# Characterization of Ion Beam Sputtered Optical Thin Film Materials for Use at Infrared Wavelengths

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**Abstract:** Ion Beam Sputtered coatings (IBS) are mostly used for wavelengths from 0.25µm to 2.1µm. We have investigated the properties of IBS coating materials and found that $Al_2O_3$ and $TiO_2$ are suitable out to 3.3µm.

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## 1. Introduction

New applications in laser physics, such as Optical Parametric Oscillators, require coatings spanning wavelengths from the visible into the infrared (IR). Coating materials traditionally used in the IR (for example, Ge and SiO) are not suited for high power laser applications at shorter wavelengths due to absorption and poor film structure. Sputtered or electron-beam coated oxides are usually used for these applications at wavelengths below 2.1µm. Many oxides have transmission in the IR region [1], but most have regions of absorption above 2.1µm.

Ion Beam Sputtering (IBS) is well suited to producing optical oxide coatings with high density, low absorption and scattering, high laser damage threshold, and high environmental durability. IBS coatings are also very uniform through coating layers and have very stable optical properties, making it possible to achieve very challenging optical coating performance specifications. This paper presents results of characterizing the most common IBS coated oxide materials up to 3.3µm and evaluates their potential for use in coatings at these longer wavelengths.

## 2. Results

Optical transmission of single-layer-coated YAG substrates was analyzed to determine the index of refraction and the extinction coefficient of the coating materials. For a homogeneous coating layer with no absorption, the transmission curve consists of a series of oscillations where the transmission returns to that of the uncoated substrate transmission for all wavelengths where the coated layer has an optical thickness equal to an integer numbers of half waves [2].

We applied the 4 coating material to 1mm thick un-doped YAG witness samples. We measured the transmission spectra with a Varian Cary 500 UV-VIS-NIR spectrophotometer which has a maximum measurement wavelength of 3.3µm. We then used a commercial software package (Essential Macleod) to fit the refractive index, *n*, and extinction coefficient of the materials to the measured transmission spectra.

Fig. 1 shows the measured transmission spectra for the 4 different coating samples, $SiO_2$, $Al_2O_3$, $Ta_2O_5$, and $TiO_2$, together with the uncoated YAG substrate. $SiO_2$ and $Al_2O_3$ have a lower index than the YAG substrate, and the transmission curves are therefore above the uncoated transmission curve. $TiO_2$ and $Ta_2O_5$ have a higher index then the substrate and have transmission curves that are below the uncoated substrate curve.

All of the materials return to the uncoated transmission curve at an integer number of half waves for wavelengths below 2µm. At wavelengths longer than 2.5µm, the curve shapes become distorted due to absorption.

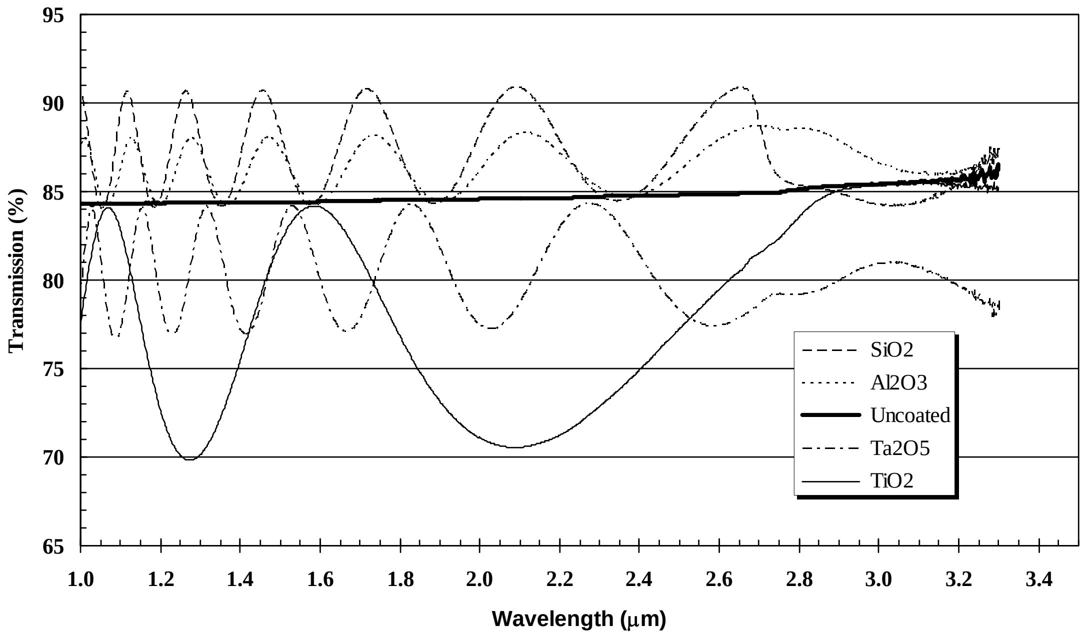


Fig. 1. Transmission spectrum for uncoated, $SiO_2$, $Al_2O_3$, $Ta_2O_5$ and $TiO_2$ coated un-doped YAG substrate.

It is clear that $Ta_2O_5$ has about 5% absorption compared to the uncoated transmission at 3μm. $Al_2O_3$ and $TiO_2$ do not have measurable absorption at 3μm. $Al_2O_3$ actually shows a slightly higher transmission than the uncoated substrate at 3μm, which does not fit our model of a homogeneous layer and is attributed to inaccuracy in the spectrophotometer measurement.

The fitted parameters of the samples are listed in Table 1. The $SiO_2$, $Al_2O_3$, and $Ta_2O_5$ coatings were coated to be approximately 3 half-waves optical thickness at 3μm, while the $TiO_2$ was coated to be 1 half-wave optical thickness at 3μm to minimize crystallization of the thick single layer coating.

| **Material** | **Coating layer thickness** | ***n* at $\lambda$ = 1.5μm** | ***n* at $\lambda$ = 3μm** | **Extinction coefficient at $\lambda$ = 3μm** |
|---|---|---|---|---|
| $SiO_2$ | 3.22 μm | 1.47 | 1.42 | 9E-4 |
| $Al_2O_3$ | 2.90 μm | 1.65 | 1.62 | - |
| $Ta_2O_5$ | 2.20 μm | 2.09 | 2.04 | 5E-3 |
| $TiO_2$ | 0.68 μm | 2.33 | 2.30 | - |

*Table 1. Overview of coating samples and parameters extracted from fitting the transmission spectra of the samples*

## 3. Conclusions

Of the tested oxide materials, $Al_2O_3$ and $TiO_2$ have negligible absorption at 3μm wavelength. Although the optical index contrast ratio is not as large as that of the usual $TiO_2/SiO_2$ material combination, an $Al_2O_3/TiO_2$ quarter-wave reflector stack still has a 500nm bandwidth when centered at 3μm and can be optimized for high transmission at shorter wavelengths.

## 4. References

[1] M. Friz and F. Waibel, “Coating Materials” in *Optical Interference Coatings*, N. Kaiser and H. K. Pulker, ed. (Springer, 2003), pp. 105-130

[2] H. A. Macleod, “Thin-Film Optical Filters”, Third Edition (Institute of Physics Publishing, 2002), pp. 420-436