Special materials

for ophthalmic coating

Titanium oxides

- Highest refractive index in visible range
- High UV-blockage
- Good environmental resistance
- Best reproducibility and lowest thermal stress for coatings on plastics using Ti_3O_5
- Stable evaporation behaviour without spitting or outgassing
- Widely tunable refractive index
- Very good environmental durability
- Well-suited for BBAR coatings on plastics

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	2.07 – 2.22
› on heated substrates, T_s = 250 °C/no IAD	2.25 – 2.40
› on unheated substrates/with IAD	2.10 – 2.50
Range of transparency (fully oxidized film)	400 nm – 11 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on unheated substrates/no IAD	Tensile
› on heated substrates, T_s ≥ 250 °C/no IAD	Tensile
› on unheated substrates/with IAD	Type and magnitude depending on IAD parameters

Data based on TiO_2 coatings deposited from Ti_3O_5 starting material.

Low-absorbing films deposited from all titanium oxide starting compositions are of the composition TiO_2. The structure of the TiO_2 films depends on the deposition conditions and starting materials ranging from amorphous to crystalline anatase or rutile. This explains the wide spread in the refractive index values. TiO_2 films have the highest and most widely tunable refractive index with the best optical contrast to SiO_2 or LIMA™. This enables AR and multilayer coatings with a minimum number of layers. TiO_2 films effectively block UV-radiation for wavelengths < 400 nm which can be used for the protection of the plastic lenses. The stress of TiO_2 films can be tuned in a wide range of tensile and compressive values. Using Ti_3O_5 starting material, thermal stresses on polymeric lenses can be kept at a minimum which makes this material an ideal choice for coatings on polymeric lenses.

Application Guidelines

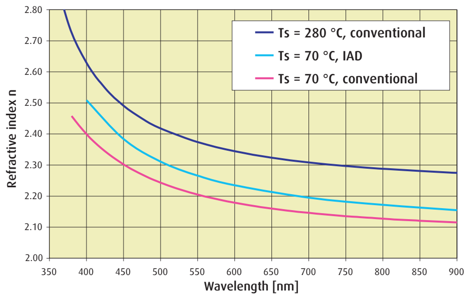
Characteristics of starting material

Chemical formula	TiO	Ti_2O_3	Ti_3O_5	TiO_{2-x}, TiO_2
Color	Gold	Purple	Black-purple	Black, white
Density g/cm³	4.9	4.6	4.6	4.2
Melting point °C	1750	~ 1760	~ 1760	1775
Form	Tablets, granulate			

Evaporation technique

All titanium oxides melt completely. Only the Ti_3O_5 melt evaporates congruently. Titanium oxides are deposited reactively by electron beam evaporation from a Cu-crucible with Mo-liner or from Mo-boats.

Typical deposition in all sizes of coating systems involves rates of 0.2 – 0.5 nm/s at O_2 pressures of 2 – 3 x 10^{-4} mbar (or equivalent O_2 flow). The intended values of refractive index and film stress can be obtained by variation of substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance (IAD). O_2 operated RF plasma ion sources are able to produce high-dense TiO_2 films with full stress compensation relative to SiO_2.



Typical dispersions of the refractive index of TiO_2 films for the indicated deposition conditions. IAD parameters for coatings on plastic substrates.

LATI™

- Superior to other lanthania-titania mixtures due to higher material density
- Complete melting and evaporation without spitting or outgassing
- Reduced refractive index compared to pure TiO_2 enabling a higher AR bandwidth
- Strongly reduced structural film stress compared to pure TiO_2
- Close-to-zero compressive-type stress possible without ion assistance
- Very good thickness homogeneity and run-to-run stability
- Direct adhesion to certain polymeric substrate types

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	1.90 – 2.02
› on unheated substrates/with IAD	2.04 – 2.08
› on heated substrates, T_s = 300 °C	2.09 – 2.12
Range of transparency	380 nm – 7.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	Type and magnitude depending on deposition parameters

Film stress of LATI™ is smaller than for TiO_2 and its type and magnitude are variable by the choice of the process parameters. Films with close-to-zero compressive-type stress can be obtained by conventional deposition. LATI™ films are well-adhering to a number of substrate types (especially certain types of plastics) and show a good environmental stability. Due to these properties LATI™ is used as the H-index material in AR or other dielectric coatings especially on plastics, partly in combination with DRALO™.

