Optical Properties, Morphology and Temperature Influence of SiO_2, Nb_2O_5 and Ta_2O_5 Films as a Function of Ion Energy

Sheetal Chanda, William Cote, Maria Slocum, Markus Fredell and Thomas D. Rahmlow, Jr.
Omega Optical, Inc, 21 Omega Drive, Brattleboro, VT. 05301
schanda@omegafilters.com

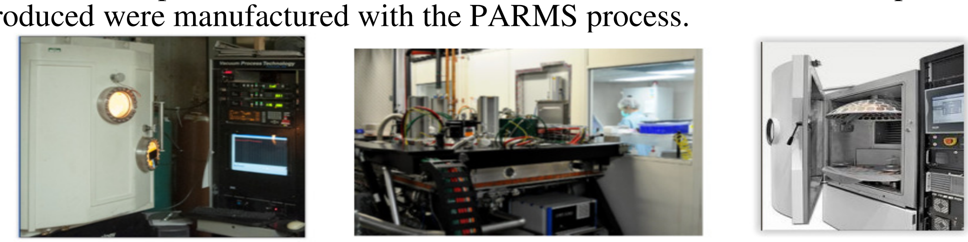
Abstract: We will present characterization of film properties of oxide thin films deposited in four production machines. Optical properties and morphology of the films from the machines will be compared. Thermal stabilization of filters comprised of oxides is demonstrated. Examples of challenging filters produced by PARMS process are presented.

1. Introduction

Hard oxide coatings provide several benefits for producing interference filters in comparison to traditional materials such as zinc sulphide and cryolite. They can provide excellent environmental stability to obviate the need for lamination. They also provide high transmission into the UV. In order to reap these benefits, the films need to be dense and chemically stoichiometric. One important factor in achieving these properties is the amount of ion energy added to the growing film. Density of the thin films also dictates how close the refractive index is to the bulk value and the stability of index in various environments. A deposition process with parameters which allow achieving the above properties makes it possible to manufacture complex optical filter designs.

2. Experimental Procedure

This paper is aimed at characterizing optical properties and morphology of oxide thin films in production machines that use different ion assist sources. Comparison is made between properties of films made in an EBeam chamber with Mark II ion gun (EBeam), EBeam chamber with a Plasma Ion Assist (PIAD) and a Plasma Assisted Reactive Magnetron Sputtering chamber (PARMS) shown in Fig.1 [1]. Single layer thin films of Nb_2O_5, SiO_2 and Ta_2O_5 were deposited. Refractive index (n) was calculated in the visible to mid infra red region from transmission measurement of thick oxide films. Film morphology was examined with cross section SEM. Measurements involved in demonstration of thermal stabilization of filters were performed by putting the filters in an environmental chamber. Filter performance was measured by fiber optic coupling of transmitted and received light to a Cary 500 spectrophotometer. Transmission measurements were performed at 25^0C increment from -50^0C to 50^0C. Examples of challenging filters produced were manufactured with the PARMS process.



E-Beam/ Mark II IAD (Ebeam) | Plasma Assisted Reactive Magnetron Sputtering (PARMS) | E-Beam Plasma-Ion Assisted Deposition (PIAD)

Fig. 1. Production machines and processes compared in this study

3. Optical Properties and Morphology

Dispersion curves of refractive index of Nb_2O_5 thin films deposited by three different processes are overlaid in Fig.2. The curves are compared to bulk Nb_2O_5 and it can be seen that the films from the PARMS and the PIAD processes are close to bulk [2]. It is evident that the ion assist is very effective in both these processes.

