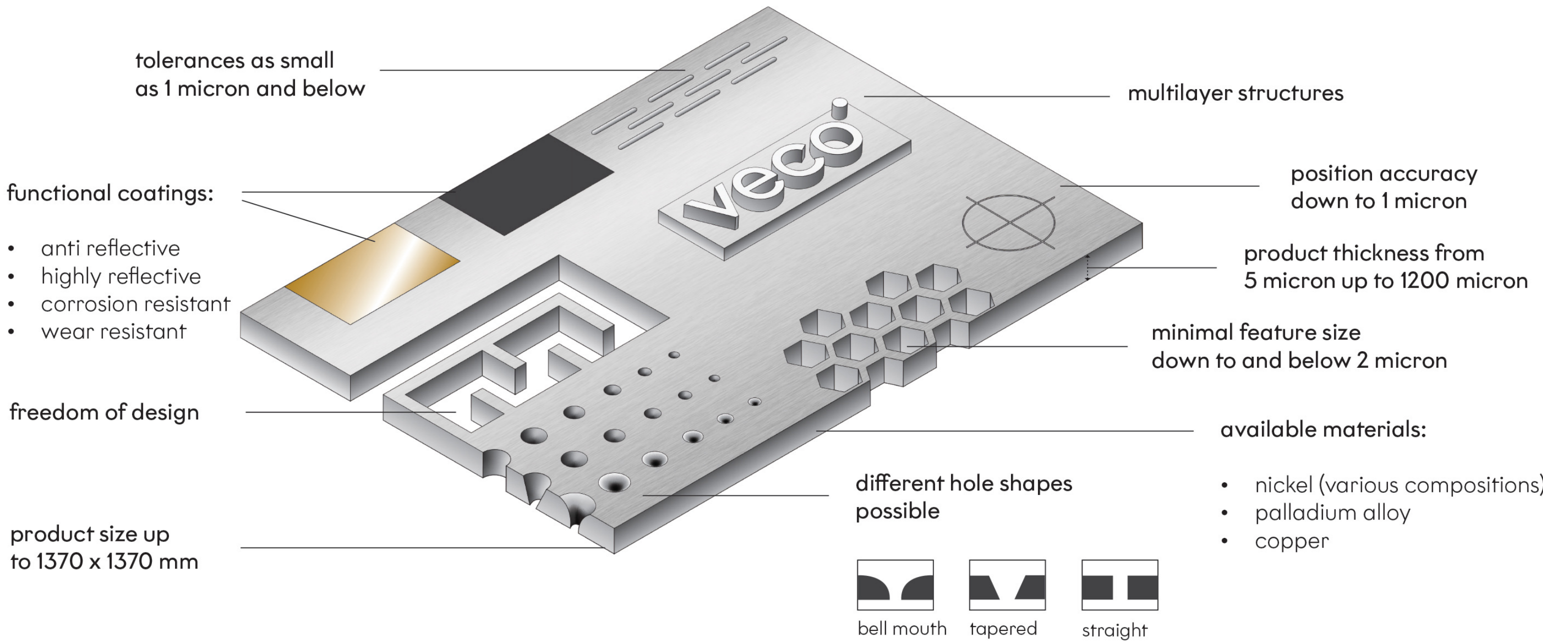
May 19, 2025



world leader in micro-precision

The basics of Electroforming

Electroforming capabilities

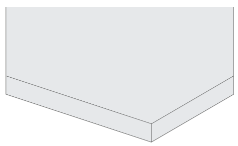


Design specifications should always be assessed in the context of the overall design.

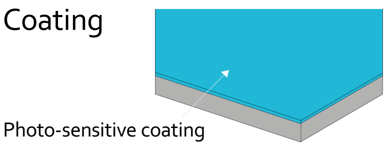
Electroforming process

The Electroforming process can be concluded in a series of steps including Cleaning, Coating, Exposing, Developing, Deposition, and Harvesting

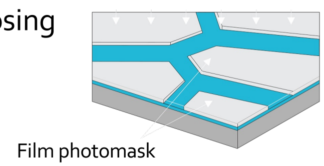
1. Cleaning



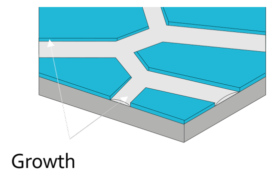
2. Coating



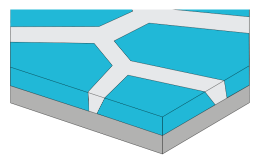
3. Exposing



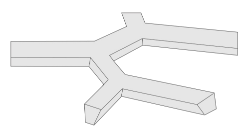
4. Developing

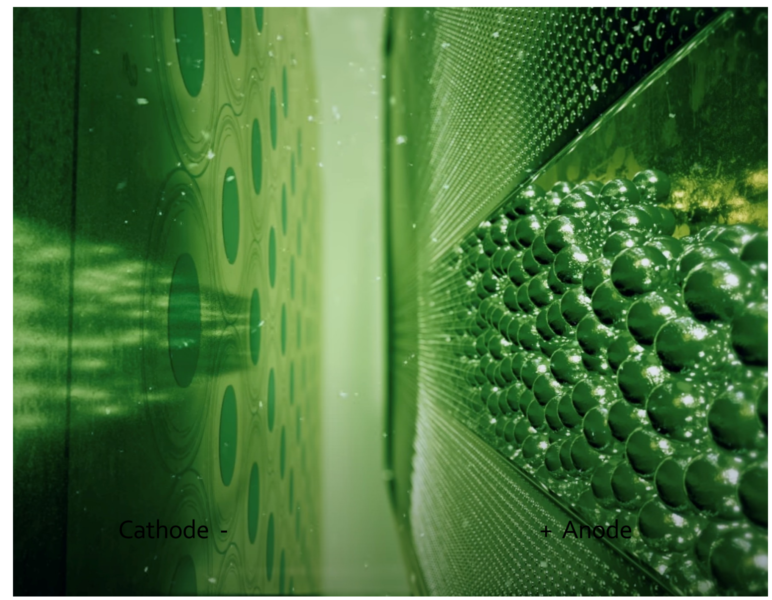


5. Deposition



6. Product harvesting





veco

The substrate

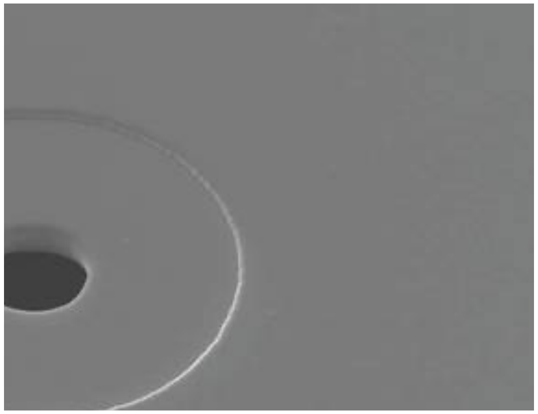
Not just a **detail**

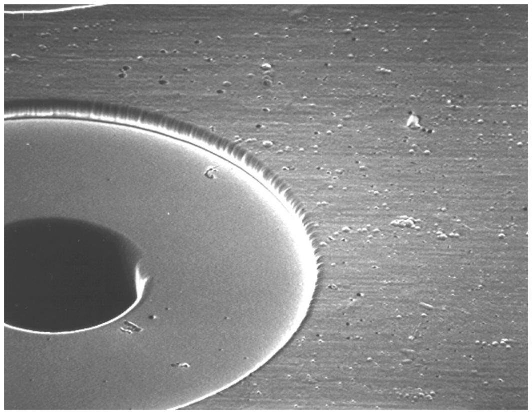
Many important parameters

- Roughness and gloss
- Dimensions
- Stiffness
- Expansion coefficient
- Conductivity
- Uniformity
- Cleanliness
- ‘Activity’

Different substrates are conceivable

- Metallic substrates like stainless steel
- Flat substrate like glass with a conductive coating





1. Cleaning
2. Coating
3. Exposing
4. Developing
5. Deposition
6. Product harvesting

The coating processes

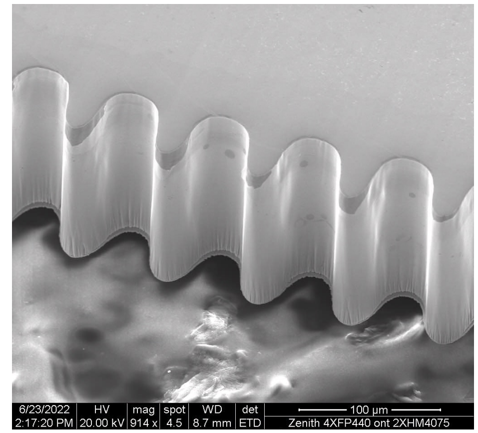
The role of photoresist

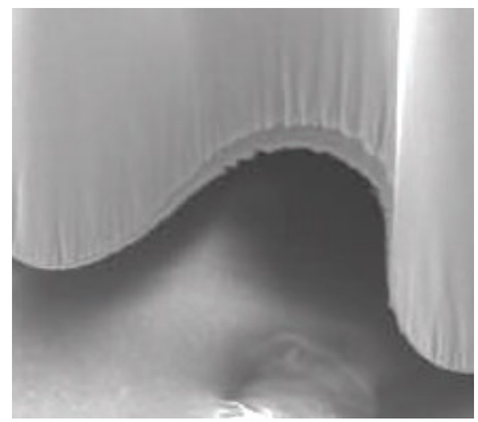
Many requirements

- **Thickness uniformity**: As uniform as possible, particularly in ‘overgrowth products’.
- **Contrast**: Sharp difference in developing speeds of exposed and non-exposed areas.
- **Sensitivity**: High sensitivity is required for high throughput.
- **Stability**: Both thermal and chemical during electroforming process, but removeable after use.
- **Adhesion**: It should inhibit contact between the electrolyte and substrate.
- **Conductivity**: It acts as isolation layer during the electroforming process.

