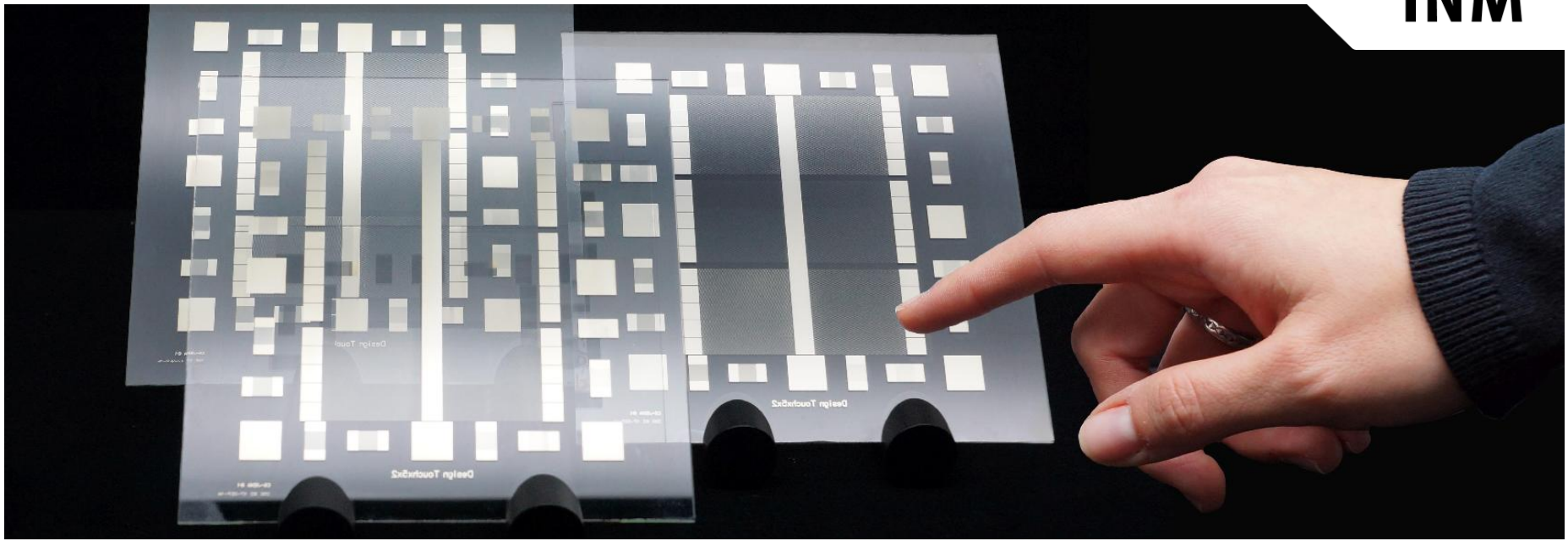
New Thinking. New Materials.

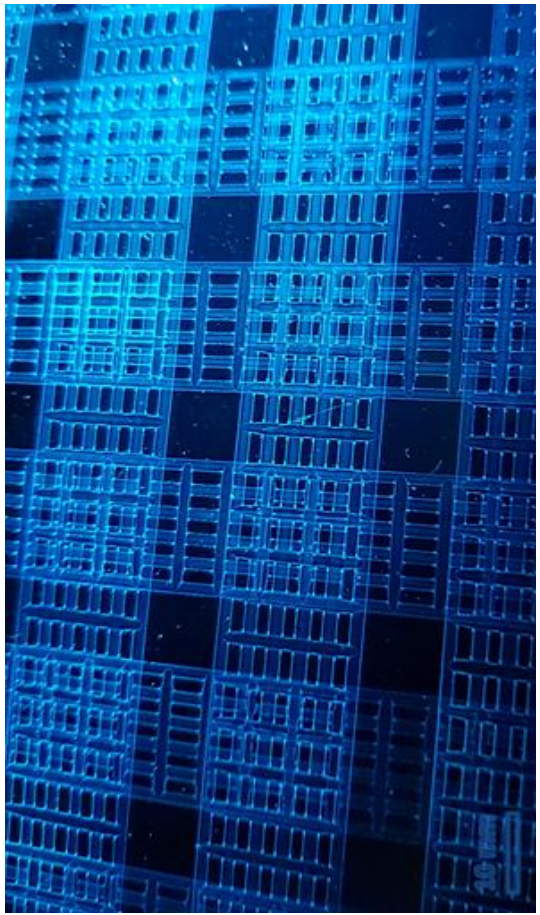
INM



TRANSPARENT AND ELECTRICALLY CONDUCTING COATINGS THROUGH WET CHEMICAL NANOTECHNOLOGY

TRANSPARENTE UND ELEKTRISCH LEITENDE BESCHICHTUNGEN DURCH NASSCHEMISCHE NANOTECHNOLOGIE

Dr. Peter William de Oliveira, Dr. Michael Opsölder



TRANSPARENT & CONDUCTING COATINGS

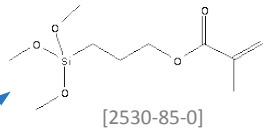
- Nanoparticular ITO coatings
- Silver structures and coatings

