Department of Graphic Arts and Photophysics

Material printing – The new opportunities for printing industry

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Pardubice

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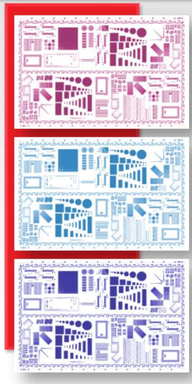
Outline

- Interduction of R&D activities
- Challenges and aspects of printed/coated functionalities
- Materials
- Printing/Coating techniques perspective
- Case studies
- Conclusion



Syrovy

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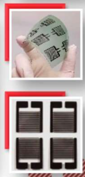
R&D activities, printing/coating techniques competency

- R&D of technology of preparation of functional structures
- R&D of ink formulation and benchmarking of comercial ink formulation
- Personally 400-800 mixed/tested ink formulations per year

- Screen printing (Sheet fed, R2R)
- Flexo
- Gravure
- Pad printing
- Offset
- IJ
- Spin coating
- Dip coating
- Spiral bar coating
- Spray coating
- Zone casting
- AJP

Syrovy, ENAS



- Negative patterning – lasers – UV/VIS, NIR, IR
- Lab2Fab experiences, Narrow web (410 mm), Wideweb production trials, pilot plant trials incl. high speed materiál printing (1.3 m, 320 m/min)

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Why coating and printing technologies?

- The printing and coating techniques should provide cheap and fast production of low cost and low-end functionalities
- Printed/coated functionalities are sometimes tens years behind to products made by traditional technologies in terms of their characteristics

SOMA

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Printed/coated functionalities

Active components/structures

- Battery (primary, secondary)
- Battery Charger
- Photovoltaic
- Display, Light source – OLED, EL, electrochromic, thermochromic, etc.
- Sensor – chemical, bio, climatic, pressure
- Memory
- RFID
- diodes
- Transistors
- ISS – Smart Objects, Smart Sensor, Smart Textiles

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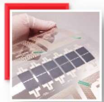

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Passive components

- Electronic circuits
- Antennas – RFID
- Capacitors, resistors, coils, transformers

Functional layers

- Healtcare aplication
- Drugs
- Termochromic, photochromic
- Catalytic layer
- Textile finishing layers
- Explosives

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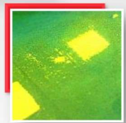
Differences to conventional coating/printing process?

- Safety - printing materials, fabrication process
- Printing/coating materials, printing substrates
- Printing forms
- Interaction of materials
- Strict observance of technology
- Printing/coating process quality/stability
- Post treatment condition
- Storing of the products
- Long term stability
- Never-ending and limitless opportunities to use or characterize anything



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(NASA)

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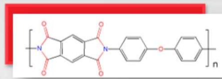
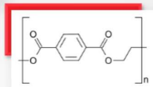
Substrates for printed functionalities/electronics

- **Flexible**
  - PET, PEN, PI (Kapton, Neopulim), PC, PVC
  - Polyolefins - PE, PP
  - Synthetic papers – Pretex (PES/PA), Synaps (PES), Tyvek (HDPE), Teslin (polyolefin)
  - Paper – un/coated paper, primer
  - Nanocellulose
  - Glass – 25 to 100 μm
  - Metals
- **Rigid**
  - Paper - heavy ream weight
  - Cardboard
  - Thick polymeric susbtrate (PET, PEN, PI, PC, PE, PP, etc.)
  - Glass – float, quartz, etc.
  - Ceramic – Al_2O_3 (Rubalit, Alunit), AlN, etc.
  - Metals



Polyimide



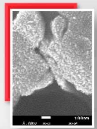
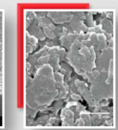
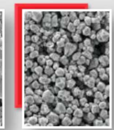
PET