Many options

- Many ways to laminate the various types of photoresist (*e.g.* dry film; spin coating)

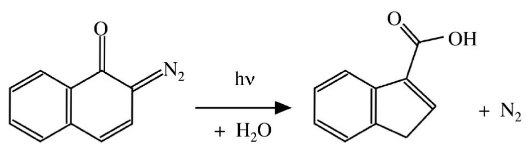




The exposure processes

Chemistry behind the process

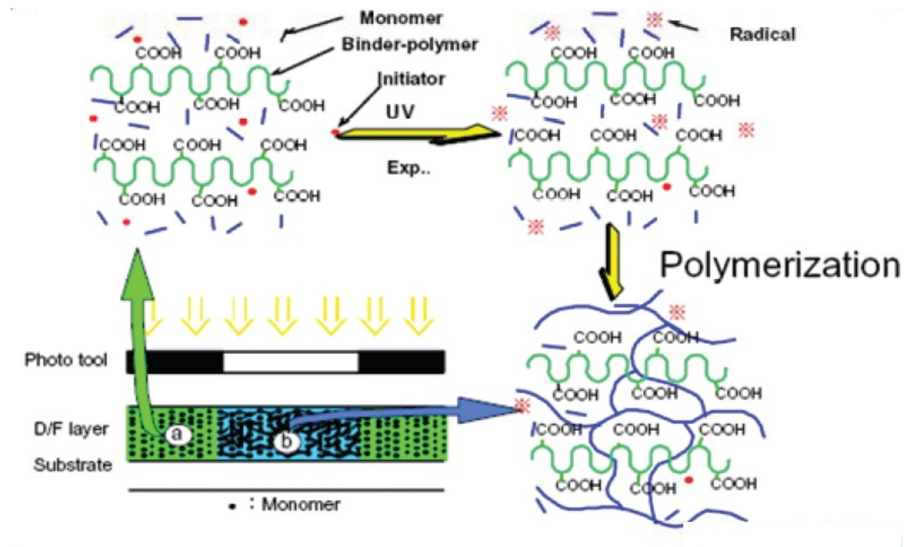
Positive photoresist



Base-insoluble sensitizer

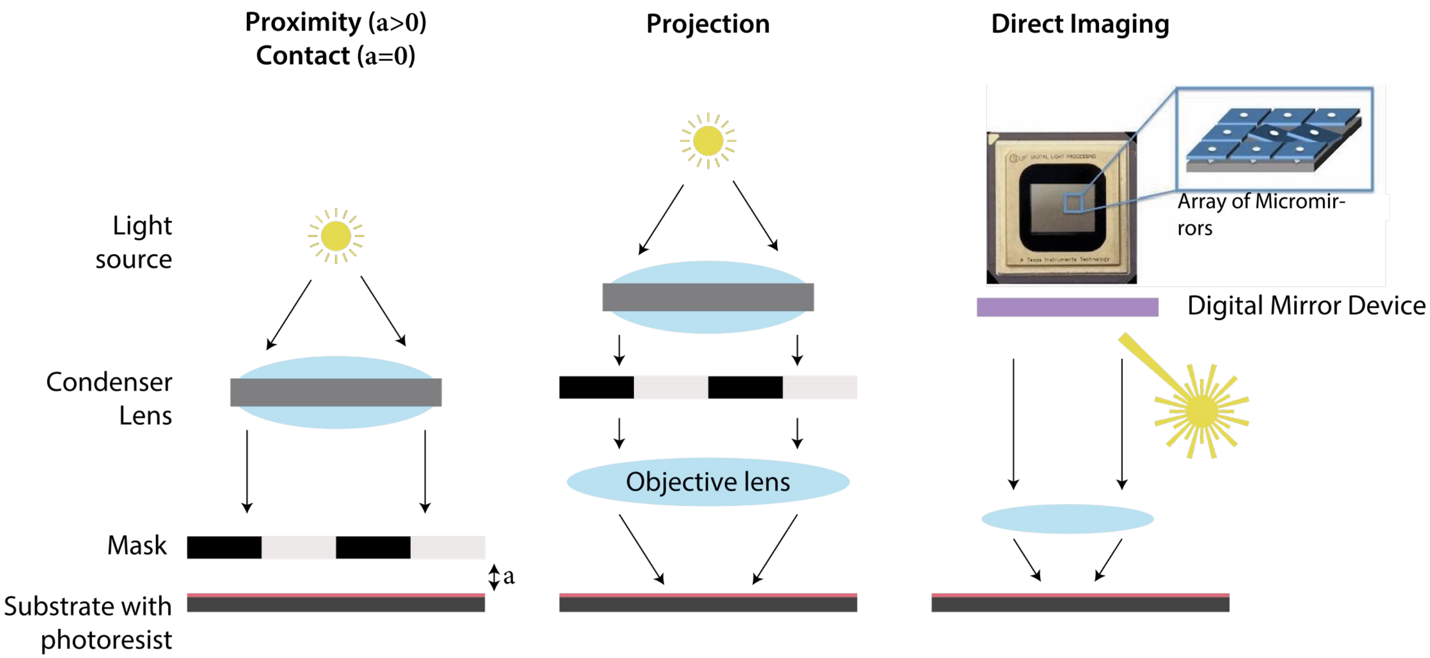
Base-soluble photoproduct

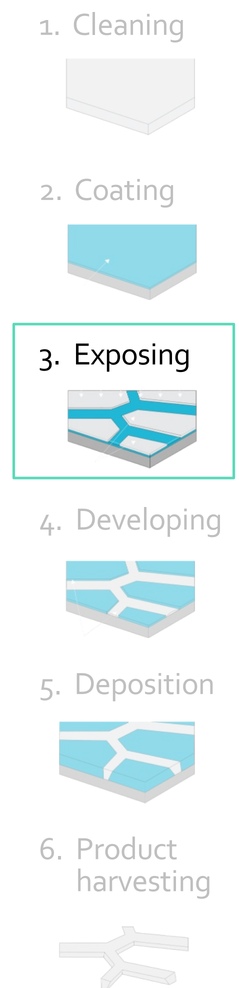
Negative photoresist



The exposure processes

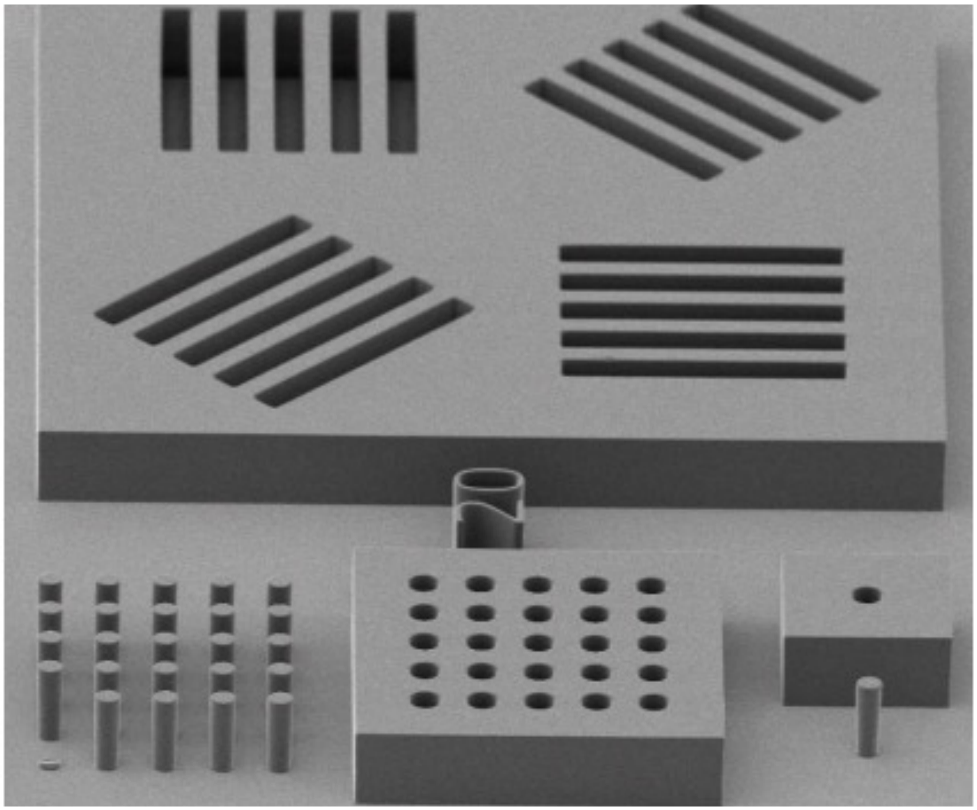
Exposure methods





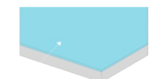
Developing

Potential structures after developing

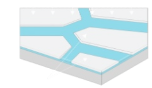


1. Cleaning

2. Coating



3. Exposing



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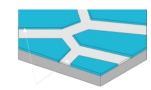
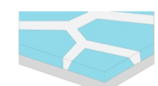


