JOANNEUM RESEARCH

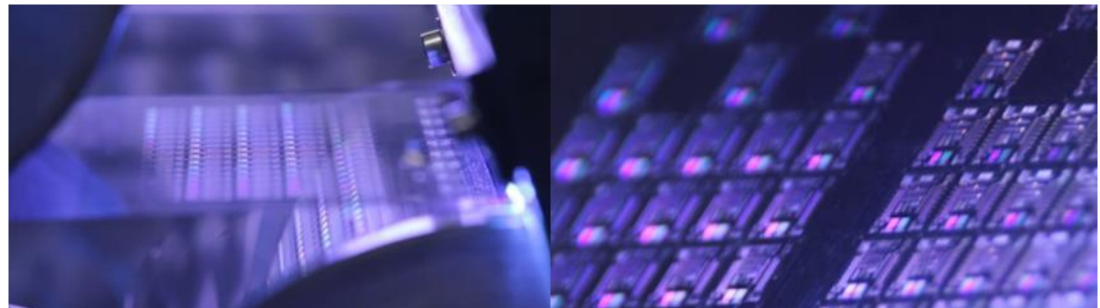
JOANNEUM RESEARCH Forschungsgesellschaft
Institute MATERIALS, Weiz, Austria

„Large-area patterning by roller-based nanoimprint lithography“

Ursula Palfinger, Dieter Nees, Stephan Ruttloff,
Markus Leitgeb, Maria Belegratis, Barbara Stadlober

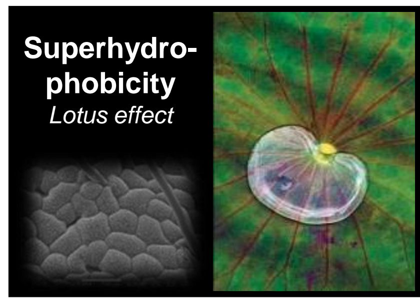
Outline

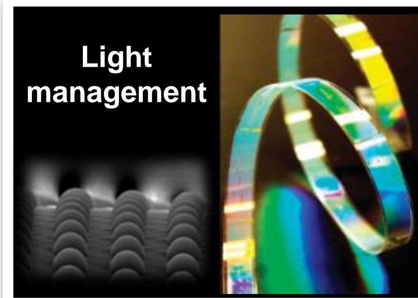
- **Motivation** – Small structures on large areas
- **Technology** – Roll-to-roll Nanoimprinting (R2R NIL)
  - Processes
  - Machinery
- **Materials** – Prerequisites for residual-free imprinting
- **Applications** – Roller-based fabrication of highly resolved metal patterns by a combination of residual-free NIL and a subsequent lift-off for transparent conductive foils and product ID features
- **Summary**

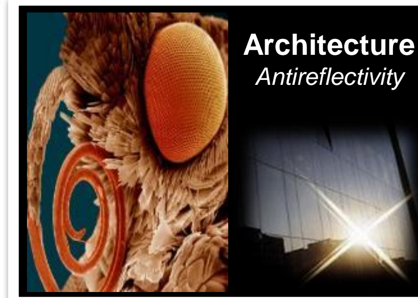


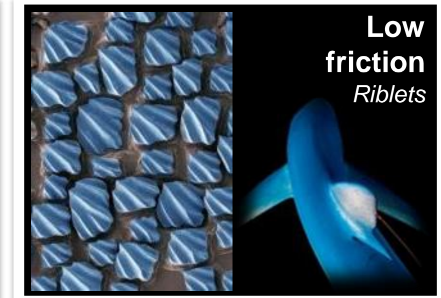
JOANNEUM RESEARCH

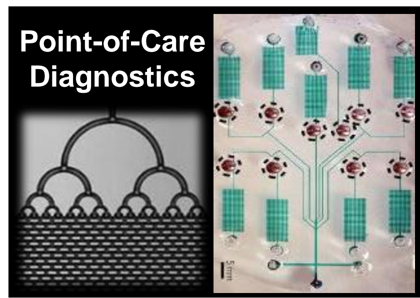
Small structures on large areas



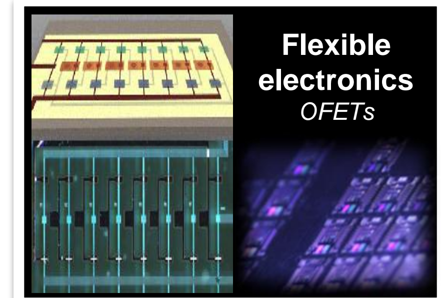




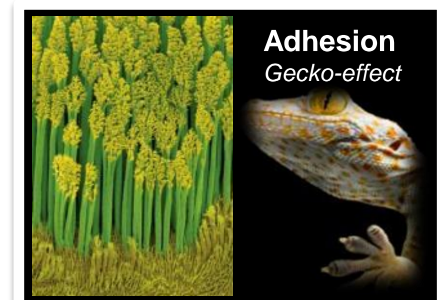




Where is highly resolved patterning on large areas interesting?

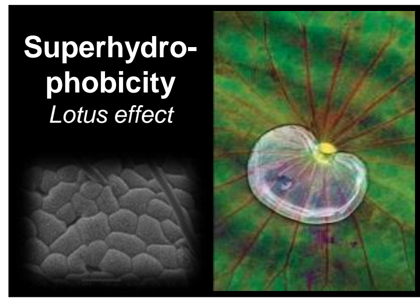


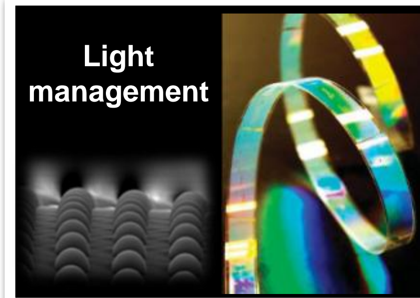
Others:
Transport
Traffic
Security
Packaging
Energy Harvesting
...

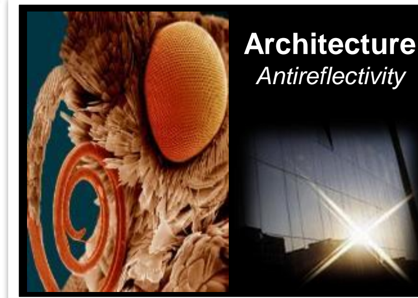


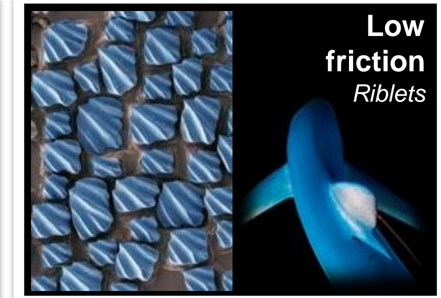
JOANNEUM RESEARCH

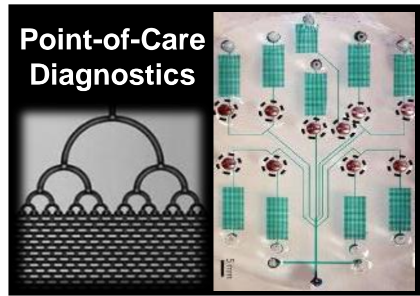
Small structures on large areas





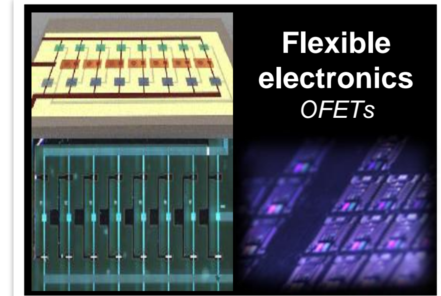


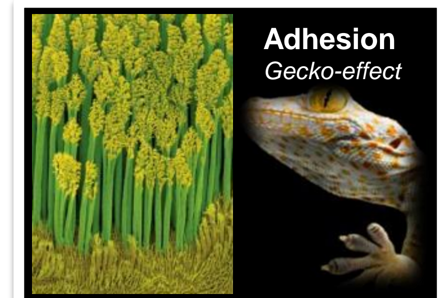




How can we produce them?

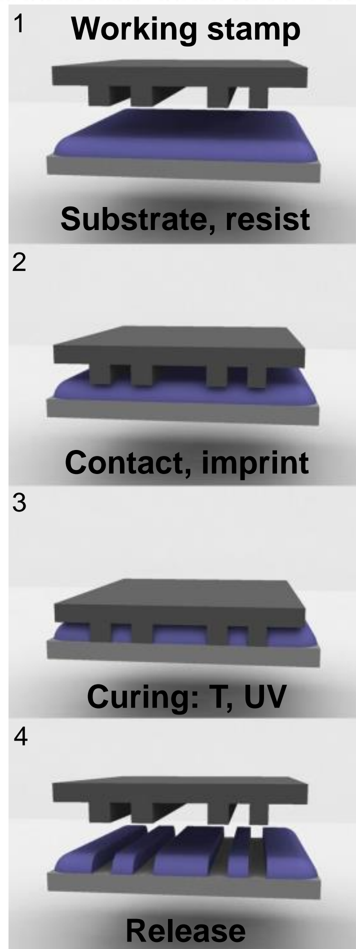
1) micro and nano
2) 2D – 2.5D
3) large flexible areas
4) industrial process





