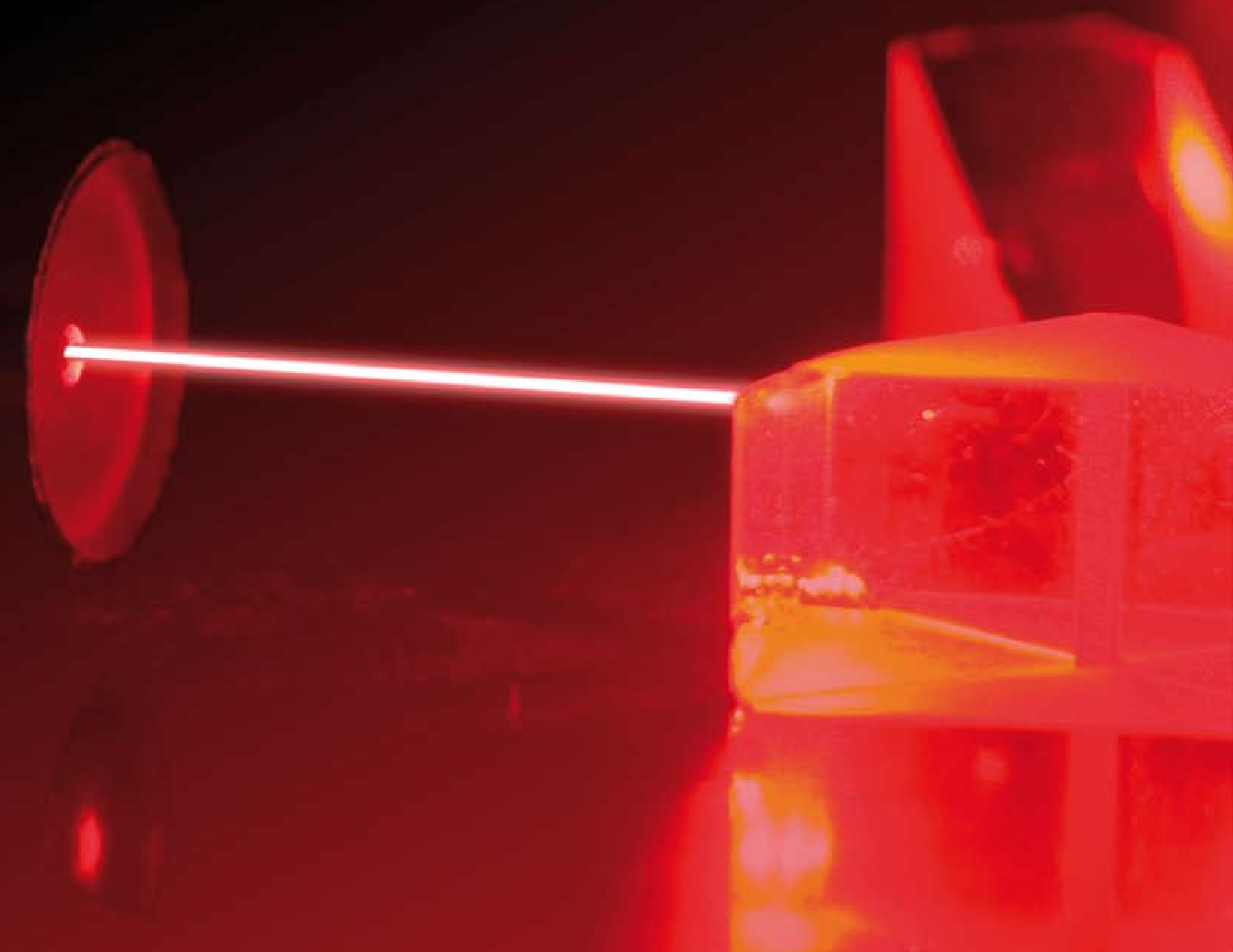
Special materials for Precision Optics & Laser Coatings