Application Guidelines

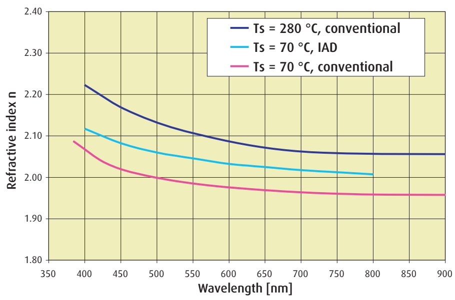
Characteristics of starting material

Chemical formula	La-Ti-oxide
Color	Dark grey with slight metallic appearance
Density g/cm³	5.9 – 6.2
Melting point °C	~ 1800
Form	Granulate

Evaporation technique

LATI™ is typically evaporated by reactive electron beam evaporation with or without ion assistance. Typical deposition in all coating systems with maximum coating distance of 900 mm involves rates 0.3 – 0.5 nm/s and O_2 pressures of 3 x 10^{-4} mbar (or equivalent O_2 flow). The intended values of refractive index and film stress can be obtained by variation of substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance.

Using LATI™ instead of pure titanium oxides requires to follow some particular guidelines to obtain reproducible, well-homogeneous films.



Typical dispersions of the refractive index of LATI™ films for the indicated deposition conditions. IAD parameters for coatings on plastic substrates.

DRALO™

› **Reduced refractive index compared to pure TiO_2 enabling a higher AR bandwidth**
› **Effective protection against UV radiation**
› **Widely tunable film stress from tensile to compressive values**
› **Reduced structural film stress compared to pure TiO_2**
› **Optimized thermal film stress on plastics compared to pure TiO_2**
› **Very good thickness homogeneity and run-to-run stability**
› **Excellent environmental durability**
› **Very good resistance against combined attack of heat, humidity and UV-radiation**
› **Controlled water barrier**

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	2.04 – 2.18
› on heated substrates, $T_S \geq 250$ °C/no IAD	2.26 – 2.28
› on unheated substrates/with IAD	2.05 – 2.30
Range of transparency (fully oxidized film)	400 nm – 7.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on unheated substrates/no IAD	Mostly tensile depending on rate and O_2 pressure
› on heated substrates, $T_S \geq 250$ °C/no IAD	Tensile
› on unheated substrates/with IAD	Type depending on IAD parameters

These properties make DRALO™ layers especially well-suited as the high-index material in AR coatings for polymeric substrates such as ophthalmic lenses.

Application Guidelines

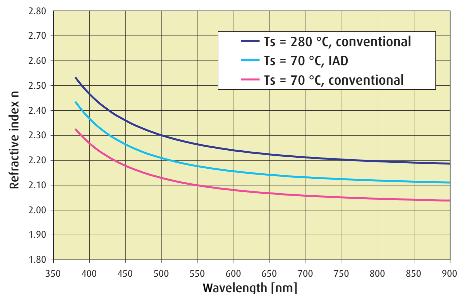
Characteristics of starting material

Chemical formula	Ti-Al-oxide
Color	Black metallic
Density g/cm³	4.5
Melting point °C	1700
Form	Granulate

Evaporation technique

DRALO™ films can be produced by reactive electron beam evaporation using Cu-crucibles with Mo-liners. Typical deposition in all sizes of coating systems involves O_2 pressures of ~3 x 10^{-4} mbar (or equivalent O_2 flow) and rates 0.2 – 0.4 nm/s. The intended values of refractive index and film stress can be obtained by variation of substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance.

Using DRALO™ instead of pure titanium oxides requires to follow some particular guidelines to obtain reproducible, well-homogeneous films.



Typical dispersions of the refractive index of DRALO™ films for the indicated deposition conditions. IAD parameters for coatings on plastic substrates.