JOANNEUM RESEARCH

Nanoimprint lithography



Fast + accurate method for structure transfer

UV or thermal curing of resist

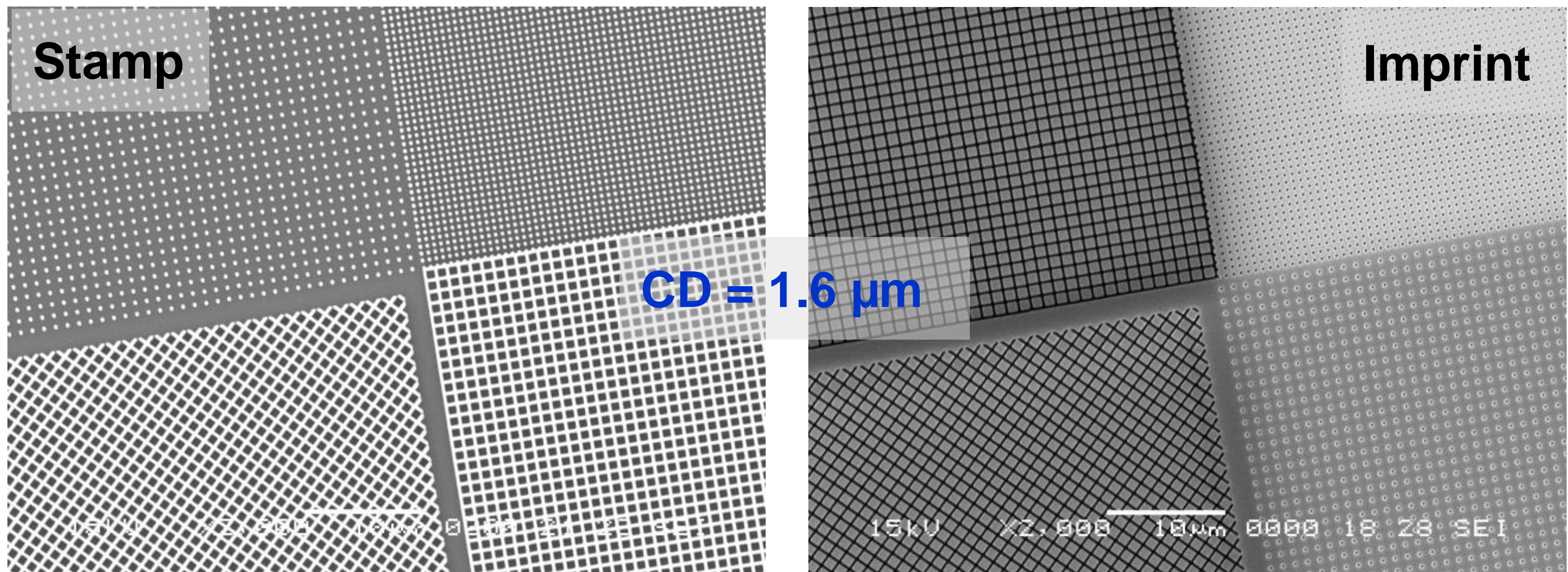
Very versatile (geometries, structure size)

Nanoimprint lithography

Fast + accurate method for structure transfer

UV or thermal curing of resist

Very versatile (geometries, structure size)



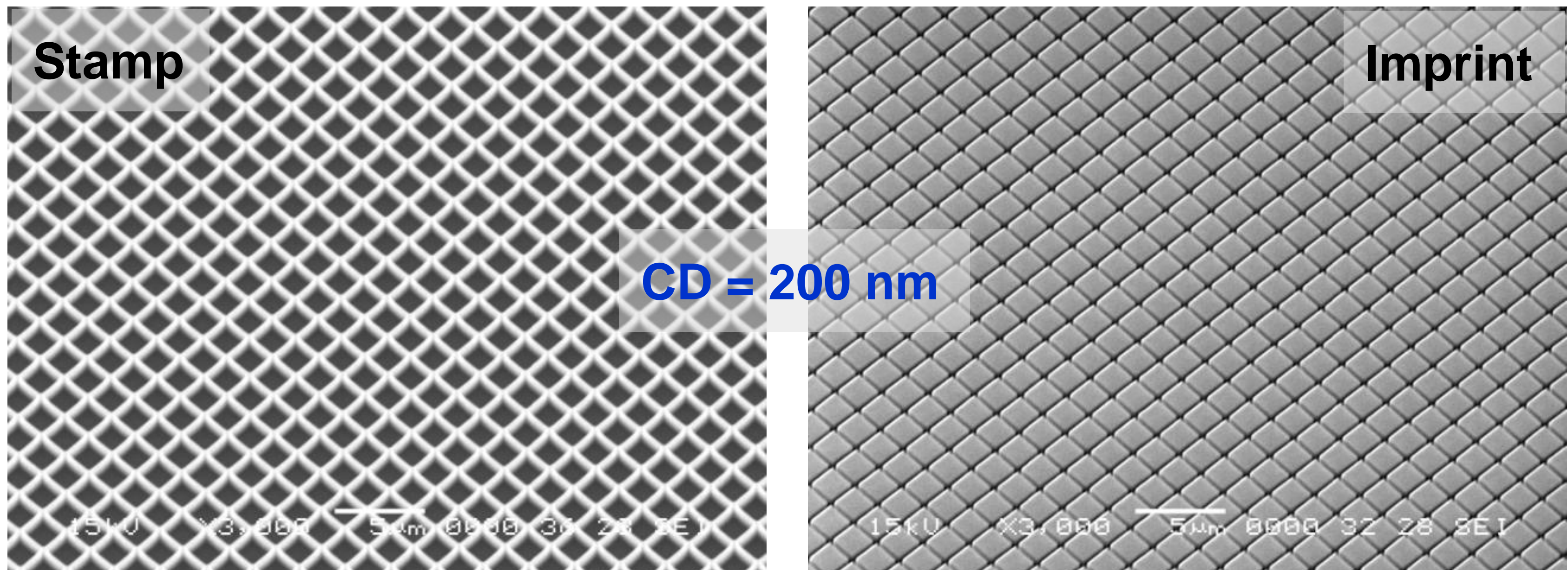
JOANNEUM RESEARCH

Nanoimprint lithography

Fast + accurate method for structure transfer

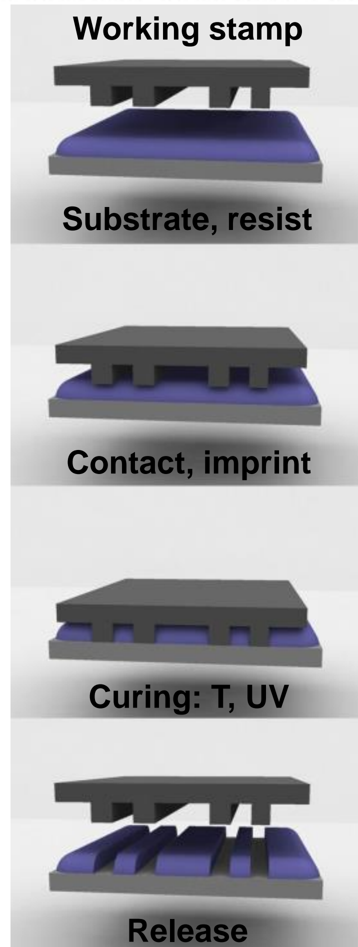
UV or thermal curing of resist

Very versatile (geometries, structure size)