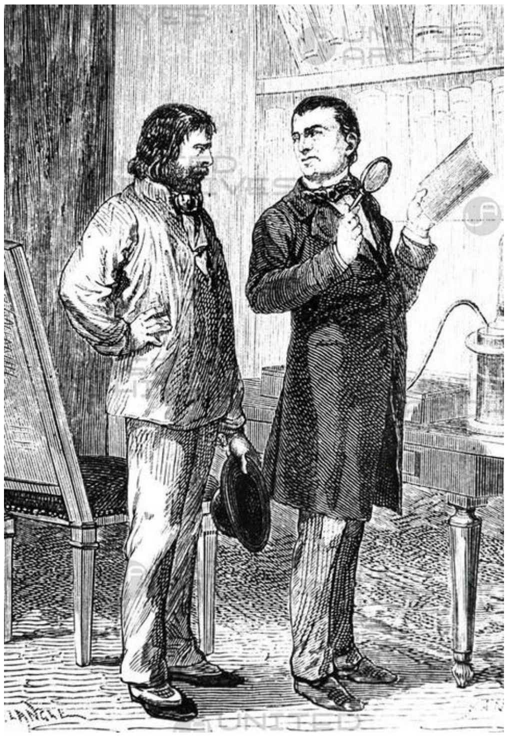
5. Deposition



6. Product harvesting

Electroforming

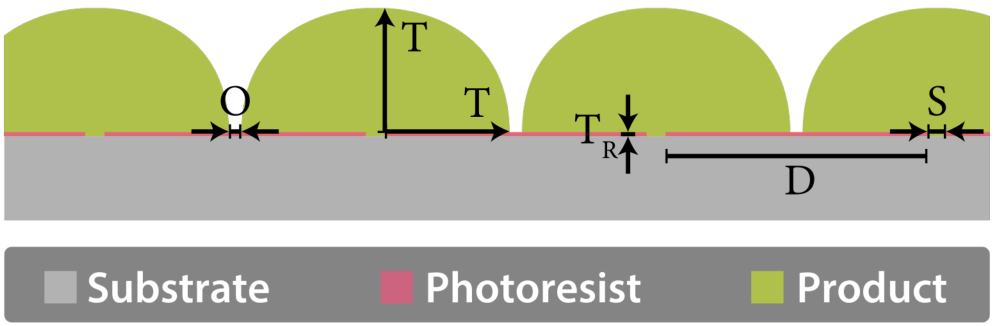
It all started in 1838



Electroforming was discovered in 1838 by Professor B.S. Jacobi . He electroformed copper upon an engraved copper plate, which he used as the cathode in a copper sulfate solution; In his report Academy (October 4th, 1838) he wrote:

> *"In the experiment with an engraved plate covered by a very thin layer of vegetable oil, it was possible to produce another copper plate on which even the **slightest imprints** on the original were produced with the **highest accuracy**".*

Plating defined electroforming



Product Thickness = $T + T_R$

Hole size (O)=D-2T

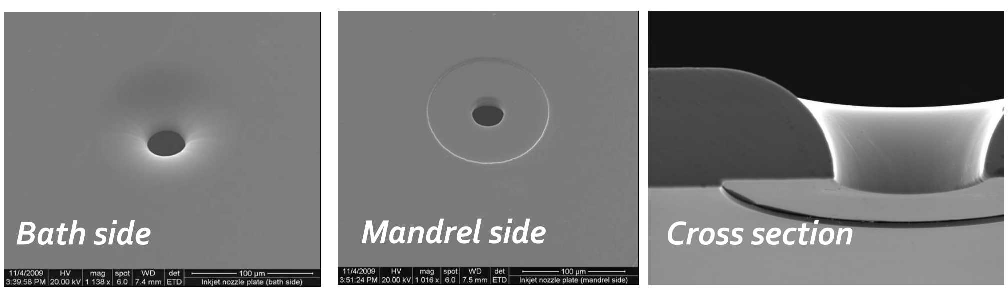
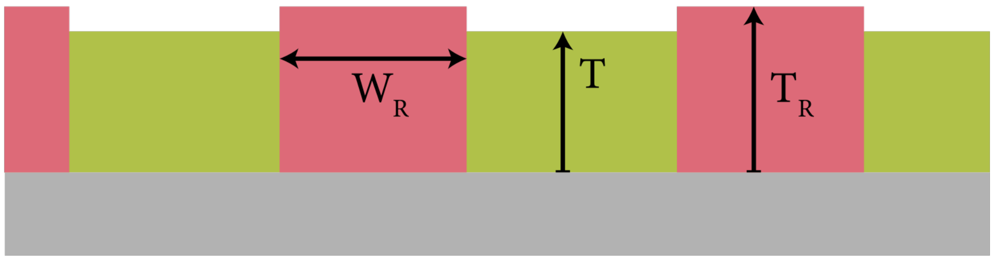
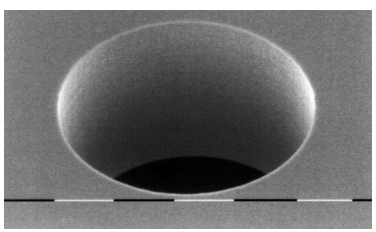
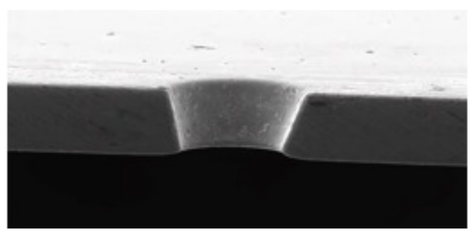


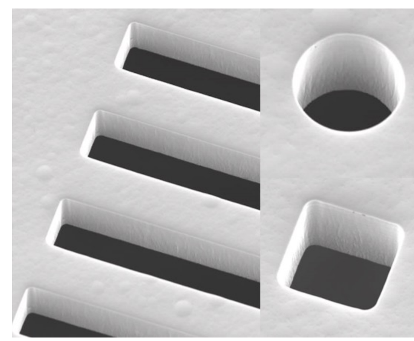
Photo defined electroforming



Substrate Photoresist Product







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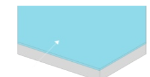
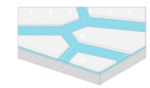
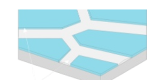
2. Coating



