Overview of Transparent Metal Mesh Electrode Technologies

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2015 DOE Solid-State Lighting

R&D Workshop

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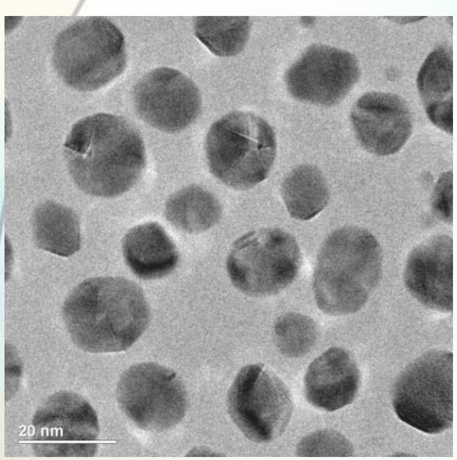
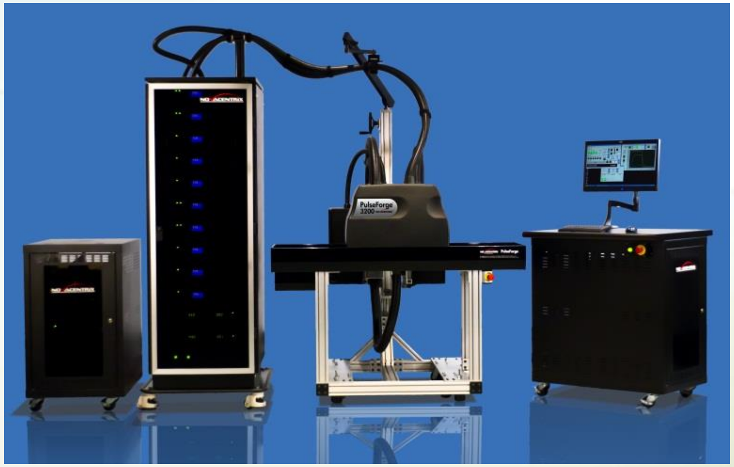
Product Snapshot

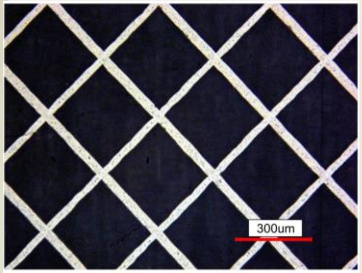
Nanomaterials

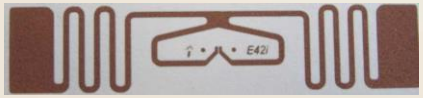


PulseForge ® Photonic Curing Tools



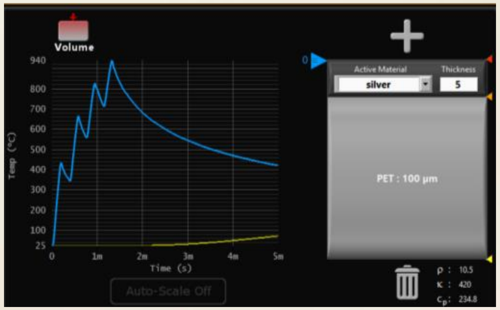
Metalon ®, **PChem** Conductive Inks





Also: Ag, Ni, Co, others

SimPulse ® Numerical Simulation



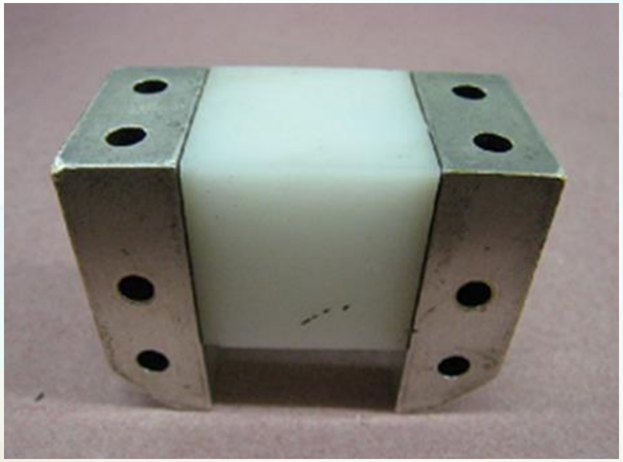
Introduction

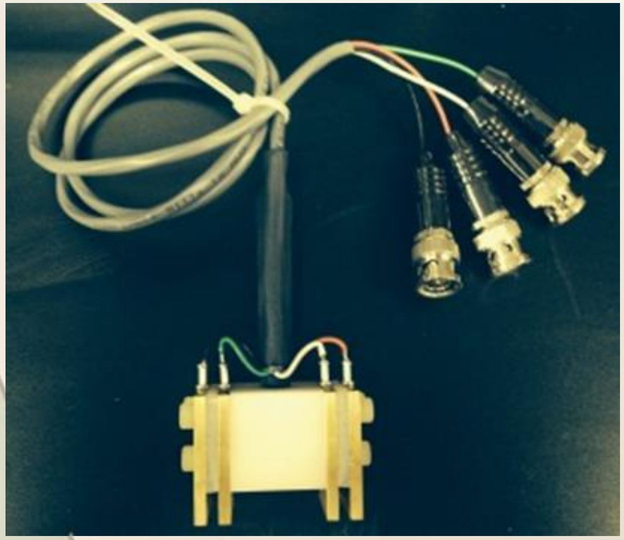
- What are transparent metal ‘mesh’ or ‘grid’ electrodes?
- Methods to produce & pattern metal mesh electrodes
  - Additive vs semi-additive vs subtractive
- Challenges to manufacturing & use

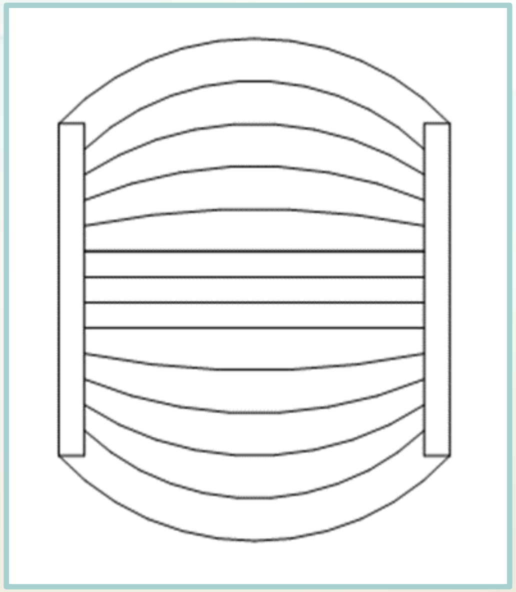
Definitions & key parameters

- ‘**Transparent**’: per the normal definition. However, typically the metal structures block light, but due to very low surface coverage and microscopic feature size they appear transparent to the observer.
- ‘**Mesh**’: the microscopic patterns of the conductive metal or metallic particles that carry current often resemble a typical macroscopic woven or stamped “mesh”. Some use the term ‘grid’.
- **Transmission or Visible Light Transmission (VLT)**: the % of light in a specified wavelength range that is transmitted by the conductive coating and substrate. Often the absorption of the substrate is subtracted and the transmission of the coating itself reported.
- **Sheet resistance** (Ω/□): the resistance across a segment of the coating of equal length and width. By itself as resistance (vs resistivity) it does not indicate how good a conductor the coating is, but when graphed as a function of VLT does indicate performance of the film.

