Fraunhofer-Gesellschaft – We Forge the Future

The Fraunhofer-Gesellschaft is Europe’s Largest Organization for Applied Research

- set up in 1949
- 66 institutes and independent research units
- 22,000 employees
- headquarters in Munich
- each institute has its own core competences
- the individual institutes act as profit centers on the market
- Non profit organization
The Research Profile of Fraunhofer

Institutes are organized in Fraunhofer Groups:

- Light & Surfaces
- Materials and Components
- Production
- Life Sciences
- Information and Communication Technology
- Microelectronics
- Defense and Security
Fraunhofer Institute for Electron Beam and Plasma Technology FEP

Evolution of Surface.
Fraunhofer FEP

- **Fraunhofer Institute for Electron beam and Plasma Technology**
- **Location: Dresden, Germany**

- **20 years experience in vacuum based large area coating and – surface modification**

- **Director: Prof. Dr. Volker Kirchhoff**
- **133 employees (2013)**
- **8,000 m² laboratories**
Core Competencies of Fraunhofer FEP for coating, refinement, treatment and modification of surfaces

- Electron beam Evaporation
- Sputtering Coatings on glass
- Plasma Activated High Rate Evaporation
- High Rate PECVD
Coatings on glass at Fraunhofer FEP

- **For industrials:**
  - Sampling: deposition and development of single layers or layer stacks,
  - Processing: power supplies, process controlling, targets/magnetrons
  - Hardware: magnetron systems, power supplies, process control

- **Our customers:** mainly from Germany, EU, Asia, US

**Sampling:**
- Mainly on glass
- LowE, AR, IR-shieldings
- TCOs
- Mirrors
- PV
Challenges for thin films coatings in glazing

- High quality refinement of glass surfaces
- Cost-effective production:
  - Cheap
  - Simple layers and layer stacks
  - In-line processes
- Green manufacturing:
  - Clean technology, eco-friendly,
  - Non toxic, non scarce, sustainable materials
- Properties:
  - High quality, long time stable, corrosion resistant
  - Modern, aesthetic design and color.
Thin film applications in window and facade glazing

- Thermal protective coatings
  - Limits the heat/“cold” output of heated/cooled rooms – LowE
  - Solar Control – SC
- Summer heat protection
  - Limits heating up of rooms caused by the sun
- Smart glazing
  - Switching of transparency, light transmission or color
- Self-cleaning coatings
- Anti-reflective coatings – AR
Thermal protective coatings - Low E and Solar Control

Transmittance/Reflectance (%)

- UV
- VIS
- NIR
- IR

sun 1.5

glass

thermal radiation 300 K

wavelength [nm]

300 1000 10000

thermal insulation

- solar control


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Low E and Solar Control

Material systems

- Based on silver
  - Double or triple Ag-coatings, packaged between dielectrics like TiO₂

- Silver free systems
  - Transparent conductive oxides, In₂O₃:SnO₂ – ITO, SnO₂:F - FTO, TiO₂:Nb
  - Dielectrics based on SiO₂ and TiO₂, only for Solar Control
Thermal losses in glazings

Definition of thermal losses:

\[ q = \frac{Q}{A \Delta t} = U_g \cdot (T_{\text{inside}} - T_{\text{outside}}) \]

- \( T_{\text{outside}} < T_{\text{inside}} \rightarrow \) need energy input by heating the room for \( T_{\text{inside}} = \text{const.} \)
- \( T_{\text{outside}} > T_{\text{inside}} \rightarrow \) need to detract energy by cooling the room

Example for single glazing:
- \( T_{\text{inside}} \) = 22°C (72°F)  
  \( T_{\text{outside}} \) = 5°C (41°F) → 100 W/m²
- \( T_{\text{outside}} \) = 35°C (95°F) → -77 W/m²
Thermal losses of glazing's

- Minimization of thermal losses by reducing the $U_g$-value of the glazing
- Solution: thin films coatings

\[ q = U_g \cdot (T_{\text{inside}} - T_{\text{outside}}) \]
Low E layer stack – position in glazing

2 pane with Low E
- Ag based

3 pane with Low E
- Ag based

1 pane with Low E
- Ag free

position 3

New: position 4

position 5

position 1 or 2
Low E layer stacks based on silver

Low E coatings based on silver:

😊 Silver is an excellent IR blocker
😊 multilayer stacks
😊 Not enough corrosion resistant

State of the art:
Low E coatings by thin films on position 3 in isolated double pane glazing

