Transparante Elektrische Circuits

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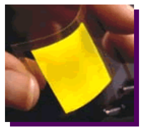
TNO | Knowledge for business

Dag van de Oppervlaktetechnologie 2010

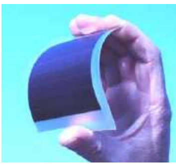
Large area flexible electronics

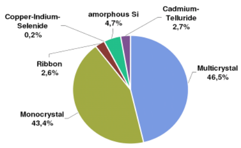
- Lighting (OLED) and Signage (Flexible)
- Thin Film Solar cells
- Sensors in Foil



- Roll-to-Roll Production
  - Cost-effective
  - Large Area
- Plastic carriers: PET, PEN, PI
  - Dimensional stability
  - Limited Temperature stability

Thin Film Photovoltaic's



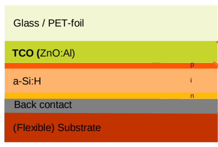


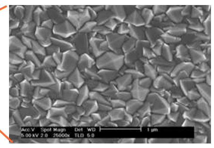
- Better energy output – kWh/KW
- Lower production costs
  - Less material usage (0.2 vs 10 kg / kWp)
  - Potential for lower costs throughout value chain
- Roadmap of glass-to-glass and flexible substrate
- Better aesthetics

sources:
Wambach et al. EU PVSEC 2007
Hesse et al. EU PVSEC 2007)

Thin Film Solar Cells

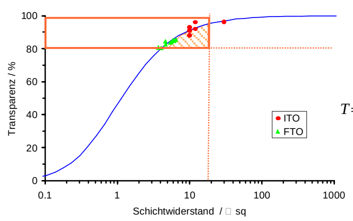
- Transparent Conductive Oxides (TCOs) window layer:
  - Transparent
  - Electrical conductive





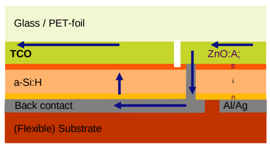
Transparent Conductive Oxides

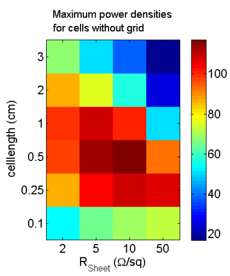
TFPV	TCO
• CuIn(Ga)Se(S)	ZnO:Al (AZO)
• a-Si / mcSi	SnO_2:F (FTO) / ZnO:Al
• OPV / DSC	In_2O_3:SnO_2 (ITO)



$$T=\left(1+\frac{1}{2R_s}\sqrt{\frac{\mu_0}{\varepsilon_0}}\frac{\sigma_{op}}{\sigma_{dc}}\right)^{-2}=\left(1+\frac{188(\Omega)}{R_s}\frac{\sigma_{op}}{\sigma_{DC}}\right)^{-2}$$

Monolithic Interconnection in Thin Film PV



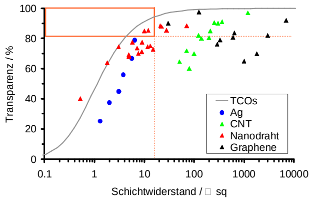


$$P_{loss}=\tfrac{1}{3}J_{cel}^2\rho_{sq}w^2$$

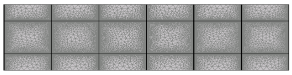
5 – 10% resistive power losses in TCO interconnection

Alternative Transparent Conductive Films

- Graphene (Nobel price 2010)
- Carbon nanot ubes (CNT)
- Thin metal films (Ag, IMI)
- Metal Nano wires

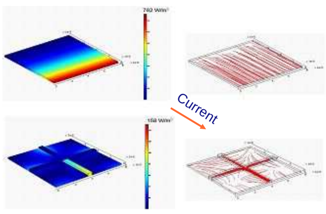


Transparent Conductive Metal Grids



- Thinner and Cheaper TCOs (Flexible foils)
- Higher Transparency of the TCO (IR-range)
- Flexibility in Cell width and Cell design
- Increased durability of TCO