NANOPARTICULAR ITO

TIN DOPED INDIUM OXIDE In_2O_3:Sn – TRANSPARENT CONDUCTOR

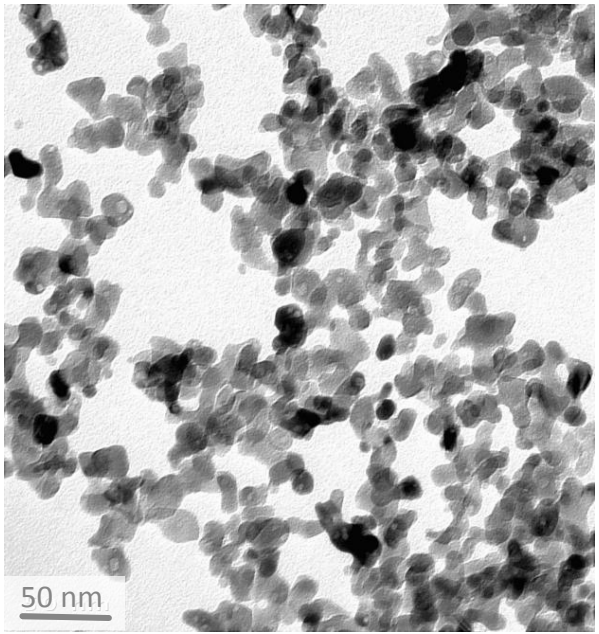
Crystalline, conductive ITO nanoparticles (10-30 nm)

- Surface modification
- Re-dispersible
- Adaption to matrix properties
- Very low light scattering effect



Bi-functional binder: organo silanes e.g. Methacryloxypropyltrimethoxysilane (MPTS) and/or siloxanes

- Chemical bonding to the particle surface
- UV-induced polymerisation
- „Gluing“ of nanoparticles and adhesion to the substrate
- Improved mechanical properties (hard and flexible)
- Improved conductivity

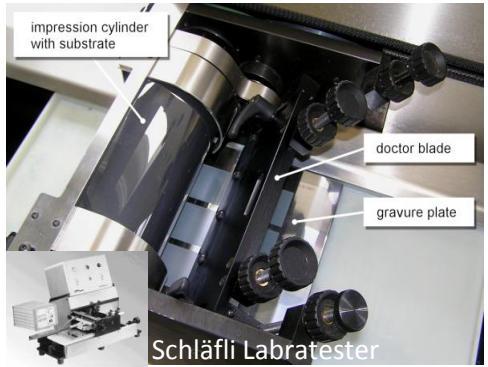


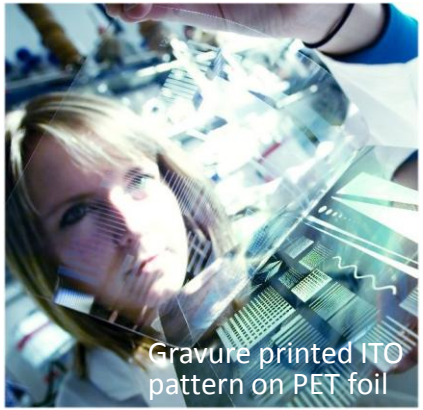
TEM picture of ITO nanoparticles

NANOPARTICULAR ITO

- Printing of transparent conducting lines and patterns
  - Gravure printing ⟶ R2R possible
  - Ink-jet printing ⟶ prototyping
- Various substrates
  - Glass
  - Flexible ITO layers on polymer films
- Cost efficient manufacturing of flexible, structured ITO layers

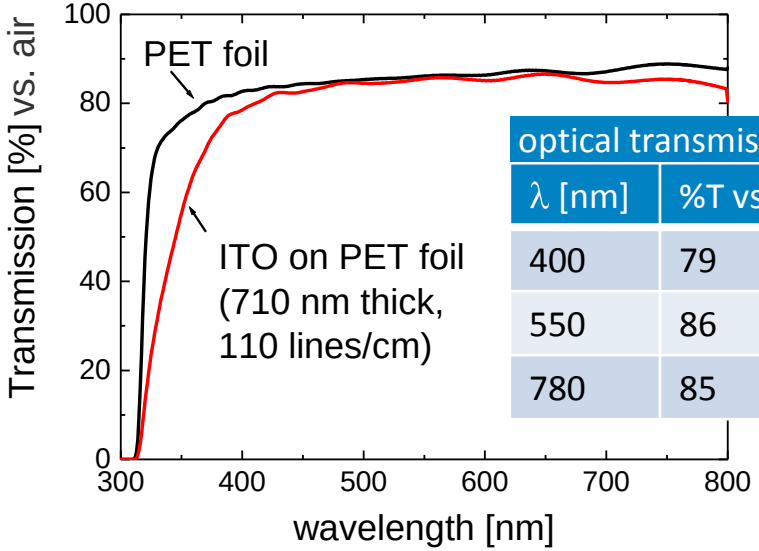
ITO structures by gravure printing
- Lines, patterns
- Resolution: min. line width 100 µm
- Sheet Resistance: 350 $\Omega_{\square}$
  after UV + thermal treatment



