Introduction

New layer stack

Different layer stack embodiments

Physical properties
- Optical performance
- Sheet resistance and emissivity
- IGU properties

Influence of tempering process

Advantages of the presented layer stack

Outlook
Leybold Optics – a part of Bühler since 2012

A 150-year success story.
Global leader with strong local roots.

Annual sales 2013:
> 1.9 billion € (2.3 billion CHF).
Number of employees:
> 10,000, including 500 trainees.
Present in over 140 countries.
Over 70 sales & service companies.
More than 20 manufacturing sites and 24 service stations around the world.
High innovation rate.
One equally high quality standard worldwide.
100 % family owned.

Bühler Leybold Optics Facts & Figures

LEYBOLD OPTICS. Established in 1850.
164 years of experience in vacuum technology.

Part of the Bühler Group since May 2012
Total installed base with more than 2.300 systems sold
> more than 100 systems for large area coating applications

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High Performance Optical Coatings
Introduction – Working principle of low emissivity coatings

High infrared reflectance
High visible transmittance

- Ag for IR reflectance
- Blocker for Ag protection
- Dielectric layers (D1 and D2) for optical properties

Introduction – Requirements for Low-E coatings

Highest visible transmittance (380 – 780 nm)
  - 70 to 85 %

Highest infrared reflectance (> 780 nm)
  - 75 – 90 %

Lowest sheet resistance or emissivity
  - 3 to 5 ohm/sq
  - 2 – 4 % emissivity

Reflectance color appearance neutral or bluish
**Introduction – Requirements for Low-E coatings**

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**Introduction – Physical properties for a complete IGU**

For a complete Insulating Glass Unit, the following parameters apply:

* IGU setup: 4mm glass/coating/16mm Ar filled space/4mm glass
Introduction – Heat treatable coatings

Additional requirements to the coating during tempering:

- Withstand tempering process
- No change in optical properties
- No color shift due to heating

- No corrosion of the Ag layer
- Dielectric layers to block ion diffusion from glass
- No change of blocker due to oxidation

Introduction – Possible materials

- Metallic layer: Ag, Au, Cu
- Blocker: NiCrO$_x$N$_y$, ZnO$_x$, Ti, Cr
- Dielectric layers: SnO$_2$, TiO$_2$, ZnO, ZnSnO$_3$, Si$_3$N$_4$, SiO$_2$, ZrO$_2$, Al$_2$O$_3$, Nb$_2$O$_3$

Best optical performance
Easy process handling
Low cost materials
High density
Non protected combination and layer stack
Introduction – Possible materials

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Easy process handling
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High density
Non protected combination and layer stack

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New layer stack – Design

Al$_2$O$_3$: hard and dense top coat for mechanical and chemical resistivity
ZnO: above blocker as dielectric layer for optical properties
ZnO$_x$: blocker
Ag: high IR reflectance
ZnO: underneath Ag as seed layer
TiO$_2$: dielectric layer for AR performance
Al$_2$O$_3$: diffusion barrier on glass
New layer stack – Different embodiments

Multiple configurations through modular stack

Physical properties – Optical performance

**Transmittance $T_Y$**
- SLE: ≥ 81%
- DLE: ≥ 79%
- TLE: ≥ 68%

**Reflectance color values**
- SLE: $-2 \leq a^* \leq 0$; $-6 \leq b^* \leq -2$
- DLE: $-4 \leq a^* \leq -1$; $-9 \leq b^* \leq -5$
- TLE: $-1 \leq a^* \leq 2$; $-5 \leq b^* \leq -1$
Physical properties – Sheet resistance and emissivity

Correlation between sheet resistance and emissivity [1]

\[ \varepsilon = 0.0129 \times R - 6.7 \times 10^{-5} \times R^2 \]

For a complete IGU*, the following values can be reached:

### Single
- U-value: 1.15 W/(sqm*K)
- LT-value: 80 %
- G-value (ISO 9050): 47 %
- LR-value: 15 %

### Double
- U-value: 1.10 W/(sqm*K)
- LT-value: 73 %
- G-value (ISO 9050): 34 %
- LR-value: 12 %

### Triple
- U-value: 1.05 W/(sqm*K)
- LT-value: 63 %
- G-value (ISO 9050): 27 %
- LR-value: 13 %

* IGU setup: 4mm glass/coating/16mm Ar filled space/4mm glass
The new layer stack compares well with current market products

