Transparent conducting oxides (TCO) are important materials for optoelectronic devices, such as flat panel displays or organic light emitting diodes.

TCOs are also required as transparent electrodes in various types of solar cells.

There are two requirements for TCOs:
- the band gap must be wider than 3 eV for transparency in the visible spectral range
- high performance TCOs must have a free carrier concentration between $10^{19} \ldots 10^{21} \text{ cm}^3$ and a free carrier mobility between 5 ... 40 cm$^2$/Vs.

In general two different types of TCOs exist; n-type and p-type TCO.

The type of TCO depends on the location of the Fermi level $E_F$.

The Fraunhofer FEP is very specialized in the deposition of various n-type TCO layers with specific properties. Also the development of p-type TCOs has started.

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Fraunhofer FEP has the technological know-how and equipment (pilot and laboratory plants) to sputter various TCO materials on flat as well as on flexible substrates.

Sputtering on flat substrates (heated/unheated):
- indium based TCOs:
  - indium-tin-oxide (ITO)
  - indium-zinc-oxide (IZO)
- zinc based TCOs:
  - aluminum doped zinc-oxide (ZnO:Al)
  - gallium doped zinc-oxide (ZnO:Ga)
  - zinc-oxide (ZnO)
- further TCOs:
  - tin-antimony-oxide (TAO)
  - tin-zinc-oxide (TZO)
  - niobium doped titania (TiO₂:Nb)

Sputtering on flexible substrates: (unheated)
- indium-tin-oxide (ITO)
- aluminum doped zinc-oxide (ZnO:Al)

Properties of several TCOs

<table>
<thead>
<tr>
<th>Material</th>
<th>ρ [Ω·cm]</th>
<th>N [cm⁻³]</th>
<th>μ [cm²/Vs]</th>
<th>k @ 550 nm</th>
<th>n @ 550 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITO</td>
<td>1.5 × 10⁻⁴</td>
<td>8.5 × 10²⁰</td>
<td>45</td>
<td>1.4 × 10⁻³</td>
<td>1.93 - 2.11</td>
</tr>
<tr>
<td>IZO</td>
<td>3.1 × 10⁻⁴</td>
<td>9.3 × 10²⁰</td>
<td>44</td>
<td>2.0 × 10⁻³</td>
<td>1.93 - 2.10</td>
</tr>
<tr>
<td>ZnO:Al</td>
<td>4.0 × 10⁻⁴</td>
<td>5.6 × 10²⁰</td>
<td>32</td>
<td>1.9 × 10⁻³</td>
<td>1.79 - 2.10</td>
</tr>
<tr>
<td>ZnO:Ga</td>
<td>2.9 × 10⁻⁴</td>
<td>6.6 × 10²⁰</td>
<td>43</td>
<td>1.5 × 10⁻³</td>
<td>1.80 - 1.88</td>
</tr>
<tr>
<td>TZO</td>
<td>2.5 × 10⁻³</td>
<td>1.1 × 10²⁰</td>
<td>26</td>
<td>3.4 × 10⁻³</td>
<td>1.95 - 2.08</td>
</tr>
<tr>
<td>TAO</td>
<td>6.7 × 10⁻²</td>
<td>2.3 × 10¹⁵</td>
<td>2</td>
<td>1.5 × 10⁻²</td>
<td>2.06 - 2.20</td>
</tr>
<tr>
<td>TiO₂:Nb</td>
<td>7.2 × 10⁻⁴</td>
<td>1.2 × 10²⁰</td>
<td>7</td>
<td>7.5 × 10⁻³</td>
<td>2.40 - 2.70</td>
</tr>
</tbody>
</table>

Our offer

- several sputtering modes:
  - DC and pulsed DC
  - RF superimposed DC
- sputtering from ceramic target (planar, rotary)
- reactive sputtering (ITO, ZnO:Al)
- thermal pretreatment and post annealing up to 450°C
- approaches for low damage coating on sensitive organic materials
- substrate size
  - flat substrates:
    - max. 1200 x 500 x 10 mm³
  - flexible substrates:
    - roll-to-roll 600 mm wide
- characterization of layer properties
  - optical (spectrometer, ellipsometer)
  - electrical (van der Pauw, Hall-measurement)
- texture: AFM, REM

Applications

- solar cells
- thin film lighting
- inorganic electroluminescent
- PDP filters
- OLED
- touch-screen
- antistatic
- electrochromic cells