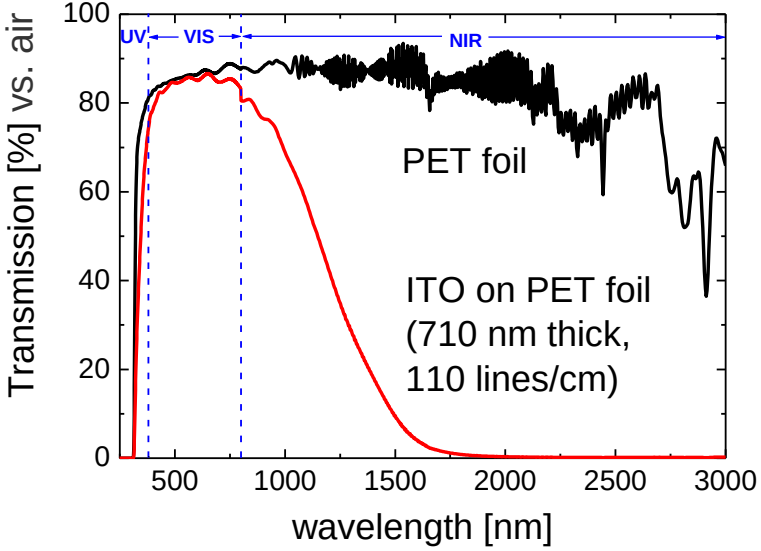


PRINTED ITO COATINGS ON PET FOIL

TRANSMISSION SPECTRA



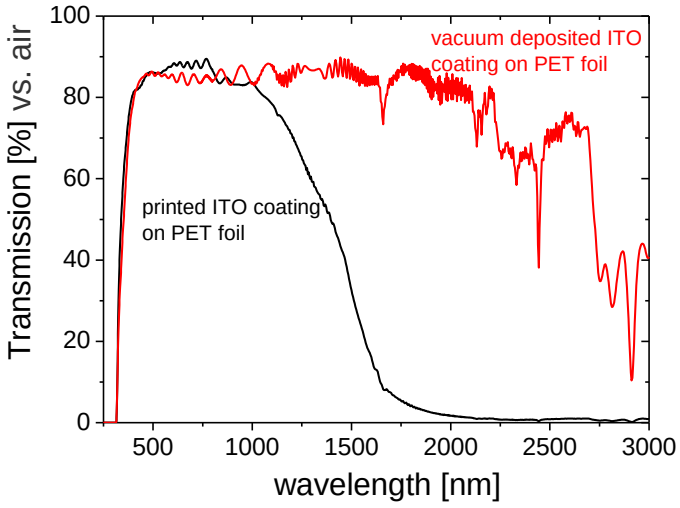
optical transmission of foil + ITO		
λ [nm]	%T vs. air	%T vs. foil
400	79	95
550	86	99
780	85	95

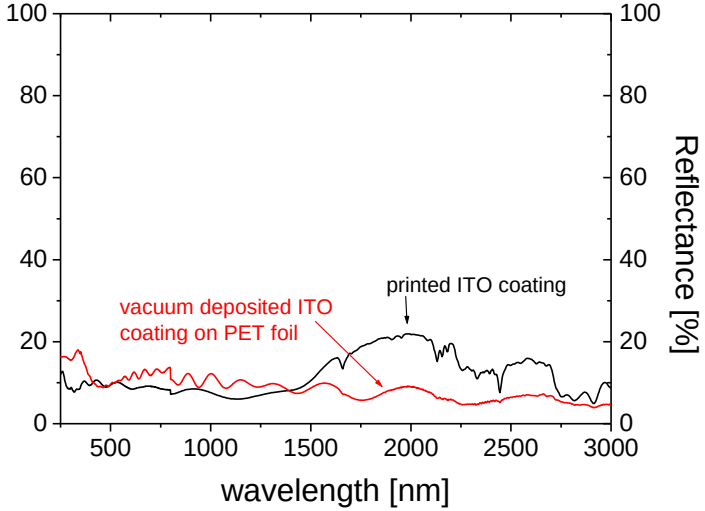


- High transmission in the visible range 380 nm < λ < 780 nm
- Low transmission T < 10 % in NIR range for λ > 1500 nm

