Titanium Oxides
For Optical Coating

Applications

Titanium dioxide (TiO_2) has been used in optical coatings for the visible region for many years. TiO_2 has two particularly desirable qualities. It provides the highest index film material for the visible region, and it is hard and stable in combination with other oxides. Coating examples using TiO_2 as the high-index material include beam splitters, cold mirrors and heat-reflecting mirrors, and AR on glass and polymer substrates. Absorption below 450 nm limits the applications to the visible and near-ir regions. When paired with SiO_2 films, multilayer combinations totaling in excess of 50 layers have been deposited that show excellent durability and low mechanical stress because the tensile stress of titania layers is balanced by the compressive stress of the silica layers.

Evaporation Notes

Titanium and oxygen form a number of stable phases, the most practical being TiO, TiO_2, Ti_2O_3 and Ti_3O_5. Any of these compositions can be evaporated and subsequently oxidized to the final stable phase, TiO_2. The lower evaporation temperatures of the latter two compounds is an advantage because particle ejection and strong outgassing is avoided. The resultant titania layers are composed of columnar microcrystallites with appreciable void volume and undesirable optical absorption unless films are grown under high -energy conditions such as high substrate temperature or Ion Assist (IAD) or by sputtering. IAD has been found to produce the highest refractive indices, yet the structure has neither the pure rutile or anatase long-range crystal phase.

When heated above their melting points, titanium oxides decompose into suboxides and liberate oxygen. It is therefore necessary to prepare a dense homogeneous slug of melted material before beginning evaporation. The material should be conditioned as follows. Condense the starting material into a homogeneous mass by melting at low power, using a swept beam. Oxygen evolves during this process, leaving a black, oxygen-deficient melt. Repeated fillings of the crucible will be required unless a premelted cone is used as the starting charge. After the outgassing stops, the melt can be raised to evaporation temperature. The evaporant will re-oxidize reactively in the supplied partial pressure oxygen to form films of colorless TiO_2.

All of the titanium oxides can be evaporated by resistance heating or electron beam. If Tungsten crucibles are used, some reaction between container and material results. For electron beam evaporation, Tantalum or water-cooled copper crucibles are recommended.

Advantages of Using Ti_3O_5 Starting Material[1,2]

Whenever any of the various oxide states of Titanium (see above) is evaporated, the vapor consists of various Ti-O combina-

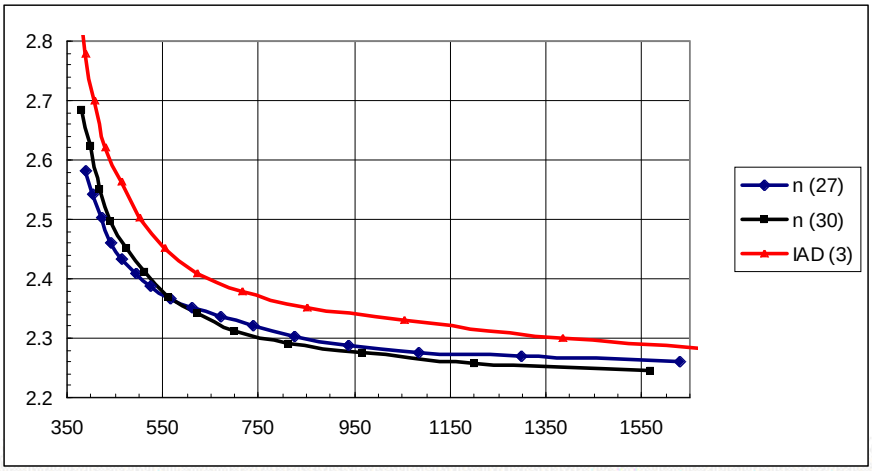

Figure 1. The use of IAD increases the refractive index ~2%.

tions, which change in oxygen content as the evaporation proceeds. The refractive index of the deposited film thus is not constant because most Ti-Ox materials evaporate incongruently.

Starting with Ti_3O_5 composition ensures that the only titanium species in the vapor is TiO, and the oxygen content in the vapor remains constant. Also the Ti_3O_5 composition has the advantage that it melts and thus a constant rate and pressure can be established for the duration of the deposition process.