Ultra-Thin Glass - SCHOTT

CeramTec

Materials for printed/coated structures

- **Conductive**
  - Metal composite – based on (Ag, Cu, Au, Ni, Pt, etc.)
    - Different shape and sizes of particles (globular, flakes, rods, wires)
    - Ag based most used
      - Up to 30 % of conductivity of bulk Ag
    - Cu – usually based on precursors CuO
      - Photonic sintering, reduction agents
    - Other metal for specific purposes
  - High temperature firing – Ag, Au, Pt, etc.
  - Precursors of metals
  - Carbon composite (graphite, carbon black, etc.)
  - Carbon based (graphene, GNP CNT (SWCNT, MWCNT))

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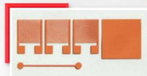
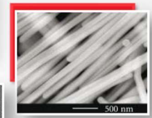
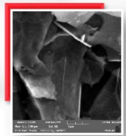
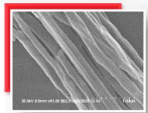



Zhu et All.



Syrovy

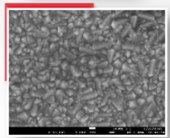


mntl.illinois.edu

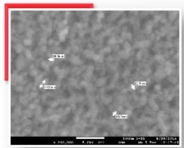
Materials for printed/coated structures - semiconductive

- **Inorganic semiconductors**
  - ZnO, ZnS, As_2S_3, TiO_2, WO_3, MoO_3, etc.
  - Si dispersions
  - **TCO**
    - Sn doped oxide s ITO, FTO, ATO
    - Zinc doped oxide AZO, GZO
    - Mainly as a transparent conductors
    - Prepared by sol-gel, nanoparticles ink, CVD

ITO/PET
www.opticalfiltersusa.com/



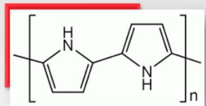
ITO



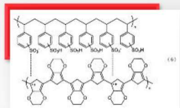
TiO_2

Materials for printed/coated structures - (Semi)conductive

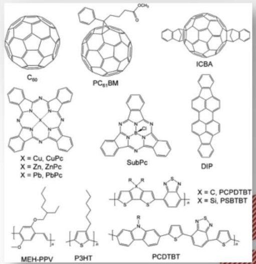
- **Polymers**
  - PEDOT:PSS – (in-situ 3000 S/cm, disp. 1000 S/cm)
  - Polyaniline
  - Polyacetylene
  - Polypyrrole
  - Polythiofene
  - MEH-PPV
  - PVK, etc.
- **Small molecules**
  - TIPS - Pentacene
  - Rubrene
  - Phtalocyanines
  - Diketopyrrolopyrrole
  - Perylenes
  - Alq3, NPD, TPD, Ru cpx
  - Some others
  - Fullerenes



polypyrrole



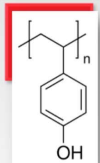
PEDOT:PSS



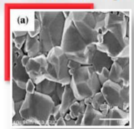
2014, Xue et Al.

Materials for printed/coated structures - dielectrics

- **Polymer based**
  - From solution/dispersion of various polymers
    - PVC (ε' ~ 3)
    - PC (ε' ~ 2.8 – 3.4)
    - PVDF (ε' ~ 6)
    - PMMA (ε' ~ 3)
  - Radiation induced polymerization (UV, EB) (Acrylate based (ε' ~ 3))
  - Thermally induced polymerization (PVP, acrylates with proper iniciators)
- **Composites**
  - Based on particles of inorganic materials with high dielectric constant
    - $BaTiO_3$ (ε' ~ 1000)
    - $SrTiO_3$ (ε' ~ 300)
    - TiO_2 (ε' ~ 100)
    - Al_2O_3, MgO (ε' ~ 9)
    - HfO_2 (ε' ~ 20)



Poly(4-vinylphenol)



Kharisov et Al.