COMPARISON: PRINTED / VACUUM ITO

TRANSMISSION AND REFLECTANCE SPECTRUM





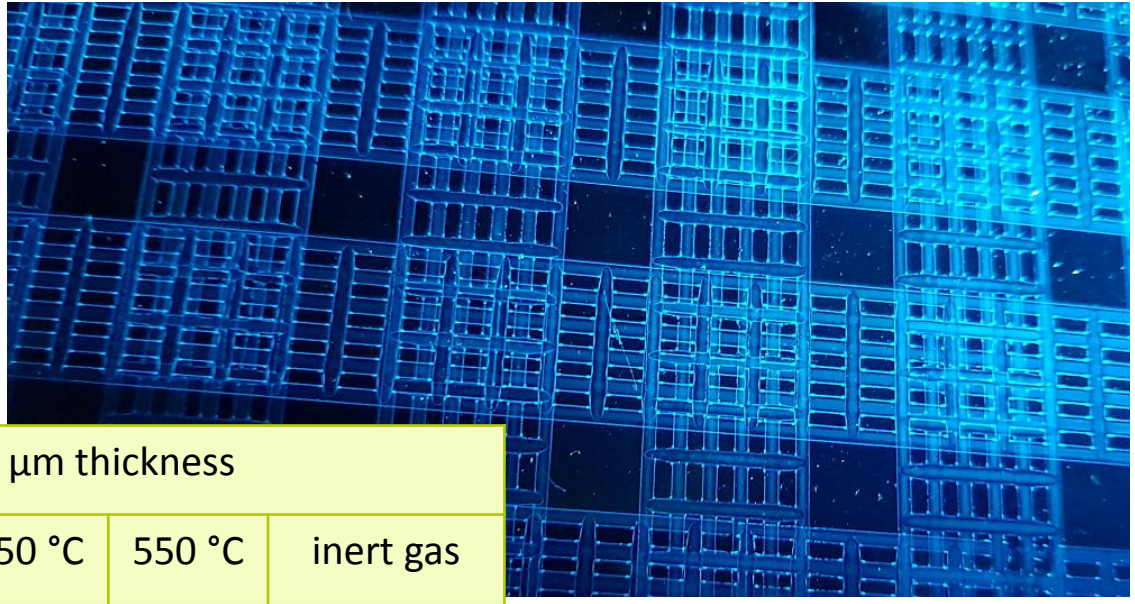
sheet resistance	$k\Omega_{\square}$
ITO_{vac}	0.25
printed ITO	2.5

refractive index	n_{546}
ITO_{vac}	1.92
printed ITO	1.61

- Printed ITO coatings:
  - Transmission in the visible range higher than vacuum deposited ITO coatings (ITO_{vac}) due to lower n
  - Lower transmission in NIR range than ITO_{vac} ($T < 10\%$ for $\lambda > 1500$ nm), absorption by plasmon resonance
  - Slightly higher reflectance in the NIR range than ITO_{vac}

ITO COATINGS ON GLASS

- Various coating techniques
  - Spin coating
  - Dip coating
  - Spraying
  - Inkjet printing



Inkjet printed touch panel grid

ITO spin-coated on glass, 0.85 ± 0.15 µm thickness				
successive treatments	UV	250 °C	550 °C	inert gas
Sheet resistance R ($k\Omega_{\square}$)	5 - 7	1.5	1.1	0.13 - 0.06
% Transmission coated glass, vs. air	90	91	93	> 90

NANOPARTICULAR ITO

SUMMARY

- Transparent conductive layers or structures
- Competitive to vacuum deposited ITO
- Simple printing process, no vacuum - potential for low cost
- Highly developed lab process for gravure printed layers and inkjet printed structures

demonstrator with curved inkjet printed touch panel

CURRENT TOPICS

- Development of working demonstrators
  - Flexible touch panels
  - Objects with touch sensors – keyword “IoT”

cooperation with startup company to build working prototype with sensor surface / user interface

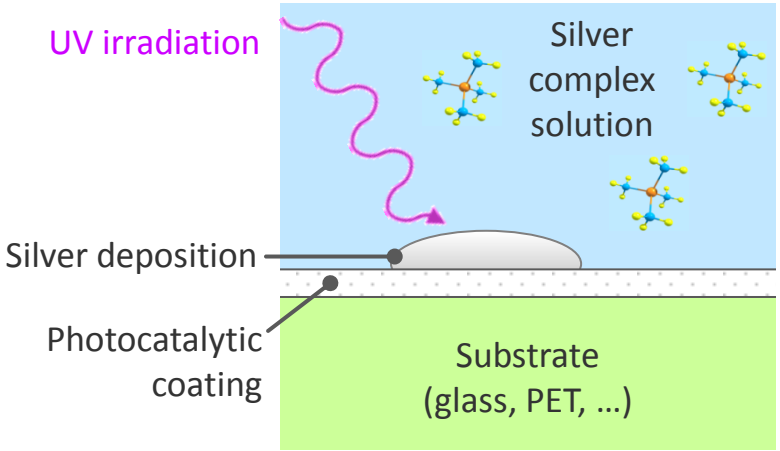
TRANSPARENT & CONDUCTING COATINGS

- Nano particular ITO coatings
- Silver structures and coatings

PHOTOMETALLISATION
PHOTOCHEMICAL PROCESS

- Reduction of silver complex by photo catalyst + UV-light
- Metallic silver precipitates from aqueous solution
- 3 Ingredients:
  - Silver complex (precursor)
  - Photocatalyst
  - UV light
- Any one of them can be structured