Oxides for Evaporation



Titanium oxides

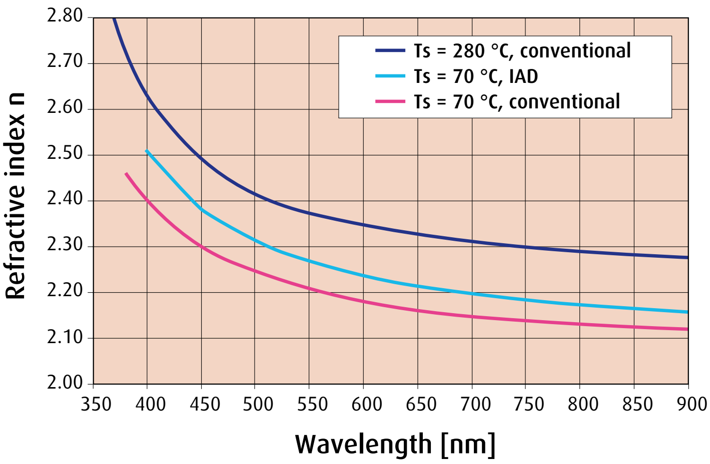
- **Highest refractive index of oxides in visible range**
- **AR and multilayer coatings on glass and polymers**
- **Best reproducibility by using Ti_3O_5**
- **Stable evaporation behaviour without spitting or outgassing**
- **High UV-blockage and low thermal substrate load for coatings on plastics**

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
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 in the visible range of all oxides with the best optical contrast to SiO_2. TiO_2 films effectively block UV-radiation for wavelengths < 400 nm which can be used for the protection of coated polymeric substrates. The stress of TiO_2 films can be tuned in a wide range of tensile and compressive values. The compensation of the SiO_2 compressive stress for common deposition conditions along with the high index contrast favours the use of TiO_2 films in AR and multilayer coatings with a minimum number of layers. Using Ti_3O_5 starting material, thermal stresses on polymers can be reduced making this material additionally an ideal choice for coatings on plastic substrates.



Typical dispersion of the refractive index for the indicated deposition conditions.

Application Guidelines

Characteristics of starting material

Chemical formula	TiO	Ti_2O_3	Ti_3O_5	TiO_{2-x}, TiO_2	Ti metal
Color	Gold	Purple	Black-purple	Black, white	Grey
Density g/cm³	4.9	4.6	4.6	4.2	4.5
Melting point °C	1750	~ 1760	~ 1760	1775	1668
Delivery form	Tablets, granulate				On request

Evaporation technique

All titanium oxides melt completely. Only the Ti_3O_5 melt evaporates congruently. Titanium oxides are deposited reactively by electron beam evaporation with a Cu-crucible and Mo-liner or from W-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). For the intended variation of refractive index and film stress, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed. O_2-operated RF plasma ion sources are able to produce high-dense TiO_2 films with full stress compensation relative to SiO_2.

Application fields

AR and multilayer coatings (dielectric mirrors, dichroics, narrowband filters, polarizers, beamsplitters) for VIS and IR spectral range, coatings for precision optics and on plastics, to a lesser extent for laser coatings.

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 precision optics.

Application Guidelines

Characteristics of starting material

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

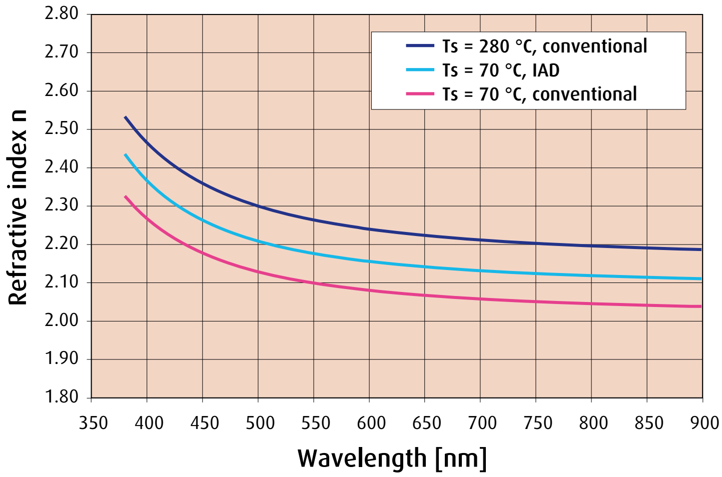
Evaporation technique

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.