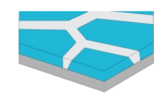
3. Exposing



4. Developing



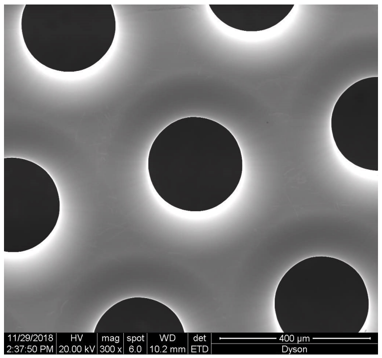
5. Deposition



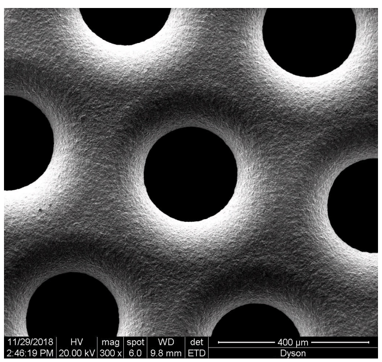
6. Product harvesting

Typical electroformed materials

Veco 84

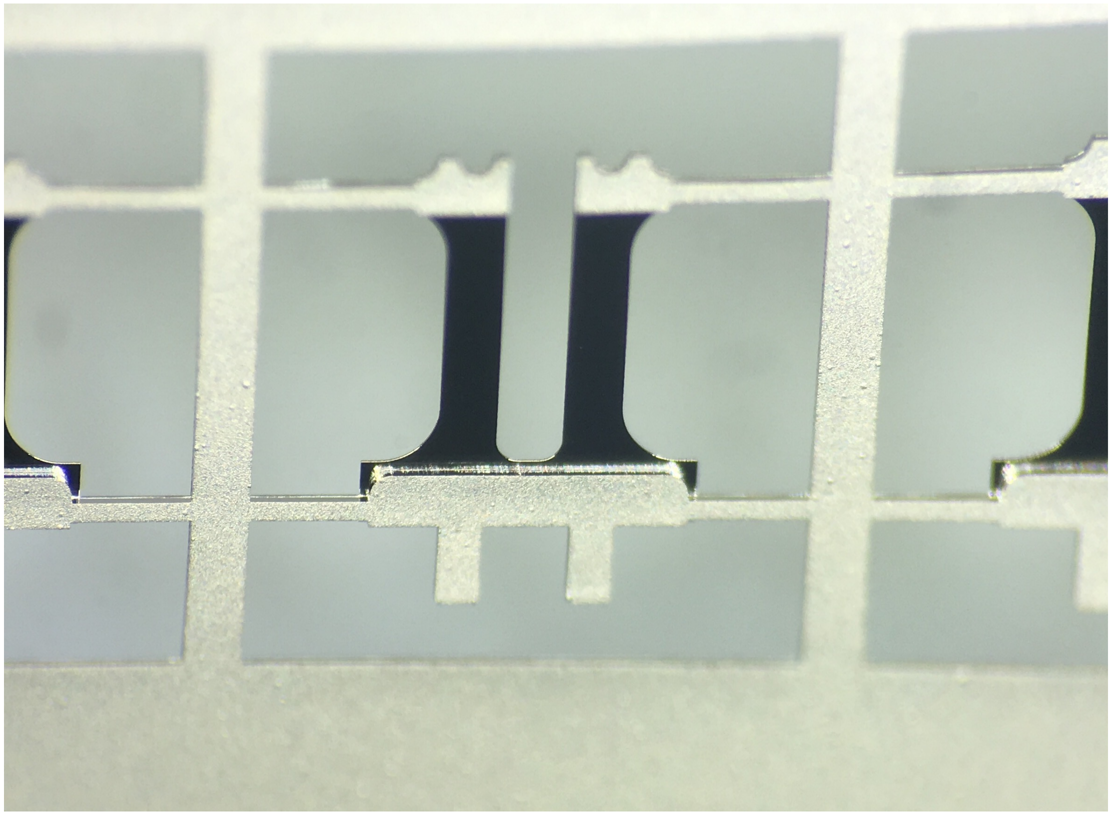


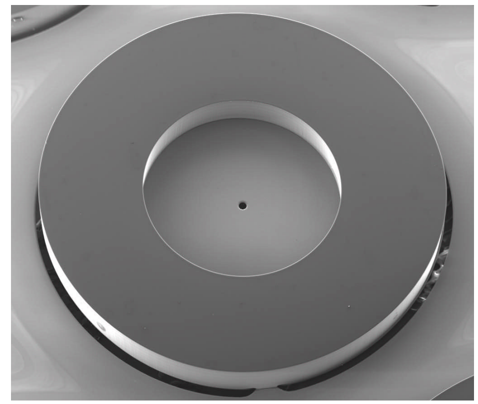
Sulfamate

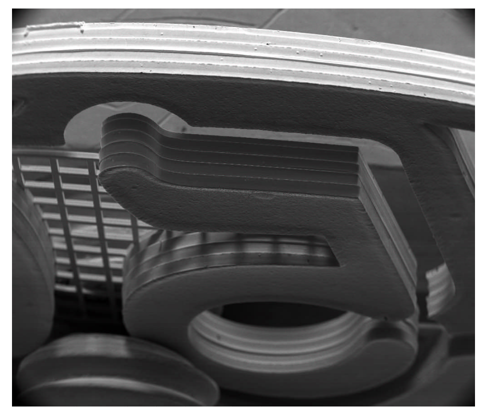


Property	Type					Comparison Stainless Steel[2]	
	Veco84	Sulfamate	Meta	HR-Ni	PdNi	SS 316L	SS 304
Tensile strength R_m [MPa][1]	2200-2300	550-570	1060-1080	1670-1690	1750-1950	680-710	680-710
Yield strength $R_{p0.2}$ [MPa][1]	1900-2100	390-405	760-785	1100-1300	1700-1750	290-330	290-330
Elasticity E [GPa][1]	130-135	80-95	80-95	90-125	95-110	130-155	130-155
Elongation at failure [%][1]	4-7	13-20	6-7	2-8	0-2	50-55	65-75
Hardness HV [N/mm²][3]	620-660	185-200	330-340	460-470	520-530	175-185	180-200
Saturation magnetization M_s [$\mu A\ m^2\ mg^{-1}$][4]	52-56	52-56	52-56	52-56	n.a. (paramagnetic)		
Chemical Purity [wt% Ni][5]	99,5	99,9	99,9	99,9	alloy		
Nickel Leaching [mg/L][6]	0,056 +/- 0,008	0,072 +/- 0,014	0,053 +/- 0,036	0,075 +/- 0,028	0,025 +/- 0,016	0,000 +/- 0,000	0,000 +/- 0,000
Gloss type	High	Semi	High	High	High		
Gloss [%]	55% @ 20°	2% @ 60°	42% @ 20°	56% @ 20°	59% @ 20°		
Surface Roughness R_a [µm]	0.03	0.3	0.02	0.04	0.03		
Surface Roughness S_a [µm]	0.03	0.2	0.03	0.06	0.05		
$HV \geq 95\% + R_m \geq 95\%$[7]	120 °C	160 °C	200 °C	200 °C	200 °C		
Bulk resistivity ρ [$x10^{-7}$ Ω.m][8]	1.3 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	1.0 ± 0.1	2.9 ± 0.1		

Multi-layer products







1. Cleaning
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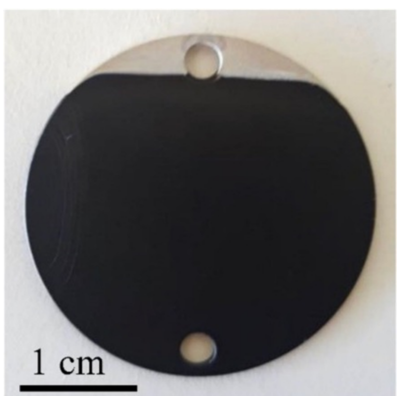
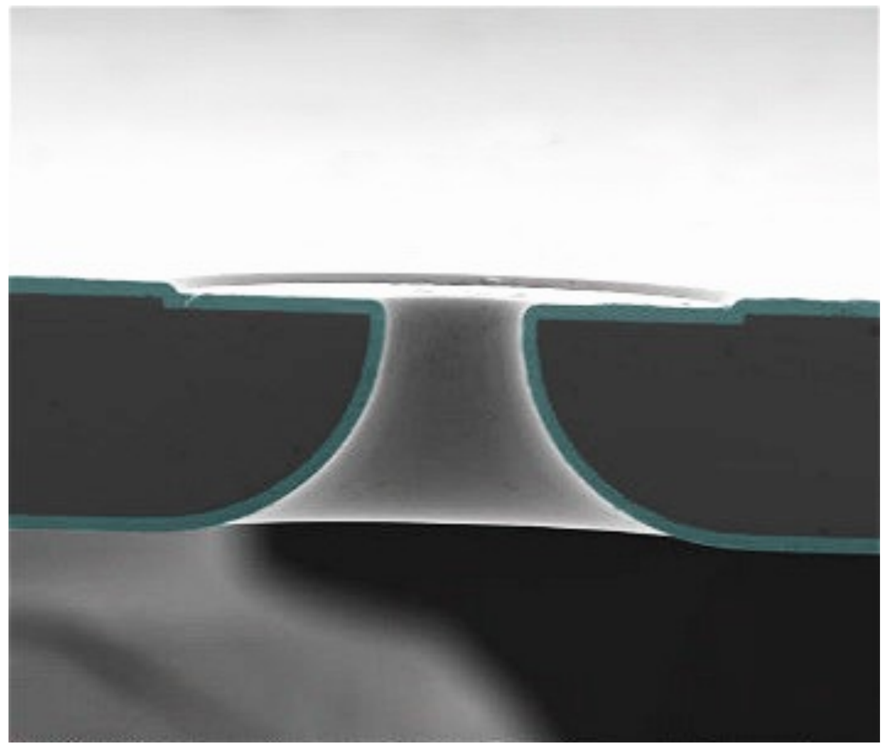
Coatings

Tailoring properties by application of (galvanic) coatings

Application of coatings to alter:

- Reflective properties
- Conductivity
- Chemical stability
- Mechanical stability
- Surface structure/properties





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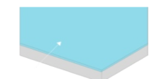

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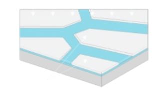

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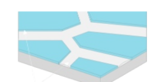

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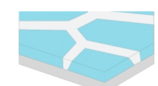
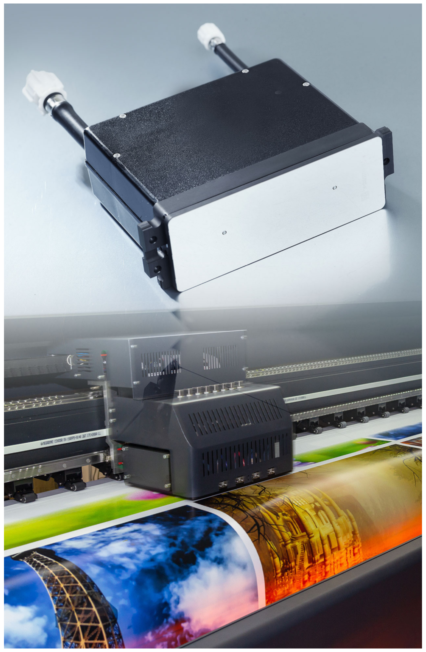