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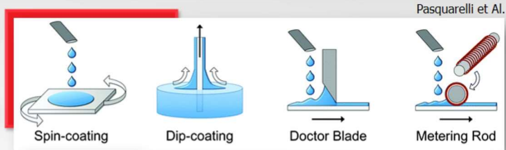
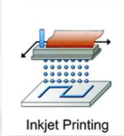
Coating and printing techniques – laboratory

- Spin coating
- DIP coating
- Doctor blade, Bar Coating
- Spray coating
- Ink-Jet
- Aerosol printing
- Electro-Hydrodynamic and Reciprocating System

Pasquarelli et Al.





Optomec

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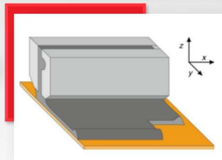
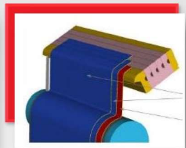
Coating techniques

- Slot Die
- Curtain coating
- Multiple slot
- Slide coating



Schmitt et Al.



www.packaging-int.com

Media Format	R2R, Sheets
Ink Waste	Low
Coating Speed	100- 500 m.min^{-1}
Ink Viscosity	10-25 000 mPa.s
Wet Thickness	5-500 µm
Dry Thickness	0.01-100 µm
Resolution	Given by shim

Frontier

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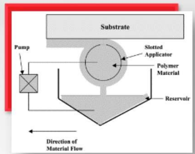
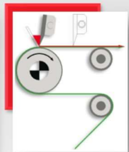
Coating techniques

- Knife-over-edge/Blade coating
- Mayer Bar, Spiral Bar Coating, Stripe coating
- Meniscus coating



www.3dit.de



Coatema

www.chemsultants.com

PEMS Co.,Ltd

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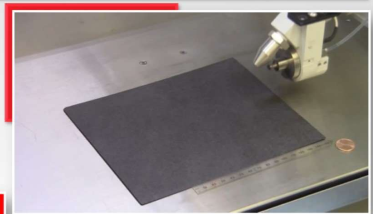
Coating techniques – Spray Coating

+ High uniformity of layers
+ Deposition to 3D object
+ Relatively high range of thickness of layers



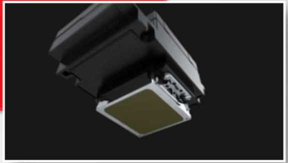
Sono-tek

Media Format	Sheets, R2R
Ink Waste	moderate
Coating Speed	Up to 100 m.min^{-1}
Ink Viscosity	10-1000 mPa.s
Wet Thickness	1-500 µm
Dry Thickness	0.01-100 µm
Resolution	Tech. Sol. dependent

- Ink Waste
- Complicated patterning
- Low resolution of patterning

Printing techniques - InkJet

+ Absence physical printing form
+ Relatively high resolution and high precise registration
+ Relatively high range of thickness of printed layers



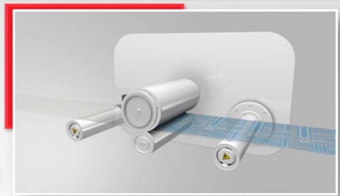
Epson

Media Format	Sheets, R2R
Ink Waste	Low
Printing Speed	Up to 280 $m.min^{-1}$
Ink Viscosity	1-50 mPa.s
Wet Thickness	1-500 µm
Dry Thickness	0.01-100 µm
Resolution	10 µm

- Problems with clothing of nozzles
- Quality strongly influenced by printing speed
- long time run stability
- Large amount of interfaces

Printing techniques – Gravure

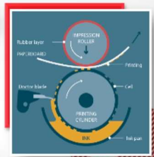
+ Very stable printing process
+ Highest printing quality
+ High printing speed
+ Printing form resistant to solvents
+ Reverse gravure for precise coating



3D-Micromac AG

Media Format	Sheets, R2R
Ink Waste	Low
Printing Speed	Up to 500 $m.min^{-1}$
Ink Viscosity	10-20 000 mPa.s
Wet Thickness	5-80 µm
Dry Thickness	0.02-80 µm
Resolution	3 µm

