Adjusting non-quarter wave optical thicknesses in narrow band pass filters

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The common design historically for narrow band pass filters has been with quarter wave optical thickness layers at the center wavelength of the passband. The control of the layer thicknesses has been by termination of the layers at their turning points where the change in transmittance with layer thickness is zero. This has been shown to be less accurate than the option of termination after a turning point, where the change in transmittance with layer thickness is greater, thus allowing more accurate/precise terminations. Procedures are given to design such filters with controlled %T change after a turning point while preserving the required passband.

OCIS codes: (310.4165) Multilayer design; (310.5696) Refinement and synthesis methods; (310.6188) Spectral properties; (310.6805) Theory and design.

1. Introduction

Narrow band pass (NBP) filters have historically been made of layers which are a quarter wave optical thickness (QWOT) at the passband wavelength, and each layer has been monitored by terminating at the turning points (TPs) of those layers. Studies[1-3] have shown that the benefits of terminating well beyond those TPs as shown in Fig. 1. This gives an advantage of making the layer terminations where the slope of the %T with increasing thickness is larger than at the TP, where it is zero. This provides more accurate/precise terminations and thereby better spectral control. The preferred strategy is to make the terminations at a certain **P**ercentage down or up from the previous **O**ptical **E**xtrema (TP) in the **M**onitoring trace (POEM). Figure 2 shows the typical monitoring curve for a NBP filter where the termination of each layer is done at a TP.

The ratio of the optical thickness of each layer-pair (which is 2 QWOTs at the passband wavelength) to its thinnest layer is 2:1 in the classic NBP design. If this ratio is changed to 4:1 as in Fig. 3 (or any other ratio), the termination points of the layers are no longer at TPs. It can be noted in Fig. 3 that layers 2, 4, and 6 have a %T distance (POE) from the previous TPs which are nearly equal. However, the %T difference is smaller for layers 8, 10, and 12. The odd-numbered layers can be terminated by the POEM, quart crystal monitor, or time/power as best suits the deposition process used. Errors in these layers will tend to be compensated for in the next layer.

This paper describes how to change a design from that of Fig. 2 to that of Fig. 3 and also how to adjust the design of Fig. 3 so that all of the POEs of layers 2, 4, 6, 8, 10, and 12 are the same, such as 25%. This can be done with the minimum impact practical on the spectral properties of the pass band. Figure 4 compares the performance of the three designs in Figs. 2, 3, and (after adjustment as shown later) in Fig. 8.

If it is desired to match the bandwidth of the 2:1 design with a 4:1 ratio, two additional layer pairs can be added to produce Fig. 5. This matches the narrow bandwidth, but still does not produce the same optical density and width in the blocking bands. The substrate in all of these cases has an index of refraction of 1.52, H is 2.35, and L is 1.48.

2. Procedures

To change from 2:1 to 4:1, several design targets (~10) are set for the 540 nm passband from 539 to 541 nm, and the prescription is changed to G (.5H 1.5L)3 2H (1.5L .5H)3 A. Figure 6 shows the spectrum of this design before adjustment, as compared to the 2:1 design. The design is optimized to the targets using **only** the 2H spacer layer thickness as a variable. This should converge to ~1.63394H for that layer's thickness. One or more layers can be added as antireflection (AR) layers on the end of the design and optimized for maximum %T in the passband. This would result in the design G(.5H 1.5L)3 1.63394H (1.5L .5H)3 .15723H 1.41283L A.

To design a two-cavity version of this 4:1, the design is copied, except the AR, onto the beginning of the one-cavity design plus a 1L coupler layer in between the two cavities. The targets are broadened to 538-542 nm, and optimized with the coupler layer and the AR layers as variables. This produces a two-cavity design. To extend this design to a three-cavity version, the same first group of the design as above is copied onto the beginning of the two-cavity design plus a 1L coupler layer in between the two cavities. The targets are further broadened to 537-543 nm, and the design is optimized with the **two** coupler layers and the AR layers as variables. This produces the three-cavity design shown in Fig. 7. The prescription is G(.5H 1.5L)3 1.63394H (1.5L .5H)3 1.28404L (.5H 1.5L)3 1.63394H (1.5L .5H)3 1.38015L (.5H 1.5L)3 1.63394H (1.5L .5H)3 .15481H 1.35186L A.

3. Adjustments

The adjustment of the one-cavity 4:1 to have equal POE (such as 25%) for all of the even layers is as follows. The parentheses are removed in the design to form 13 layers plus AR layer(s). The %T versus thickness is calculated. In layer 2, the %T of the maximum and minimum of the simulated monitor trace are measured. The 25% of this excursion from maximum to minimum is calculated, and subtracted from the maximum (in this case). This is the %T target at which to terminate layer 2 for a POE of 25%. The physical thickness for layer 2 which brings the signal to this %T is found. The design value for layer 2 is replaced with this new value and the %T versus wavelength of that design is evaluated. The passband will have shifted a small amount. The new design is then reoptimized by varying only the thickness of layer 3, the layer following the one which has just been adjusted. This restores the peak to 540 nm.