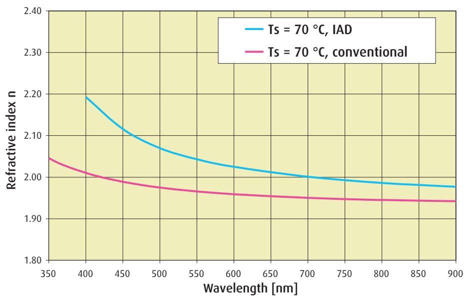
Zirconium oxides

› **Hard and durable films**
› **H-index material for AR coatings especially on plastics**
› **ZrO starting material with higher density and complete melting for easier evaporation**

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	1.92 – 1.97
› on unheated substrates/with IAD	1.95 – 2.05
› on heated substrates, T_S = 300 °C	2.00 – 2.07
Range of transparency	350 nm – 7.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› without IAD	Tensile
› on unheated substrates/with IAD	Tunable type and magnitude

Regardless to the starting material composition, low-absorbing zirconia films are of the composition ZrO_2. Such films are hard and durable and they can be used in AR coatings – partly along with thin layers of TiO_2 or DRALO™ to adjust the reflection characteristic.



Typical dispersions of the refractive index of ZrO_2 films for the indicated deposition conditions. IAD parameters for coatings on plastic substrates.

Application Guidelines

Characteristics of starting material

Available as zirconium dioxide ZrO_2 (with or without minor deficiency x of oxygen) or zirconium monoxide ZrO.

Chemical formula	ZrO_2	ZrO_{2-x}	ZrO
Color	White	Grey-black	Dark grey to black
Density	5.6	5.6	6.4
Melting point °C	~ 2700	~ 2700	~ 2200
Form	Tablets, granulate		

Evaporation technique

Zirconium oxides are mostly evaporated by reactive e-beam evaporation from a Cu-crucible with Mo-liner. Zirconium dioxide ZrO_2 melts only superficially and predominantly sublimes. Therefore it requires a very uniform beam pattern to avoid craters and uniformity problems. ZrO is fully melting and can be used to prevent such problems. It can also be evaporated from W-boat. The intended values of refractive index and film stress can be obtained by variation of substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance.

Deposition occurs typically at O_2 pressures of 1 – 3 x 10^{-4} mbar (or equivalent O_2 flow) for ZrO_2/ZrO_{2-x} and 2 – 3 x 10^{-4} mbar (or equivalent O_2 flow) for ZrO. Typical deposition in all sizes of coating systems involves rates 0.2 – 0.5 nm/s. The tendency to inhomogeneity can be counteracted using IAD.

Zr-Ti-oxides

- **Zr-Ti-oxide tablets show a stable evaporation behaviour without spitting or outgassing**
- **Optimized film stress compared to pure ZrO_2 and TiO_2 films**
- **Widely tunable refractive index n**
- **Very good environmental durability**
- **Well-suited for BBAR coatings on plastics with refractive indices n > 1.60**

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	1.80 – 1.88
› on heated substrates, T_s = 250 °C/no IAD	2.01 – 2.03 (2.10 at 300 °C)
› on unheated substrates/with IAD	1.94 – 1.96
Range of transparency (fully oxidized film)	400 nm – 11 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on unheated substrates/no IAD	Tensile
› on heated substrates, T_s ≥ 250 °C/no IAD	Tensile
› on unheated substrates/with IAD	Tensile

Thin films made from Zr-Ti-oxide effectively block UV-radiation for wavelengths < 240 nm. Compared to pure ZrO_2 and TiO_2 films, Zr-Ti-oxide films have a reduced tensile film stress. Refractive index and reduced mechanical stress of Zr-Ti-oxide films made from Zr-Ti-oxide source material by conventional or slightly assisted deposition without substrate heating makes this material a good choice for coatings on plastics with refractive indices n > 1.60.

Zr-Ti-oxide with higher refractive index is available.

Application Guidelines

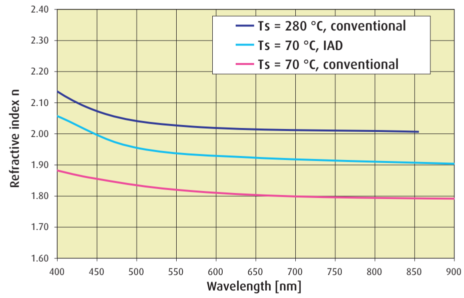
Characteristics of starting material

Chemical formula	Zr-Ti-oxide
Color	Black to dark gray
Density g/cm³	~ 5.1
Melting point °C	~ 1850
Form	Tablets, granulate

Evaporation technique

Zr-Ti-oxide films can be produced by reactive deposition from Zr-Ti-oxide tablets by electron beam evaporation using water cooled Cu-crucibles with Mo-liners. Typical deposition in all coating systems with maximum coating distance of 900 mm involves O_2 pressures of ~3×10^{-4} mbar (or equivalent O_2 flow) and rates 0.2 – 0.4 nm/s. The intended values of refractive index and film stress can be obtained by variation of substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance.