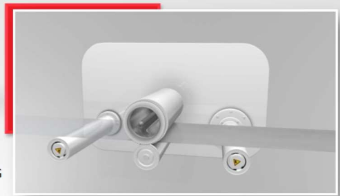
- Expensive printing form/ cyllinder
- Mainly gravure is suited to flexible substrates



www.iggesund.com

Printing techniques – Screen printing

+ Most used production technique
+ Variety of thickness of layers
+ Relatively easy preparation of stencil

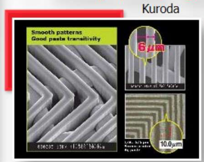


3D-Micromac AG

Media Format	Sheets, R2R
Ink Waste	Low
Printing Speed	Up to 50 $m.min^{-1}$
Ink Viscosity	100-20 000 mPa.s
Wet Thickness	3-1000 µm
Dry Thickness	0.02-1000 µm
Resolution	6 µm

- Printing speed, high viscosity

Kuroda

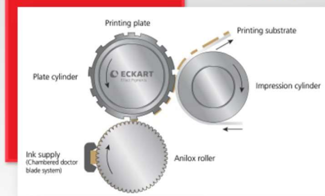


Coatema

Printing techniques – Flexography

+ Stable printing process
+ High printing speed
+ Rigid and flexible substrates
+ Relatively inexpensive printing form

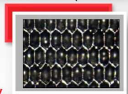
Altana

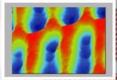


Media Format	Sheets, R2R
Ink Waste	Low
Printing Speed	Up to 1000 $m.min^{-1}$
Ink Viscosity	10 -1 000 mPa.s
Wet Thickness	5 - 30 µm
Dry Thickness	0.03 - 10 µm
Resolution	30 µm

- Limited thickness of layers
- Uniformity of topology of fine lines
- NIP pressure is crucial

Simec Group





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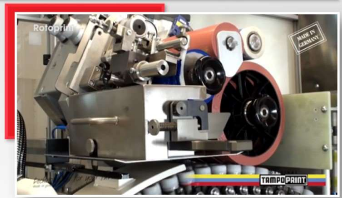
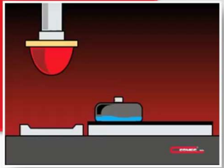
Printing techniques – Pad printing, offset gravure

+ Rigid and flexible substrates
+ Printability of 3D surface
+ Printing quality
+ Printing speed

Media Format	Sheets, R2R
Ink Waste	Low
Printing Speed	Up to 120000 parts/hr
Ink Viscosity	10 -1000 mPa.s
Wet Thickness	5- 80 µm
Dry Thickness	0.05 - 20 µm
Resolution	25 µm


Tampoprint


TRI Elektronik

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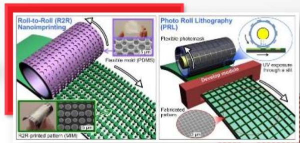
Others „printing" techniques for µ-Patterning

- Nanoimprinting lithography NIL
- Soft Lithography
  - Microcontact Printig µCP
  - Micromolding in Capillaries MIMIC
  - Nanotransfer printing nTP
  - Replica molding REM
  - Microtransfer molding µTM
  - Solvent-assisted micromolding SAMIM


www.miplaza.com


OKNANOLAB

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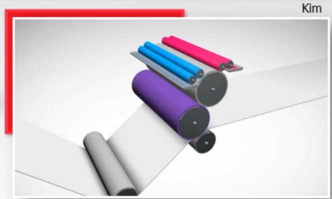
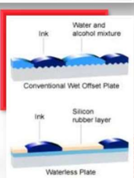
Printing techniques – Offset printing

+ Printing speed
+ High resolution
+ inexpensive printing plates fabrication
+ Frequently used printing technique