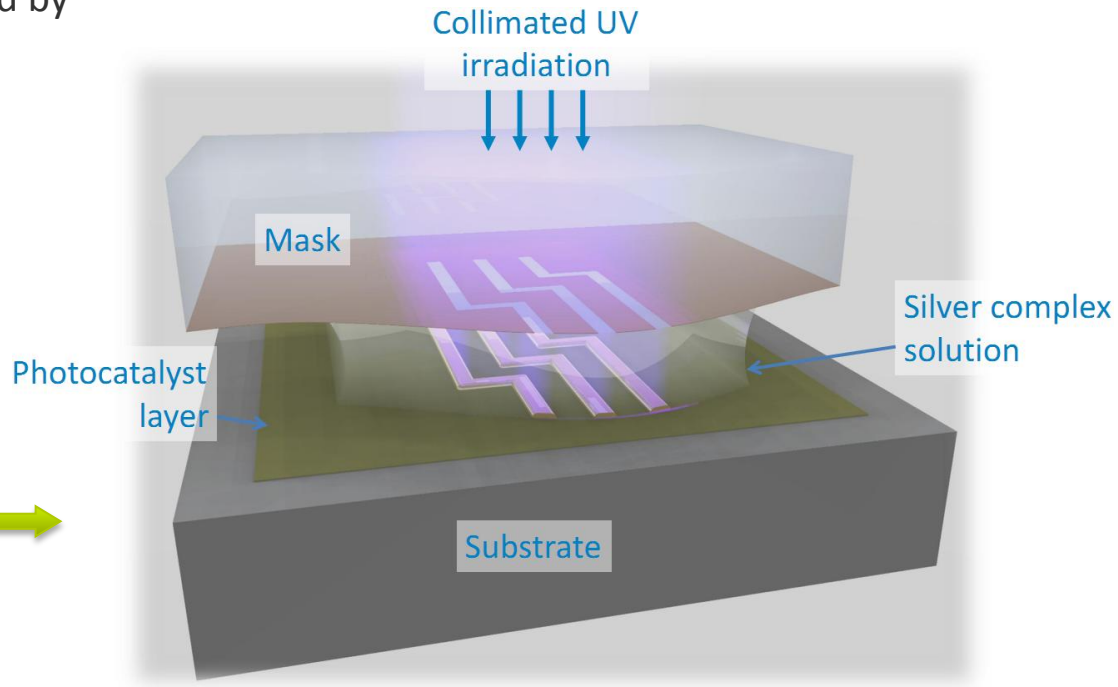
➡ Multiple options for processing



PHOTOCHEMICAL PROCESS

REDUCTION OF SILVER COMPLEX BY PHOTO CATALYST + UV-LIGHT

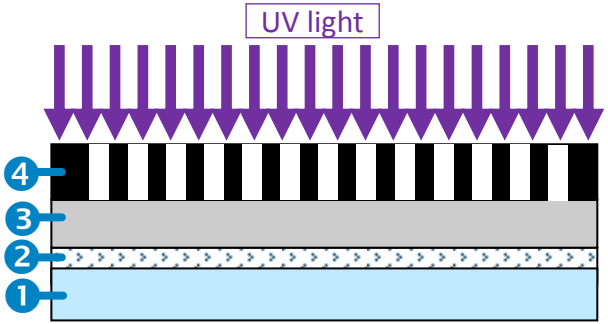
- Advantage: Patterning can be realized by different approaches:
  - Local application of photo catalyst
    - inkjet printing
    - screen printing
  - Local application of silver complex
    - inkjet printing
    - screen printing
    - silicone stamp
  - Mask irradiation with UV-light
  - Direct writing with UV-laser