A little bit on sheet resistance





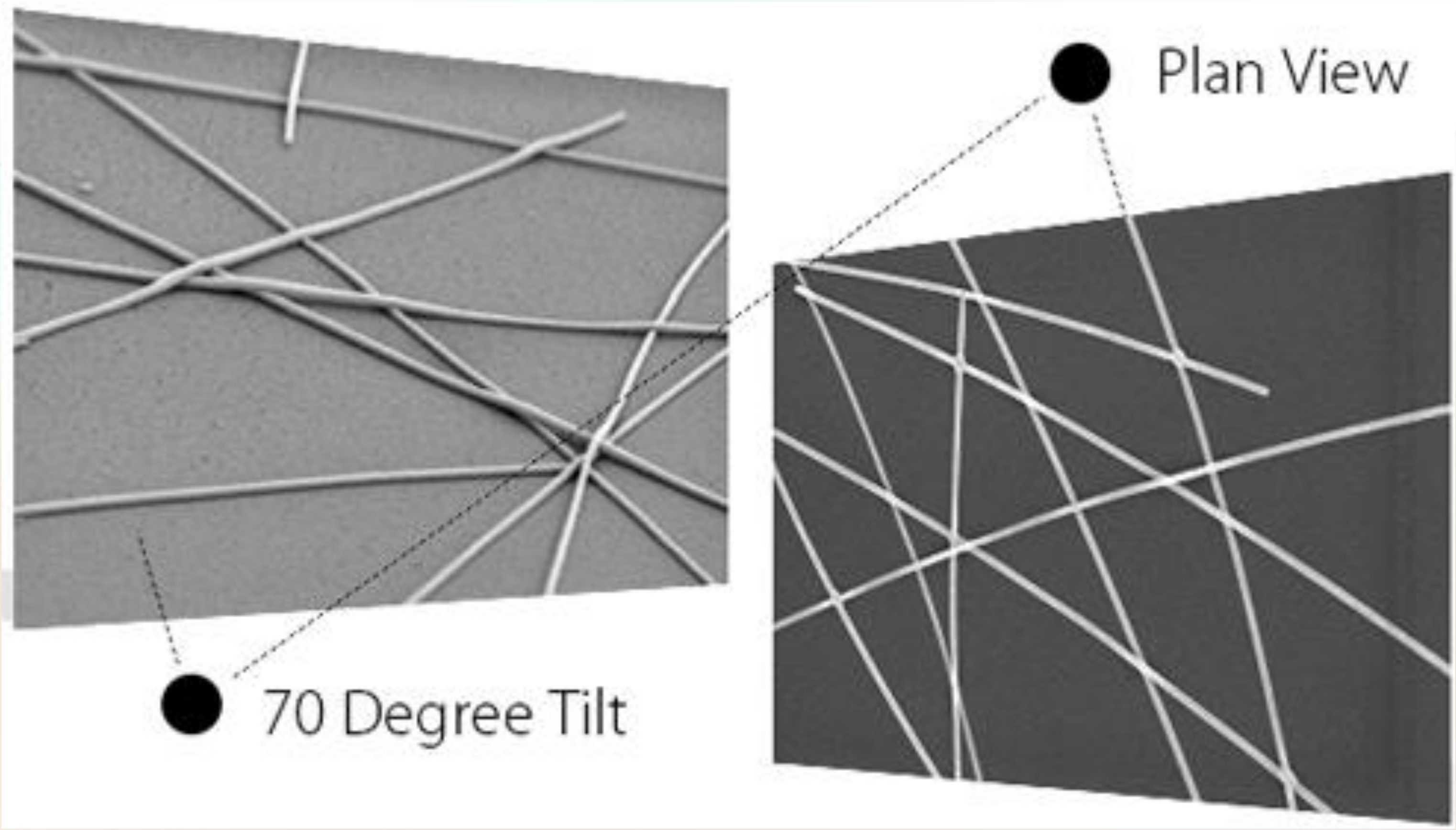


Electric field spreading will result in lower than actual sheet resistance values if sample is not cut to width of “square probe” !!!

Types of metal meshes

- Percolated networks of high aspect ratio silver nanowires
- Self assembled and sintered nanoparticle (NP) films
- Etching of PVD films patterned by lithography
- ‘Trenches’ filled with sintered nanoparticles
- Printed and sintered nanoparticle films