Media Format	Sheets, R2R
Ink Waste	Low
Printing Speed	Up to 1000 m.min^{-1}
Ink Viscosity	10 -100 Pa.s
Wet Thickness	10 µm
Dry Thickness	3 µm
Resolution	25 µm

Kim


www.brancher.com



– Limited thickness of layers
– High resistivity of conductive layers
– Lack of commercial functional ink

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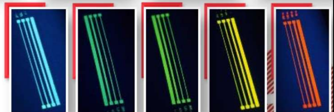
Simple functional layers

- Antistatic
- Antimicrobial
- Barrier
- UV protective
- Luminescent
- Thermochromic
- Photochromic
- Electromagnetic shielding
- Antifogging
- Oxygen, moisture scavangers, etc.


Syrovy



Case study 1 - Antimicrobial layers

- Special functional material
- Creation of small amounth of reactive form of oxygen - bacteriostatic effect with **99.99 %** efficiency
- Activated by **visible** light
- Nice blue tint for medical, some other colour under development
- Ink formulation developer for **Flexography** – passed production trials at 320 m/minute with several Km produced


Snaa Industries

320 m/min

Syrovy

Case study 2 - Smart Nappies

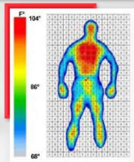
- Developed Smart Nappies
- Moisture sensor with capability to measure state of fullfillment
- Flexography >200 m/minute
- For elderly people or babies
- Wireless management of monitoring with implementation to MIS
- Bluetooth communication for homecare/households optional
- Low price of sensor is crucial
- Implementation by producer of nappies

Syrovy

200 m/min

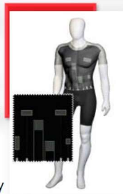
Case study 3 - Thermistors

- Medical
  - Monitoring of human body temperature map
  - Monitoring of local temperature or mapping of temperature within wound dress
- Wearables for free times activities
  - Human body temperature
  - Environmental temperature

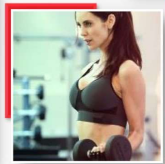


Tactilus®


MIT



SmartLife® Technology



OM Bra - OMsignal

TempTraq

Case study 3 - Thermistors

- Protection of human health of professionals
  - Army
    - Tactic waistcoat
    - Tactic helmet
  - Firefighters
    - Smart Gloves
    - Smart Suite/uniform
- Flow sensing
  - Gas
  - Liquid
  - Speedometer
  - Accelerometer
- Sensing in industrial application

BAE Systems

Syrovy, Kaltas

Case study 3 – Thermistors, HR, LR NTC ink formulation

- DC Measurements
- T range ~ 25 – 75 °C
- 4-point method
- L50, L70, L90, L110, L130 was measured
- All IDE passed except 50/50 µm
- Difference of resistance in dependence to real N° of SQ
- Finer IDE ~ lower resistance

HR

LR

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COST – European Cooperation in Science and Technology. COST is supported by the EU Framework Programme Horizon 2020

COST Action FP1405

Active and intelligent fibre-based packaging – innovation and market introduction **(ActInPak)**

ActInPak is a pan European (COST) network of the leading experts in active and intelligent packaging of over 150 institutes, universities and companies from 37 countries. Main goal of action is to develop a knowledge-based network on sustainable, active and intelligent fibre-based packaging in order to facilitate its introduction on the market.

http://www.actinpak.eu
http://www.cost.eu/COST_Actions/fps/Actions/FP1405
https://www.linkedin.com/groups/COST-FP1405-ActInPak-8254568/about

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Conclusion

- Carefully inspect real market needs
- The best is to start with the most simple functional layers/solution with relatively small technological requirements
- The R&D of selected products needs strong interest, effort and financial support of industrial partner
- The printing ink formulation, technology process have to be very good established/tailored, than the processes have to be strictly observed during the production.
- The simple tools for estimating the functionality of products have to be present within printing house together with well understanding by personal.

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flexprint

Program **Centra kompetence**

TA ČR

Thank you for your attention

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