High-Rate Metal and Clear Barrier Deposition for Packaging Applications

Roland Trassl
Applied Materials

CCR workshop on Barrier Technologies
Sep 20th 2012, Arlington, VA
Outline

- About the Company

- Web Coating Products
  - Barrier Coatings by Al Metallization
  - Transparent Barriers by Reactive Evaporation
  - Transparent Barriers by Plasma-Assisted Reactive Evaporation
  - Barrier Improvement and Protection by TopCoat
  - High-Barrier Layers by PECVD

- Summary
VISION

We apply nanomanufacturing technology to improve the way people live.
at a glance...

Stock Ticker: Nasdaq: AMAT
Market Cap\(^*\): $13.8 billion
Fiscal 2011 Revenue: $10.5 billion
Fiscal 2011 R&D: $1.1 billion
Founded: November 10, 1967
Headquarters: Santa Clara, California
Global Presence: 88 locations in 19 countries
Fortune 500 Ranking: 251
RD&E and/or Manufacturing Centers: China, Germany, Israel, Italy, Singapore, Switzerland, Taiwan, United States
Employees\(^*\): ~14,600 worldwide
Patents: ~10,050 issued

\(^*\) As of May 16, 2012. Fiscal year-end October 30
The Most Exciting Industries on Earth

**Semiconductor**

20,000,000x reduction in COST PER TRANSISTOR in 30 years\(^1\)

**Display**

20x reduction in COST PER AREA in 15 years\(^2\)

**Solar**

5x reduction in COST PER WATT in 4 years\(^3\)

At 1976 transistor prices, an iPod\(^\circledast\) would cost $3.2B

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1 Source: SIA, IC Knowledge LLC
2 Source: Display Search, Nikkei BP, Applied Materials
3 Source: Photon Consulting 2012
Mega Trends

The Mobility Age

Clean Energy
Business Segments

- Semiconductor
- Display
- Energy and Environmental Solutions
- Applied Global Services
#1 PV Equipment Provider*

Powering the c-Si Roadmap
Driving down cost/watt and balance of system (BOS)

- Advanced cell technologies
- Both scale and technology
- Greater efficiency
- Lower production costs
- Grid parity

Accelerating global photovoltaic (PV) adoption by delivering cost-effective solutions that integrate technology, equipment and materials to improve factory productivity and increase cell efficiency.

* Source: VLSI Research 2012
Global Scale and Reach

FOR THE PAST DECADE, ~$1Billion invested annually in RD&E
Technology Center Alzenau

- **Display Coatings**
  - Color Filter
  - TFT
  - OLED

- **Roll to Roll Coatings**
  - Flex Electronics
  - Flex PV
  - Packaging
  - Special applications

- **Solar Coatings**
  - Wafer based solar cells
  - Equipment TF PV

- **New Technologies**
  - Electrochromics
  - Advanced energy products
Challenges for Barrier Coatings at High Productivity

- **Barrier**
  - OTR, WVTR dependent on substrate material
  - wide variety of materials and qualities

- **Layer Properties**
  - high uniformity over large substrates and long coating length

- **Adhesion of the Coating to the Substrate**
  - optimization on downstream processes

- **Minimum Defects**
  - Roll edge, wrinkles, tramlines, splashes, substrate overheating, electrostatic charging, blocking, …….

- **Cost**
Machine Quality

Machine must ensure stable product quality for 24/7 mass production

- **Barrier**
  - Closed-loop inline coating control, stable and homogeneous vacuum conditions, data logging of all relevant machine parameters

- **Layer Properties**
  - Closed-loop inline process control

- **Adhesion of the Coating to the Substrate**
  - Substrate Pretreatment

- **Minimum Defects**
  - High quality winding system, general machine lay-out
Web Product Portfolio

**TopMet**

*World's largest & fastest evaporation metallizers for packaging (up to 20m/sec coating speed)*

**Standard applications**
- TopMet Std. for Al Barrier Metallization

**New advanced applications**
- TopMet Clear for transparent AlOx barrier layers
- TopMet Freshure® for enhanced barrier performance

**SmartWeb**

*Most advanced modular R2R sputtering system for flexible electronics and PV (up to 1.4m wide)*