JOANNEUM RESEARCH

Nanoimprint lithography

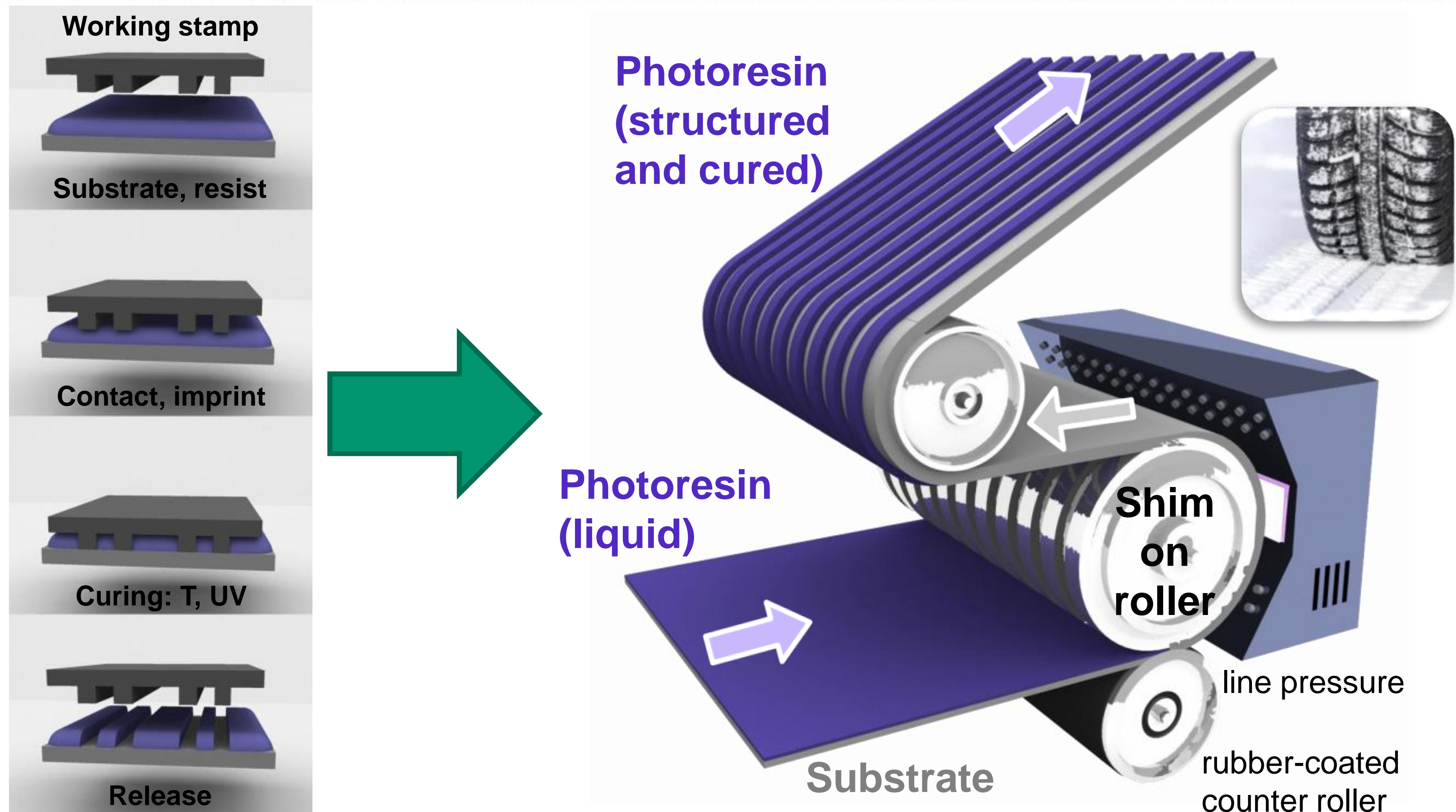


Critical issues – Batch NIL (serial)

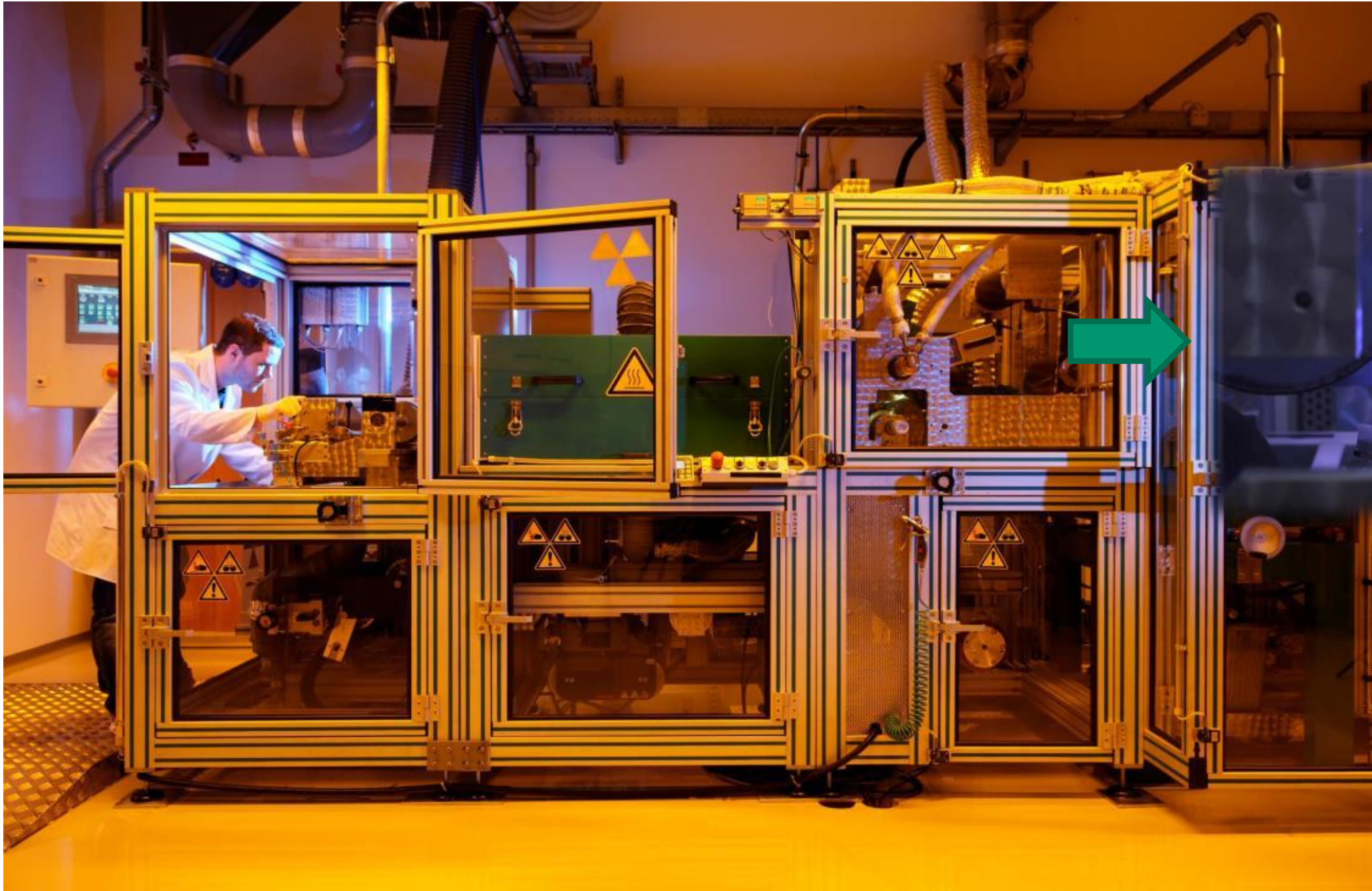
- Master (pattern quality, roughness)
- Control of adhesion between master and resist
- Resist viscosity (filling)
- Curing behavior (fast, low shrinkage)
- Fabrication volumes and process time
- Upscaling?

JOANNEUM RESEARCH

Roll-to-Roll Nanoimprint lithography



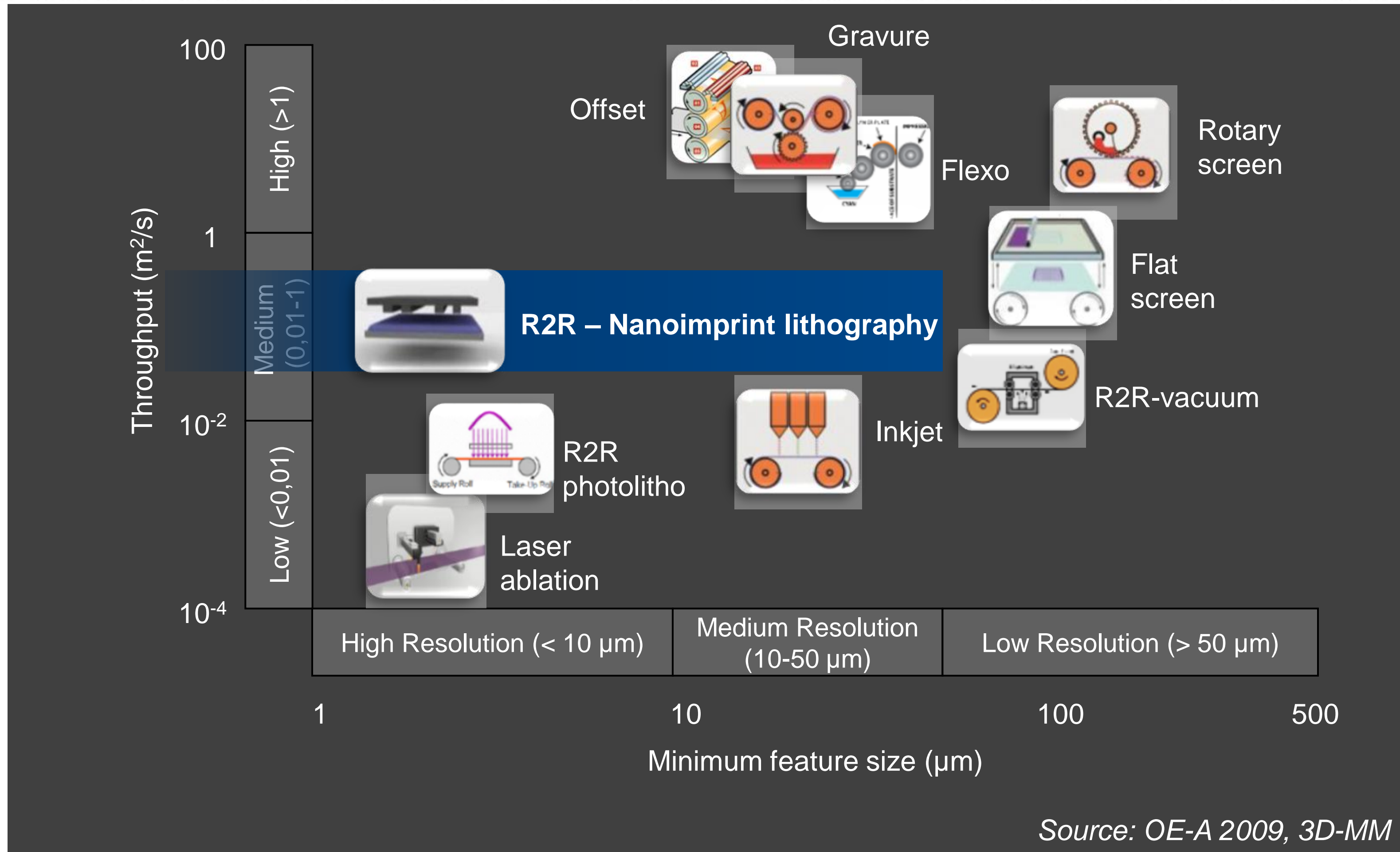
Roll-to-Roll Nanoimprint lithography



Max. web width = 250 mm
Web speed = 0.5 – 30 m/min
Max. UV intensity = 200 W/cm
Line pressure UV-NIL = 18 kN
Line pressure HE = 100 kN