Using Zr-Ti-oxide instead of pure zirconium oxide requires to follow some particular guidelines to obtain reproducible, well-homogeneous films.



Typical dispersions of the refractive index of Zr-Ti-oxide films for the indicated deposition conditions.
IAD parameters for coatings on plastic substrates.

ROMA™

- **Stable evaporation behaviour without spitting or outgassing**
- **Yields homogeneous layers in contrast to pure ZrO_2 and an improved oxidation behaviour relative to Ta_2O_5**
- **Optimized film stress compared to pure ZrO_2 films**
- **Moisture barrier leading to considerably increased environmental durability**
- **Well-suited for BBAR coatings on plastics**

Film properties

Refractive index at 550 nm	
› on heated substrates, T_s ≥ 250 °C/no IAD	2.04 – 2.07
› on unheated substrates/with IAD	1.85 - 2.10
Range of transparency (fully oxidized film)	350 nm – 10 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on heated substrates, T_s ≥ 250 °C/no IAD	Depending on deposition conditions
› on unheated substrates/with IAD	Tensile

ROMA™ has been designed to yield very homogeneous layers in contrast to pure ZrO_2 and an improved oxidation behaviour relative to Ta_2O_5. ROMA™ films also show a considerably improved climate test resistance due to their increased water impermeability.

Thin films made from ROMA™ effectively block UV-radiation for wavelengths < 350 nm. Compared to pure ZrO_2 films, ROMA™ films have a reduced tensile film stress. Refractive index, reduced mechanical stress and environmental durability of ROMA™ films from assisted deposition without substrate heating makes this material a good choice for coatings on plastics.

Application Guidelines

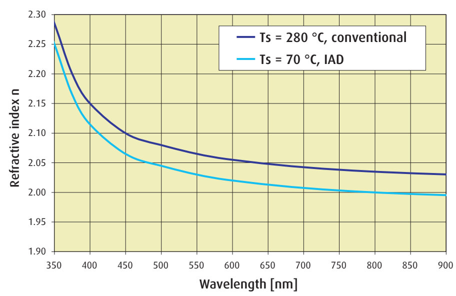
Characteristics of starting material

Chemical formula	Zr-Ta-oxide
Color	Black to dark gray
Density g/cm³	~ 6.82
Melting point °C	~ 2100
Form	Tablets, granulate

Evaporation technique

ROMA™ films can be produced by reactive electron beam evaporation using water cooled Cu-crucibles with Mo-liners. Typical deposition in all sizes of coating systems involves rates of 0.2 – 0.4 nm/s at O_2 pressures of $2 - 4 \times 10^{-4}$ mbar (or equivalent O_2 flow) at increased substrate temperature or with ion assistance. The intended values of refractive index and film stress can be obtained by variation of substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance.

For ROMA™ containing coatings on plastic lenses ion assistance is indispensible to obtain low-absorbing layers. Using ROMA™ instead of pure zirconium or tantalum oxide requires to follow some particular guidelines to obtain reproducible, low-absorbing and well-homogeneous films.



Typical dispersions of the refractive index of ROMA™ films for the indicated deposition conditions.
IAD parameters for coatings on plastic substrates.

LIMA™

- L-index material for AR coatings especially on plastics
- Refractive index and hardness similar to SiO_2
- Optimized water impermeability compared to SiO_2
- Higher environmental durability than SiO_2

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	~ 1.48
Range of transparency (fully oxidized film)	190 nm – 9.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on unheated substrates/no IAD	Mostly compressive
› on unheated substrates/with IAD	Compressive

LIMA™ films have optical properties (refractive index, transmission range) and mechanical properties (hardness, stress) that are similar to those of pure SiO_2. LIMA™ is designed to obtain films with water impermeability that leads to an increased resistance against environmental impact. For certain coating conditions, LIMA™ films exhibit smaller values of compressive stress than films of pure SiO_2.