Electrical modeling of TCO with grid

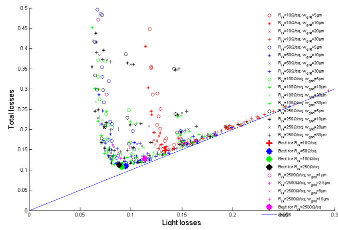


Power loss for 5 mm PV-cell

50 Ω/sq TCO
- 0.19 W m^{-1} (~25%)

10 µm x 5 µm line grid
5% surface coverage
- 0.012 W m^{-1} (~7%)

Modeling of the total power losses



- Simple configuration (lines, rectangular grids) are optimal
- Thin lines with low surface coverage: line widths < 50 µm
- Current concentration in grid lines: high conductivity metal

Manufacturing of Metal Grids

Requirements
- Low surface coverage
  - Minimal Shading losses
- Cost-effective
  - Metal grid deposition is an additional process
- Large area manufacturing

Manufacturing methods
- Sputtering through a Mask
- Screen printing
- Aerosol / Ink-jet printing
- **Electrodeposition**

Electrodeposition of metal grids

- High electrical conductivity
  - 1.2 - 2 times bulk Metal
  - 20-150 nΩ m
- High resolution
  - < 100 nm
- Low material losses
  - < 10% of metal
  - Additive process
- Cost-effective large area production

Electrodeposited Ag front contact for silicon solar cells:
- 0.4 % absolute efficiency gain
- 2-3 year RoI

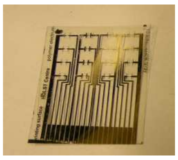
G. Allardyce, et.al, PVSEC (2007)

Patterned Electrodeposition @ TNO

Cost-effective electronic circuitry production

MID base for LED-Lighting

- Moulded Integrated Devices (3D-MID)
- PV front contact grids
- Flexible Electronics



Circuitry for flexible DNA sensor

- **Selective electroless deposition on**
  - **Plastic Moulded parts and foils**
  - **Ceramics and TCOs**

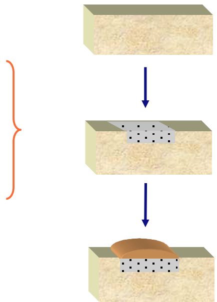
Combining patterning and electroless deposition

Patterned (de)activation

- Injection Moulding
- Milling
- Inkjet-printing
- Micro contact printing
- Laser
- Plasma

Additive metallization

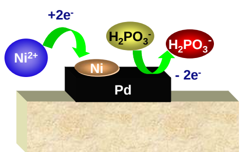
- Electroless
- Electrodeposition



Activation for electroless metal deposition

$$Ni^{2+} + 2e \rightleftharpoons Ni$$

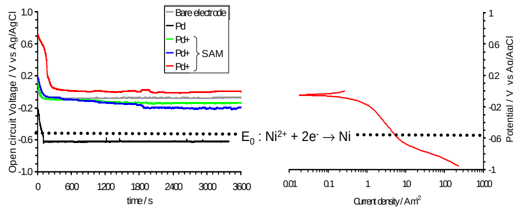
$$H_2PO_3^- + 2H^+ + 2e \rightleftharpoons H_2PO_2^- + H_2O$$



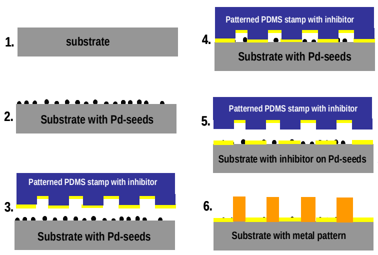
Pd catalyzed electrodeposition on non-conductive substrates

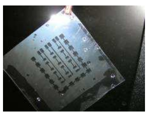
Inhibition by Self Assembling Molecules

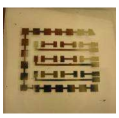
- Electroless nickel deposition is prevented by inhibition of the hypophosphite oxidation on Pd-seeds



