

Advanced transparent conductive coatings on flat and flexible substrates

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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 $10^{19} \dots 10^{21} \text{ cm}^{-3}$ 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.

Contact

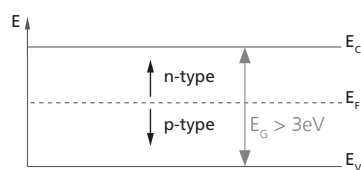
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E_c - conduction band energy, E_f Fermi level,
 E_v - valence band energy, E_g band gap

Location of E_F determines the conduction type



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)

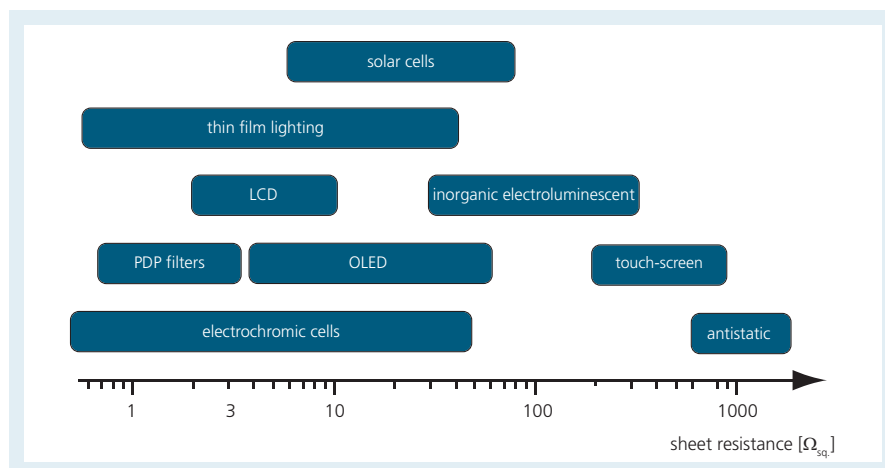
Properties of several TCOs

	ρ [$\Omega \cdot \text{cm}$]	N [cm^{-3}]	μ [cm^2/Vs]	k [cm^2/Vs]	n @ 550 nm
ITO	1.5×10^{-4}	8.5×10^{20}	45	1.4×10^{-3}	1.93 – 2.11
IZO	3.1×10^{-4}	9.3×10^{20}	44	2.0×10^{-3}	1.93 – 2.10
ZnO:Al	4.0×10^{-4}	5.6×10^{20}	32	2.0×10^{-3}	1.79 – 2.10
ZnO:Ga	2.9×10^{-4}	5.6×10^{20}	43	1.5×10^{-3}	1.80 – 1.88
TZO	2.5×10^{-3}	1.1×10^{20}	26	1.5×10^{-3}	1.95 – 2.08
TAO	6.7×10^{-2}	2.3×10^{19}	2	1.5×10^{-2}	2.06 – 2.20
TiO₂:Nb	7.2×10^{-4}	1.2×10^{21}	7	7.5×10^{-3}	2.40 – 2.70

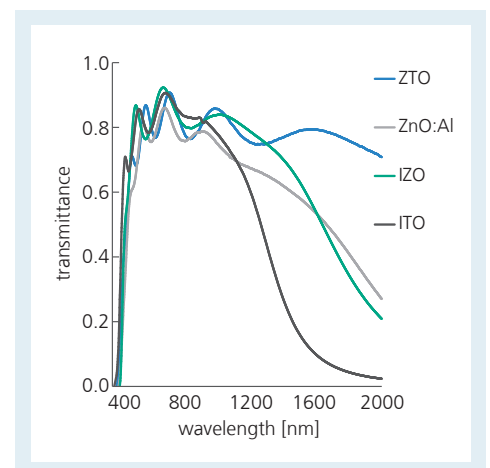
resistivity (ρ), carrier concentration (N), carrier mobility (μ), extinction coefficient (k), refractive index (n)

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



Transmittance for 500 nm thick TCO films



We focus on quality and the ISO 9001.