Application Guidelines

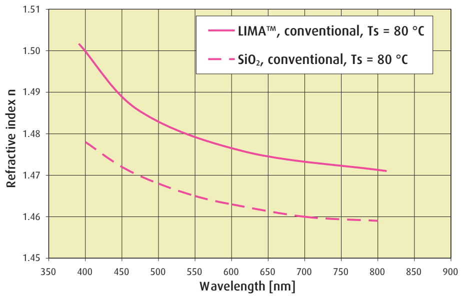
Characteristics of starting material

Chemical formula	Si-Al-oxide
Color	White to light grey
Density g/cm³	2.25
Melting point °C	~ 1730
Form	Tablets, granulate

Evaporation technique

LIMA™ predominantly sublimes. LIMA™ films are deposited by reactive or non-reactive electron beam evaporation using Cu-crucibles with Mo-liners. Typical deposition rates are 0.5 – 2.0 nm/s. The intended values of refractive index and film stress can be obtained by variation of substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance. Post-deposition treatment of the last LIMA™ layer with ion assistance can be used to increase the climate resistance of the film stack.

Using LIMA™ instead of pure SiO_2 requires to follow some particular guidelines to obtain reproducible, well-homogeneous films.



Typical dispersions of the refractive index of LIMA™ films for the indicated deposition conditions.

ITO

- Transparent conductive material for conducting or antistatic function
- Antistatic function complements easy-to-clean coatings on AR and color coatings
- Additional function as adhesion promoter for use as the first layer
- Inhouse raw material source and recycling capabilities

Film properties

Refractive index at 550 nm	1.9 – 2.2
Range of transparency (T ≥ 80%)	~400 nm – ~1.1 µm
Sheet resistance	Ω/sq to the MΩ/sq-range
Environmental Stability	MIL-C-675 B/C passed

Low-absorbing ITO films are transparent in the visible and near-infrared spectral ranges, but strongly reflecting in the IR range. Depending on the In-/Sn-oxide ratio and the deposition conditions, ITO films can be electrically conductive with sheet resistances from the Ω/sq to the MΩ/sq-range. Resistances in the kΩ/sq-range are enough for an antistatic effect and can be achieved with an ITO thickness of only a few nanometers.

The ratio of transmittance in the visible range and conductivity can be adjusted by post-deposition thermal treatment in vacuum or air (increase or decrease of conductivity, respectively).

For coatings on plastics, for example AR coatings on eyeglasses, the absorption of ITO for an unassisted deposition can be compromised by the small layer thickness. Also, it can be improved by ion assisted deposition.

Application Guidelines

Characteristics of starting material

Chemical formula	In-Sn-oxide
Color	Steel-grey to green
Density g/cm³	~ 7.1 (In-/Sn-oxide 90/10)
Melting point °C	~ 1730
Form	Tablets, granulate

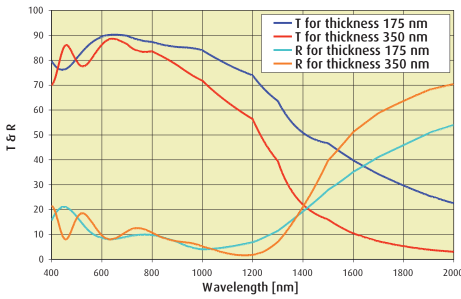
The material can be supplied in different ratios In-/Sn-oxide from 83/17 to 95/5 %wt.

Evaporation technique

ITO fully sublimes. ITO films are deposited by reactive or non-reactive electron beam evaporation using Cu-crucibles with Mo-liners or thermal evaporation using Mo-boats with cover.

The refractive index of ITO films, the degree of transmittance in the VIS, the onset of reflectance in the IR spectral range and the conductivity can be tuned using the composition of the starting material or the deposition parameters like temperature, oxygen pressure and the parameters of ion assistance.

To obtain the required low absorption for ITO films in coatings on plastics it is possible to use either a very small layer thickness or ion assistance with an O_2 flow through the ion source.



Typical transmittance and reflectance spectra for ITO.

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