Extremely Stable and Uniform Coating with MICROGRAVURE™

Hikaru Takeuchi
YASUI SEIKI CO., LTD.
Highlights

MICROGRAVURE™ is a Japanese reverse-kiss coating method widely used in the world for low weight coatings that require coating uniformity with a tolerance of less than +/- 2%. Anti-reflective coating, for example, is a very unforgiving coating application, which requires the tolerance to be within +/- 5 nanometers. How does MICROGRAVURE™ work? What are the challenges?
MICROGRAVURE™ Unit

Movable Guide Roll Unit

Web

Dryer

Doctor Blade

Solution Tray

MICROGRAVURE™ roll
MICROGRAVURE™ Cylinders

<table>
<thead>
<tr>
<th>MICROGRAVURE™</th>
<th>FEATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating Method</td>
<td>Reverse Kiss</td>
</tr>
<tr>
<td>Gravure OD</td>
<td>20-65 mm</td>
</tr>
<tr>
<td>Coating Width</td>
<td>120-2450 mm</td>
</tr>
<tr>
<td>Options</td>
<td>Gravure Mesh: 20-250 lines/inch</td>
</tr>
<tr>
<td></td>
<td>Machined Gravure for Stripe Coating</td>
</tr>
</tbody>
</table>
Why is the outer diameter of MICROGRAVURE™ roll so small?

- General Reverse Gravure
  Larger than 10 inches OD

- MICROGRAVURE™
  2.5 inch or less outer diameter

To make narrower width of stable bead for thin wet coating
Coating Bead on MICROGRAVURE™

2 mm wide uniform coating bead using 50mm OD MG roll
How does the MICROGRAVURE™ roll make such a small bead?

\[ Q_0 = V_r \times (C + k \times \sqrt{\mu \times V_r / (\rho \times g)}) \] ---(1)

- **Q0**: Pick up volume quantity by gravure roll
- **C**: Cell volume of gravure roll
- **Vr**: rotation velocity of gravure roll
- **\( \mu \)**: coating viscosity
- **\( \rho \)**: coating density
- **g**: acceleration of gravity
- **k**: constant

\[ V_r = R \times 3.14 \times n \] ---(2)

- **R**: diameter of gravure roll
- **n**: number of rotational speed in rpm
TD Thickness Variation of Dry Coating

**MICROGRAVURE™**

[Graph showing dry coating thickness variations in the TD for Coating Head = Yasui's Microgravure_180R]

**Rod type**

[Graph showing dry coating thickness variations in the TD for Coating Head = Alternative_2 (rod type)]

Center runout
TD Thickness Variation of Dry Coating

Dry Coating Thickness Variations in the TD by Coating Unit

Web Position in the TD (mm)

Dry Coating Thickness in mic

Rod Type
- MICROGRAVURE (TM)
MD Thickness variation of Dry Coating

Coating Thickness Variations in the MD by Coating Unit

- **Alternative_2 (Rod type)**
  - UCL = 4.31%
  - Average = 3.09%
  - LCL = 1.87%

- **MICROGRAVURE(TM)**
  - UCL = 2.68%
  - Average = 2.49%
  - LCL = 2.30%
Practical Examples

Required tolerance in dry thickness

1. Anti-reflective film
   • Low RI layer: 100nm+/-5nm
   • High RI layer: 100nm+/-5nm

2. Anti-static coating, Conductive coating: 150+/-50nm - 450+/-50nm

3. Silicone release coating: 200+/-20nm - 500+/-50nm
Case Study of AR films

Indoor Display Image using AR Film  Outdoor Display Image w/o AR Film
Case Study of Anti-Reflective (AR) Films for Flat Panel Displays Market

• FPDs market is growing based on new technology enabling very attractive display products. The FPD market can be segmented a number of ways: traditional LCD-TVs followed by OLED-TVs, smart phone, PC monitor.

• A key issue with increasing outdoor use or the size of LCD-TVs and OLED-TVs is the image quality. AR coatings are a key technology to improve quality by reducing glare.

• Multilayered inorganic oxide-based sputter coatings on clear hard-coated substrates were commercially offered for anti-reflective films (AR), but recently single- or two-layer products coated in wet process are getting more attractive from a price and performance perspective.

• MICROGRAVURE™ is a critical processing tool for thin layer applications like AR.
Principle of AR Film

The AR coats control the light reflection on the surface by interference, which occurs when two rays meet.

When two waves of the same waveform are superimposed in phase — their crests and troughs coincide with each other — they form a larger, amplified wave. This is called constructive interference. On the other hand, destructive interference occurs when these waves are out of phase, forming a smaller wave or canceling each other out.
Dry Thickness Specification of AR film

Most common composition of AR film (in order):
1. Substrate – traditionally 80um triacetylcellulose (TAC) or 100um PET
2. Hard coat
3. High RI layer
4. Low RI layer

<table>
<thead>
<tr>
<th>Layer</th>
<th>Process</th>
<th>Material</th>
<th>Refractive Index</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARs</td>
<td>Wet</td>
<td>Fluoropolymer based low RI layer</td>
<td>1.41</td>
<td>100 +/- 5nm</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>Inorganic oxide based high RI layer</td>
<td>1.63</td>
<td>100 +/- 5nm</td>
</tr>
<tr>
<td>Hard Coats</td>
<td>Wet</td>
<td>Acrylic silca hybrid coating</td>
<td>1.51</td>
<td>5 mic</td>
</tr>
<tr>
<td>Base Films</td>
<td>NA</td>
<td>TAC or PET</td>
<td>TAC: 1.49, PET: 1.66</td>
<td>TAC: 80 mic, PET:100 mic</td>
</tr>
</tbody>
</table>
Why is the thickness of AR layer within +/- 5nm.

Interference Unevenness and Color Matching

Reflective Spectrum
MICROGRAVURE™ makes dry thickness of both High RI and Low RI coating possible to control within approximately ±3nm to average thickness.
Reflectance Spectrum of AR Film by MICROGRAVURE™

Two layers of AR film wet coated by MICROGRAVURE™ demonstrates low reflectivity less than 0.5% to meet theoretical spectrums:

1. TiO2 High RI= 1.63, 110nm+/-2nm
2. Fluoropolymer+SiO2 Low RI=1.41, 97nm+/-3nm
Key Elements for AR Films

AR Films

- Precise Coating
  - Coating Head
  - Dryer
  - Thickness Control

Optical Design

- Refractive Index
- Thickness
- Color

AR formulations

- Viscosity
- Surface Tension
- Evaporation Rate
- Durability
Summary

• The narrower coating bead on MICROGRAVURE™ is the key to making nanometer order level of thin coating possible.

• When comparing TD and MD dry coating tolerance using MICROGRAVURE™ and standard rod coating for battery applications, MICROGRAVURE™ shows 2.5% in sigma/average dry thickness whereas rod coating shows 3.1%.

• Two layers of AR film wet coated by MICROGRAVURE™ demonstrates low reflectivity of less than 0.5% to meet theoretical spectrums:
  • TiO2 High RI= 1.63, 110nm +/-2nm
  • Fluoropolymer+SiO2 Low RI=1.41, 97nm +/-3nm