Application fields

AR and multilayer coatings in precision optics.



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

Niobium oxides

› **High refractive index oxide material for AR and multilayer coatings**
› **High-temperature resistant films**

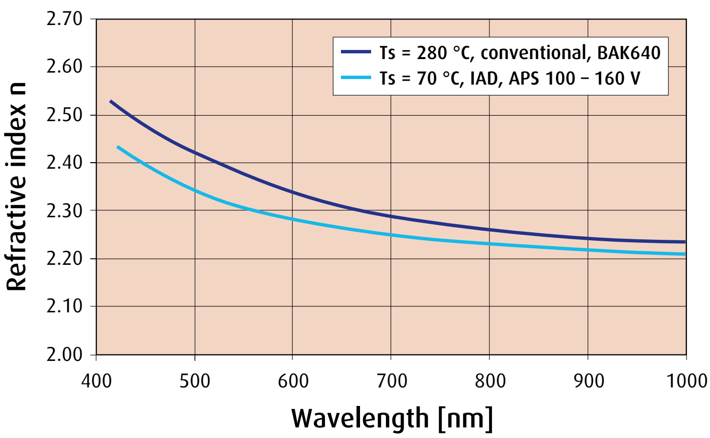
Film properties

Refractive index at 550 nm	
› on unheated substrates/with IAD	2.27 – 2.31
› on heated substrates, T_s ≥ 300 °C	2.29 – 2.33
Range of transparency	380 nm – 8.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on unheated substrates/with IAD	Tunable type and magnitude
› on heated substrates, T_s ≥ 300 °C	Tensile

Thin films made from Nb_2O_{5-x} source material have a refractive index in the range of 2.27 – 2.33 at 550 nm and a low absorbance over the whole VIS and near-IR region for a suitable deposition process or post-depositon procedure. This makes Nb_2O_5 layers especially well-suited as H-index materials in AR coatings and filters.

The excellent thermal and long-term stability of films deposited at high substrate temperatures or with plasma ion assistance make this material furthermore a good choice for thermally loaded optical applications such as heat protection filters and lighting (e.g. cold light mirrors).

The exact characteristics of individual films depend on the respective evaporation conditions such as substrate temperature, oxygen pressure, deposition rate, possibly ion assistance parameters.



Typical dispersion of the refractive index for the indicated deposition conditions.

Application Guidelines

Characteristics of starting material

Availability as niobium pentoxide with a minor deficiency x of oxygen Nb_2O_{5-x}.

Chemical formula	Nb_2O_{5-x}
Color	Black metallic
Density g/cm³	6.1 – 6.2
Melting point °C	1512
Delivery form	Granulate

Evaporation technique

Nb_2O_{5-x} source material has an excellent melting and evaporation behaviour without spitting or outgassing.

Nb_2O_5 films can be produced from Nb_2O_{5-x} granulate or disks by reactive e-beam evaporation. For the intended variation of refractive index and film stress, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed.

Low-absorbance films can be obtained either at low substrate temperatures with a post-deposition thermal treatment or by plasma or ion assistance or for substrate temperatures > 300 °C with oxygen pressures of 2.0 – 6.0 x 10^{-4} mbar or equivalent flow.

Typical deposition in all sizes of coating systems involves rates 0.2 – 0.7 nm/s.

Application fields

AR and multilayer coatings (dielectric mirrors, heat protection filters, dichroics, narrowband filters, polarizers, beamsplitters) for VIS to IR spectral range. Occasional use in pure or mixed form for electrochromic coatings.

Tantalum oxides

› **High refractive index material with high laser damage resistance**
› **Hard and durable films**
› **Moisture blocking and increased climate resistance**
› **Lithographically structurable films**

