Error self-compensation mechanism in optical coating production with direct narrow band monitoring

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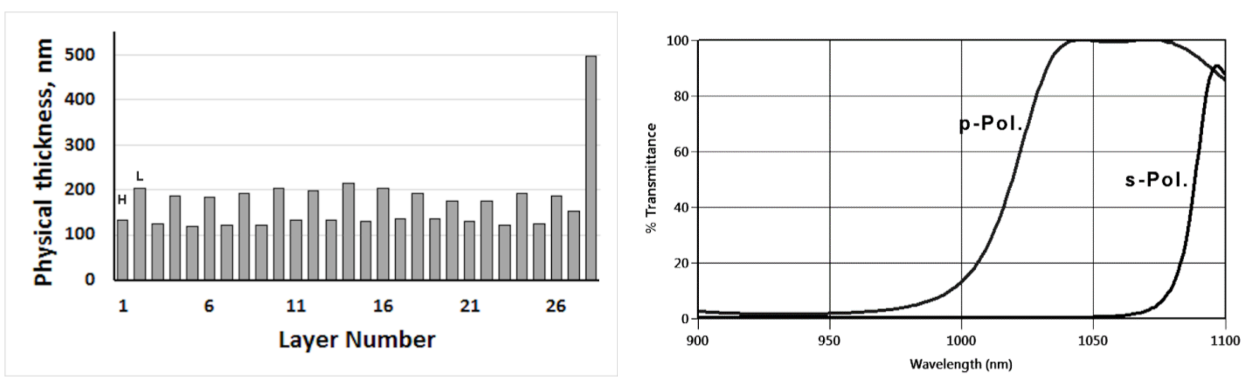
ABSTRACT

The application of broad band optical monitoring (BBOM) has been reported and demonstrated to have an error self-compensation mechanism. This report shows the alternative of narrow band optical monitoring (NBOM) to have the same or better benefits in such an application. The application reported in both cases is a Brewster Angle Polarizer in a narrow band for lasers in the 1054 to 1064 nm spectral region. Narrow band monitoring at the filter wavelength has been successfully used for the production of narrow band-pass Fabry-Perot optical interference filters since the 1950s where the self-compensation mechanism was discovered to be of major benefit. Logic would suggest that broad band monitoring should be most beneficial for broad band coatings such as broad band antireflection, spectral shaping filters over a broad band, etc. In narrow band applications, the coating properties at some spectral distance from the narrow band of interest are of little or no interest. Such is the case in the previous report and in this report; therefore narrow band monitoring is appropriate.

INTRODUCTION

Tikhonravov, et al.[1] reported on the error compensation benefits of the use of broad band optical monitoring to control the layer thicknesses of a Brewster Angle Polarizer in the 1054-1064 nm spectral region. They also provided a mathematical description of how the compensation operates. The design which was analyzed there was from a paper by Zhupanov, et al.[2]. That design is approximated here as shown in Fig. 1. The design is on a substrate of index 1.52 at an angle of incidence of 55.6° so that the back side of the substrate needs no antireflection coating because it is at the Brewster Angle for the *p*-polarization of index 1.52 in air.



(a) (b)

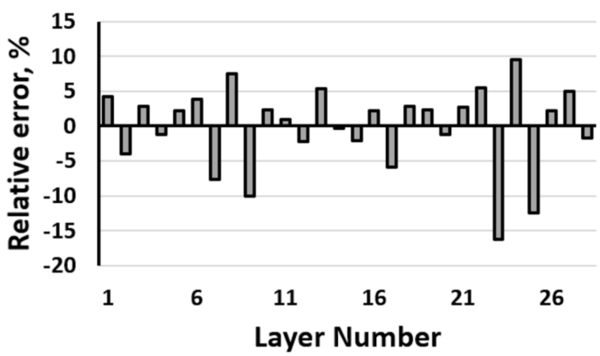
Fig. 1. Physical thickness (a) and theoretical *s*- and *p*-transmittances (b) of the 28-layer polarizer design angle or 55.6° (Brewster Angle) to eliminate reflection of the *p*-polarization from the uncoated back side of the substrate.

Tikhonravov, et al.[1] monitored this coating with a BBOM; in this present paper, NBOM is used with comparable or even improved results. This polarizer is only a narrow band application for the 1054 to 1064 nm, which is related to a narrow band pass filter (NBP) which has historically been monitored at the single wavelength of its pass band, for which error compensation has been shown to be powerful. Because the present case is to be applied at 55.6°, but monitored at near-normal incidence, the single narrow-band monitoring wavelength is chosen at 1235 nm, which is the result of ~1044 nm at 55.6° being observed at 0°.