6. Product harvesting

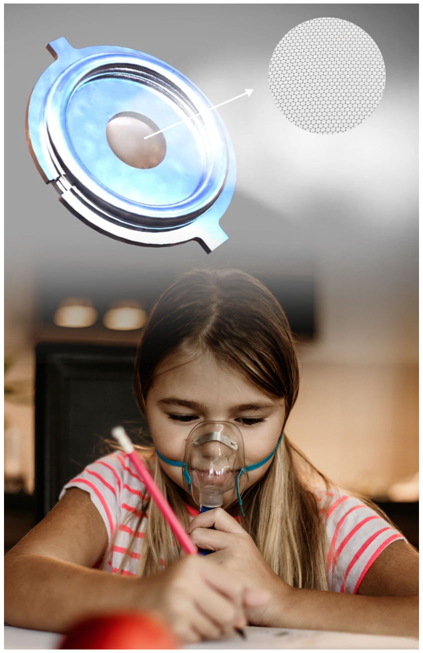
Real life application examples

a day in the life

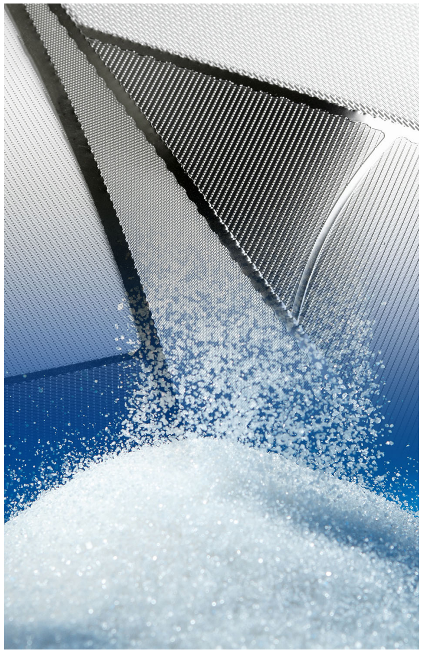
Coffee filters



Inkjet nozzle plates



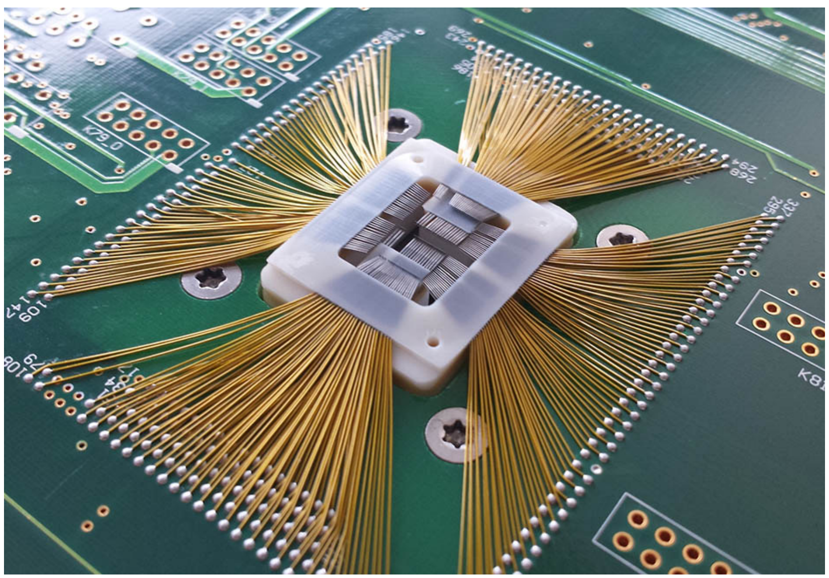
Nebulizer plates

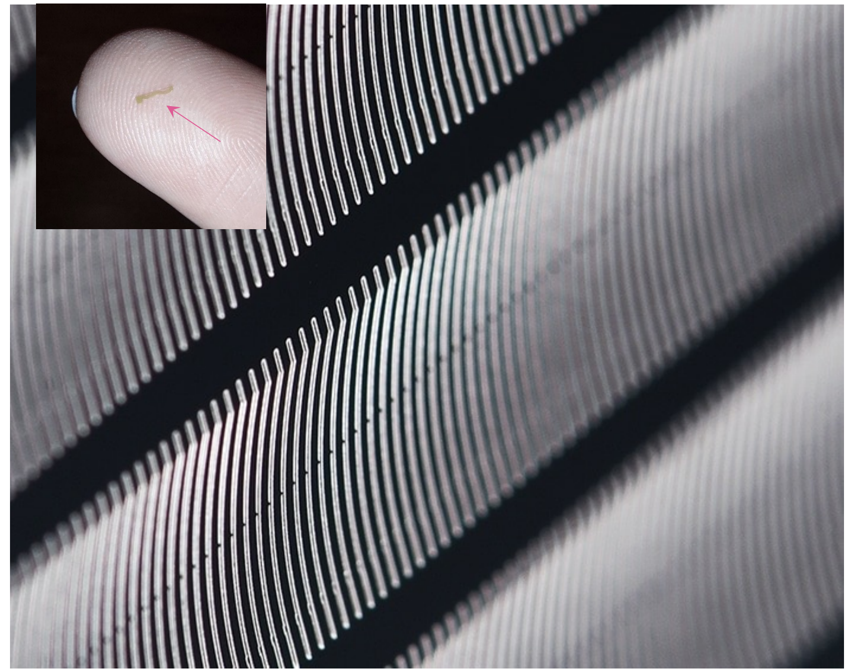


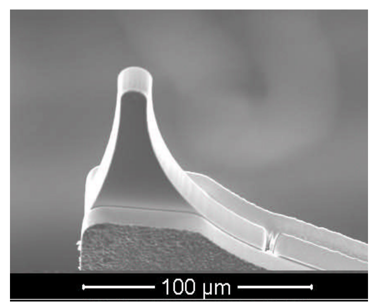
Sugar screens

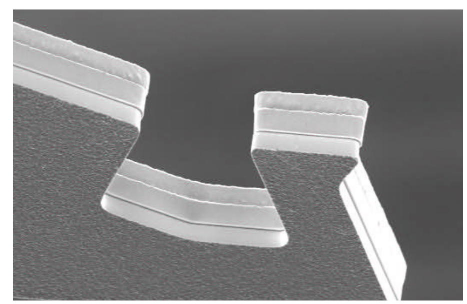
Current trends in electroforming

- Higher precision
- True-multi layer capabilities
- Development of Functional materials



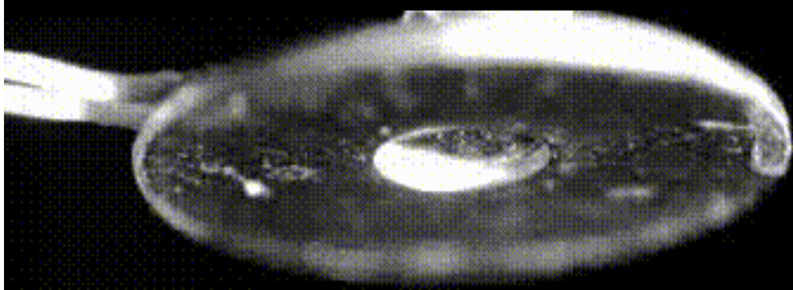




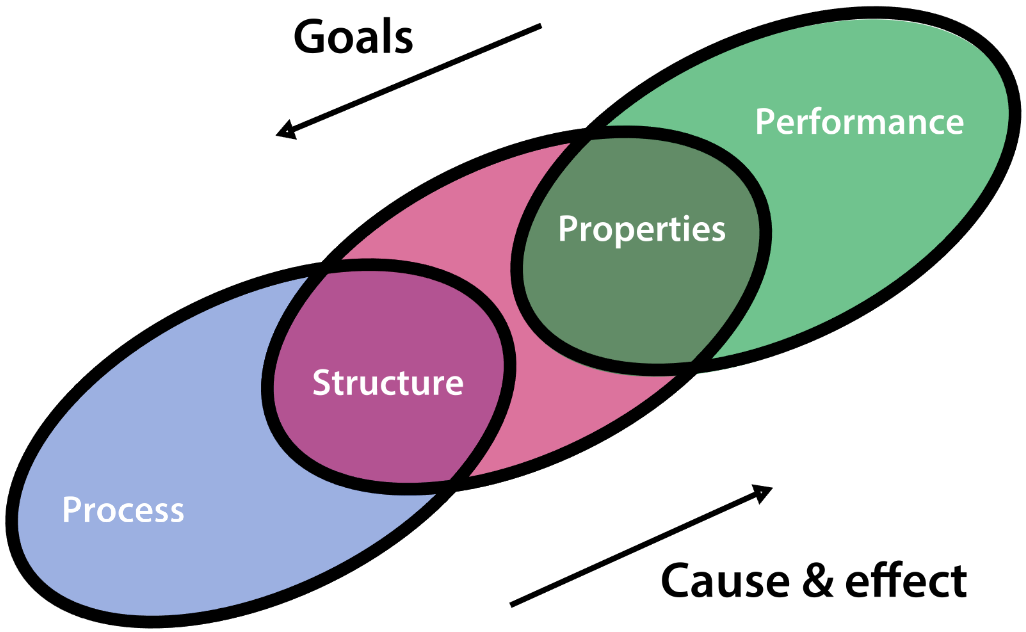


Application Example

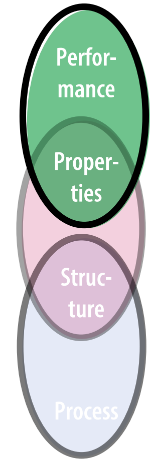
Nebulisers: Life saving micro-precision parts.



