Manipulation and control of spatial ALD layers for flexible devices

Aimcal Memphis 2016; Edward Clerkx
Meyer Burger Netherlands

Equipment manufacturer

- Based in Eindhoven, the Netherlands
- Part of world-wide Meyer Burger group

- Functional inkjet printing
- PECVD and ALD Thin film coating

- 90 people
- Founded in 1987
Applications and Products
Focus on Electronic Markets

- OLED & Displays
- Photo Voltaic & Battery
- Printed Electronics & Semiconductors

Thin Film Plasma and ALD tools
Inkjet Printers
Multi Process Tools
Equipment Portfolio
From Research to Production

Inkjet

Engineering
Versatile

Pilot Production
Flexible

Mass Production
Efficient

Thin Film
Equipment Portfolio
From Research to Production

Application Lines & Cluster systems

- Sheet to sheet, Large area and Roll to roll
- Foil, (thin) glass, wafer, etc. substrates
- Integrated Pre- and Post-processing
- Inert environment
Masking Inks

<table>
<thead>
<tr>
<th>Applications</th>
<th>Plating and etching masks (replacement of photo resist)</th>
<th>Protective masks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer thickness</td>
<td>5 – 20 µm</td>
<td></td>
</tr>
<tr>
<td>Ink types</td>
<td>Hotmelt, UV-curable, Polyimide</td>
<td></td>
</tr>
<tr>
<td>Feature size</td>
<td>&gt; 50 µm (cover)</td>
<td>&gt; 20 µm (space)</td>
</tr>
<tr>
<td>Properties</td>
<td>Etch resistant (acid, alkaline)</td>
<td></td>
</tr>
<tr>
<td>Post treatments</td>
<td>Drying, UV curing</td>
<td></td>
</tr>
</tbody>
</table>
# Conductive Inks

<table>
<thead>
<tr>
<th>Applications</th>
<th>Printed electronics, Antennas Photovoltaics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Silver nano-particle</strong></td>
<td>Dispersion in solvent Up to 40% solid content</td>
</tr>
<tr>
<td><strong>Layer thickness</strong></td>
<td>100 nm up to several µm</td>
</tr>
<tr>
<td><strong>Conductivity</strong></td>
<td>Up to 50% of bulk silver</td>
</tr>
<tr>
<td><strong>Feature size</strong></td>
<td>&gt; 25 µm</td>
</tr>
<tr>
<td><strong>Silver particle size</strong></td>
<td>&lt; ~1 µm (5% of nozzle size)</td>
</tr>
<tr>
<td><strong>Post treatments</strong></td>
<td>Drying Sintering (thermal, photonic, laser)</td>
</tr>
</tbody>
</table>
## Dielectric Inks

<table>
<thead>
<tr>
<th>Applications</th>
<th>Electrical isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Protection and sealing</td>
</tr>
<tr>
<td></td>
<td>Stress buffer</td>
</tr>
<tr>
<td></td>
<td>Solder mask</td>
</tr>
<tr>
<td>Layer thickness</td>
<td>5 – 30 µm</td>
</tr>
<tr>
<td>Ink types</td>
<td>Polyimide (solvent-based)</td>
</tr>
<tr>
<td></td>
<td>Acrylates, epoxies</td>
</tr>
<tr>
<td>Feature size</td>
<td>&gt; 30 µm</td>
</tr>
<tr>
<td>Properties</td>
<td>Solder mask &lt; 290 °C</td>
</tr>
<tr>
<td></td>
<td>Pencil Hardness up to 4H</td>
</tr>
<tr>
<td></td>
<td>Resistivity up to $10^{16}$ Ω.cm</td>
</tr>
<tr>
<td>Post treatments</td>
<td>Baking</td>
</tr>
<tr>
<td></td>
<td>Drying</td>
</tr>
<tr>
<td></td>
<td>UV curing</td>
</tr>
</tbody>
</table>

Wafer scribeline filling
# Adhesive Inks

| Applications          | Die bonding  
|-----------------------|---------------
|                       | Image sensor assembly  
|                       | Glass bonding  
| **Layer thickness**   | 5 – 80 µm  
| **Ink types**         | Acrylate  
|                       | Epoxy (solvent-based)  
| **Feature size**      | > 30 µm  
| **Adhesion**          | Silicon  
|                       | Glass  
|                       | PET/PEN foil  
|                       | Metals  
| **Post treatments**   | Baking  
|                       | Drying  
|                       | UV curing  

Die attach on leadframe

Die attach on foil
Thin Film Barriers

- Improved reliability
- Thinner
- Flexible
- Design freedom
- Scalable for Volume
- Low Cost
Barrier Goals and Challenges

- **Goal**
  - WVTR up to \(< 1 \times 10^{-6} \) g/m²/day
  - Flexible

- **Challenges**
  - Deal with particles
  - Conformal coating
  - Low temperature
Device Encapsulation