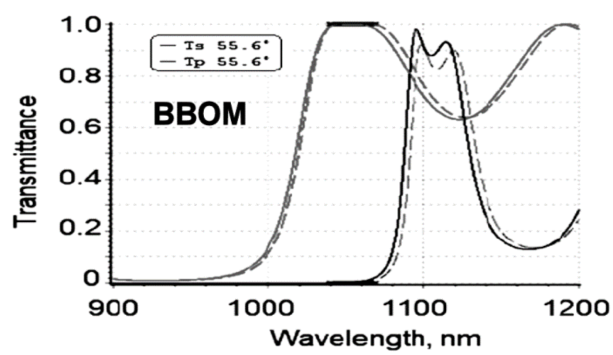
NBOM VERSUS BBOM STRATEGY AND EFFECTS OF NOISE

The monitoring wavelengths of a few matching layers before and after the regular layers of the "blocking band QWOT stack" have been adjusted for better cut point sensitivity per the report of Willey[3]. Each layer of the NBOM strategy was monitored using the POEM strategy as detailed in Ref. 4.

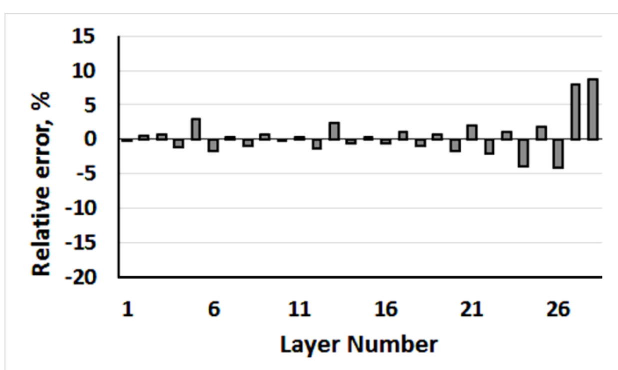
Figures 2a-d and 3a-d compare the layer errors and resulting spectra for the BBOM of Ref. 1 with the NBOM of this report.



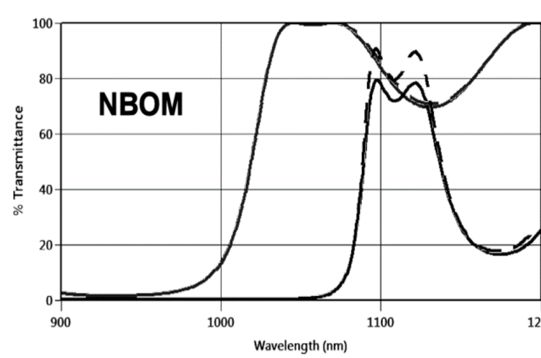
(a)



(b)



(c)



(d)

Fig. 2. (a) Thickness errors determined for the first BBOM simulated polarizer production run, (b) solid curves are *s*- and *p*-transmittances corresponding to the design with these errors, the dashed curves are transmittances of the design without thickness errors, (c) thickness errors determined for the first NBOM simulated polarizer production run, (d) solid curves are *s*- and *p*-transmittances corresponding to the design with the first set of errors, dashed curves are transmittances of the design without thickness errors.