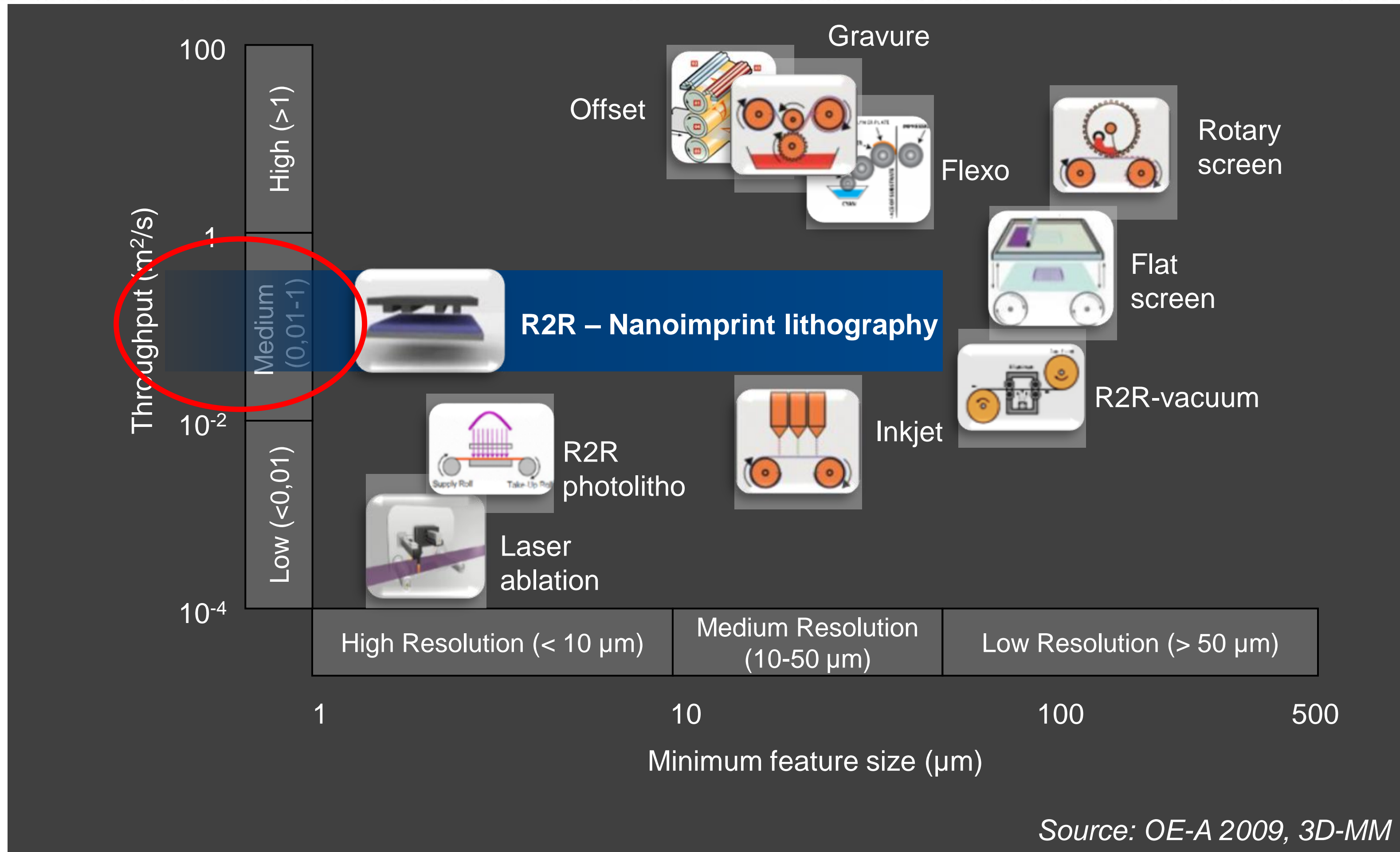
JOANNEUM RESEARCH

Resolution and throughput of printing technologies



JOANNEUM RESEARCH

Resolution and throughput of printing technologies



Creation of highly resolved metal patterns in R2R environment

Resist Printing

UV-Nanoimprinting

Lift-off

UV-lamp

Evaporation

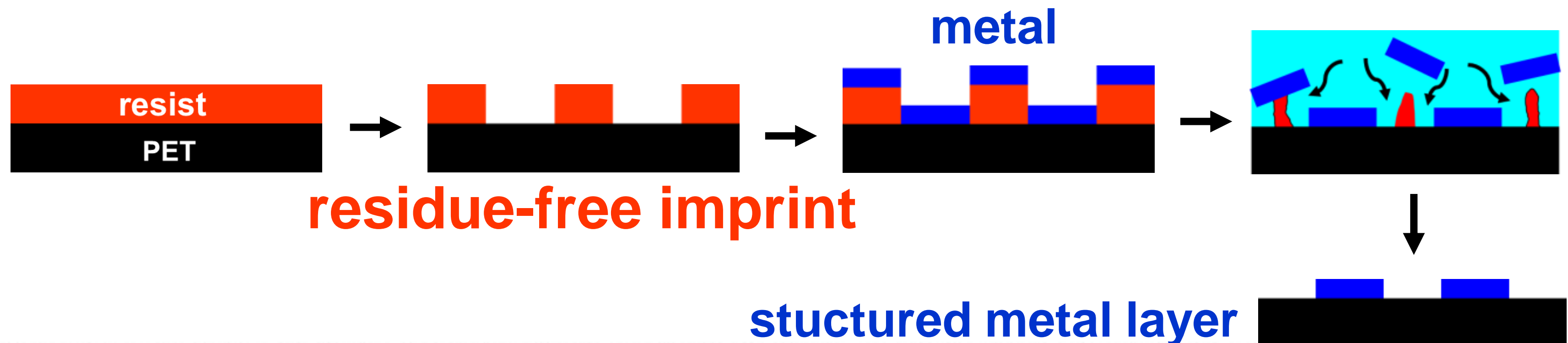
Gate lines

UV- Imprint Resin

Imprint Mould

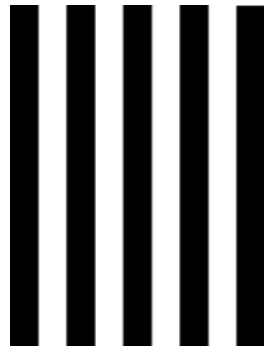
Gate metal

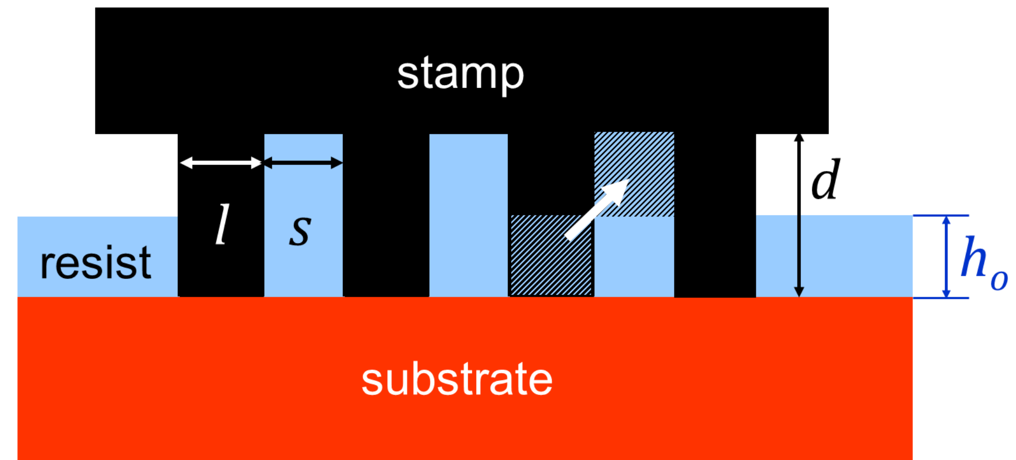
Water



Critical for residual-free imprint: PATTERN GEOMETRY

Structure depth and resist thickness





l : line width

s : space width

d : structure depth

h_o: initial resist film thickness

$$\frac{d}{h_o} > \left(1 + \frac{l}{s}\right)$$

for open patterns

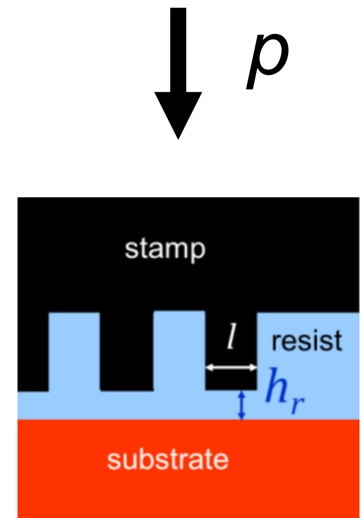
Critical for residual-free imprint: RESIST FLOW BEHAVIOR

Squeeze flow model

"Stefan's equation":

$$t = \frac{\eta l^2}{2p}\left(\frac{1}{{h_r}^2} - \frac{1}{{h_o}^2}\right)$$

- t : imprint time
- η : resist viscosity
- l : imprinted line width
- p : imprint pressure
- h_r : residual resist film thickness
- h_o : initial resist layer thickness