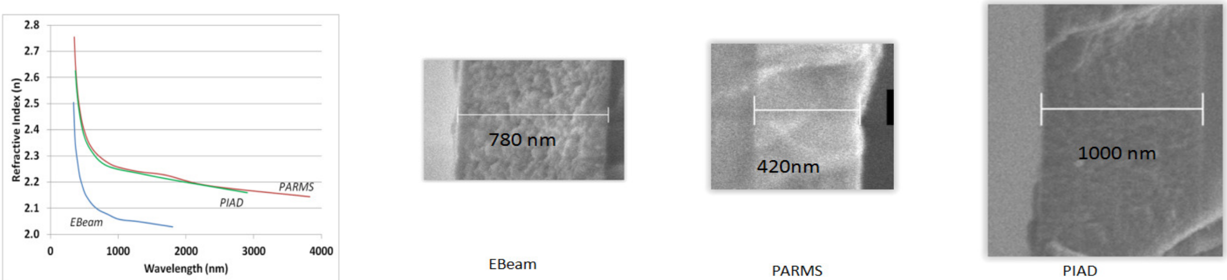


Fig. 2. Dispersion curve of refractive index and SEM pictures of Nb_2O_5 from different processes

Fig.2 also shows preliminary cross-section SEM pictures of the three Nb_2O_5 films. The films from the PARMS and the PIAD process appear to be amorphous with no signs of a columnar structure. The film from the EBeam process has a structure in it and suggests a porous structure. The porosity in the EBeam film agrees with the refractive index being lower. The above statements can be confirmed with XRD measurements.

Fig 4. presents an overlay of dispersion curves of refractive indices of Nb_2O_5, Ta_2O_5 and SiO_2 from two machines working on the PARMS principle. It is shown that the films from both machines match very well and are stable.

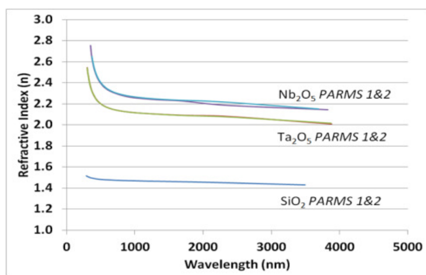


Fig. 4. Dispersion curve of refractive indices of different oxides produced with the PARMS process

4. Thermal Stabilization

One key requirement for narrow and ultra-narrow bandpass filters, in addition to the working at a wider AOI, is the performance of the filter to be stable over the operating temperature range of the instrument. The amount of shift in wavelength due to change in temperature has been shown be dependent on the coefficient of thermal expansion (CTE) of the substrate used [3]. Thermal shift is measured for the same filter deposited using PARMS process on three different substrates types. The plot in Fig. 5 shows the measured shift in central peak wavelength versus the CTE of each glass for narrow bandpass filter (1550BP2.3) made with Nb_2O_5 and SiO_2. The zero intercept for this filter is a substrate with a CTE of 9.3 ppm [4]. The thermal shift of the filter on B270 is 0.22 nm over a temperature range of 100^0C.

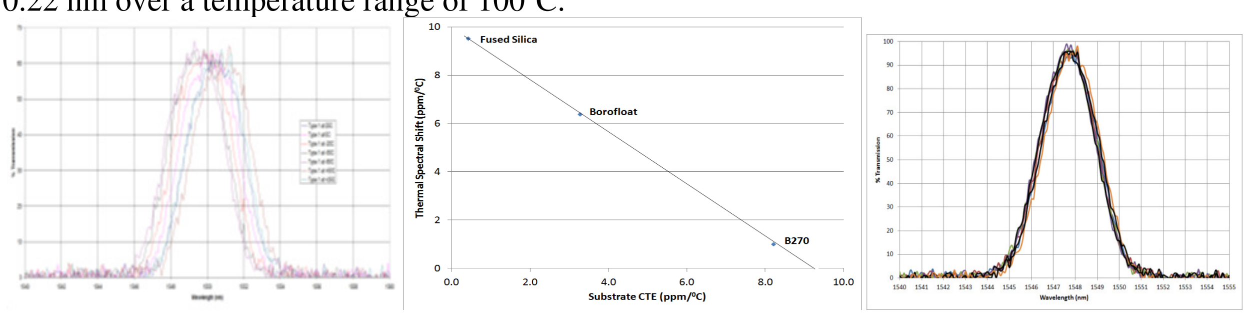
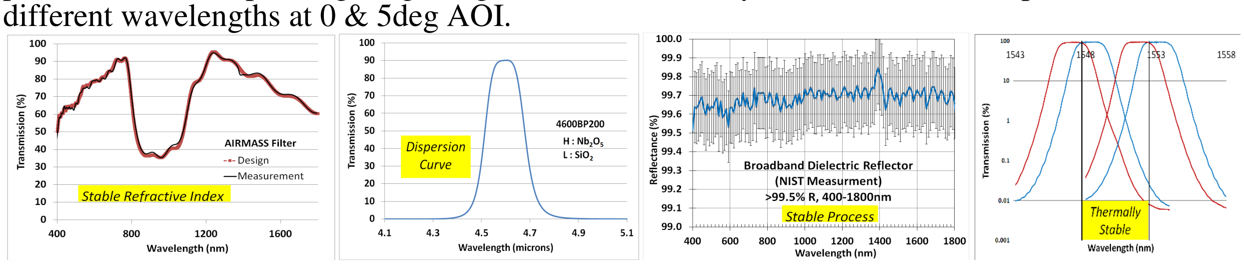