Percolated networks of high aspect ratio silver nanowires

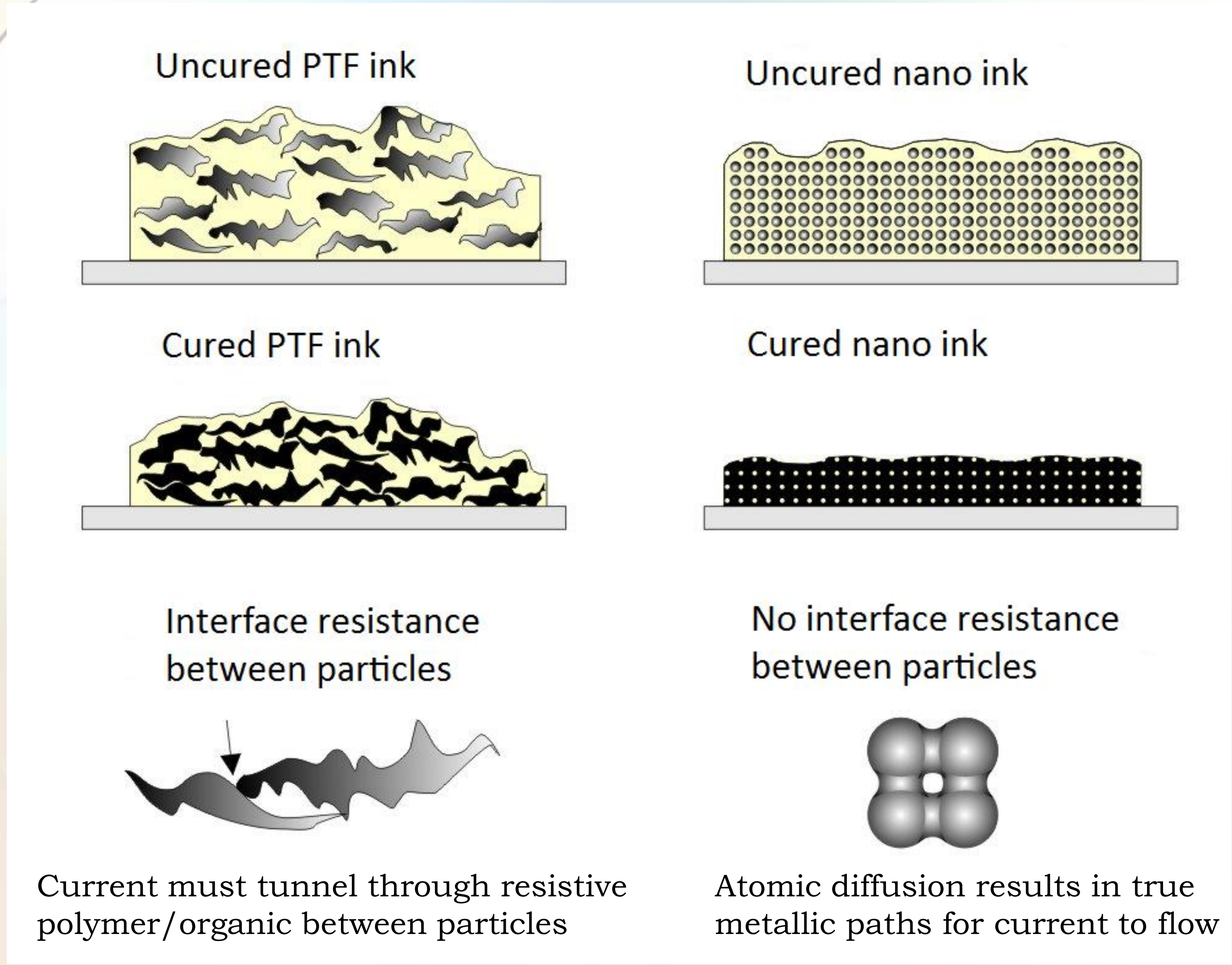


Typical avg. diameters of 25-200 nm and lengths from 2-100+ µm

Image: http://www.cambrios.com/sites/all/themes/cambrios/images/technology.png

CAMBRIOS

Percolation vs metallic conduction



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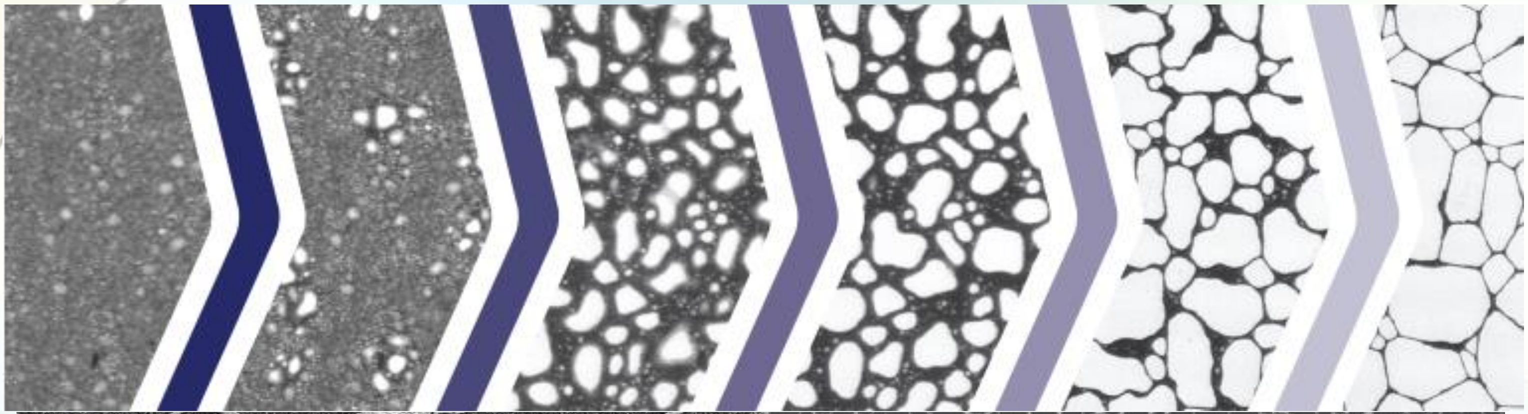
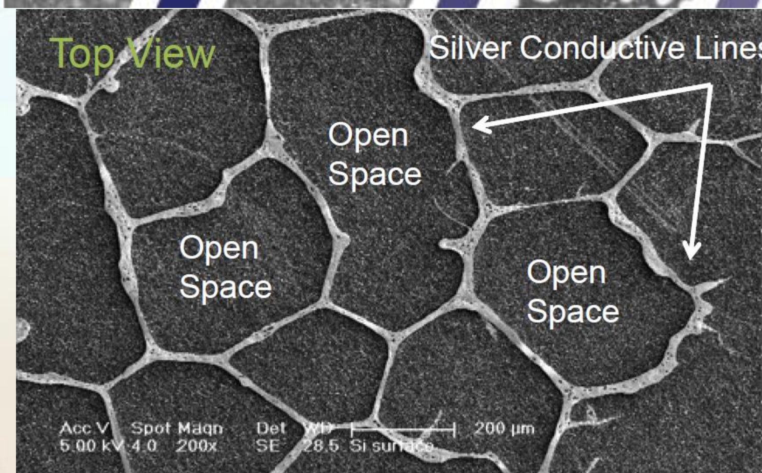
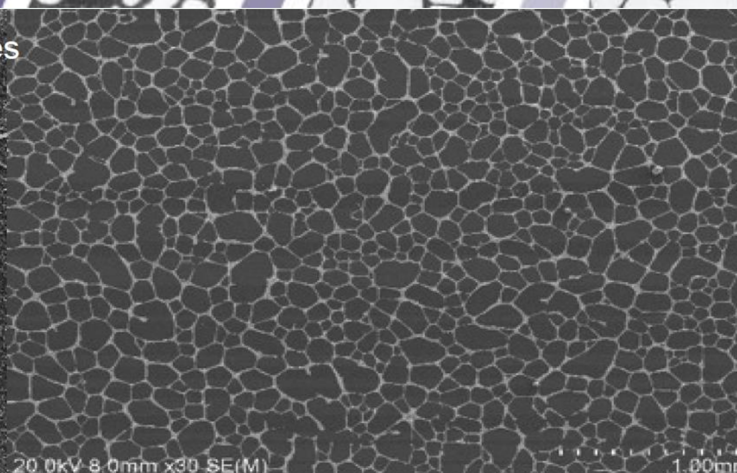
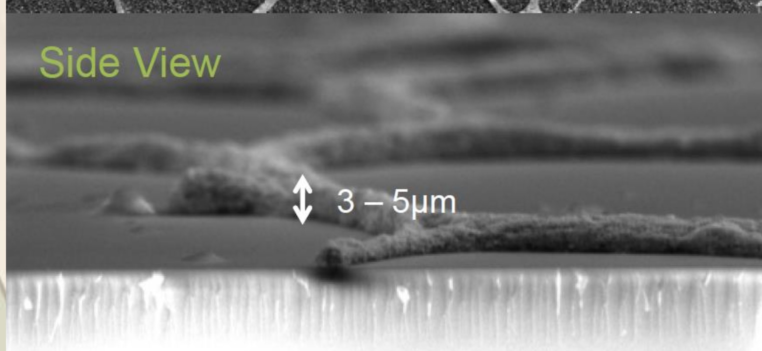
Sinter able metallic nanoparticle and metallorganic based inks allow for reduced metal usage and potentially lower materials cost