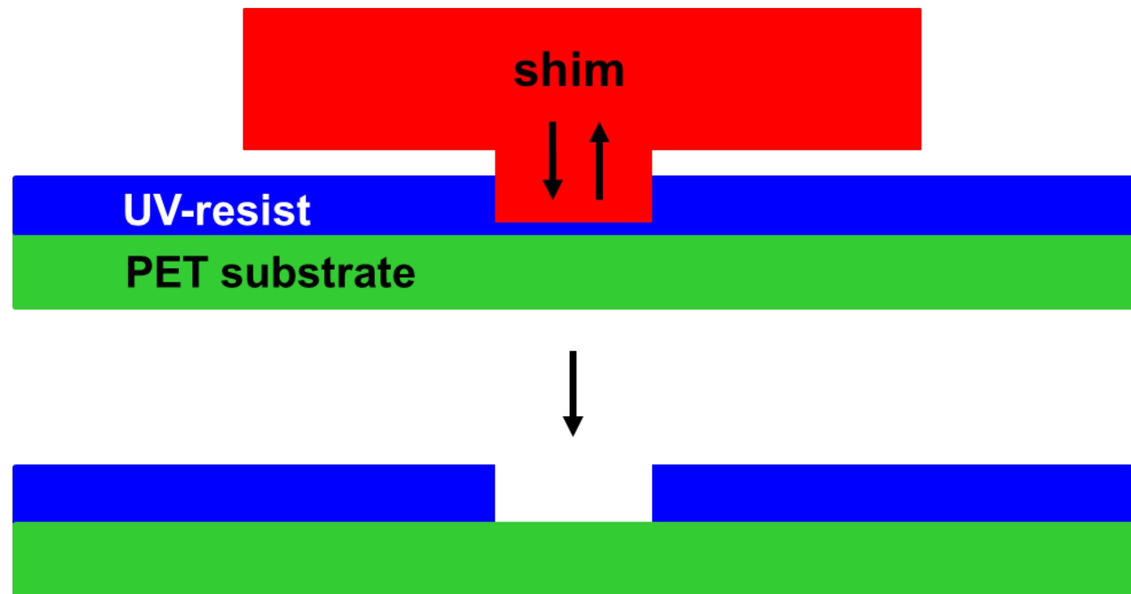
For vanishing residual resist film thickness the imprint time approaches infinity ...

H. Schift, J. Vac. Sci. Technol. 2008

Critical for residual-free imprint: SURFACES VS. RESIST CHEMISTRY

Spontaneous dewetting and balance of interfacial forces

$$S = \gamma_{Substrate/Shim} - (\gamma_{Substrate/Resin} + \gamma_{ResinShim}) < 0$$



$\gamma_{X/Y}$: interfacial energy   S: spreading coefficient

SJ Choi, J. Colloid. Interface Sci. 2009

JOANNEUM RESEARCH

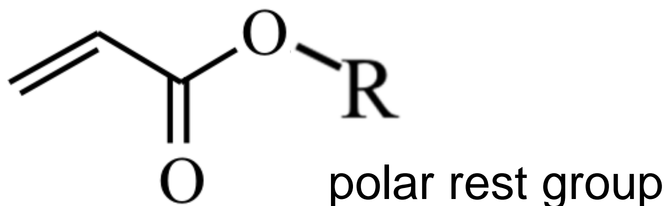
Critical for residual-free imprint: CHOICE OF RESIST

UV-NIL resist for aqueous lift-off

Monomer

- low viscosity
- water soluble
- monofunctional

Acrylate

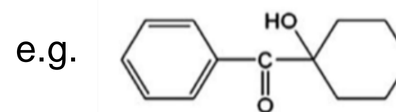


polar rest group

η = 10 mPas

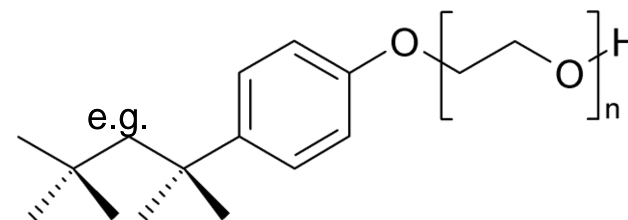
Photoinitator

e.g.



Non-ionic surfactant

e.g.



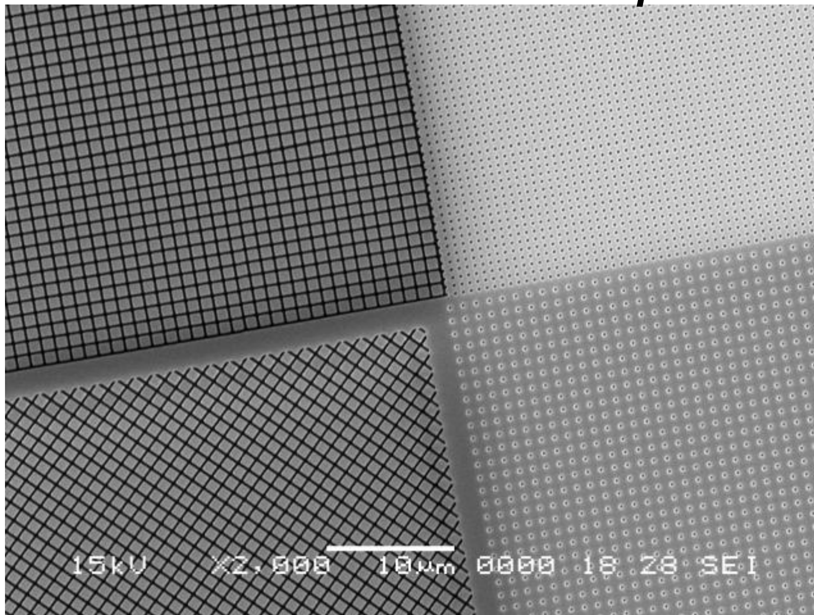
Tuning of interfacial energies

20 mN/m < γ < 45 mN/m

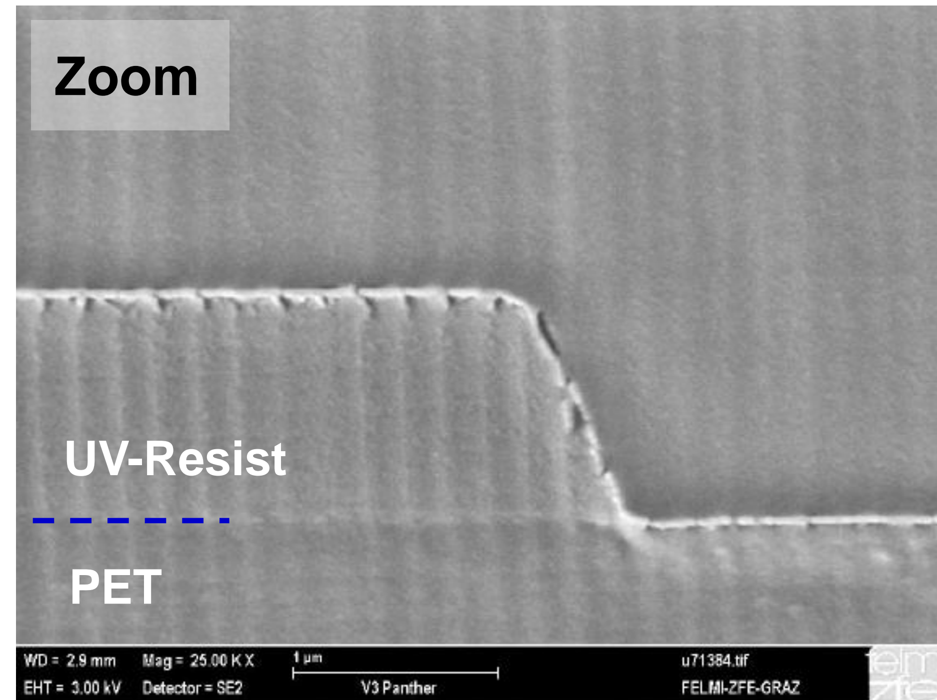
Auner, Palfinger et al, Organic Electronics, 2009+2010