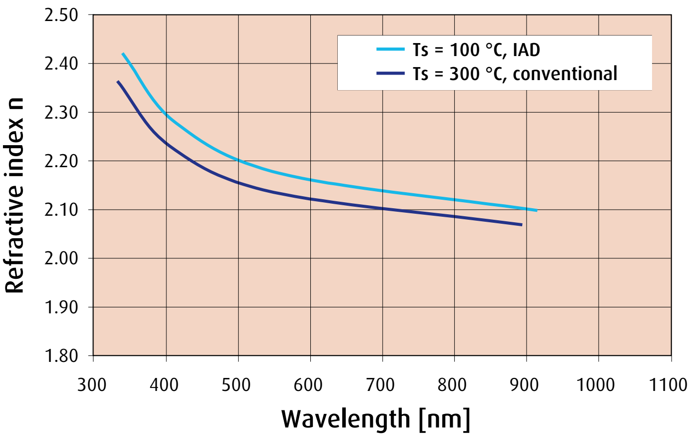
Film properties

Refractive index at 550 nm	
› on unheated substrates/with IAD (O_2)	2.07 – 2.17
› on unheated substrates/with IAD ($Ar+O_2$)	2.07 – 2.18
› on heated substrates, T_s = 300 °C	2.12 – 2.13
Range of transparency	300 nm – 10 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on unheated substrates/with IAD (O_2)	Compressive
› on unheated substrates/with IAD ($Ar+O_2$)	Tunable type and magnitude
› on heated substrates, T_s ≥ 300 °C	Tensile

Low-absorbing films deposited in appropriate conditions from all tantalum oxide starting compositions are of the composition Ta_2O_5. They have refractive indices ~ 2.07 – 2.18 in the visible range. The obtainable transparency in the near infrared spectral range is superior to titanium oxides and therefore enables the Ta_2O_5 films for laser and bandpass coatings in this range.

Film stress of transparent Ta_2O_5 films can be tuned between compressive and tensile type. Due to a reduced thermal radiation from the melt of tantalum oxides, thermal stresses on polymers can be reduced using Ta_2O_5.

Tantalum oxide films are hard, durable and among the oxides with a high laser damage threshold. They block effectively moisture and can be structured lithographically.



Typical dispersion of the refractive index for the indicated deposition conditions.

Application Guidelines

Characteristics of starting material

Availability as Ta_2O_5, Ta_2O_{5-x} with minor deficiency x of oxygen or RENA TaO_y.

Chemical formula	Ta_2O_5	Ta_2O_{5-x}	RENA TaO_y
Color	White	Grey-black	Dark grey – metallic
Density	8.3	~ 8.3	8.8
Melting point °C	1880	< 1880	< 1880
Delivery form	Tablets, granulate, discs		

Evaporation technique

Tantalum oxides are commonly evaporated by reactive e-beam evaporation from a Cu-crucible or with Mo-liner. For the intended variation of refractive index and film stress, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed. To obtain low-absorbing Ta_2O_5 films, it is indispensable to use strong ion assistance and/or high substrate temperature or post-deposition annealing in air. Also, the oxygen partial pressure has to be properly adjusted for deposition of the Ta_2O_5 films and their adjacent layers to avoid oxygen deficiency and absorption.

Deposition occurs typically at O_2 pressures of 3 – 6 x 10^{-4} mbar (or equivalent O_2 flow). Typical deposition in all sizes of coating systems involves rates 0.2 – 0.7 nm/s.

Application fields

AR and multilayer coatings (dielectric mirrors, dichroics, narrowband filters, polarizers, beamsplitters) for near UV (> 300 nm), VIS and IR spectral range for precision optics and laser coatings. Special use for DWDM filters in telecommunications and for lithographically structured coating applications. Due to relative low thermal radiation from melt and humidity resistance use for coatings on plastics.

Zirconium oxides

- **Very hard and durable films**
- **High laser damage resistance**
- **High refractive index material for multilayer and AR coatings on glass and 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	230 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 of the starting material composition, low-absorbing zirconia films are of the composition ZrO_2. Such films are very hard and durable and they have a high laser damage resistance. Fully oxidized ZrO_2 films can be deposited with an optical transparency down to 230 nm and adhere well to glass, many oxides, some polymers and to metals like aluminium and silver. Due to their resistance to flexing (bending) zirconia films can be employed for coatings on plastic web. In AR coatings they can be used – partly along with thin layers of TiO_2 – to adjust the reflection characteristic.