PHOTOMETALLISATION

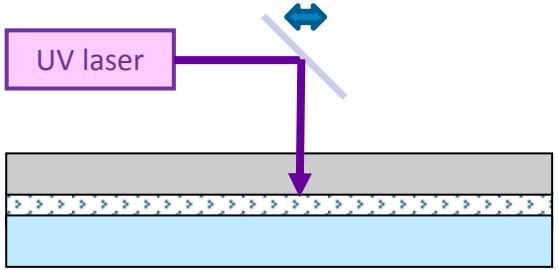
PATTERNING BY IRRADIATION METHODS

Photomask



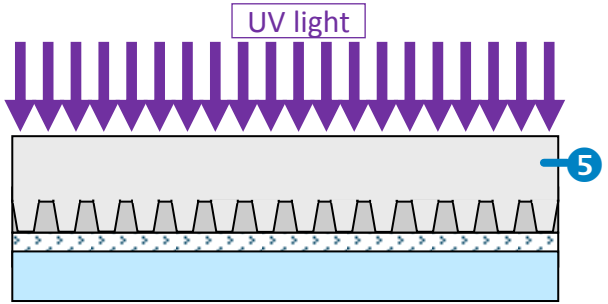
Lithography
e.g. for glass sheets

Laser writing



Laser writing of Ag-lines,
e.g. for prototyping

Stamp



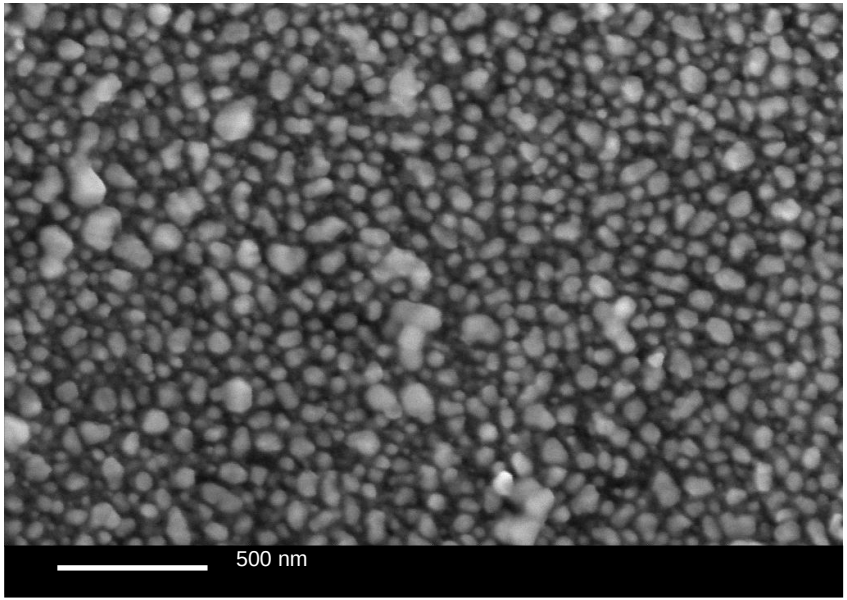
UV-irradiation through
silicone stamp, e.g. for R2R

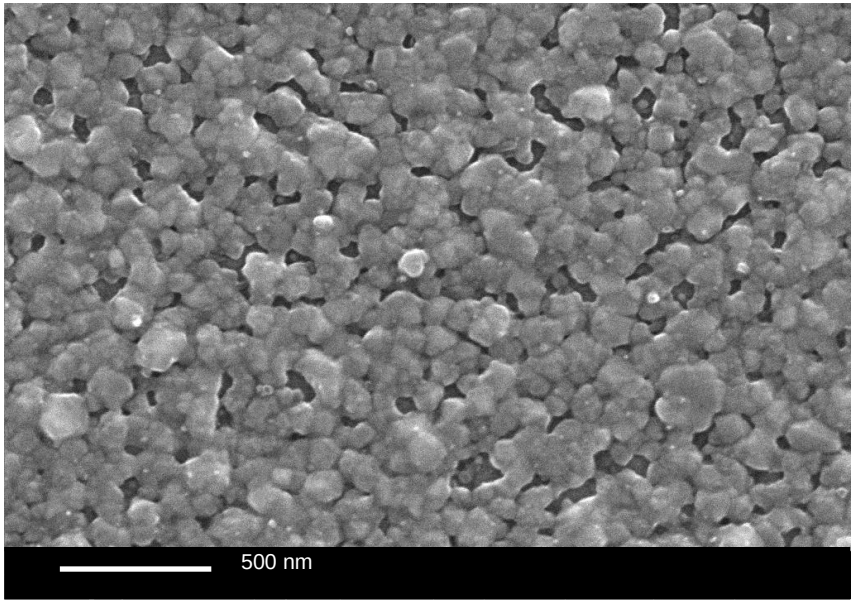
❶ substrate ❷ photo catalyst ❸ Ag complex solution ❹ mask ❺ stamp