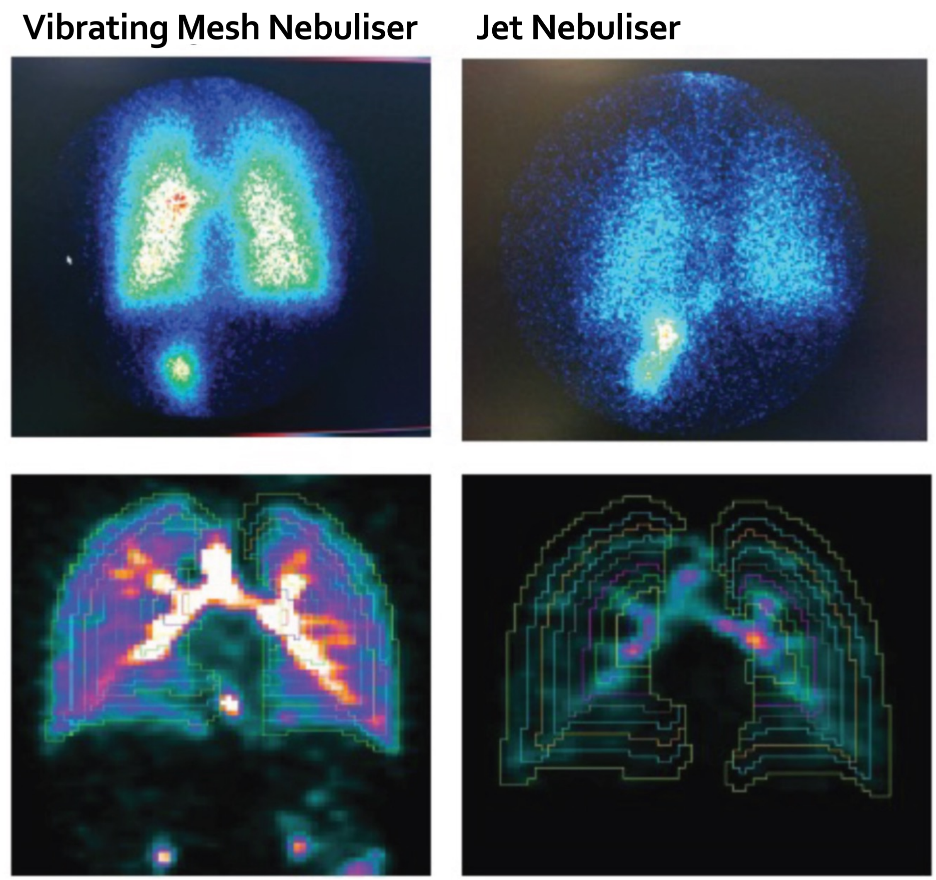
The (bumpy) road from idea to product



Optimized Nebuliser Performance

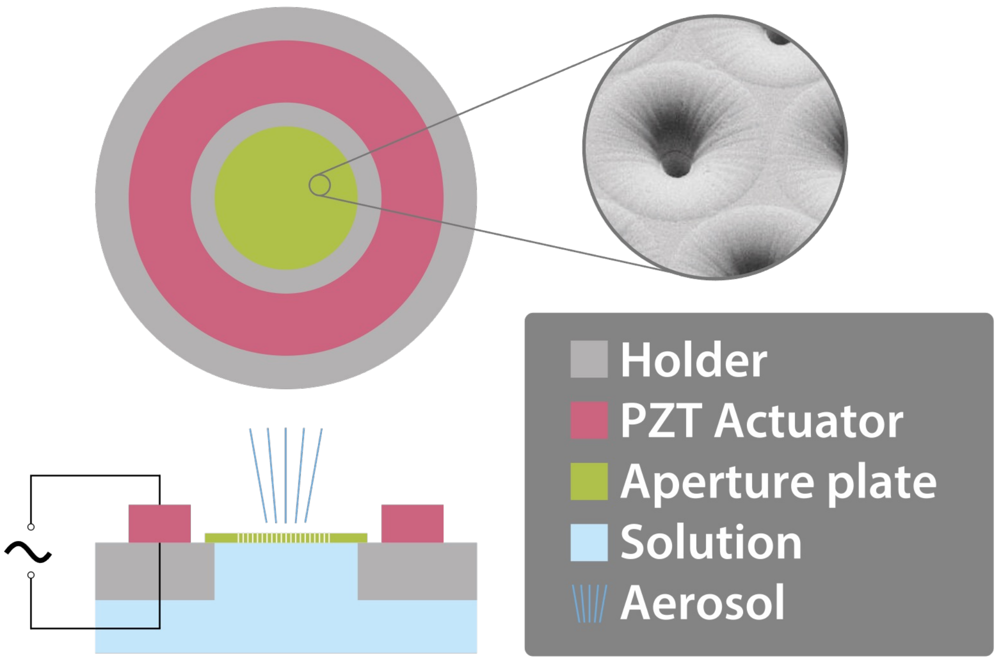


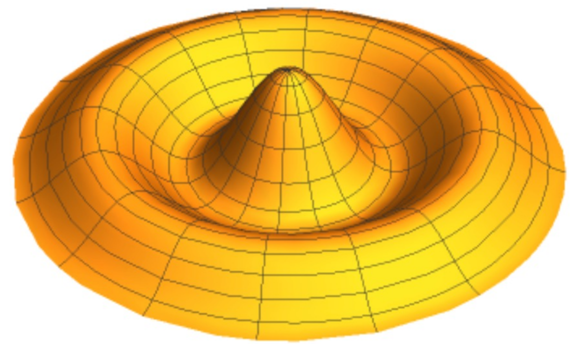
Performance characteristics
- Precise flow control
- Ideal droplet size
- Low size distribution
- Product life-time
- Bio-compatible
- Easy operation

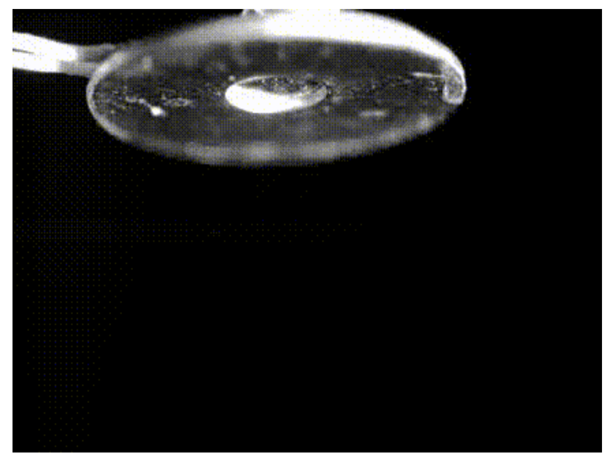


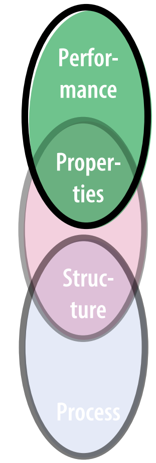
Vibrating Mesh Assembly

The beating heart of the device









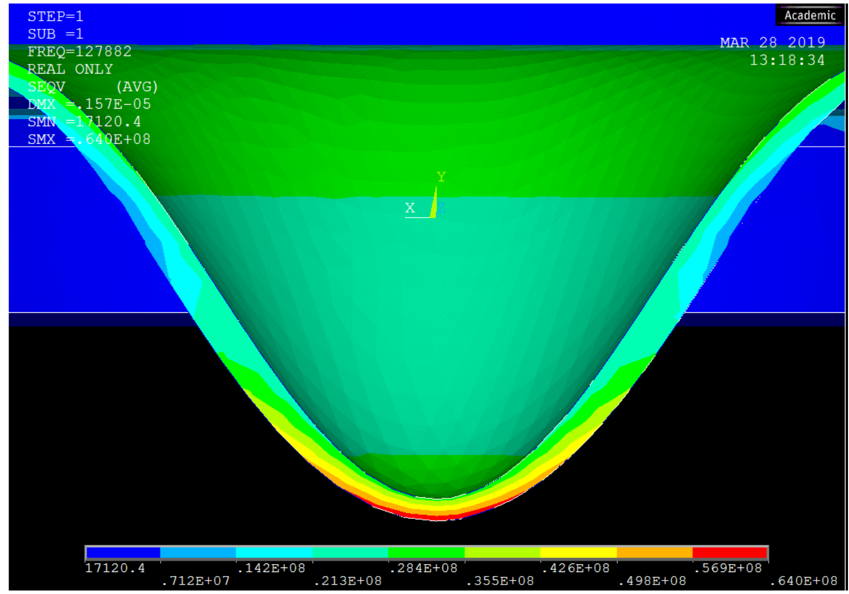
The aperture plate

What is Critical to Quality?

- **Dimensional characteristics**
  - Average orifice diameter
  - Orifice diameter distribution
  - Orifice shape
  - Product thickness

- **Materials characteristics**
  - Elastic modulus/ductility

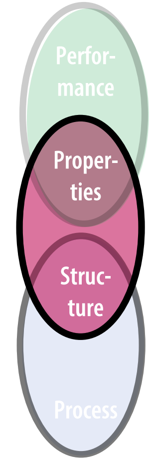
- **Materials structure**
  - Composition
  - Crystal orientation
  - Crystal size
  - Defect density



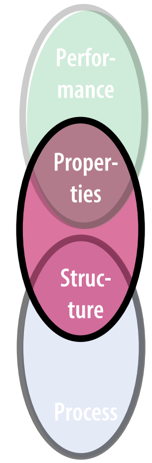
ANSYS modelling of Aperture Plate exit side

- Aperture plate displacement = 2.5 µm
- max stress = **95 MPa**
- Natural frequency:

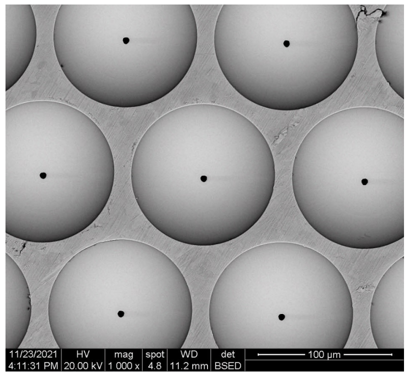
$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

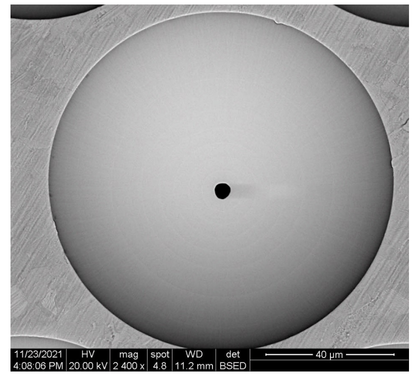


Altering materials structure and properties

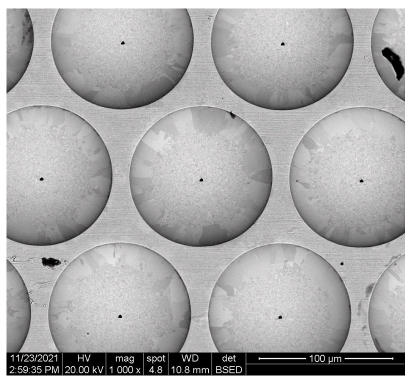


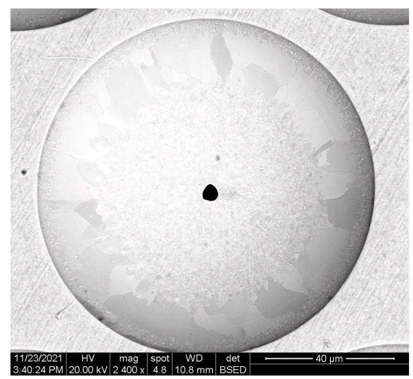
As plated
- nm-sized grains, not visible by BSE



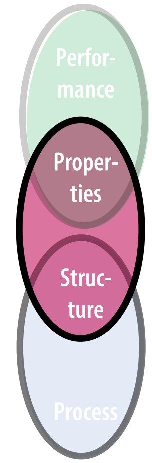


Annealed
- Grains visible, both fine and coarse

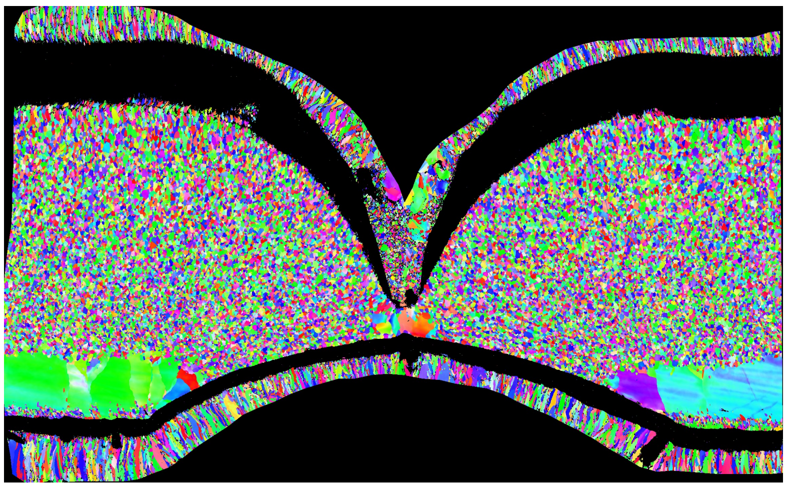




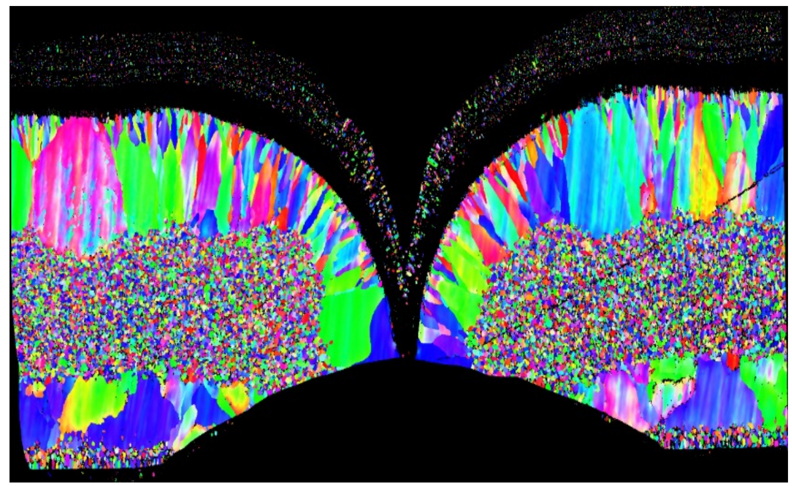
Distribution of coarse and fine grains after annealing