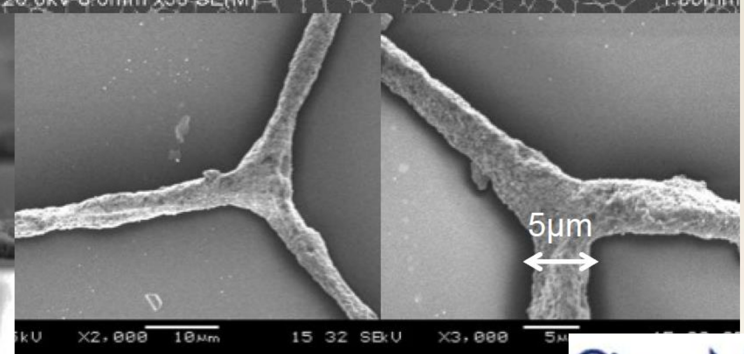
Self assembled & sintered NP films











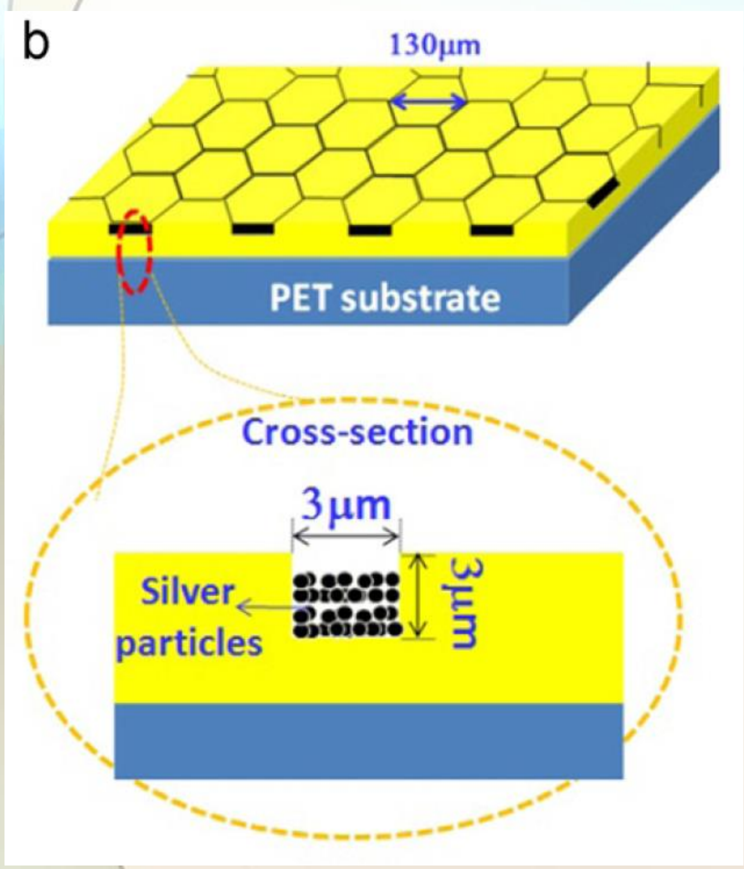
Images source: http://www.sid.org/Portals/5/pdf/Cima_Nanotech_DW2013.pdf

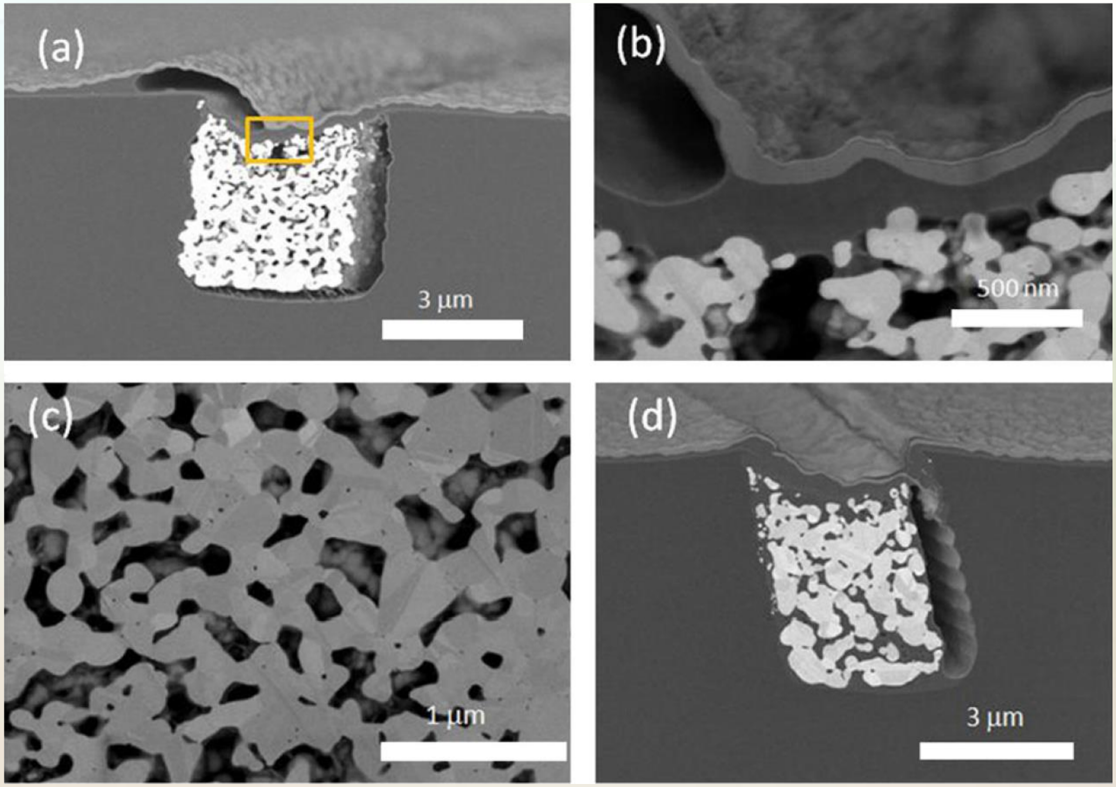
Cima NanoTech

Etched (PVD) metal films patterned by lithography

- Nanowire and self assembled NP films are also primarily etched to pattern
- Nano Imprint Lithography (NIL)
- Rolling Mask Lithography (RML™)
- Micro contact printing of a self-assembled monolayer ‘resist’
- Traditionally printed resist