PHOTOMETALLISATION

STRUCTURES BY DIFFERENT METHODS: LASER WRITING

- SEM pictures after short and long UV laser irradiation

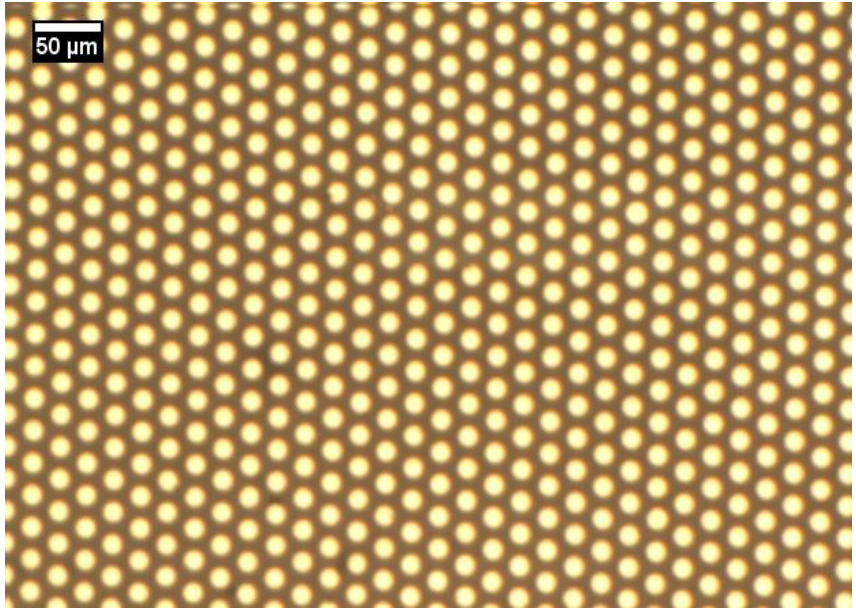


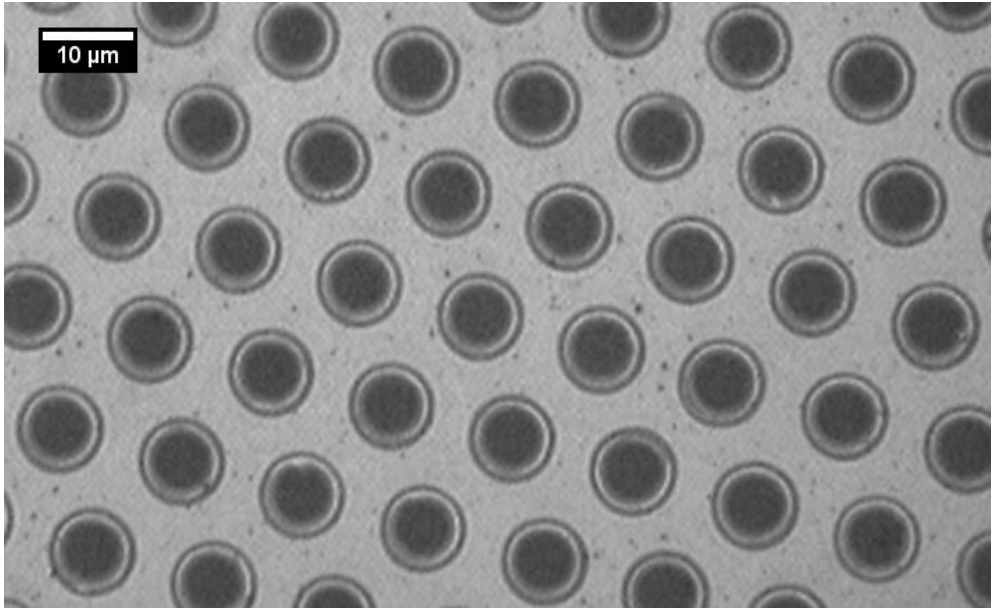


PHOTOMETALLISATION

STRUCTURES BY DIFFERENT METHODS: SILICONE STAMP

- Light microscope and SEM picture of stamp structures

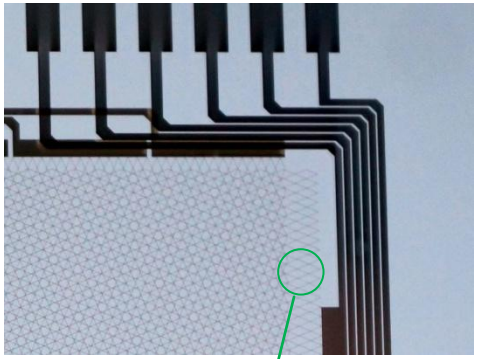




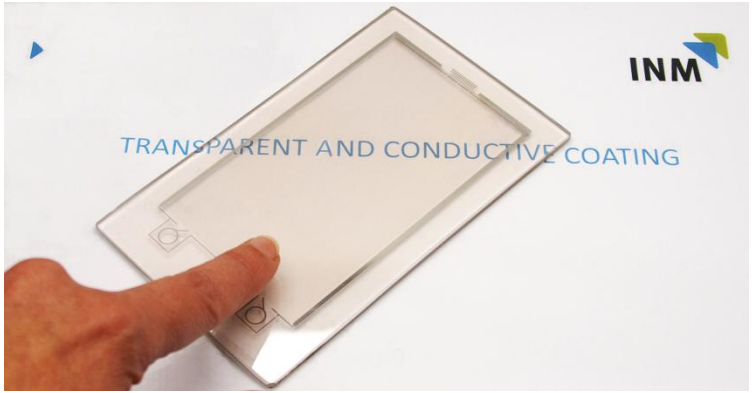
TOUCH SCREEN BY LITHOGRAPHY

DEVELOPMENT OF TOUCH SCREEN AT INM

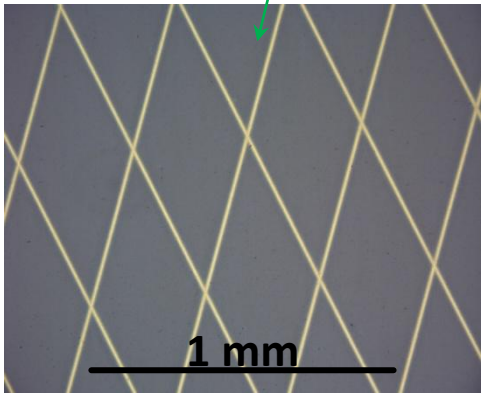
- Typically anisotropic pattern with line widths from 3 - 7 µm
- Sheet resistance down to 15 $\Omega_{\square}$
- Optical transmission up to 92 %
- w/o further treatment: dark from substrate side, reflective from top side
- Fully functional capacitive touch panel demonstrated



touch panel structure (2 sided)



silver mesh touch panel structure on glass

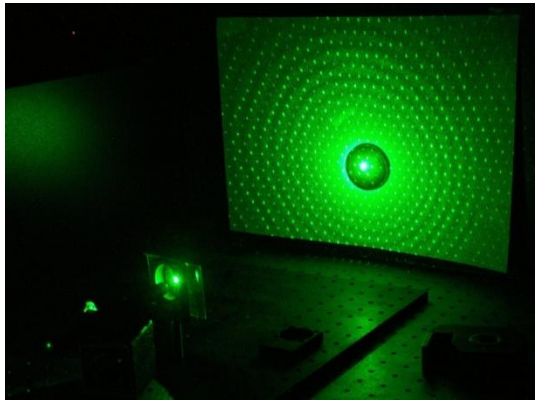


micrograph of silver mesh structure

PHOTOMETALLISATION

APPLICATIONS

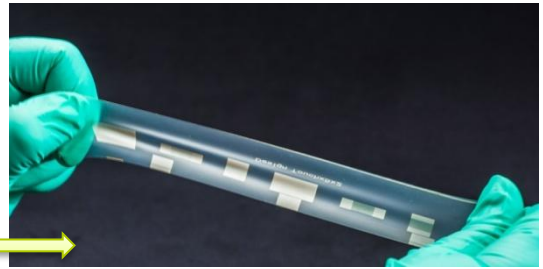
- Photovoltaics
- Optics
- Electronics
- Low-E glasses
- Product labelling
- Packaging industry (RFID)