Desired state:
Fine-grained and randomly distributed



Undesired state:
Coarse-grained with preferential orientation



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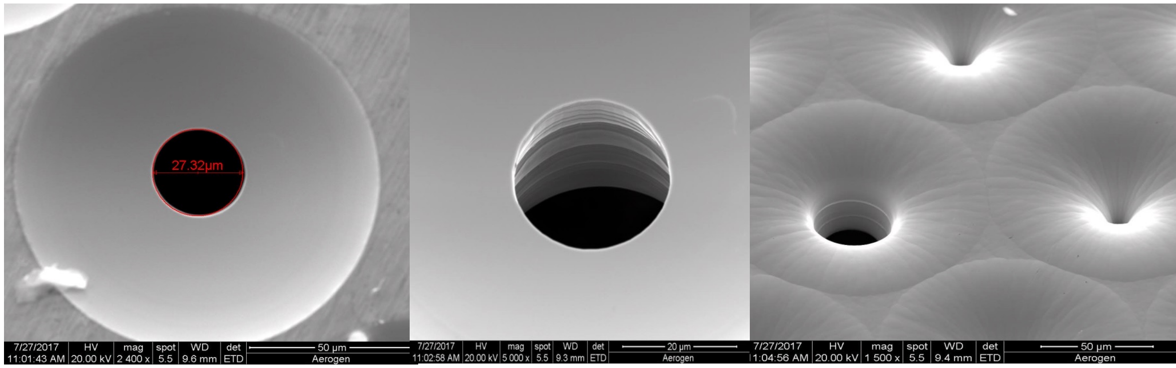

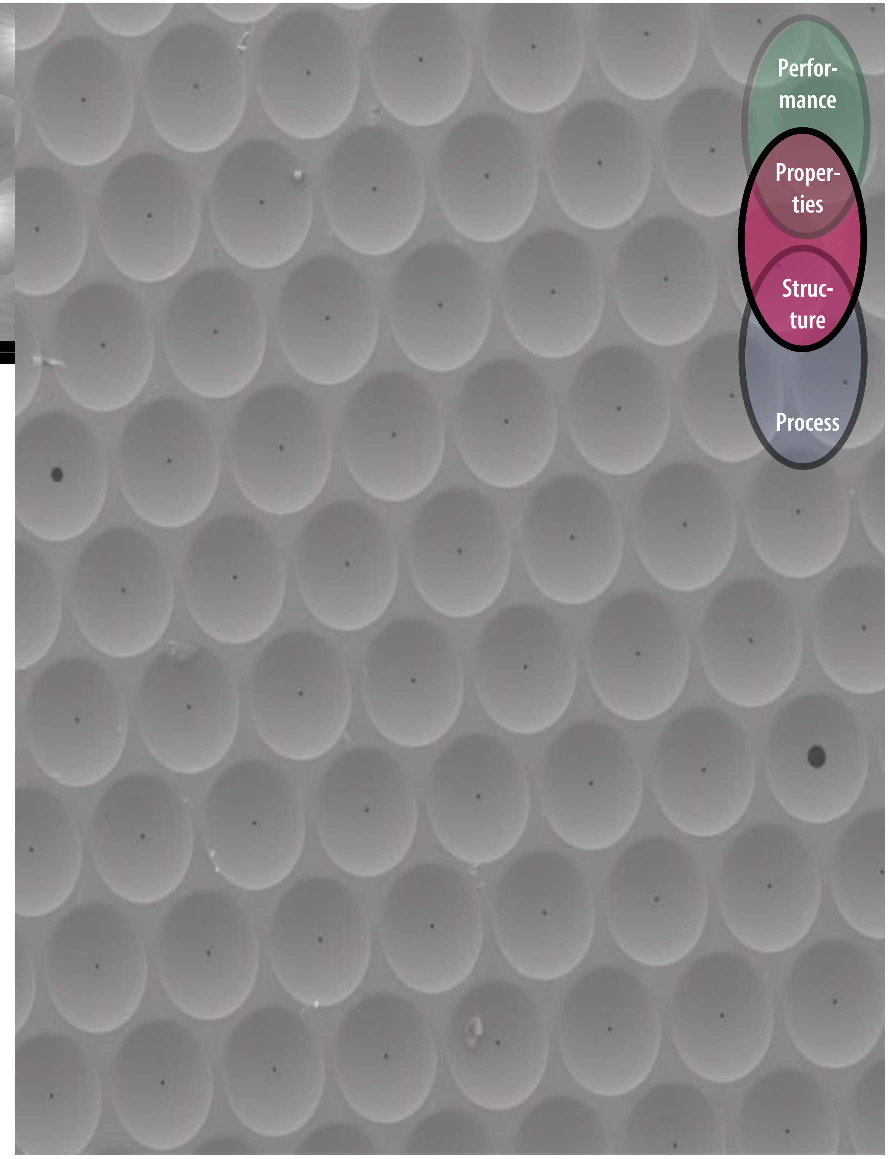

Hole size distribution

Oversized orifices

- Max. oversized holes allowed <100 ppm

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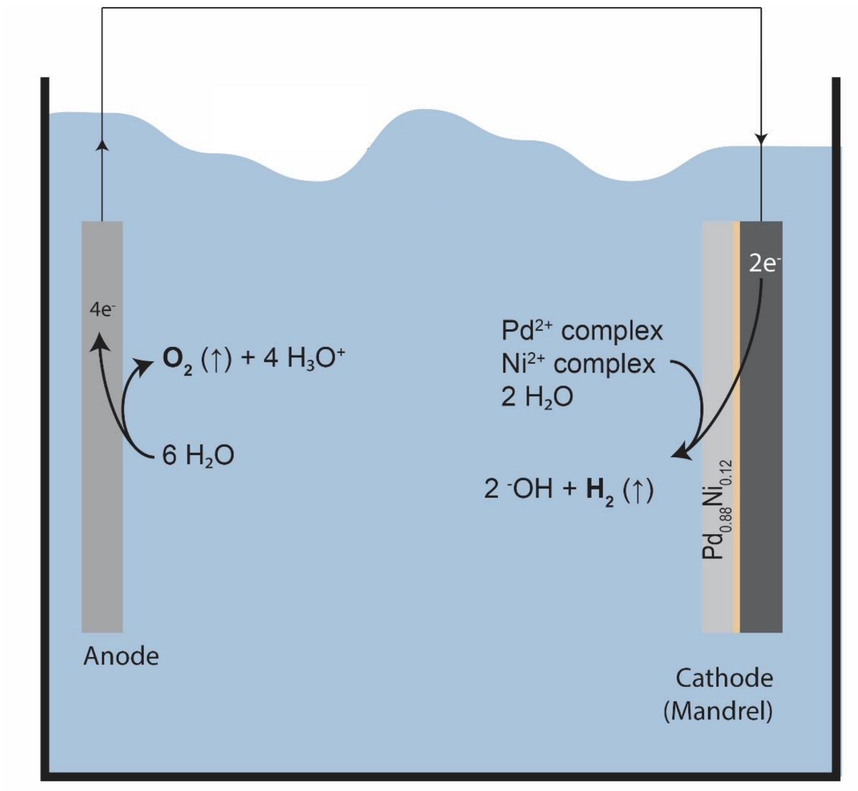
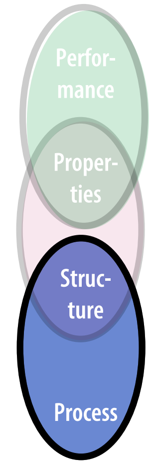
The electroforming process