Transmittance!
Low E layer stack – double Ag-system

**Function of the single layer:**

- **TiO$_2$, Zn$_2$SnO$_4$:** dielectric functional layer/antireflection
- **Ag:** conductive layer for minimized transmittance in IR
- **Blocker:** protective layer against oxidation of the Ag layer
- **Optional ZnO:** increased conductivity of Ag, adjustment of color index
Low E layer stack – Influence number of Ag layers

<table>
<thead>
<tr>
<th>Type</th>
<th>( R_\square ) [( \Omega )]</th>
<th>( T_{\text{VIS}} ) [%]</th>
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<tbody>
<tr>
<td>single</td>
<td>1.64</td>
<td>50</td>
</tr>
<tr>
<td>double</td>
<td>1.55</td>
<td>75</td>
</tr>
<tr>
<td>triple</td>
<td>1.55</td>
<td>72</td>
</tr>
<tr>
<td>quadruple</td>
<td>1.45</td>
<td>76</td>
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</table>

**Costs and benefits**

- **Smiley face** properties
- **Sad face** Complex layer stack of maximum 13 layers
- **Sad face** High production costs
Low E layer stack – Influence TiO2 film thickness

- Double Ag Low E layer stacks with constant Ag layer thickness
- Small deviations in film thickness for TiO2:
  - TiO₂ has no influence on the electrical properties
  - Only small influence on T and R | shift to longer wavelength
  - Shift of color values and the human color impression
Example – application of silver free Low E

- if $T_{\text{outside}}>T_{\text{inside}}$ than condensation of water on the outside of the glazing, e.g. in tropical climate conditions

- Limited view

- Preferred conditions for corrosion
Silver free Low E coatings by TCOs

- TCOs – transparent conductive oxides
  - doped metal oxides
  - high transmittance in VIS, wide bandgap > 3 eV
  - resistivity lower than $1 \times 10^{-3} \Omega \text{cm}$ for low sheet resistance and emissivity

- Single layer system,

- Adjustment of high IR reflectance by the film thickness,

- Materials:
  - $\text{In}_2\text{O}_3:\text{SnO}_2$ – ITO, Expensive material, established
  - $\text{SnO}_2:F$ – FTO, Toxic process, established, no production in EU!
  - $\text{TiO}_2:Nb$, Low price, „green“ material, are on the advance

- For outward-facing glasses in window and facade applications

- position 1 and 2 (one pane), Position 1 and 4 (two panes)
IR blocking of silver free and silver based Low E coatings

<table>
<thead>
<tr>
<th>Material</th>
<th>T_{VIS} [%]</th>
<th>R_{sq.} [\Omega]</th>
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<tbody>
<tr>
<td>Low E</td>
<td>82</td>
<td>4.2</td>
</tr>
<tr>
<td>ITO</td>
<td>83</td>
<td>4.6</td>
</tr>
<tr>
<td>TiO\textsubscript{2}:Nb</td>
<td>63</td>
<td>20</td>
</tr>
</tbody>
</table>


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Main technologies for large area coatings on glass

- **Vacuum based in-line technologies**
  - Magnetron sputtering
  - PECVD processes
    - magPECVD
    - arcPECVD

Sputtering from planar magnetron

Sputtering from rotatable magnetron
R&D at Fraunhofer FEP – In-line deposition on glass

Sampling, Processing, Hardware

Lab scale in-line coating machine

Large area TCO coating on glass

Pilot scale in-line coating machine
Industrial technologies for large area coatings on glass

- Inline process
- Target length: 3.8 m
- Cycle time: 45 s...90 s
- Annual production: 5 Mio m² glass

source: von ARDENNE Anlagentechnik GmbH
Trends – Thin film coatings

- Alternative layer materials
  - Innovative, sustainable, resource-efficient materials

- Multi functional coatings
  - Combination of different functions in one layer stack
    - optical + electrical + mechanical + chemical + barrier function

- Low E coatings on position 4 in 3 pane glazing's
- Low E coatings on web foil for refurbishments
- Coatings for smart windows

Photoinduced hydrophilic surface:
  top: uncoated glass
  bottom: activated TiO$_2$ thin film
Trends – applications for window and façade glasses

- Smart glazing's
  - No blends

- Application of thinner glass ~ 2 mm thickness
  - Lower weight
  - Lower construction effort

- Vacuum isolated glass for large area
  - With guaranteed lifetimes of 25 years

- Giga lite glasses, size maximum 18 x 3,2 m²

- Building integrated PV
Thank you very much for your attention!

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