Top layer coatability on barrier coatings

Roger Bollström
Mikko Tuominen, Anni Määttänen, Jouko Peltonen, Martti Toivakka
Electronics on paper

- Inexpensive
- Recyclable
- Easily upscalable to mass production
- Existing product base
  - Communication papers
  - Packaging
  - Technical papers
- Potential for numerous value-added product concepts
  - Disposable electronics
  - Smart packaging
  - Home diagnostics
  - Simple displays
  - Sensor applications
Printing electronics

- Fast process for transferring of material (ink) to substrate
- Developed for graphical printing with visual properties in focus

Graphical printing

Printed device

```
PEDOT:PSS
PVP
Ag  P3HT  Ag
Substrate
```

“You can cheat the human eye but not the conductivity”
Multilayer coating structure

Background

Basepaper

Precoating (GCC)
RMS 580 nm

Smoothing layer (Kaolin)
RMS 300 nm

Barrier layer (Latex)
RMS 260 nm

Calandered topcoating (Kaolin)
RMS 55 nm

Mylar® A
RMS 30 nm

Smoothing layer
RMS 300 nm

Barrier layer
RMS 260 nm

Topcoating
RMS 55 nm

Precoating
RMS 580 nm

WO 2010/086511, PCT/FI2010/050056, Method for creating a substrate for printed functionality, substrate, and printed functional device
Bollström Roger, Määttänen Anni, Ihalainen Petri, Toivakka Martti, Peltonen Jouko
Multilayer coating structure

Background

Precoating (GCC)
RMS 580 nm
Mylar®

Precoating (GCC)
RMS 30 nm
Mylar®

Topcoating (Kaolin) 0.5 - 5 µm

Barrier layer (Latex) 1 - 10 µm

Smoothing layer (Kaolin)

Precoating (GCC)

Basepaper

20.0 kV X600 10 µm WD 18.7 mm

X2,000 10 µm WD 18.5 mm

WO 2010/086511, PCT/FI2010/050056, Method for creating a substrate for printed functionality, substrate, and printed functional device
Bollström Roger, Määttänen Anni, Ihalainen Petri, Toivakka Martti, Peltonen Jouko
Proof of concept - Printed transistors on paper

- Output and transfer characteristics

Background

Logic circuits
- Inverter
- Ring oscillator: Odd number of inverters in parallel
Multilayer structure
- Combined printability and barrier properties

References

Frontside
- Stora Enso Lumiart 150
- Copypaper

Backside
- P3HT in DCB
  - Drop size: 5 μl
  - Mylar® A

Topcoating added

Frontside
- Precoating
- Smoothing layer (Kaolin)
- Barrier layer (Latex)
- PCC
- Kaolin

Backside
- Precoating
- Smoothing layer
- Barrier layer
- Topcoating

R. Bollstrom et al. A multilayer coated fiber-based substrate suitable for printed functionality, Organic Electronics, 10, 1020 (2009)
Multilayer structure
- Combined printability and barrier properties

\[ \gamma_{LW} \text{ [mN/m]} \]

\[ R = 0.97 \]

Inkjet printed droplet \((V = 10 \text{ pl})\)

Printability – functional inks

Inkjet printed silver electrodes

Printability by controlled properties in topcoating
Objectives

• Create barrier properties by dispersion coating
• Understand factors impacting top layer coatability

• Surface properties of barrier layer
  • Wettability
  • Surface energy
  • Surface roughness

• Properties of top coat dispersion
  • Surface tension
Evaluation of coatability

- Visually evaluated
  - 1: No wetting
  - 2: Inadequate wetting, large areas still uncoated
  - 3: Small defects, on the limit to required wetting
  - 4: Proper wetting, adequate coatability
Materials – dispersion coated barrier layer

**Materials & Methods**

**Pigments**
- **Talc** (barrier layer)
  - Mondo Minerals B.V., C10B
- **Kaolin** (barrier layer)
  - Imerys Minerals Ltd., Barrisurf HX
- **PCC** (topcoating)
  - Specialty Minerals Opacarb 3000

**Latexes**
- Styrene acrylate
- SA1: Ciba Finland Oy, (Particle size: 130 nm, Tg 7,5°C)
- SA2: Styron Europe GmbH., (Particle size: 110 nm, Tg 0°C)
- Two experimentallatexes, Exp1 and Exp2 (Styron Europe GmbH.)
Materials -coating recipes

- Woodfree basepaper and precoating with coarse GCC (107 g/m²)
- Smoothing layer consisting of kaolin + 5 pph SB latex (10 g/m²)