Residual-free R2R imprint

SEM: top view



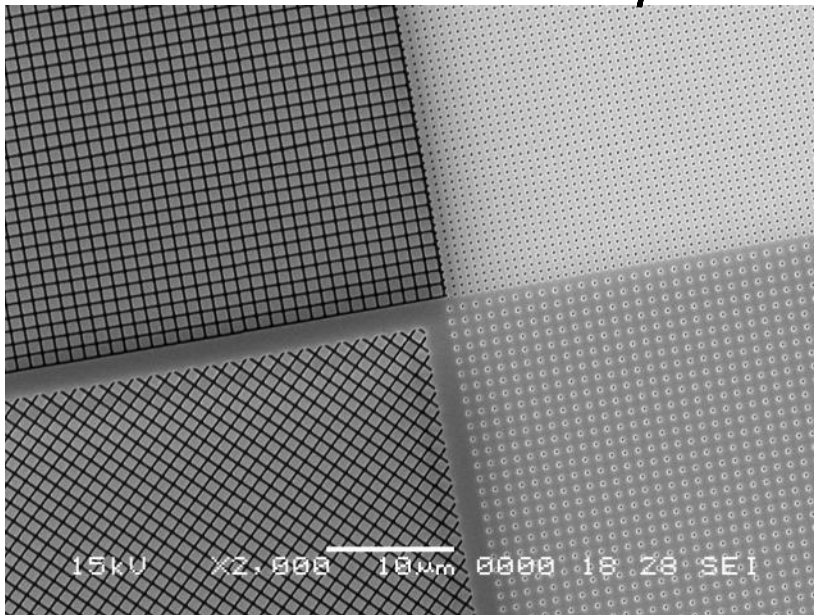
SEM: cross section



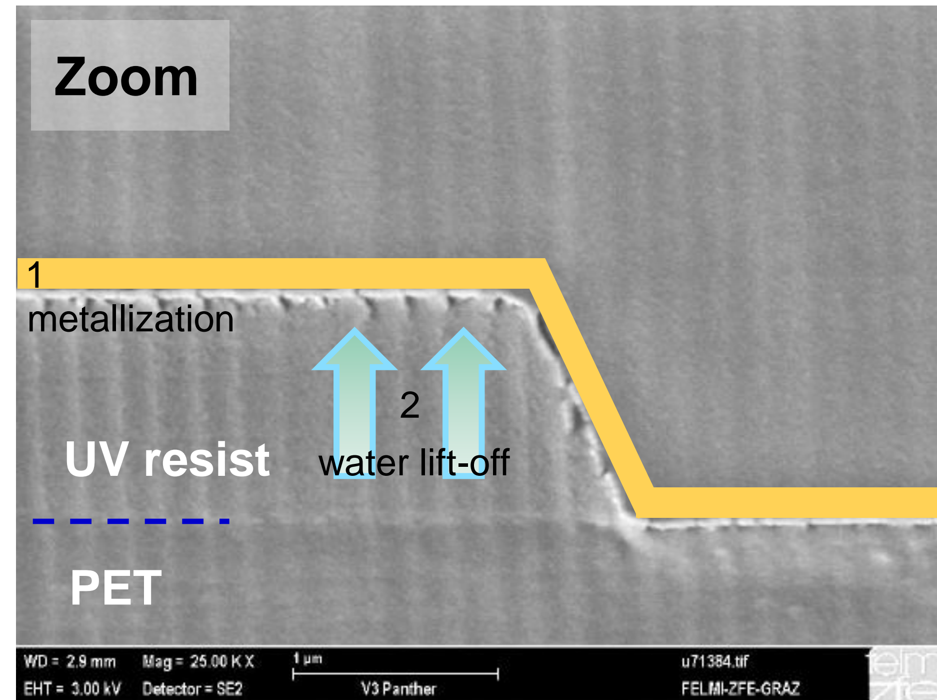
JOANNEUM RESEARCH

Residual-free R2R imprint

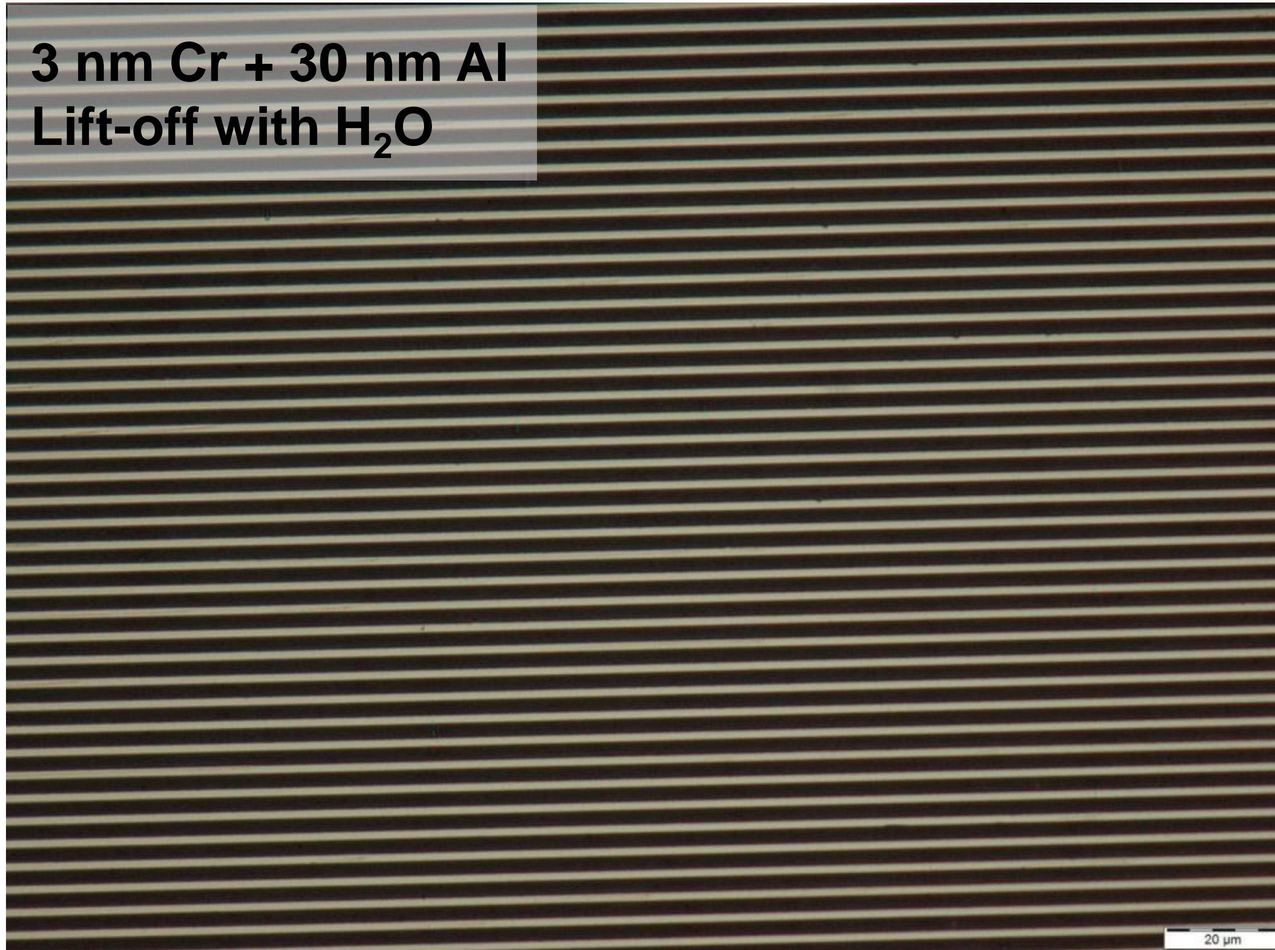
SEM: top view



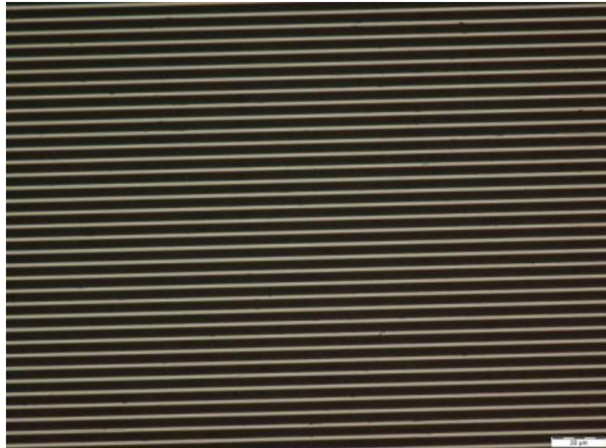
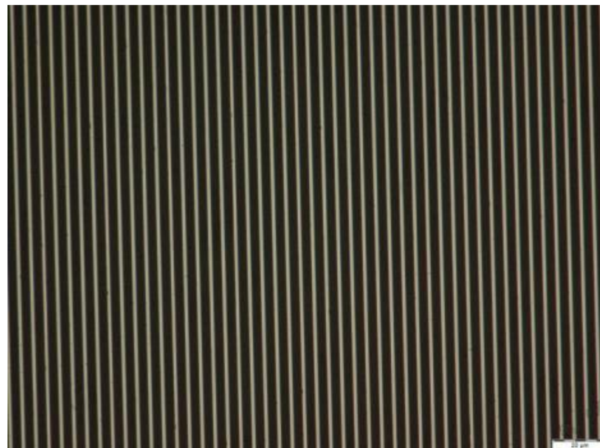
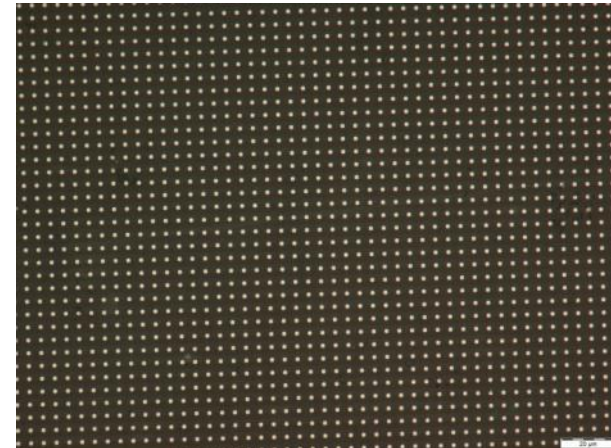
SEM: cross section