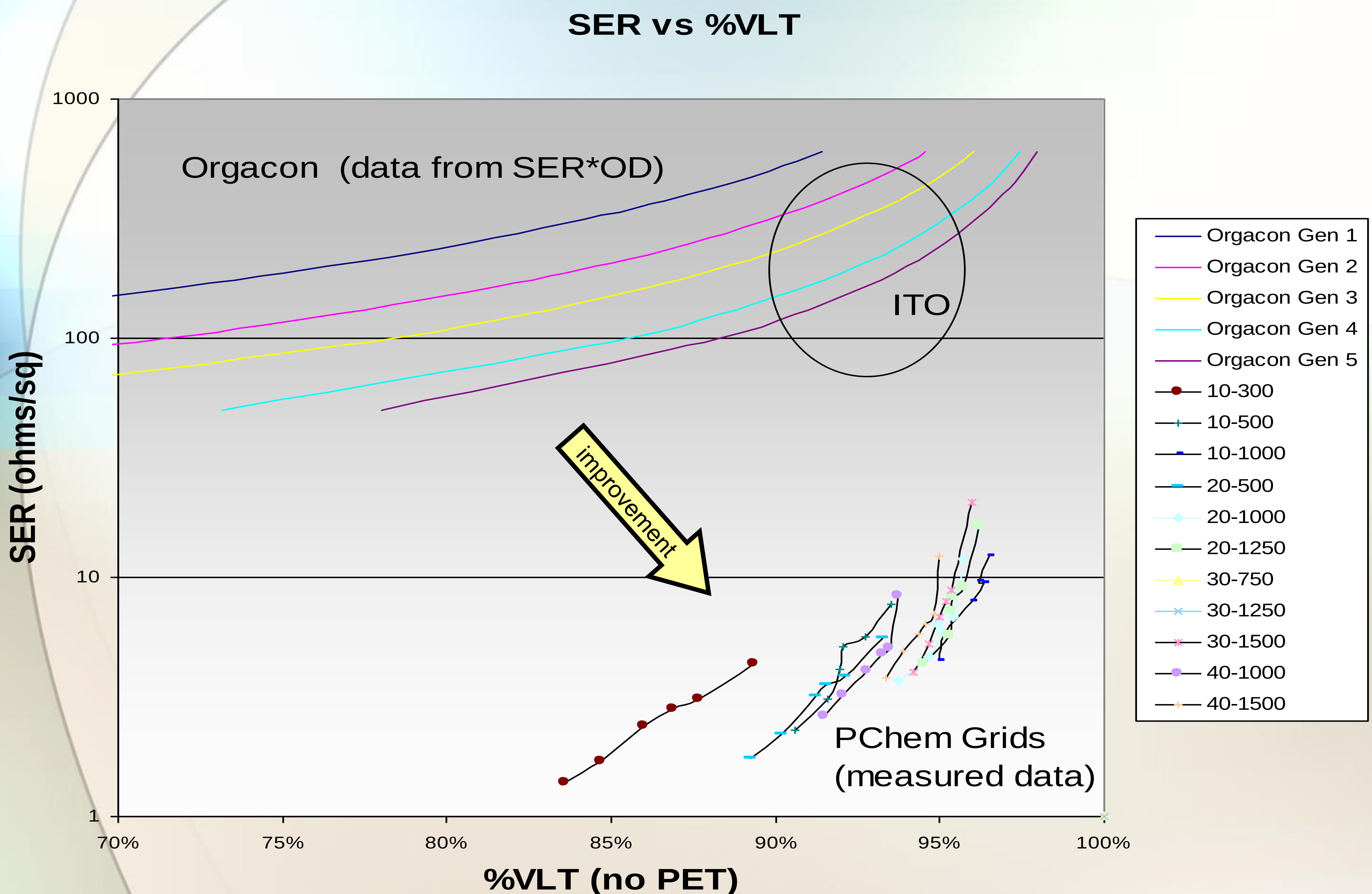
‘Trenches’ filled with sintered NPs





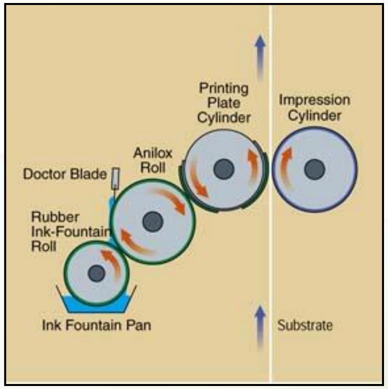
Yaowen Li, et al. ITO-free photovoltaic cell utilizing a high-resolution silver grid current collecting layer. Solar Energy Materials & Solar Cells 2013. 113, pp. 85–89. Elsevier.

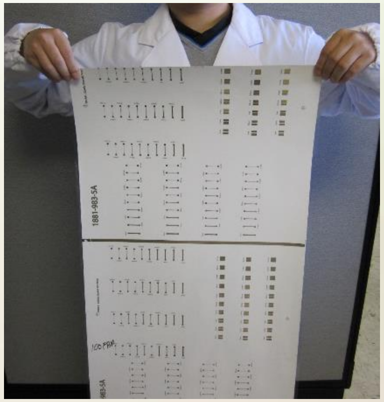
Printed and sintered nanoparticle films



SER vs %VLT
1000
100
10
1
SER (ohms/sq)
70%
75%
80%
85%
90%
95%
100%
%VLT (no PET)
Orgacon (data from SER*OD)
ITO
improvement
PChem Grids
(measured data)
Orgacon Gen 1
Orgacon Gen 2
Orgacon Gen 3
Orgacon Gen 4
Orgacon Gen 5
10-300
10-500
10-1000
20-500
20-1000
20-1250
30-750
30-1250
30-1500
40-1000
40-1500