This process is then repeated to achieve 25% POE for each of the even layers through 12 in order and the odd layer after each is reoptimized to restore band centering. The peak %T of the passband can be expected to drop as this procedure progresses, but this can be corrected, after layer 12 is done, by optimizing layer 13 (and 14 or more) as the AR layers for the passband. This should result in the monitor trace seen in Fig. 8 where all of the even layers have a POE of 25% and its spectral plot seen in Fig. 4.

As can be seen in Fig. 4, the passband widens and the blocking bands become less deep when the designs depart from the 2:1 QWOT stacks. However, Fig. 5 shows that the passband can be restored by adding a few layers to the new design. More blocking can be gained by more cavities.

Simulation software shows this design to be robust in the presence of optical monitor noise of more than ±0.7%. This is much greater noise than that reported as typical in private conversations with optical monitor producers at Leybold Optics[4] and Intellemetrics[5]. POEM shows as great a benefit from error compensation as does the classical TP monitoring. However, in the POEM case, the passband and the sidebands are much more precise, accurate, and controlled than in the TP cases.

4. Another Observation

When the monitoring traces of the 2:1, 4:1, and adjusted 4:1 designs are overlaid as seen in Fig. 9, it can be noticed that each layer-pair has the same thickness, independent of the design. This indicates that the passband is determined by the interactions of the reflections from those common interfaces, and the rest of the spectral structure details result from the other interface reflections.

5. Conclusions

The positions of the layer terminations for the monitoring of NBP filters can be adjusted over a wide range for the benefit of the monitoring precision/accuracy, for the benefit of stress control, etc. The adjustment procedure has been described. It appears that the constant element is the thickness between the interfaces of the layer pairs, and interfaces between those can be positioned for the benefit of monitoring, stress balancing, spectral shape outside the passband, etc. The passband can remain relatively undisturbed by large changes in interface positions (layer thicknesses) when properly readjusted.

6. References

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Figure Captions

Fig. 1. Terminations at a percentage down or up from the previous optical extrema (TP) in the monitoring trace (POEM).

Fig. 2. Monitoring trace for a normal 2:1 design with TP monitoring. The prescription for this is G (1H 1L)3 2H (1L 1H)3 A.

Fig. 3. Monitoring trace for a 4:1 design which would use the POEM strategy. The prescription for this is G (.5H 1.5L)3 1.63394H (1.5L .5H)3 A.

Fig. 4. Traces for 2:1 (narrowest band), the 4:1, and the 4:1 adjusted for 25% POE (Fig. 8).

Fig. 5. Spectrum for the 2:1 design and the 4:1 with G (.5H 1.5L)4 1.61682H (1.5L .5H)4 A.

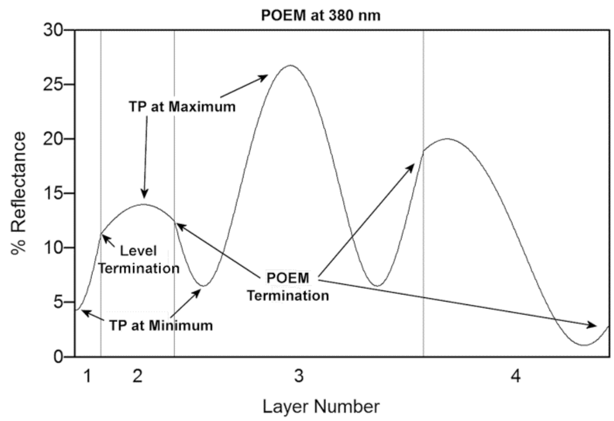
Fig. 6. Design of 4:1 before adjustment of the spacer layer as compared to the 2:1 design.

Fig. 7. Results of three-cavity design at 4:1.

Fig. 8. Monitoring trace for the adjusted 4:1 design which is G .5H 1.52637L .48442H 1.49294L .52253H 1.45555L 1.65607H 1.69498L .27266H 1.65497L .33142H 1.56113L .42147H A.

Fig. 9. Overlaid monitoring traces from Figs. 2, 3, and 8 showing that each layer-pair has the same thickness.