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	Zr metal
Color	White	Grey-black	Dark grey – black	Silver metallic
Density	5.6	5.6	6.4	6.5
Melting point °C	~ 2700	~ 2700	~ 2200	1852
Delivery form	Tablets, granulate			On request

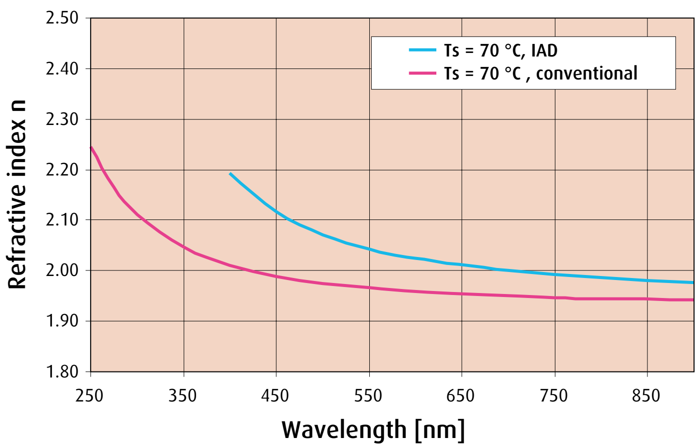
Evaporation technique

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. For the intended variation of refractive index and film stress, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed.

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 heterogeneity can be counteracted using IAD.

Application fields

AR and multilayer coatings (laser mirrors, dichroics, narrowband filters, polarizers, beamsplitters) for DUV (> 230 nm, excimer lasers), VIS and IR spectral range for precision optics and laser coatings. Use for coatings on plastics, potentially on flexible substrates.



Typical dispersion of the refractive index for the indicated deposition conditions.

Hafnium oxides

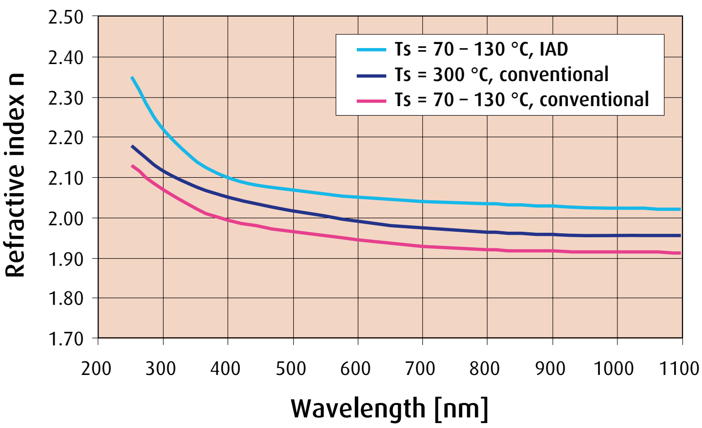
› **High refractive index films for AR and multilayer coatings**
› **Low-absorbing, hard, adherent and abrasion-resistant films**
› **High laser damage threshold**

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	1.90 – 2.00
› on unheated substrates/with IAD	1.97 – 2.02
› on heated substrates, T_S = 300 °C	2.04 – 2.07
Range of transparency	230 nm – ca. 8.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on unheated substrates/no IAD	Tensile
› on unheated substrates/with IAD	Tunable type and magnitude
› on heated substrates, T_S ≥ 300 °C	Tunable type and magnitude

Thin films made from HfO_2 or HfO_{2-x} source material have a refractive index in the range of 1.90 – 2.07 at 550 nm and a wide spectral range of transparency extending from the near-UV to the near-IR spectral ranges. HfO_2 films deposited at high substrate temperatures or with plasma/ion assistance and/or post-deposition annealing are very low-absorbing and stable against environmental impact and high-energetic laser radiation.

These properties make HfO_2 layers especially well-suited as the high-index material in AR coatings, filters and other dielectric coatings especially for laser components.



Typical dispersion of the refractive index for the indicated deposition conditions.

Application Guidelines

Characteristics of starting material

Availability as hafnium dioxide HfO_2 or HfO_{2-x} (with minor deficiency x of oxygen).