Source: Cardinal technical bulletin #IG05-04/13

Physical properties – Processes During Tempering

- Temperatures up to 650°C leading to very high mobility of particles
  ➢ Unwanted diffusion processes taking place

- Ions (especially Na\(^+\)) diffuse from glass to coating
  ➢ Change of optical properties of the dielectric layers and damaging Ag

- Free radicals (singular oxygen) diffuse into Ag
  ➢ Oxidation of Ag leading to high resistivity and loss of functional layer

- Annealing of micro crystalline structure
  ➢ Reduced resistance of Ag layer
Physical properties – Optical performance before tempering

Transmittance $T_Y$
- SLE: ≥ 81%
- DLE: ≥ 79%
- TLE: ≥ 68%

Reflectance color values
- SLE: $-2 \leq a^* \leq 0$; $-6 \leq b^* \leq -2$
- DLE: $-4 \leq a^* \leq -1$; $-9 \leq b^* \leq -5$
- TLE: $-1 \leq a^* \leq 2$; $-5 \leq b^* \leq -1$

Physical properties – Optical performance after tempering

Transmittance $T_Y$
- SLE: ≥ 84%
- DLE: ≥ 82%
- TLE: ≥ 75%

Reflectance color values
- SLE: $-3 \leq a^* \leq -1$; $-5 \leq b^* \leq -3$
- DLE: $-5 \leq a^* \leq -2$; $-7 \leq b^* \leq -4$
- TLE: $-4 \leq a^* \leq 0$; $-5 \leq b^* \leq -1$
Physical properties – Sheet resistance and emissivity

**Values before tempering:**

- SLE: $R_{\square} \leq 5\,\Omega/\square$, $\varepsilon \leq 5.5\%$
- DLE: $R_{\square} \leq 4\,\Omega/\square$, $\varepsilon \leq 4.4\%$
- TLE: $R_{\square} \leq 3\,\Omega/\square$, $\varepsilon \leq 3.3\%$

*Correlation between sheet resistance and emissivity [1]*

$$\varepsilon = 0.0129 \times R_{\square} - 6.7 \times 10^{-5} \times R_{\square}^2$$

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Physical properties – Sheet resistance and emissivity

**Values after tempering:**

- SLE: $R_{\square} \leq 4\,\Omega/\square$, $\varepsilon \leq 4.4\%$
- DLE: $R_{\square} \leq 3\,\Omega/\square$, $\varepsilon \leq 3.3\%$
- TLE: $R_{\square} \leq 2\,\Omega/\square$, $\varepsilon \leq 2.2\%$

*Correlation between sheet resistance and emissivity [1]*

$$\varepsilon = 0.0129 \times R_{\square} - 6.7 \times 10^{-5} \times R_{\square}^2$$

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– In: Thin Solid Films, Volume 351, Pages 254-259
Advantages — Fulfilling all requirements

- Highest visible transmittance
- Lowest sheet resistance or emissivity
- Small U value for final product
- Reflectance color appearance neutral or bluish
- Small changes due to heat treatment
- Excellent chemical and mechanical durability
- Nitrogen free sputter processes

Advantages — Benefits for glass manufacturer

- High performance product
  Lives up to market levels
- Simple coater
  Fewer process gases
  Relaxed requirements for gas separation
- Low cost targets
  Avoid costly and exotic materials
- Simple process
  Fewer different materials
- Freedom to operate
- High quality
- Lower invest
- Low operating cost
- No license costs on Bühler equipment
Advantages – Bühlers’ solution for architectural glass coating

Leybold Optics GLC series H

- Annual production capacity: standard 2.8–18 Mio m²
- Fastest mechanical cycle times: 20 sec US size / 28 sec Jumbo size
- Campaign time: 3-4 weeks as standard
- Standard coating uniformity: Down to ± 1.0 %
- Champion results for uniformity: Rotary ± 0.5 % / Planar ± 0.6 % on Jumbo size

Applications
- SLE/DLE/TLE coatings
- Low-e Sun coatings
- Solar control coatings
- AR & Mirror coatings

Outlook

Performance verification of presented layer stack
- Climate testing
- Certifying U value by external lab
- Certifying according EN 1096
- Mechanical stress testing

Development of special coatings on request
- By requests of customers
THANK YOU FOR YOUR ATTENTION

www.buhlergroup.com