High Speed Flexo Printing Video

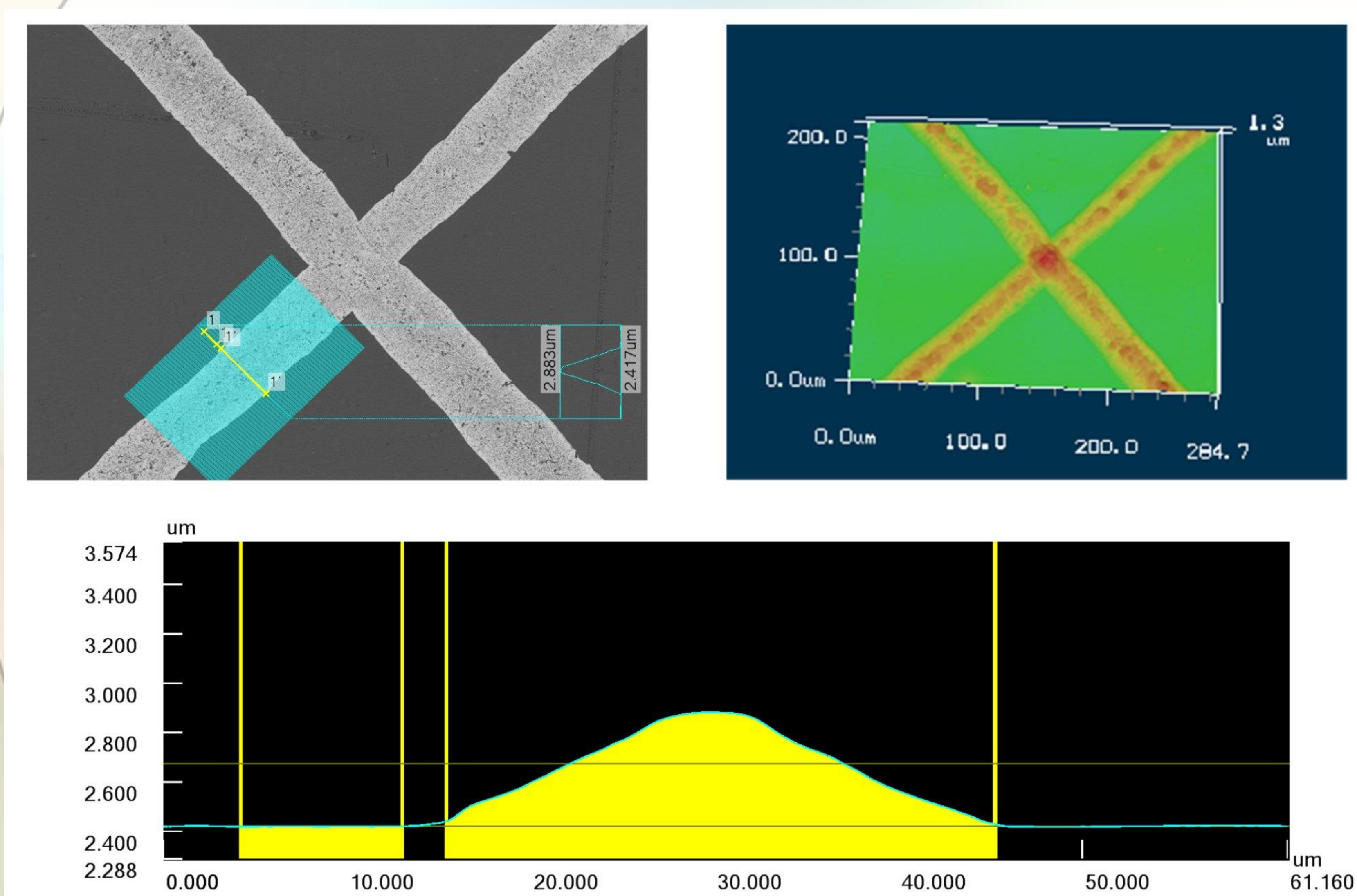




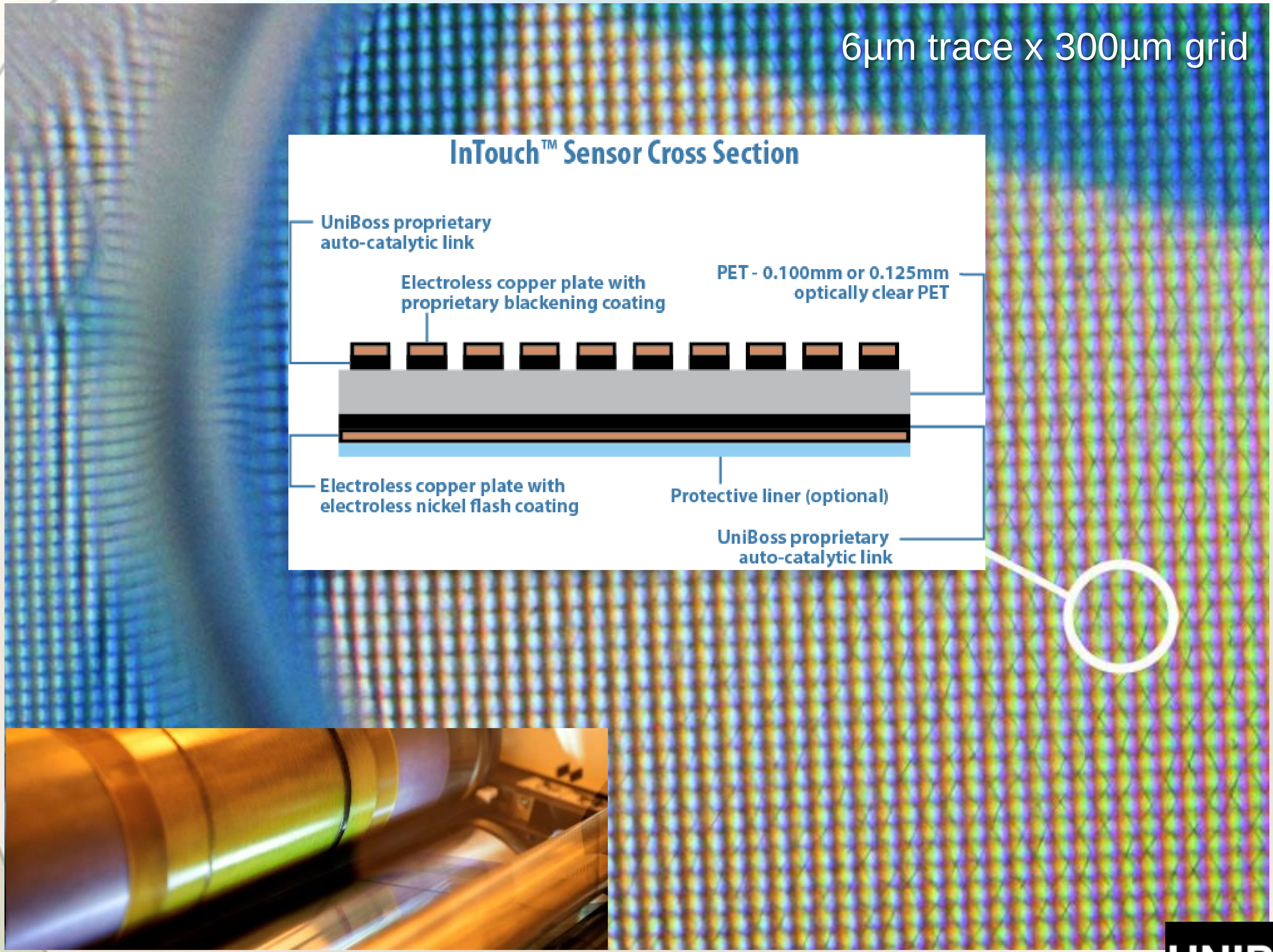
Inexpensive plates, widths from 6-60”, 660 FPM demonstrated at Clemson