**Inkjet printing**
- Decouple pinholes
- Embed particles
- Add barrier functionality
- Protect inorganic coating
- No masking required

PECVD
- Very Gentle MW PECVD
- Low temperature
- Good barrier performance
- Deposition and etching

[Graph showing improvement in SiO-NOP-SiN stack over time at 60/90 hours]
Atomic Layer Deposition (ALD) principle

- ALD is cyclic exposure of different precursors separated by purge cycles
- No pinholes
- Thickness control on atomic scale
- Very good conformality
- High potential in flexible electronics

For high volume production higher grow speeds are necessary!
Spatial Atomic Layer Deposition

- Grow rates > 1 nm/s
- No parasitic deposition
- Atmospheric pressure
- No contact to web
- Multiple precursors possible
- Materials deposited R&D
  
  \[ \text{Al}_2\text{O}_3, \text{TiO}_2, \text{SiO}_2, \text{HfO}_2, \text{In}_2\text{O}_3, \]
  \[ \text{ZnO, ZnO:Al, ZnO:In, IGZO, ZnSnO}_x, \text{Zn(O,S), silver, Alucone} \]
- Materials deposited Roll to Roll
  
  \[ \text{Al}_2\text{O}_3, \text{TiO}_2, \text{Zn(O,S), ZnO, ZnO:Al} \]
Ensuring contactless ALD

- Parameters
  - Temperature
  - Web height
    - Trade off between gas separation and no web contact
  - Web to Drum speed
    - Trade off between gas separation and output
Gas Separation - Parameters

- Bearing pressure
- Exhaust pressure
- Web tension
- Speed
Gas separation – Modeling 1

Web displacement (micron)

Pressure distribution

Distance rotational direction (mm)

Distance radial direction (mm)

Distance rotational direction (mm)
Gas separation – Modeling 2

Concentration $\text{H}_2\text{O}$

Distance radial direction (mm)

Distance rotational direction (mm)

Injection $\text{H}_2\text{O}$
N2 gas bearing
exhaust
Injection TMA
exhaust

Concentration TMA

Distance radial direction (mm)

Distance rotational direction (mm)

Injection $\text{H}_2\text{O}$
N2 gas bearing
exhaust
Injection TMA
exhaust

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Gas separation

![Graph showing helium leak rate vs. relative speed in mm/s for different systems: FLEex R2R T1, Pilot T2, and Pilot T3.](image)

- **Helium Leak rate**: Logarithmic scale from $1.00 \times 10^{-5}$ to $1.00 \times 10^0$
- **Relative speed in mm/s**: Range from 0 to 500
Barrier Performance

- 20nm Al₂O₃ on 125µm PET foil

*Laser absorption spectrometry*

<table>
<thead>
<tr>
<th>Result</th>
<th>Value</th>
<th>Measurement 5. Diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>WVTR</td>
<td>6.2E-5 g/(m²·d)</td>
<td></td>
</tr>
<tr>
<td>Permeance</td>
<td>6.04E-6 g/(m²·d·mmHg)</td>
<td></td>
</tr>
<tr>
<td>Equivalent permeability</td>
<td>4.83E-5 mm·g/(m²·d·mmHg)</td>
<td></td>
</tr>
</tbody>
</table>

*Calcium test*

Overall WVTR $2 \times 10^{-5}$ g/m²/day
Calcium test @ 20°C/50% RH (ISO_DIS_15106-7)
S-ALD Barrier Performance
Optical Properties

Transmittance, reflection and absorption measured with spectrophotometry

- PET with 20nm $\text{Al}_2\text{O}_3$ coating
- No absorption by $\text{Al}_2\text{O}_3$
- Transmittance is determined by PET
Spatial-ALD summary

- Spatial-ALD drum
  - No web contact at deposition side
  - Precise web movement control
  - Multiple precursor slots

- Optional modules
  - Wet coating
  - UV or temperature curing
  - Plasma treatment
  - Particle cleaning

- Applications
  - Barrier coatings
  - Optical coatings
  - Buffer layers
FLEX R2R Spatial-ALD
Benefits

- Atmospheric process, no vacuum
- Thickness control at atomic scale
- Barrier WVTR of $2 \times 10^{-5}$ [g/m²/day] with 20nm Al₂O₃
- Barrier WVTR $<<10^{-6}$ in stack
- Fast growth rate of $>1$nm/s
- No pinholes
- Perfect coating conformality
- No parasitic deposition
- Up to 1600 mm web width
- Supports various foil types
- Compact footprint
- Low maintenance, high uptime
Summary

Industrial inkjet, ALD and PECVD equipment

Dedicated to the electronic industries

From engineering to mass production

Extensive knowledge network

Working with customers on whole solutions
High-end solutions for high-tech industries

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