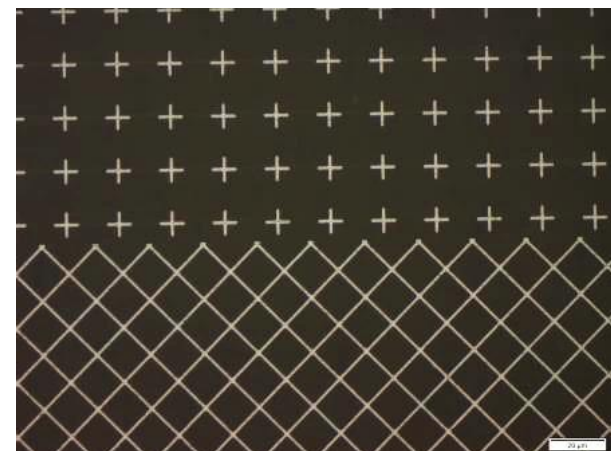


Al lines, CD = 1.6 µm



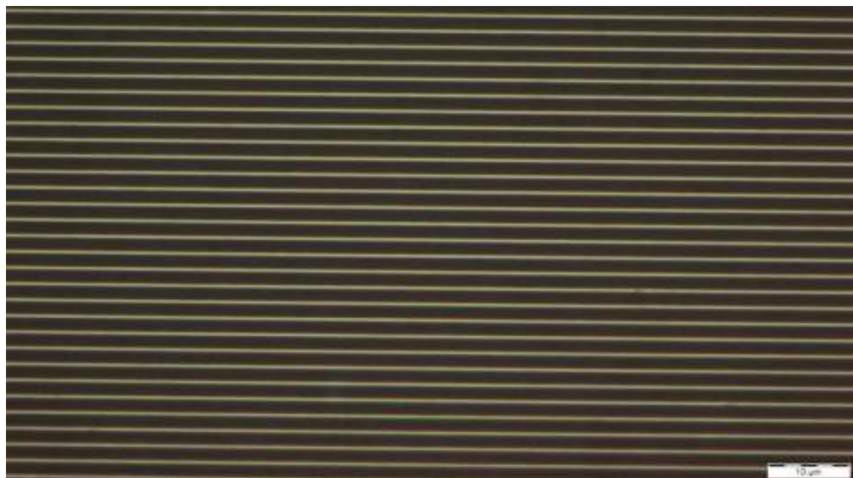
Al patterns, CD = 1.6 µm

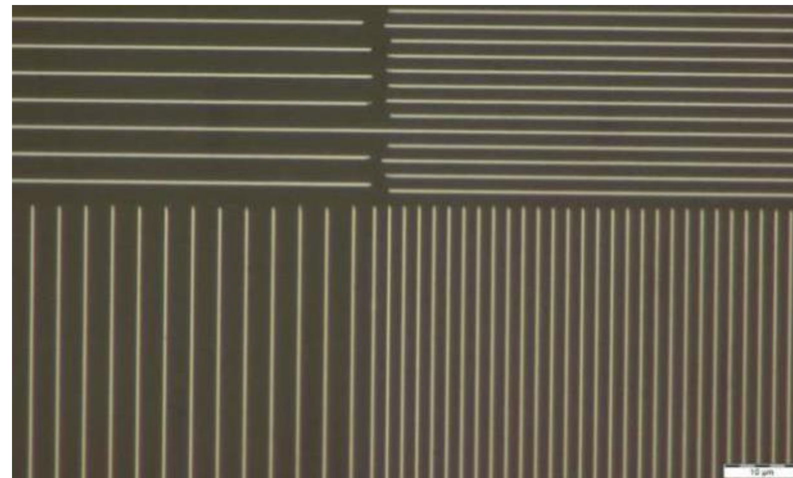




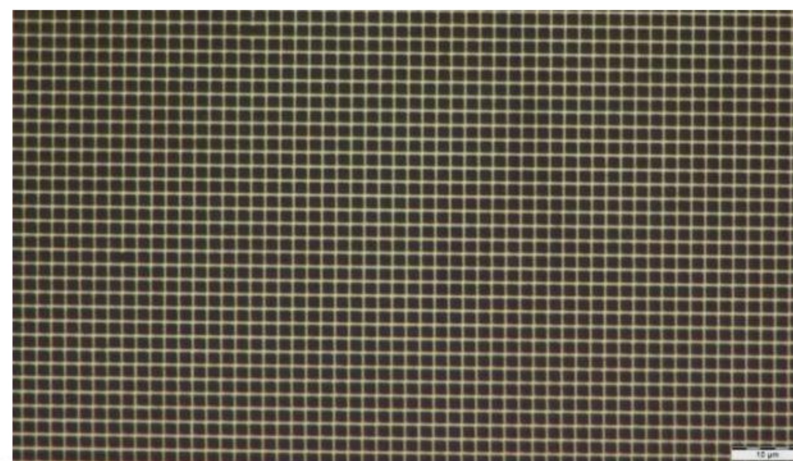


→ web direction

Al patterns, CD = 400 nm

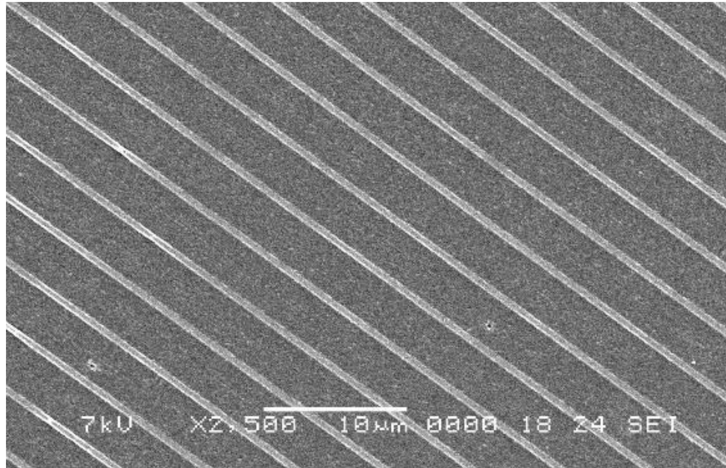


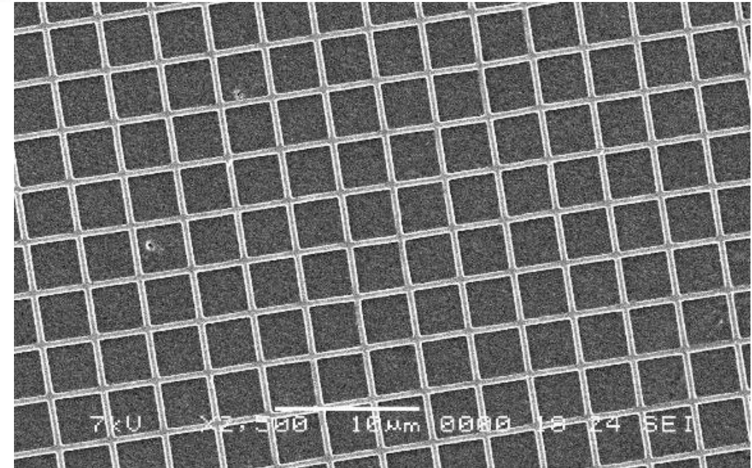




web direction

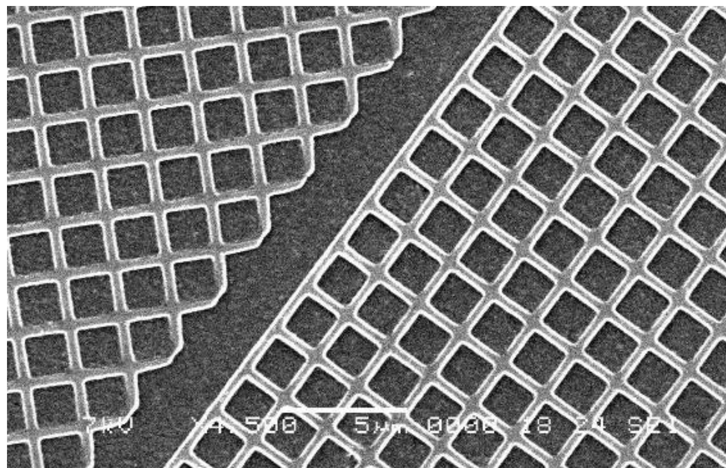
Application “nano”: Metal grids for transparent conductive foils