http://www.youtube.com/watch?v=W6n4OOAp3og

Profile of a flexo printed grid line



Print & plate approach



Source: http://www.unipixel.com/home/products/intouch-sensors-2/

Metal mesh electrode obstacles

- Mesh line resolution
  - Narrower metal features result in improved VLT, but higher SR.
- Mesh thickness
  - Thicker metal structures have lower SR, but are a challenge to level prior to coating the OLEP materials.
- Electric field isolation
  - In OLEDS an electric field is established through the stack between upper and lower electrodes. Depending on spacing the field lines may not fully extend into the areas between grid lines to activate the material there.
  - A second transparent conductor like PEDOT, Ag nanowire, CNT coatings, etc. is often required as a charge spreading layer for OLED applications to replace ITO

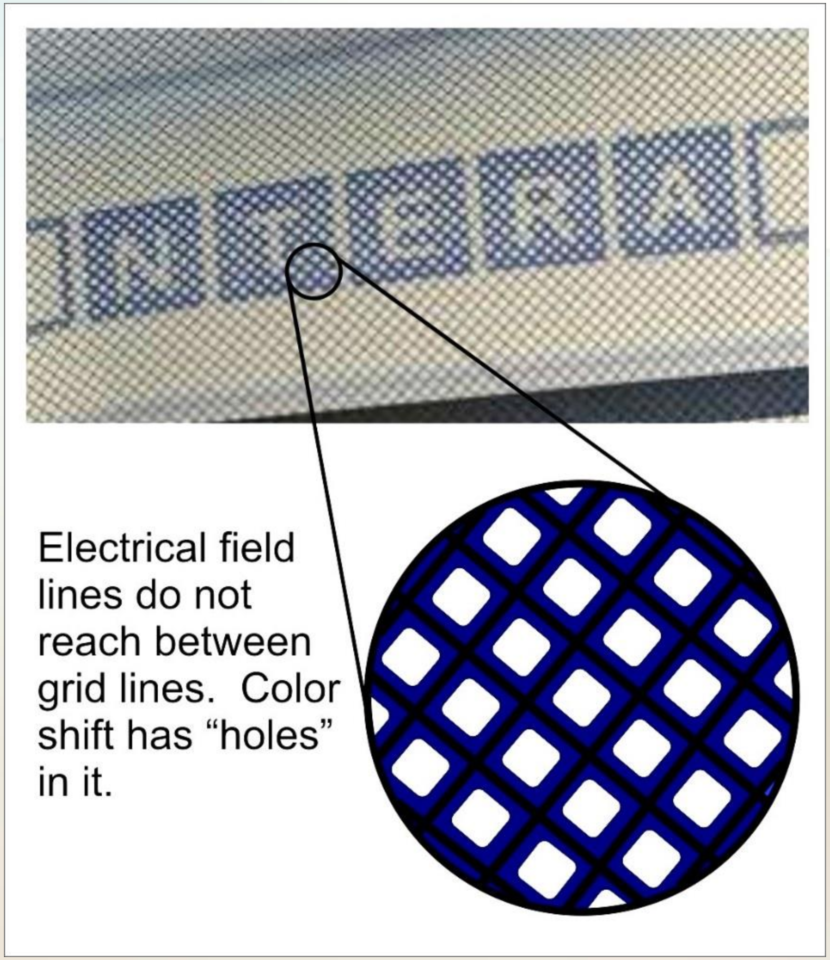
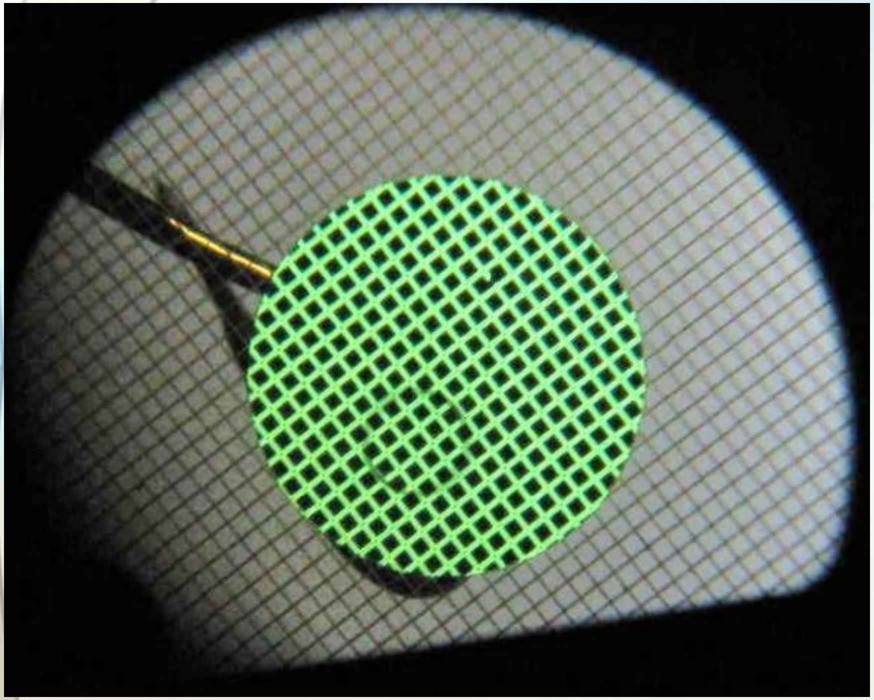
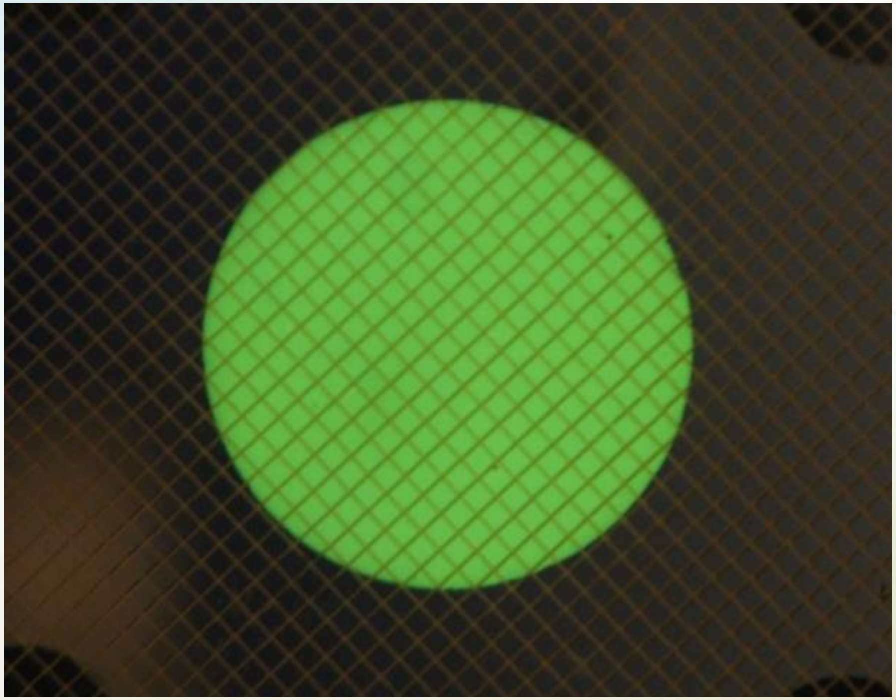