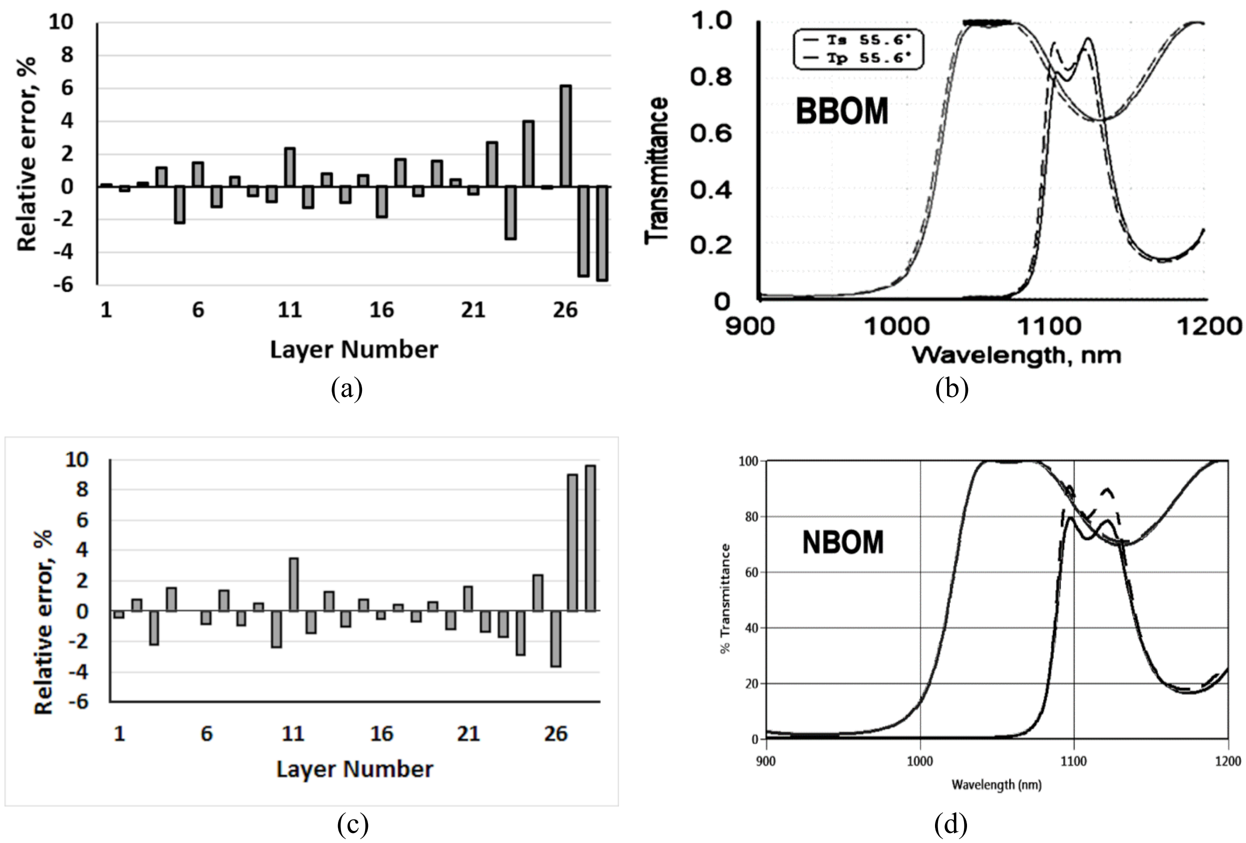


Fig. 3. (a) Thickness errors determined for the second BBOM simulated polarizer production run, (b) solid curves are *s*- and *p*-transmittances corresponding to the design with these errors, the dashed curves are transmittances of the design without thickness errors, (c) thickness errors determined for the second NBOM simulated polarizer production run, (d) solid curves are *s*- and *p*-transmittances corresponding to the design with the second set of errors, dashed curves are transmittances of the design without thickness errors.

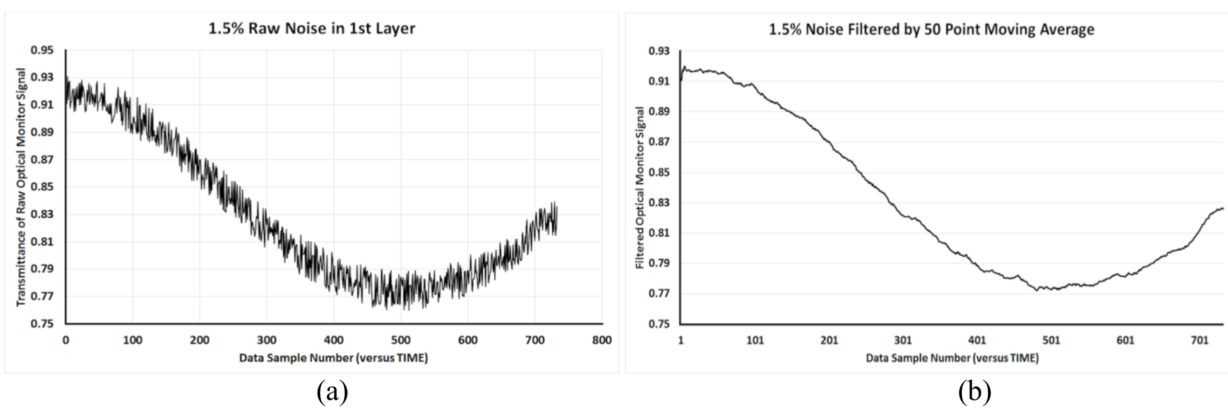


Fig. 4. (a) 1.5% random noise in the raw optical monitor signal at the monitoring wavelength, and (b) that noise after mathematically filtering with a 50 point moving average before determining the layer termination point.