Fig. 5. Thermal shift of filters on 7980 (left) and B270 (right). Plot showing the zero intercept at 9.3 ppm

5. Examples of challenging filters produced using PARMS process

By virtue of having a stable refractive index over time, knowing the dispersion curve over wide range of wavelengths, a stable process over long run times and ability to thermally stabilize filters, we were able to produce challenging filters in the recent past.

Fig 6(a) shows an example where as a result of having a stable index, it is possible to make spectral shaping filters with reproducibility. An airmass filter whose performance matches very closely with the model is shown. Knowing the dispersion curve very well allowed us to produce a very high performing band pass filter (4600BP200) in the MIR region shown in fig. 6(b). This filter is monitored at a higher order as the highest wavelength that can be detected was only 1750nm. Optical monitoring systems are limited by the wavelength range where the detector is responsive. A key requirement for any production machine is to perform in a stable manner over long durations of time. Fig 6(c) shown one example where by having a stable process, a broad band dielectric mirror with reflectance over 99.5% between 400-1800nm was easily achieved. The NIST measurement confirms the result. An application required narrow band filters to work between 0-5^{0} AOI, transmit and reject adjacent laser wavelengths in the ITU Grid C-Band. An additional requirement was to have the filter perform over a wide temperature range. Manufacturing the filter on a B270 glass substrate allowed us to thermal stabilize the filter and perform over the operating range. Fig. 6(d) shows overlay of the narrow band pass filters at two different wavelengths at 0 & 5deg AOI.



(a) (b) (c) (d)

Fig. 6. Examples of filters produced using PARMS process

6. Conclusion

Characterization of thin film oxide layers deposited in four production machines is presented. Optical properties and morphology of Nb_2O_5 single layers from different processes are compared. Thermal stabilization of filters using different substrates has been demonstrated. Examples of filters produced using PARMS process have been presented.

7. References

[1] M. Scherer; U. Schallenberg; H. Hagedorn; W. Lehnert; B. Romanov; A. Zoeller
SPIE Proceedings Volume 7101: Advances in Optical Thin Films III, Norbert Kaiser; Michel Lequime; H. Angus Macleod, Editors, 71010I, 2008

[2] R. Chow, M.A. Schmidt, A.W. Coombs, J.Anguita, M.J. Thwaites, Niobium Oxide Film Deposition Using a High-Density Plasma Source, 49th Annual SVC Technical Conference, April 2006.

[3] Brown, Jeffrey; “Center wavelength shift dependence on substrate coefficient of thermal expansion for optical interference filters deposited by ion beam sputtering”, Applied Optics, Vol 43, No 23, 10 Aug 204.

[4] Sung-Hwa Kim and Chang Kwon Hwangbo, “Derivation of the center wavelength shift of narrow-bandpass filters under temperature change”, Optics Express 5634, 15 Nov 2004.

Acknowledgment: SEM support from Claire E. Marvinney, Christina L McGahan and Dr. Richard F. Haglund of Vanderbilt University.