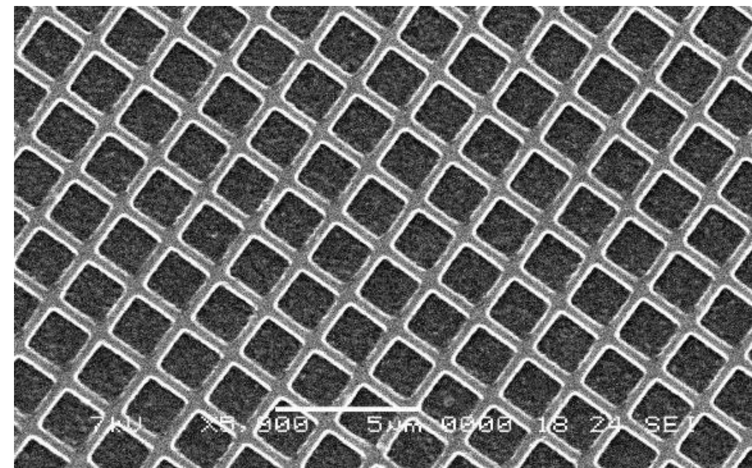




SEM

400 nm





JOANNEUM RESEARCH

Application "nano": Metal grids for transparent conductive foils

Source: PolyIC

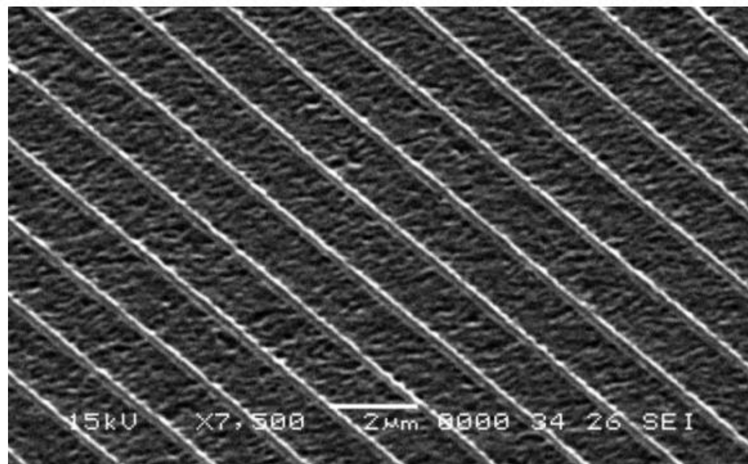
Source: Samsung

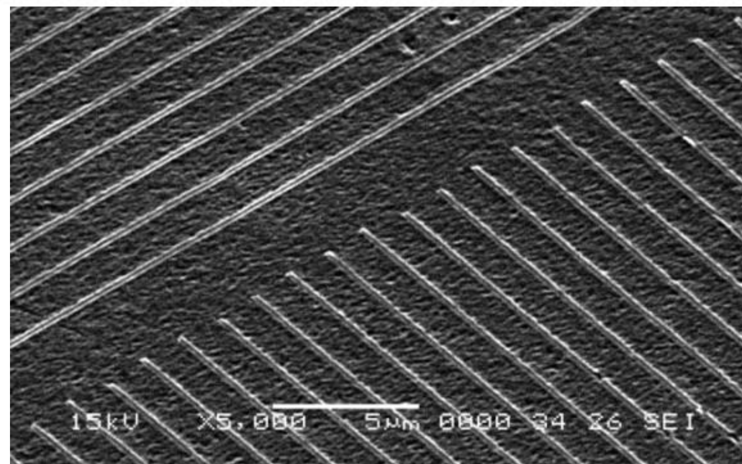
PyzoFlex technology

Flexible displays, touch panels, sensor surfaces, shielding foils,…

JOANNEUM RESEARCH

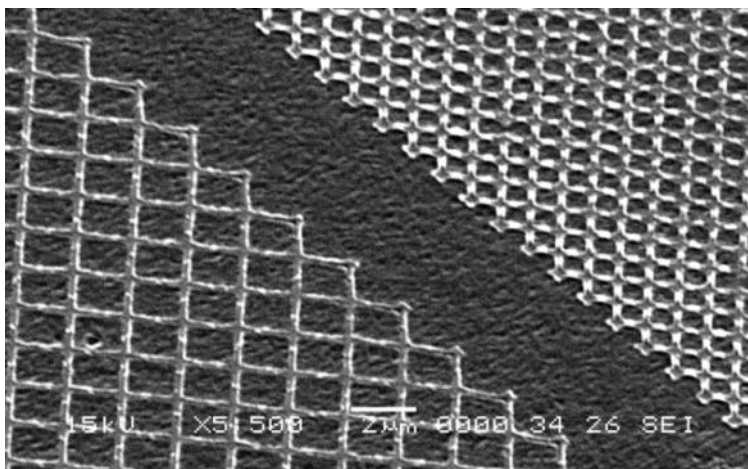
Application “nano”: Metal grids for transparent conductive foils

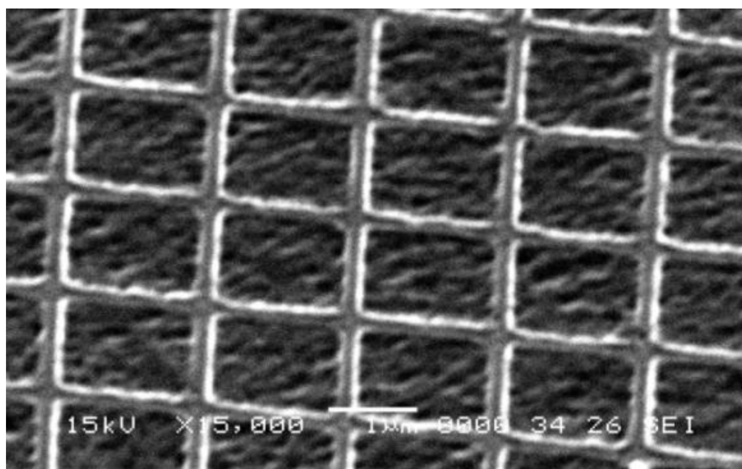




SEM

200 nm





Summary

- Roller-based nanoimprinting is a large area, high resolution patterning process with very high potential.
- Residue-layer free R2R UV-NIL is possible, when pattern geometries and stamp and resin surface chemistry is optimized.
- We developed an acrylate-based imprint resin for water-based lift-off and used it for highly-resolved metal patterning on foil without the need of etching.
- Applications can be seen in electronics, optics, sensing, security features…, shown examples: transparent conducting, packaging

FFG
FORSCHUNG WIRKT.

bmwfw
Bundesministerium für
Wissenschaft, Forschung und Wirtschaft

bmvit

SEVENTH FRAMEWORK PROGRAMME

JOANNEUM RESEARCH

Acknowledgements

Dieter Nees
Markus Leitgeb

Herbert Gold

Stephan Ruttloff

Laco Kuna
Volker Schmidt

Maria Belegratis

Barbara Stadlober

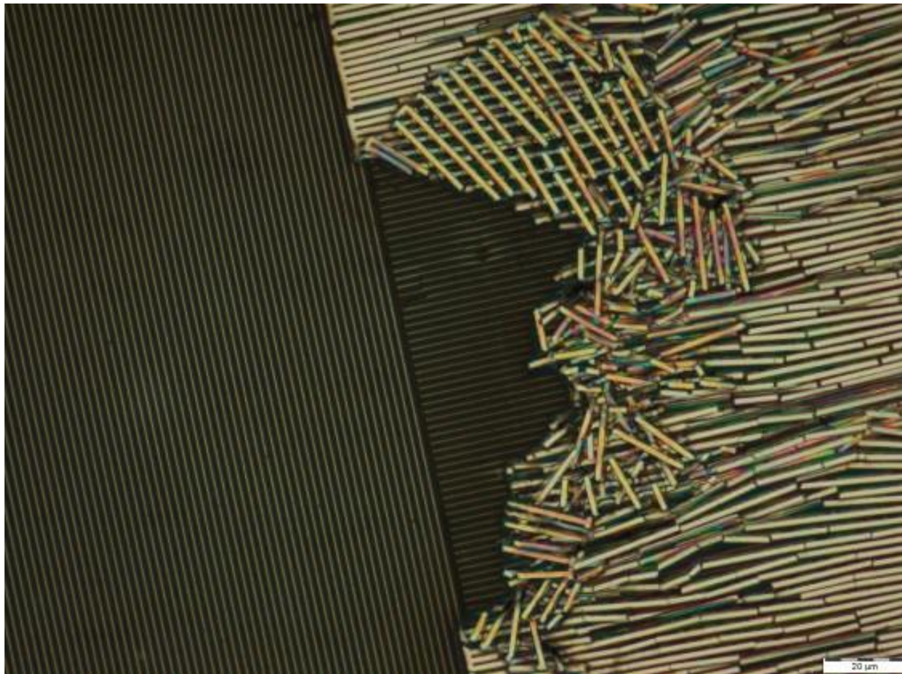
THE INNOVATION COMPANY

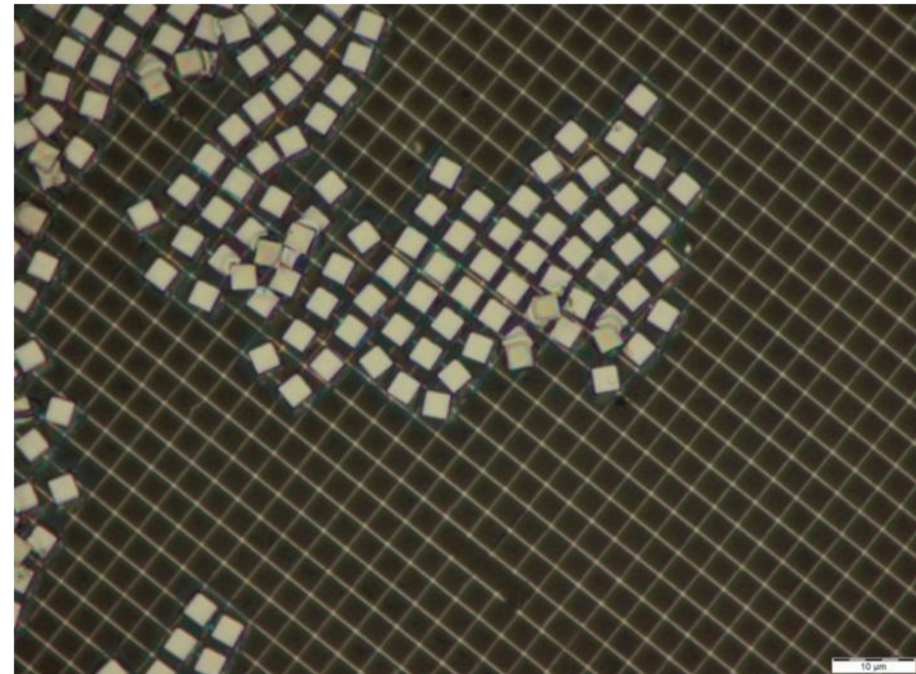
FFG
FORSCHUNG WIRKT.

bmwfw
Bundesministerium für Wissenschaft, Forschung und Wirtschaft

bmvit

Lift-off in progress





Thank you for your interest!