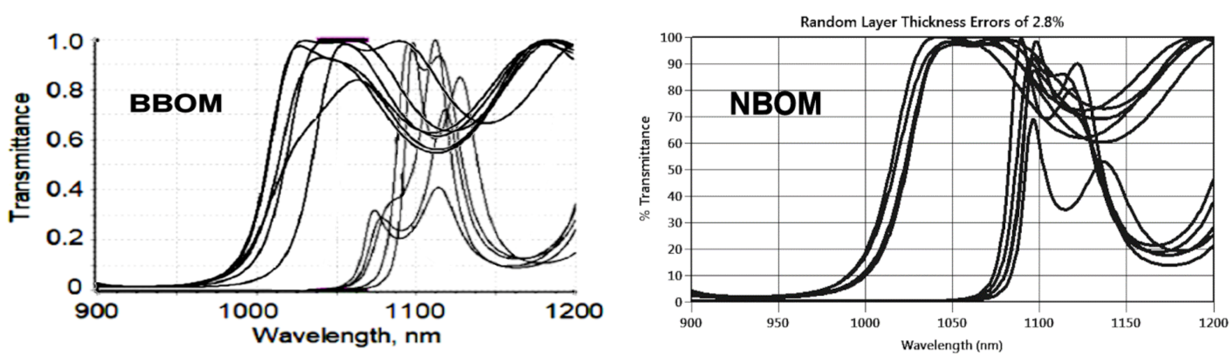
Figures 2a-d and 3a-d show the resulting errors of two successive cases of the simulated production of the BBOM monitored and NBOM monitored design in the presence of 1.5% noise in the raw optical monitor signal as shown in Fig. 4a and its filtered signal in Fig. 4b. This is considered to be a very large amount of noise for industry standards as reported in Ref. 5 which states: "Experience seems to indicate that the typical real world photometric noise may be as little as 0.1%, it is usually less than 0.5%, and it rarely is worse than 0.9%".

RESULTS

The noise in the BBOM of Ref. 1 was not reported, but Figs. 2a and 2c of that reference have been measured to show STDev of the errors at 5.9% and 2.5% respectively. The data for the current NBOM work shows a STDev of 2.8% over 15 samples. This implies that the NBOM used here is at least as effective in compensating for errors as the BBOM, and it is possibly better, depending on the noise level in the BBOM system.

Figures 2d and 3d for the NBOM with error compensation as compared to Figs. 2b and 3b for the BBOM with error compensation seem to show somewhat better control of the edges of the s- and p-polarization. It is surmised that the BBOM would control the spectrum better than the NBOM over a wider range than plotted here, but that wide range is of no concern to the task of this coating.

Figure 5a and 5b, with no error compensation, are shown for direct comparison of Fig. 3 of Ref. 1 (reproduced in Fig. 5a) with the NBOM equivalent of this work. Both show results which demonstrate that error compensation is **necessary** for usable production results in a coating of this nature.



(a) (b)

Fig. 5. Examples of *s*-transmittances and *p*-transmittances for five simulated runs with 2.8% random uncorrelated thickness errors in this design (Fig. 1 from Ref. 1) in (a) (BBOM) and the current NBOM work in (b) .

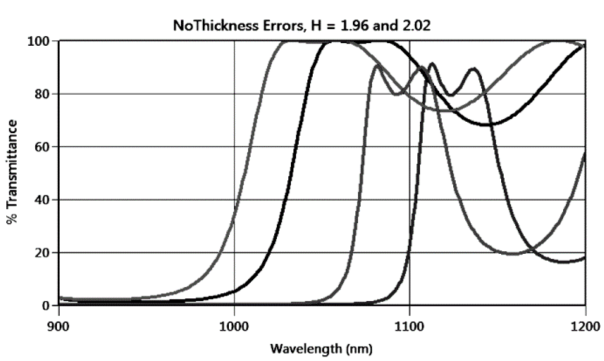


Fig. 6. Influence of high index variations from 1.96 to 2.02.

Figure 6 shows the influence of the high indices other than the design index (1.99). Both BBOM and NBOM can preserve the shape of the spectrum in the pass band, but these edges will shift in either strategy. This is because the edges on the shot wave side of the pass bands are determined by the blocking stack differences in indices of refraction. These cannot be reasonably compensated for by changes in layer thicknesses.

CONCLUSIONS

Error compensation has been shown to function well with both BBOM and NBOM of parts which are direct monitored. The area of spectral interest for this Brewster Angle Polarizer is only for the narrow band of wavelengths from 1054 to 1064 nm, and this is therefore similar to a NBP filter. Logic would imply that a NBP filter might be best controlled by a NBOM, while a wide pass band coating (such as a broad band antireflection coating or a spectral shaping filter) might be better controlled by a BBOM.

REFERENCES

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