- Barrier layer
  - Thickness ~ 20μm
  - Grammage 23 – 40 g/m²

- Barrier layer formulation
  - Talc or kaolin as pigments
  - Latexes (SA1 and SA2) in 10 – 20 – 30 – 50 – 70 pph

- Topcoating
  - PCC + 10 pph SB latex
Surface treatment - barrier layer

- **Plasma**
  - Argon

- **Corona**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Power</th>
<th>Speed</th>
<th>Width</th>
<th>Efficiency value</th>
<th>Gas feed</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corona low (CL)</td>
<td>1300 W</td>
<td>50 m/min</td>
<td>500 mm</td>
<td>52 W/min/m²</td>
<td>-</td>
<td>24.8 kHz</td>
</tr>
<tr>
<td>Corona high (CH)</td>
<td>1300 W</td>
<td>20 m/min</td>
<td>500 mm</td>
<td>130 W/min/m²</td>
<td>-</td>
<td>24.8 kHz</td>
</tr>
<tr>
<td>Plasma low (PL)</td>
<td>780 W</td>
<td>50 m/min</td>
<td>380 mm</td>
<td>41 W/min/m²</td>
<td>30 l/min</td>
<td>28.3 kHz</td>
</tr>
<tr>
<td>Plasma high (PH)</td>
<td>780 W</td>
<td>20 m/min</td>
<td>380 mm</td>
<td>103 W/min/m²</td>
<td>30 l/min</td>
<td>28.3 kHz</td>
</tr>
</tbody>
</table>

- **UVC**
  - Laboratory scale
  - 50 mW/cm² at $\lambda_{\text{max}}$ 254 nm for one minute
Contact angle and PPS roughness

Results
Barrier properties - water and vapor

Results

Water Vapor Transmission Rate (23 °C 85 % RH)

<table>
<thead>
<tr>
<th>Material</th>
<th>Precoating</th>
<th>Precoating</th>
<th>Precoating</th>
<th>Precoating</th>
<th>Precoating</th>
<th>Precoating</th>
<th>Precoating</th>
<th>Precoating</th>
<th>Precoating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lumiart</td>
<td>Mylar</td>
<td>Stora Enso</td>
<td>Dupont</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 30 SA1 Talc
- 50 SA1 Talc
- 30 SA1 Kaolin
- 50 SA1 Kaolin
- 30 SA2 Kaolin
- 50 SA2 Kaolin
- 100 SA1 Smoothing

Values:
- 864 g/m²/day
- 804 g/m²/day
- 8 g/m²/day
- 13 g/m²/day
- 36 g/m²/day
- 16 g/m²/day
- 89 g/m²/day
- 79 g/m²/day
- 0 g/m²/day
- 715 g/m²/day
- 1 g/m²/day
Coatability - as function of wettability

Results

Coatability of topcoating

<table>
<thead>
<tr>
<th></th>
<th>Coatability</th>
<th>Surface tension of topcoat</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49.4 mN/m</td>
<td>35.2 - 49.4 mN/m</td>
</tr>
<tr>
<td>2</td>
<td>43.3 mN/m</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>35.2 mN/m</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>26.5 mN/m</td>
<td></td>
</tr>
</tbody>
</table>

Surface tension of topcoat

- PCC: 100 pph
- SB latex: 10 pph
- CMC: 2.5 pph
- Solids content: 44%
- Viscosity: 500 mPas
- IPA: 0-20%

- Surface tension in topcoat dispersion adjusted
  - Replacing water with isopropanol
  - Solids content and viscosity constant
Influence of roughness

Results

Contact angle for water between 103° and 112°

L = 100 pph latex  T = Talc + 30 to 50 pph latex  K = Kaolin + 30 to 50 pph latex.
Conclusions

• Water contact angle most important factor
  - Preferably below 100°

• A lower surface tension in top coat dispersion improves coatability
  - In the water contact angle range 100 - 110°

• No significant effect by roughness
  - Could only be studied on water contact angles higher than 100°

• Particles sticking out from the surface might pin the coating color

• Thin topcoatings not possible to coat using blade technique

• Curtain coating alternative method for industrial scale production
Products of tomorrow?
Acknowledgements

• Industrial partners
  • Imerys Minerals Ltd.
  • Styron Europe GmbH
  • Mondo Minerals B.V.
  • Specialty Minerals Nordic Oy
  • Ciba Finland Oy (BASF)

• B.Sc. Thesis worker
  • Vesa Tertsunen

• Adjunct professors
  • Pekka Salminen (Styron Europe GmbH)
  • Janet Preston (Imerys Minerals Ltd.)

• The Academy of Finland (Grant 118650)