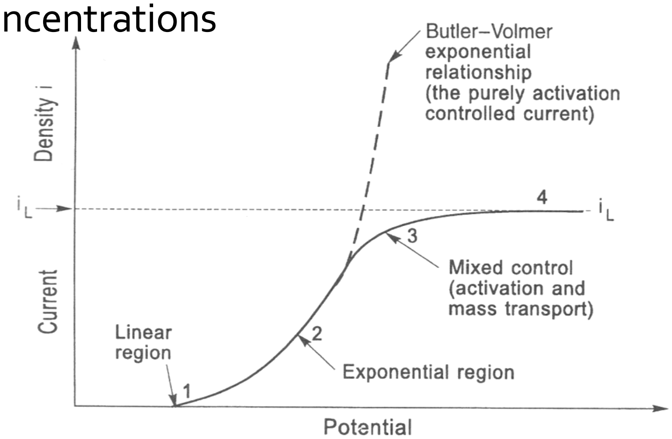
Electrolyte composition

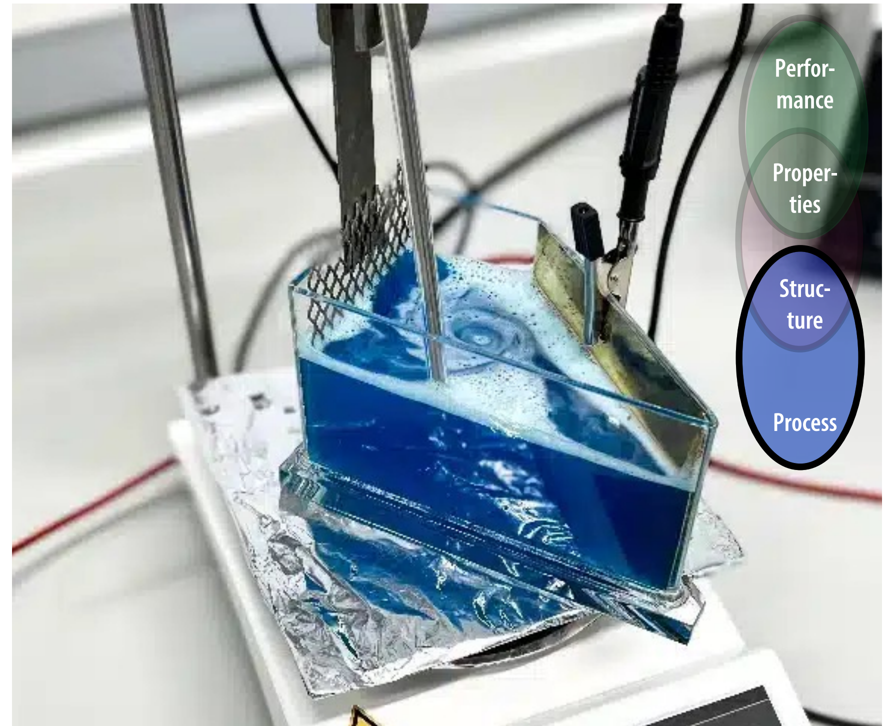
- Pd complex
- Ni complex
- Conducting Salt
- Additives
  - Stress Reducer
  - Brightener
  - Surfactant

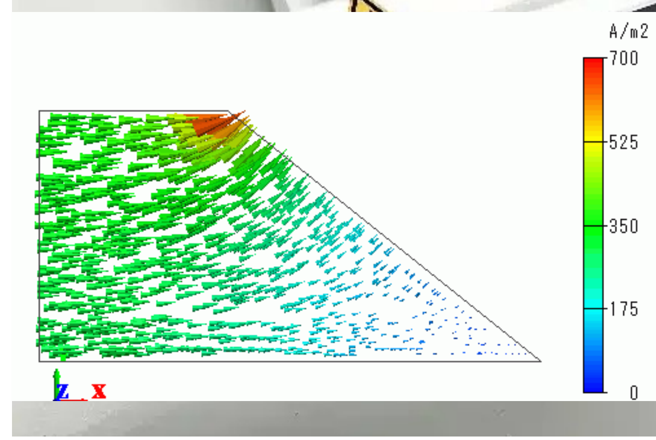


How to control Pd to Ni ratio?

- **Altering overpotentials and double layer**
  - Changing complex stability (*e.g.* pH, conducting salt)
  - Additives
  - Anode material (e.g. MMO or Pt Ti)
  - Liquid flow
- **Learning from theory (e.g. Butler-Volmer)**
  - Changing current density
  - Changing temperature
  - Changing concentrations







veco

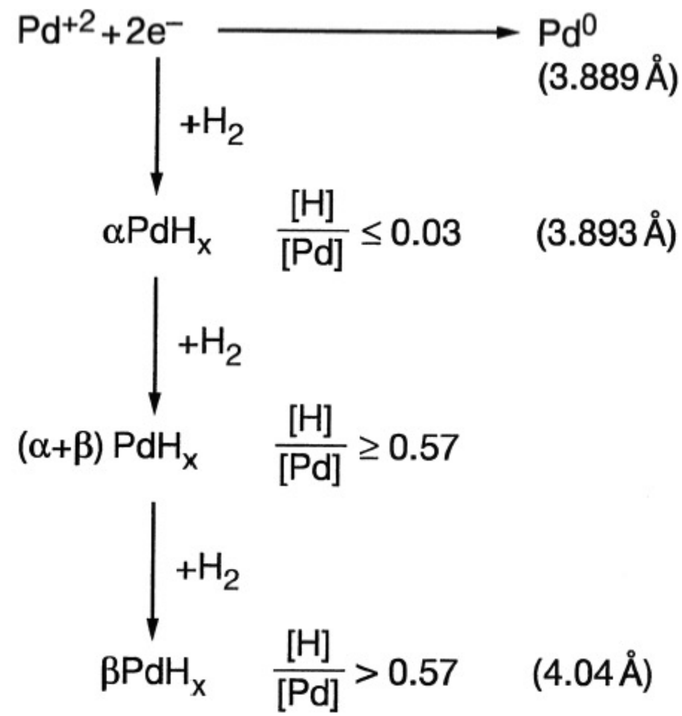
Why should we control the H_2 reaction?

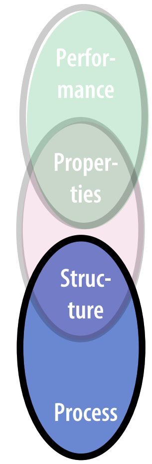
Hydrogen Embrittlement
- β-phase instable, decomposition leads to stress.

Influence on crystal structure
- By (temporary) incorporation into the crystals
- By preferential adsorption on certain atomic planes and subsequent inhibition of growth of these planes.

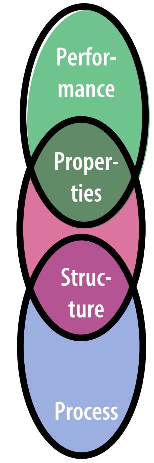
- **Macroscopic imperfections due to H_2 gas bubbles**

- **Changes in pH may lead to undesired (electro)chemical processes:**
  - Stripping of photoresist
  - Influences on the stability of the metal complexes
  - Metal-hydroxide formation
    - Leading to stress…
    - Or leading to local passivation.

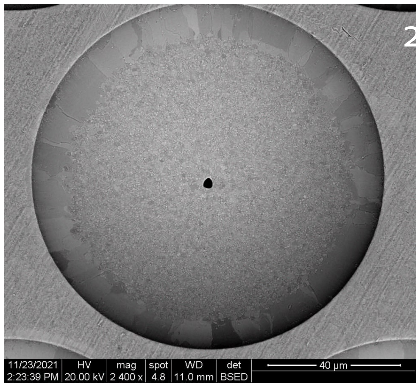


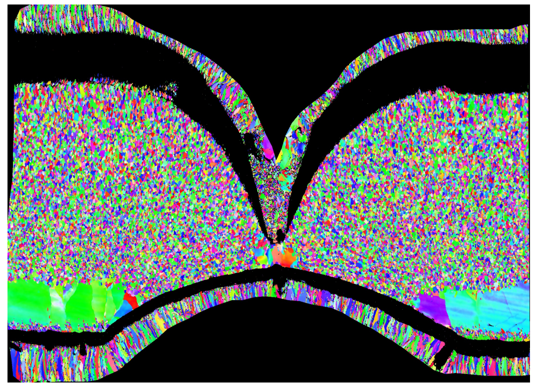


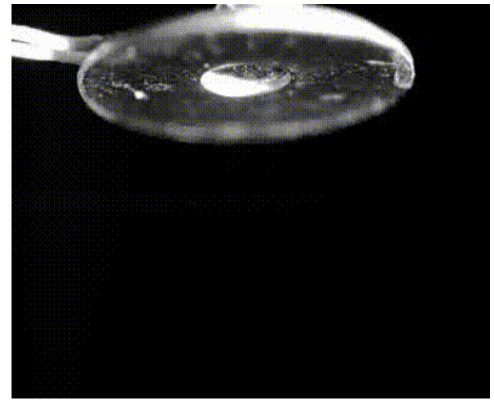
Small differences can have a giant impact



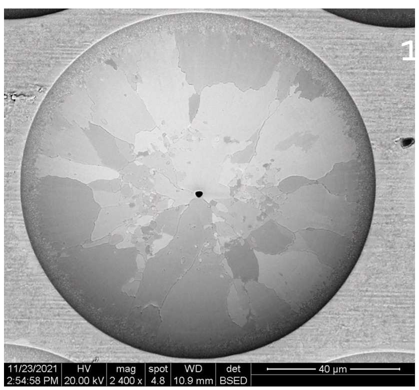
Desired state:
Ideal process settings

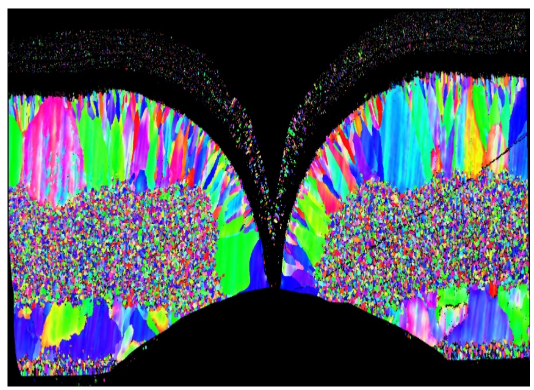


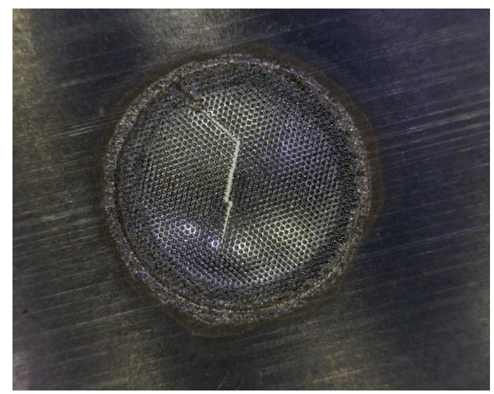




Undesired state:
Just a tiny difference







Thank you
for your attention

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