Laser diffraction pattern of hexagonal stamp structure

CURRENT TOPICS

- Improvement of mask process for PET (performance, reproducibility)
- Development of imprinting process from lab scale proof of principle demonstration into pilot scale R2R process
- Development of process for stretchable substrates such as silicone

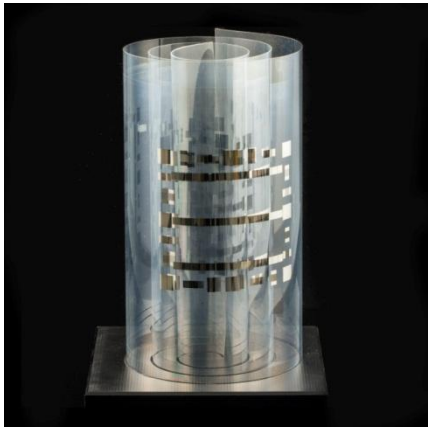


Test structures on PDMS sheet

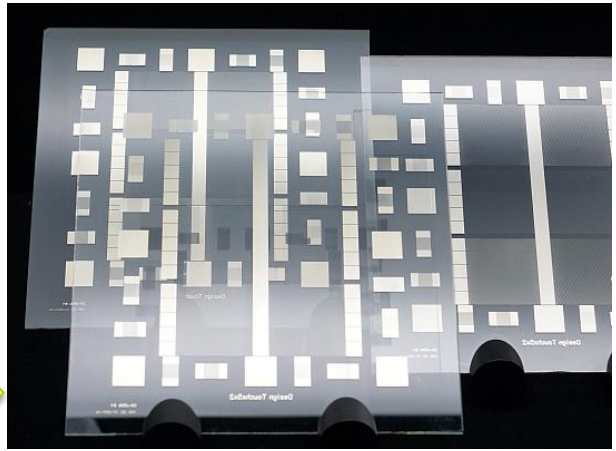
PHOTOMETALLISATION

SUMMARY

- Process for direct structured deposition of silver structures
- Offers advantages of lithographic and printing processes
- Low material usage (< 100 nm), simple process – low costs
- Structure sizes < 1 µm (periodic) possible
- Sheet resistance down to 200 $m\Omega_{\square}$
- No thermal post-treatment necessary
- Various substrates possible
  - Glass
  - PET ➡ flexibility
  - silicone ➡ stretchability
- Highly developed lab process for mask irradiation on glass and PET substrates ➡



Test structures on PET foil



Test patterns on glass by mask irradiation

THANK YOU VERY MUCH FOR YOUR ATTENTION

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