Chemical formula	HfO_2 with traces of ZrO_2	HfO_{2-x} with traces of ZrO_{2-x}
Color	White	Grey-black metallic
Density g/cm³	9.7	9.7
Melting point °C	~ 2812	~ 2812
Delivery form	Tablets, granulate, discs	

Evaporation technique

HfO_2 films can be produced from HfO_2 or HfO_{2-x} source material by reactive electron beam evaporation using Mo-crucibles/liners and prefentially rotation of the source. Due to the high melting point, the source material mostly sublimes during evaporization.

For the intended variation of refractive index and film stress, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed. Homogeneous and low-absorbing films with highest stability, optical index and widest spectral range of transparency can be obtained at high substrate temperatures (TS ~ 280 – 300 °C) or on unheated substrates using plasma or ion assistance and O_2 pressures 1 – 2 x 10^{-4} mbar. Typical deposition in all sizes of coating systems involves rates 0.2 – 0.5 nm/s.

Application fields

AR and multilayer coatings (laser mirrors, dielectric mirrors, polarizers, beamsplitters) for UV (> 240 nm), VIS and IR spectral range for precision optics and laser coatings. Protective coating for metal mirror coatings.

Scandium oxides

› **Hard and durable films**
› **Intermediate high refractive index material for AR and filters**
› **High laser damage resistance**
› **Adhesion promoter**

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	~ 1.76 – 1.88
› on unheated substrates/with IAD	~ 1.80 – 1.95
› on heated substrates, T_s = 270 °C	~ 1.82 – 1.92
Range of transparency	230 nm – ca. 12.0 µm Lower limit can vary in the range of 220 – 350 nm dependent on the deposition conditions
Environmental Stability	MIL-C-675 B/C passed
Stress	
› on unheated substrates/no IAD	Tensile
› on unheated substrates/with IAD	Tunable type and magnitude
› on heated substrates, T_s ≥ 270 – 300 °C	Tensile

Large spectral range of transmission and high laser damage threshold. AR, HR, Filters for DUV (248, 355 nm), adhesion promoter for UV- and IR.

Application Guidelines

Characteristics of starting material

Availability as scandium oxide Sc_2O_3 in different purity grades.

Chemical formula	Sc_2O_3
Color	White
Density g/cm³	~ 3.9
Melting point °C	~ 2400
Delivery form	Granulate (recommanded), tablets

Evaporation technique

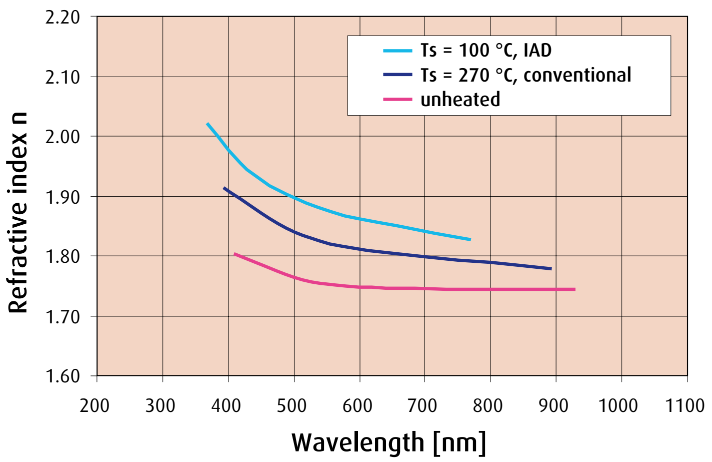
Scandium oxide is mostly evaporated by reactive e-beam evaporation from a Cu-crucible with Mo- or graphite liner. Scandium oxide Sc_2O_3 melts only superficially and predominantly sublimes. Therefore it requires a very uniform beam pattern and/or rotating crucible to avoid craters and uniformity problems.

For the intended variation of refractive index and film stress, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed.

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

Application fields

AR and multilayer coatings (dielectric mirrors, dichroics, narrowband filters, polarizers, beamsplitters) for DUV (> 230 nm), VIS and IR spectral range for precision optics and laser coatings. Potential adhesion promoter.



Typical dispersion of the refractive index for the indicated deposition conditions.