Micro-contact printing of inhibitors

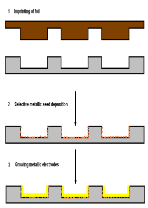


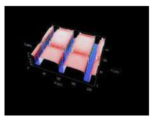


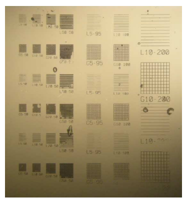


Foil embedded grid by embossing and µCP

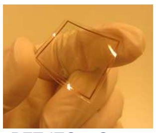
Patterned substrate



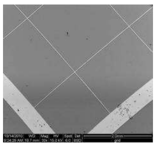




Electrodeposited metal grids on 50 Ω/sq TCOs



PET-ITO + Cu

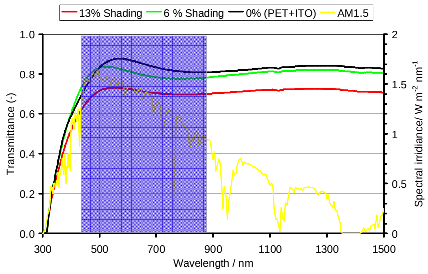


Glass-AZO+Ni

Line width	Aspekt-ratio	*Surface coverage*	*Sheet resistance*
20 μm	**0.40**	**20%**	**0.05 ± 0.02 *Ω/sq***
60 μm	**0.45**	**6%**	**0.09 ± 0.08 *Ω/sq***
30 μm	**0.40**	**6%**	**0.12 ± 0.02 *Ω/sq***
30 μm	**0.30**	**3%**	**0.6 ± 0.7 *Ω/sq***
110 μm	*0.01*	*17%*	*0.6 ± 0.1 Ω/sq*
160 μm	*0.01*	*6%*	*1 Ω/sq*

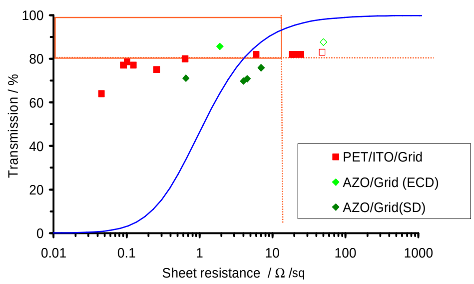
2% Surface coverage 20 μm wide 5 μm thick metal grids

Transmittance of TCO with grid



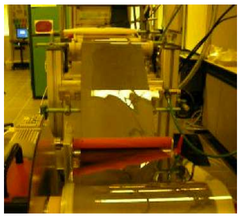
Grid surface coverage	0%	6%	13%
$T_{400\text{-}800\ nm}$ / %	83	79	70

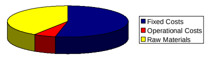
Transparent Conductive Metal grids



Outlook

- TNO R2R Pilot line
  - 26 cm wide foil ; 1 m/min.
  - Patterning by micro contact printing
  - Electrochemcil baths
- Cost-of-Ownership estimate
  - Costs additional Process
    - 3 – 5 € / m²





- Benefit through higher power output ?
  - Solar cells with metal grids

Summary

- Metal grids have the potential to reduce the power losses in TCO window layers used in thin film photovoltaic cells
- Interconnection circuitry on plastic and TCOs can be achieved by
  - Patterned inhibition by SAMs
  - Selective electro(less) metal deposition
- Patterned electrodeposition is promising method to make transparent conductive layers:
  - 1 – 50 μm line width grids reduce TCOs resistance
  - 0.1 – 5 Ω sq on 50 Ω sq ITO
  - Transmittance loss of less than 10%

Acknowledgement

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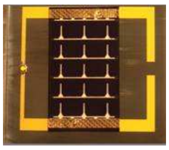
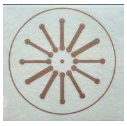
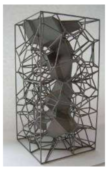
Thank you for your attention







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