**Applications**
- Flex Touch Panels (ITO, Dielectric Layers, Metals)
- Flex PV (TCO Front Contact, Metal Back Contact)
- Display (TFT)
Large Installed Base >625

WORLDWIDE INSTALLATIONS
Roll-to-Roll Coating Systems

Pacific Rim 238
- Australia: 3
- China: 97
- Indonesia: 23
- Japan: 51
- Malaysia: 6
- Philippines: 4
- Singapore: 1
- S. Korea: 28
- Taiwan: 15
- Thailand: 6
- Vietnam: 4

Americas 101
- Argentina: 2
- Brazil: 11
- Canada: 2
- Chile: 2
- Colombia: 4
- Mexico: 15
- USA: 65

Europe 233
- Austria: 1
- Belgium: 9
- Bulgaria: 3
- Croatia: 1
- Czech Republic: 1
- Denmark: 2
- Finland: 9
- France: 17
- Germany: 80
- Greece: 2
- Hungary: 4
- Italy: 30
- Lithuania: 1
- Luxembourg: 3
- Netherlands: 8
- Poland: 2
- Romania: 2
- Russia: 28
- Slovenia: 5
- Spain: 7
- Switzerland: 4
- Turkey: 5
- Ukraine: 1

Middle/Near East & Africa 52
- Bangladesh: 1
- Egypt: 2
- India: 32
- Israel: 2
- Oman: 4
- Pakistan: 4
- Saudi Arabia: 4
- South Africa: 2
- UAE: 1

Total Installed Systems: 626
June 2011
Barrier Landscape

Targeted range for TOPMET barrier

Source: Alcan Packaging
TopMet® - the Machine ...

Barrier and Decorative Coating

- Wide range of substrates from thin plastic films; PET, OPP, BOPP & more, to pre-coated papers
- Extremely thin, highly uniform layer of Aluminum or AlOx as protective barrier to improve freshness and longer shelf life and/or decorative coating for packaging materials.

... to metallize the materials for sophisticated packaging systems.
Industry Proven Since Early 1990s

• Recognized as industry standard for:
  — Flexibility
  — Productivity
  — Reliability
  — Quality

• Over 50 years of flexible coating technology experience

• ~200 TopMet® coaters; 600+ overall coating systems installed worldwide

TopMet® 4450

World's largest & fastest evaporation metallizers for packaging (up to 4.5 m wide, 20m/sec coating speed)
# Overview Product Family

## TopMet® Systems for Film and/or Paper Substrates

<table>
<thead>
<tr>
<th>1250</th>
<th>1650</th>
<th>2050</th>
<th>2450</th>
<th>2850</th>
<th>3250</th>
<th>4450</th>
</tr>
</thead>
</table>

### Substrate types:
- PET, OPP, BOPP, CPP, PVC, Nylon: 10-60µm
- Paper: 20-200g/m²

### Standard Roll Diameter:
- 1000 mm
- Optional for Film: 1250 mm
- Optional for Paper: 1500 mm

### Possible Coating Speed
- 1 - 14 - 17 - 20 m/sec
Basic System Layout – Al Metallization

- Pivot arm
- Guide rollers
- Tension roller
- Metrology
- View port
- View port
- Scoposcope
- Operator desk
- Evaporator
- Boats
- Aluminum wire
- Transformers
- Vacuum Chamber
- Coating Drum
- Rewind Roll
- Unwind Roll
- Diffusion pump
The two chamber-principle ...

Patented chamber separation by a pneumatic sealing. Inflation by ambience pressure during pump down.
HiRES™ TopMet® high rate evaporator

- 25% higher coating speed
- Better layer uniformity
- 10%+ lower costs/sqm or costs/kg
- 5% higher Al efficiency
- System down time less due to bigger roll diameters (1250mm)

The solution is...