Optical Properties

As seen in figures 1 and 2, the curves show the influences of IAD and post-deposition air baking on the refractive indices. The air bake consisted of holding the film layer at 400°C for 4 hours.

The application of IAD increases the extinction coef. from <0.002 to ~0.005 in the visible region. The practical useable wavelength limit (when k ~0.01) for the IAD film is ~400 nm.

Evaporation Parameters

Source	Electron Beam
Crucible	Ta, water-cooled copper
Substrate temperature	250°C min.
Rate of condensation	~3-5 Å/sec.
Partial pressure of supplied oxygen	~1-2 x 10^{-4} Torr
Refractive Index of film	2.4 at 450nm 2.35 at 500nm 2.26 at 700nm 2.20 at 1000-1200nm

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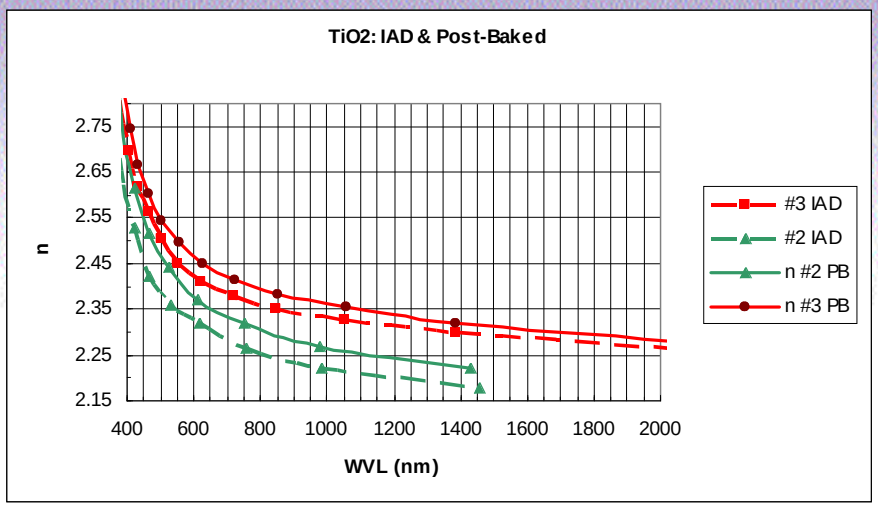

Figure 2. Post-deposition air baking increases the index further.

Forms and Sizes Available

CERAC offers materials for evaporation as well as sputtering targets. To view pricing on our standard catalog items, please visit our on-line catalog at www.cerac.com and look-up by item number, chemical name or CAS number. If you require a custom manufactured item, please contact our sales department at +1-414-289-9800 or cerac-sales@beminc.com with your specific requirements. You can also fill out our quotation request form.

Formula	Item Number	Description
TiO	T-2038	Gold tablet 8-9mm dia. x 6-7mm thick
TiO_2	T-1183	White tablet, fully oxidized, 8-9mm dia. x 4-5 mm thick cone
	T-1192	3-6mm irregular sintered pieces, fully oxidized
	T-5003	Pre-melted ingot
	T-5503	Pre-melted, sized pcs
Ti_2O_3	T-1257	Purple tablet 8-9mm dia x 6-7mm thick
Ti_3O_5	T-2039	Black tablet 8-9mm dia x 7-9mm thick
Ti_3O_5	T-2100	1-4 mm pieces

Ordering Information

For specific product information or to place an order, contact CERAC customer service at cer-accustserv@beminc.com or by phone at +1-414-289-9800. Visit www.cerac.com for a complete list of global sales and service locations.

References

1. "Refractive Indices of TiO_2 Films Produced by Reactive Evaporation of Various Titanium-Oxygen Phases" H.K. Pulker, G. Paesold and E. Ritter, Applied Optics, Vol 15, No. 12 (1976), p. 2986-2990.
2. "Method of Depositing Titanium Dioxide Layers by Evaporation of a Molten Titanium-Oxygen Phase," H.K. Pulker, U.S. Patent 3,927,228.