Yttrium oxides

› **Intermediate high refractive index material with small optical dispersion**
› **Wide spectral range from near UV to mid-wave IR**
› **Adhesion promoter**

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	1.78 – 1.85
› on unheated substrates/with IAD	1.80 – 1.90
› on heated substrates, T_S = 300 °C	1.82 – 1.85
Range of transparency	~ 250 nm – 12.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› without IAD	Tensile
› on unheated substrates/with IAD	Tunable type and magnitude

Regardless of the starting material composition, low-absorbing yttria films are of the composition Y_2O_3. Y_2O_3 films have an intermediately high refractive index with a small dispersion.

Such films are hard, durable and well-adhering and they can be used in AR and multilayer coatings – along with thin layers of SiO_2 or high index materials or as protective coatings.

Films of yttrium oxide of only several nanometers thickness are a good adhesion promoter for a number of oxides, sulfides and fluorides on mineral glasses and IR substrate materials.

Application Guidelines

Characteristics of starting material

Availability as yttrium oxide Y_2O_3 or Y_2O_{3-x} (with minor deficiency x of oxygen).

Chemical formula	Y_2O_3	Y_2O_{3-x}
Color	White	Grey-black
Density g/cm³	5.0	5.0
Melting point °C	~ 2410	~ 2410
Delivery form	Tablets, granulate	

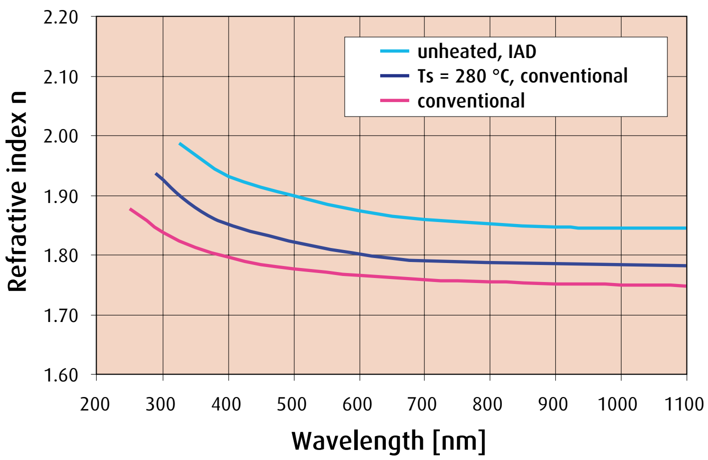
Evaporation technique

Yttrium oxide is mostly evaporated by reactive e-beam evaporation from a Cu-crucible with Mo-liner. Deposition from W-boats has also been reported. Yttrium oxide melts only superficially and predominantly sublimes. Therefore it requires a very uniform beam pattern and or rotating crucible to avoid craters and uniformity problems. For the intended variation of refractive index and film stress, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed.

Deposition occurs typically at O_2 pressures of 8.0×10^{-5} – 4×10^{-4} mbar (or equivalent O_2 flow). Typical deposition in all sizes of coating systems involves rates of 0.2 – 1.5 nm/s. The tendency to heterogeneity can be counteracted using IAD.

Application fields

AR coatings and multilayer coatings for near-UV, VIS and IR spectral range for precision optics and laser coatings. Protective coating on metal mirrors. Potential use for coatings on plastics. Optical function and adhesion promoter.



Typical dispersion of the refractive index for the indicated deposition conditions.

Magnesium oxides

› **Hard and durable films**
› **Intermediate refractive index**
› **Adhesion promotor**

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	1.65 – 1.70
› on heated substrates, T_s = 300 °C	1.70 – 1.74
Range of transparency	200 nm – 8.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› without IAD	Compressive
› on unheated substrates/with IAD	Compressive with tunable magnitude

Magnesium oxide films are hard and durable.

They have an intermediate refractive index and a wide range of transmission that enable their use in coating application from DUV to IR spectral range.

Magnesium oxide films facilitate adhesion for a number of oxides and fluorides on mineral glasses and typical IR substrates.

Application Guidelines

Characteristics of starting material

Availability as magnesium oxide MgO.