Image of functioning NanoChromic display made with PGrid TCF courtesy of NTERA

Printed Grid/PEDOT TCFs





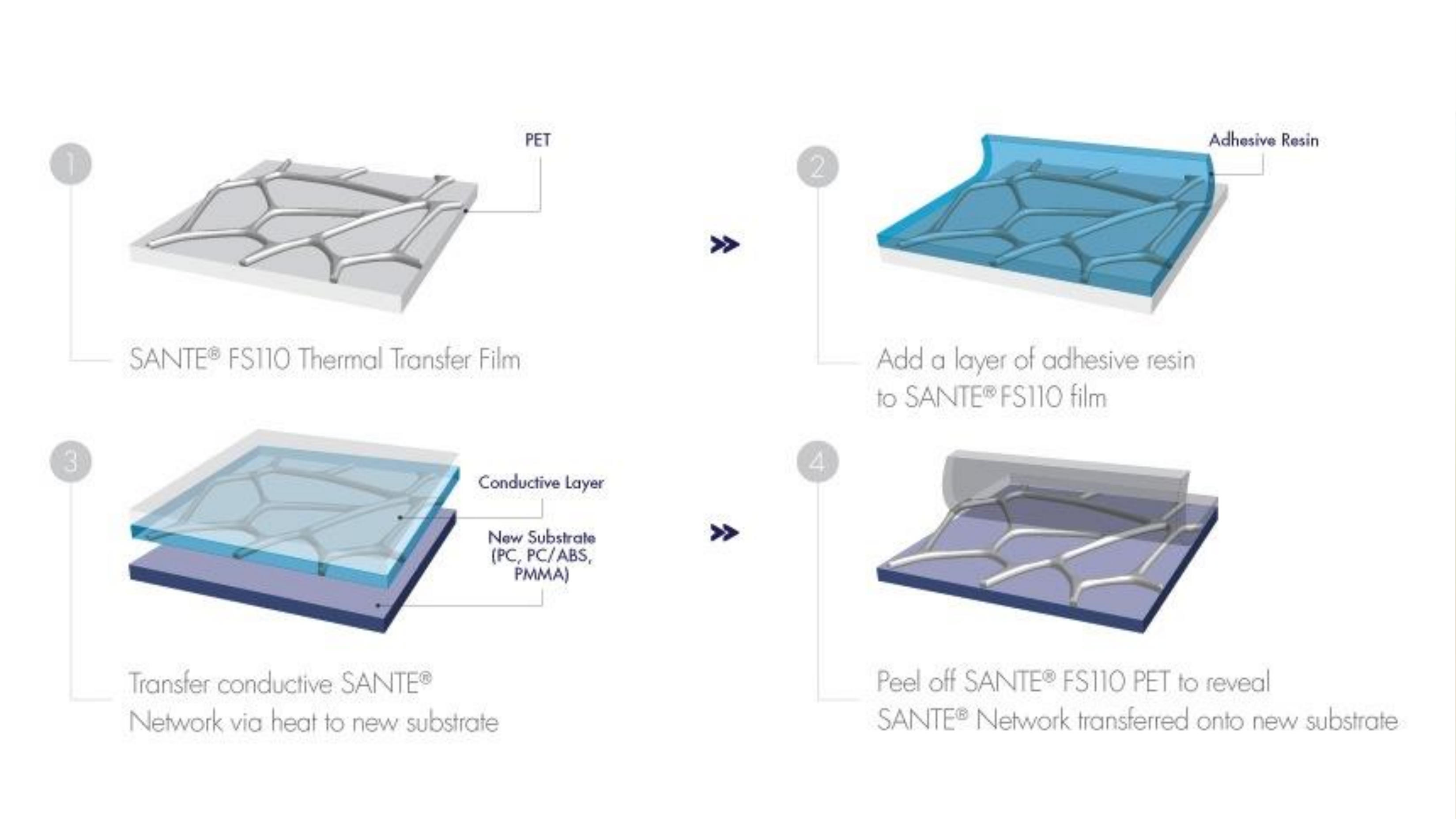
OLED made with:
- PChem PGrid100
  - ~35/300 µm L/S
- Heraeus Clevios™ P VP AI 4083
  - Conductivity: 10^{-3} S/cm

OLED made with:
- PChem PGrid100
  - ~35/300 µm L/S
- Heraeus Clevios™ F CE
  - Conductivity: 200 S/cm

OLEDs & Photos courtesy of A. Elschner, Heraeus Precious Metals GmbH & Co. KG

Heraeus

Planarizing metal meshes for deposition of OLED layers



http://www.cimananotech.com/sante-technology/transfer

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Transparent anode & cathode

Transparent metal 'mesh' electrodes

- Allow for an improved VLT/SR performance ratio over ITO and IMI (ITO-Ag-ITO)
- Can potentially offer lower cost
- Better mechanical performance