HiRES™ = HIGH RATE EVAPORATOR SYSTEM with patented staggered-boat design
In-Line Process Control
Uniformity of Al Evaporation

- $2\sigma$ uniformity $\sim \pm 2.5\%$
Adhesion: TreatMag™ for Substrate Pre-treatment

- Adhesion is key issue for later processing like laminating or retorting
- Can be influenced with inline plasma pretreatment
eCharge: Advanced Film Cooling
Innovative System Increases Web Speed & Quality

Benefits
- Better cooling allows higher speeds for heat sensitive films
- Example: eCharge boosts CPP film coating speed from 8 to 13 m/s
- Resulting in 62% boost in speed and 26% reduction in CoO

Problem
- Normal winding tension leaves small gaps between film and coating drum
- Low contact force=poor heat transfer

Solution
- Apply electrostatic charge to film to increase contact force and improve heat transfer

Patented eCharge enables faster coating speeds for heat-sensitive substrates
Effect of Electron Charging on Coating Productivity

<table>
<thead>
<tr>
<th>SUBSTRATE</th>
<th>NO E-CHARGE</th>
<th>WITH E-CHARGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPP 20µm</td>
<td>web speed: 10m/s&lt;br&gt;tram lines: Increased Potential</td>
<td>web speed: 13 m/s&lt;br&gt;tram lines: none</td>
</tr>
<tr>
<td>PLA 25µm</td>
<td>web speed: 6m/s&lt;br&gt;tram lines: Increased Potential</td>
<td>web speed: 10m/s&lt;br&gt;tram lines: none</td>
</tr>
</tbody>
</table>
Barrier Performance of Metallized Substrates

<table>
<thead>
<tr>
<th>substrate</th>
<th>OTR [cc/m²day]</th>
<th>WVTR [g/m²day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>0.1 – 0.7</td>
<td>0.1 – 0.6</td>
</tr>
<tr>
<td>OPP</td>
<td>15 – 30</td>
<td>0.1 – 0.3</td>
</tr>
<tr>
<td>CPP</td>
<td>16 – 40</td>
<td>0.1 – 0.5</td>
</tr>
</tbody>
</table>

measurement conditions:
OTR  @ 23°C, 50% RH
WVTR @ 38°C, 90% RH
Reactive AlO\textsubscript{x} - Evaporation

Evaporation of Al + Oxygen Inlet = AlO\textsubscript{x} on Substrate
Basic System Layout – AlOx

- Oxygen inlet
- Evaporation boats
Reactive AlO$_x$ - Evaporation: Optical Inline Coating Control

Evaporation of Al in oxygen:
- increase in optical transparency
- decrease in barrier performance

Due to the narrow process window optical inline coating control is essential
AlOx ECON – Performance

- Winding and boat conditioning
- AlOx process
- Coating width: 1250 mm
- Process speed: 12 m/s

AlOx uniformity over complete foil ~ ± 3% (2-sigma)
Barrier Performance of AlOx Coated Substrates

<table>
<thead>
<tr>
<th>Substrate</th>
<th>OTR [cc/m²day]</th>
<th>WVTR [g/m²day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>0.8 – 1.2</td>
<td>0.3 – 0.7</td>
</tr>
</tbody>
</table>

reactive evaporation

measurement conditions:
OTR @ 23°C, 50% RH
WVTR @ 38°C, 90% RH
Plasma-Assisted AlO$_x$ - Evaporation

New advanced process developed by and up scaled with the Fraunhofer FEP in Dresden
Basic System Layout – AIOx – HAD

- Plasma source
- Evaporation boats
Plasma Assisted Evaporation in TopMet CLEAR™

$\text{AlO}_x$ process proven for web speed $\leq 8\text{m/s}$ and coating length 50,000m
Process Window for Reactive Evaporation with **Plasma Assistance**

With plasma increased process window
Effect of Plasma Activated Evaporation: \( \text{Al}_2\text{O}_3 \) on PET

\( \text{Al}_2\text{O}_3 \) by Reactive Evaporation

Plasma assistance creates denser and more uniform coating structure
Barrier Properties of Plasma-Assisted AlO$_x$ Process

- Substrate: RHBY 12µm
- Optical transmission $\geq 98\%$

Optimal barrier properties at low layer thickness
Mechanical Barrier Stability $\text{AlO}_x$ with Plasma

- Improved mechanical stability due to plasma assisted process.
- Better downstream robustness
Barrier Performance of AlOx Coated Substrates

<table>
<thead>
<tr>
<th>Substrate</th>
<th>OTR [cc/m²·day]</th>
<th>WVTR [g/m²·day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>0.8 – 1.2</td>
<td>0.3 – 0.7</td>
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</table>