Chemical formula	MgO
Color	White or glassy transparent
Density	3.6
Melting point °C	2640
Delivery form	Tablets, granulate

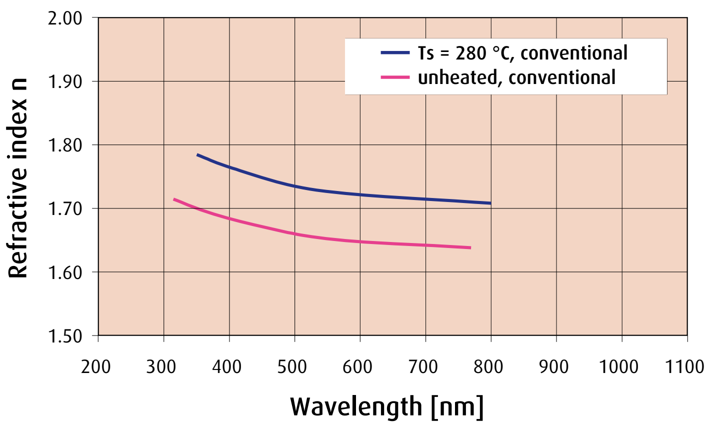
Evaporation technique

Magnesium oxide can only be evaporated by reactive e-beam evaporation. It sublimes completely and does not show any reduction in the crucible. For the intended variation of refractive index and film stress, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed.

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

Application fields

AR coatings for precision optics and laser coatings in DUV (> 200 nm), VIS and IR spectral range. Adhesion promoter.



Typical dispersion of the refractive index for the indicated deposition conditions.

Aluminium oxides

› **Only high refractive index material for DUV**
› **Medium index material for VIS and IR spectral range**
› **Good laser damage resistance 193 – 1064 nm**

Film properties

Refractive index at 550 nm	
› on unheated substrates/no IAD	1.60
› on unheated substrates/with IAD	1.63 – 1.68
› on heated substrates, T_S = 300 °C	1.63
Range of transparency	> 190 (193) nm – ca. 7.0 µm
Environmental Stability	MIL-C-675 B/C passed
Stress	
› without IAD	Tensile
› on unheated substrates/with IAD	Tensile

Application Guidelines

Characteristics of starting material

Availability as aluminium oxide Al_2O_3.

Chemical formula	Al_2O_3
Color	White or glassy transparent
Density	~ 4.0
Melting point °C	2046
Delivery form	Granulate (white and glassy), tablets (white)

Evaporation technique

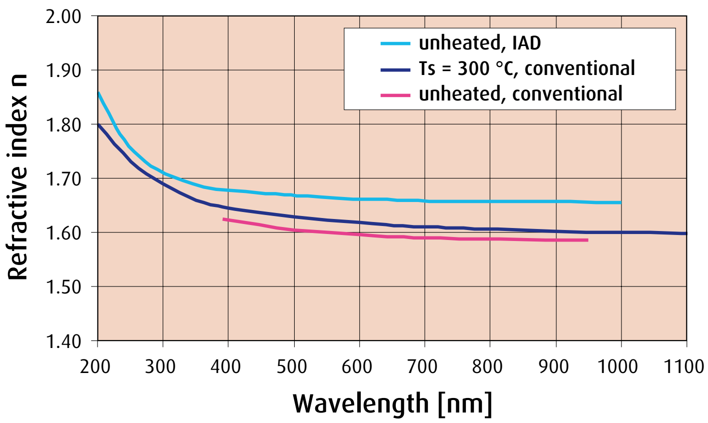
Aluminium oxides are mostly evaporated by reactive e-beam evaporation from a Cu-crucible with a small Mo-liner.

For the intended variation of refractive index, substrate temperature, oxygen pressure or flow, deposition rate and the parameters of ion assistance can be employed.

Deposition occurs typically at O_2 pressures of 1 – 2 x 10^{-4} mbar (or equivalent O_2 flow). Typical deposition in all sizes of coating systems involves rates 0.25 – 0.5 nm/s.

Application fields

AR and multilayer coatings (dielectric mirrors, dichroics, narrowband filters, polarizers, beamsplitters) for DUV (> 190 nm), VIS and midwave IR spectral range for precision optics and laser coatings. Use for coatings on lithographic equipment (≥ 193 nm) and for coatings on plastics.



Typical dispersion of the refractive index for the indicated deposition conditions.

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