**Reactive evaporation**

<table>
<thead>
<tr>
<th>Substrate</th>
<th>OTR [cc/m²·day]</th>
<th>WVTR [g/m²·day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>0.5 – 1.0</td>
<td>0.3 – 0.5</td>
</tr>
<tr>
<td>OPP</td>
<td>25 – 40</td>
<td>0.15 – 0.4</td>
</tr>
<tr>
<td>PLA</td>
<td>25 – 70</td>
<td>&gt;0.12</td>
</tr>
</tbody>
</table>

**Plasma-assisted evaporation**

Measurement conditions:
OTR @ 23°C, 50% RH
WVTR @ 38°C, 90% RH
Basic System Layout – Al/AIOx + Top Coat

- Top coating
- Oxygen inlet
- Evaporation boats
**Freshure® Top Coat**

<table>
<thead>
<tr>
<th>Specification of process step</th>
<th>OTR [cc/m²/day @23°C; 0% RH]</th>
</tr>
</thead>
<tbody>
<tr>
<td>12µmPET-AlOx without Freshure® Top Coat</td>
<td>12µmPET-AlOx with Freshure® Top Coat</td>
</tr>
<tr>
<td>After Coating</td>
<td>1.2</td>
</tr>
<tr>
<td>After printing (rotogravure)</td>
<td>6.0</td>
</tr>
<tr>
<td>After retort*)</td>
<td>5.8</td>
</tr>
</tbody>
</table>

*) Laminated against OPA/CPP. Retort condition: 30 min at 121°C

**Better Barrier:** Freshure® Top Coat provides better barrier and protects the film during downstream processing.

**Better Printability:** Freshure® Top Coat provides good ink adhesion without loss of glossy appearance of metallized film.

Source: DSM
Freshure® Top Coat

Freshure parameters:
50 nm @ 8m/s
NU ~ ± 5%

oxygen barrier improvement on PET by Freshure Top Coat

top coat acts as protection for barrier layer
possibility to eliminate downstream processes
Freshure® Top Coat

improvement of adhesion through post treatment  
→ printability of barrier-coated substrates
## Barrier Performance of Freshure® Coated Substrates

**single coat**

<table>
<thead>
<tr>
<th>substrate</th>
<th>OTR [cc/m²/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET</td>
<td>~3</td>
</tr>
<tr>
<td>OPP</td>
<td>40</td>
</tr>
<tr>
<td>PLA</td>
<td>20</td>
</tr>
<tr>
<td>OPA</td>
<td>1</td>
</tr>
</tbody>
</table>

**measurement conditions:**
- OTR @ 23°C, 50% RH
- WVTR @ 38°C, 90% RH
Barrier Requirements for Electronic Applications

<table>
<thead>
<tr>
<th>Barrier Performance (g/m²/day)</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-6}$</td>
<td>OLEDs</td>
</tr>
<tr>
<td>$10^{-5}$</td>
<td>Solar Cells</td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>Thin-Film Batteries</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td>Sensors, Electrophoretic Displays</td>
</tr>
<tr>
<td>$10^{-2}$</td>
<td>RFID</td>
</tr>
<tr>
<td>$10^{-1}$</td>
<td>Electrochromic Displays</td>
</tr>
<tr>
<td></td>
<td>Medical Packaging</td>
</tr>
<tr>
<td></td>
<td>Food Packaging</td>
</tr>
</tbody>
</table>

Barrier required to protect active layers from oxygen & water vapour
PECVD SiNₓ Barrier Coating on Polyimide @ 200°C

With a Film Thickness for Approximately 50nm WVTR decreases to 2.0E-2 g/m²/day
Summary

- High rate metallization process with excellent uniformity

- Different processes for AlOx based on thermal boat evaporation
  - Without plasma: For transparent barrier on PET
  - With plasma: For robust transparent barrier on PET, OPP, CPP, PLA

- Stable processes based on proven technology

- Environmental-friendly coatings

- High process flexibility for metallizing, different transparent AlOx-processes (depending on required coating properties) and for Freshure® top- or single coating

- Development of new R2R processes, e.g. PECVD, for future high-barrier requirements
Turning innovations into industries.