Figures



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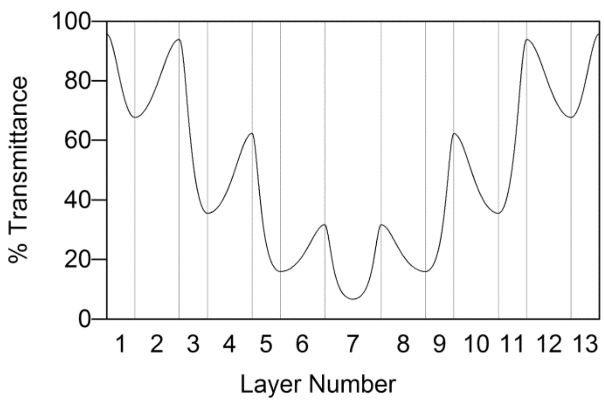

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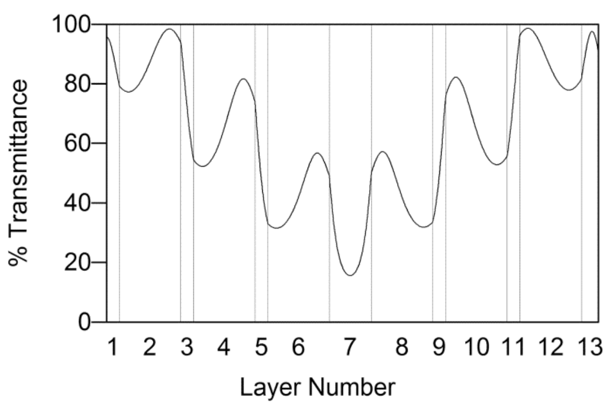

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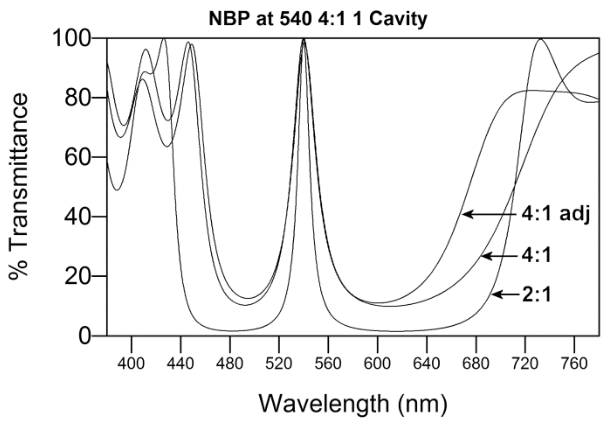

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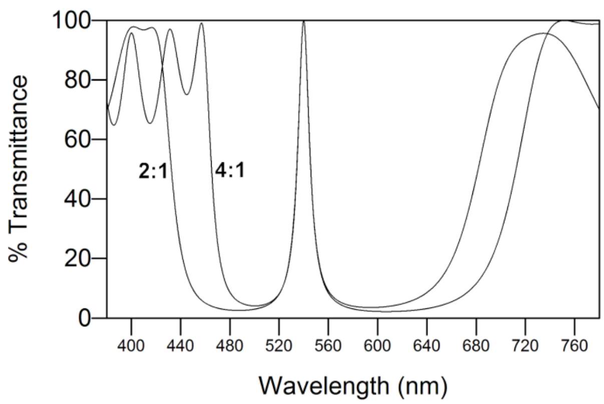

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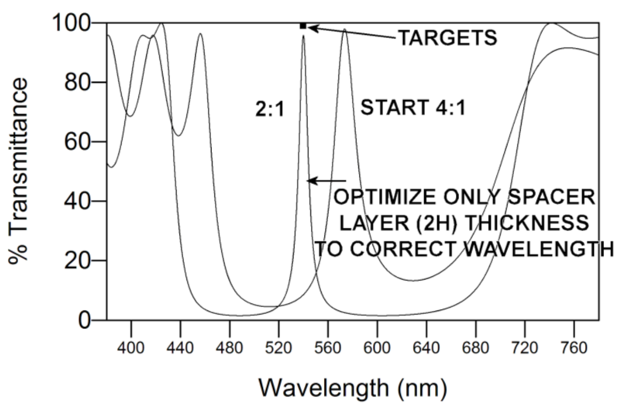

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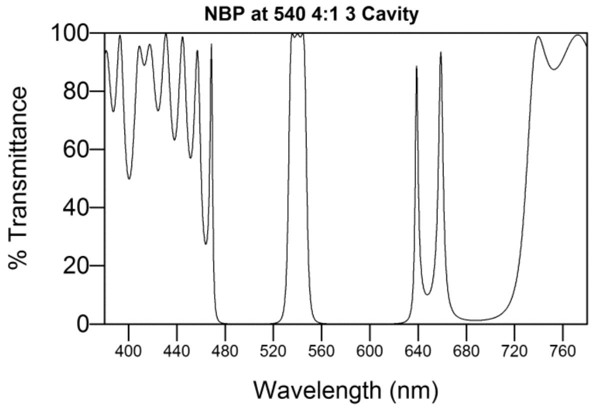

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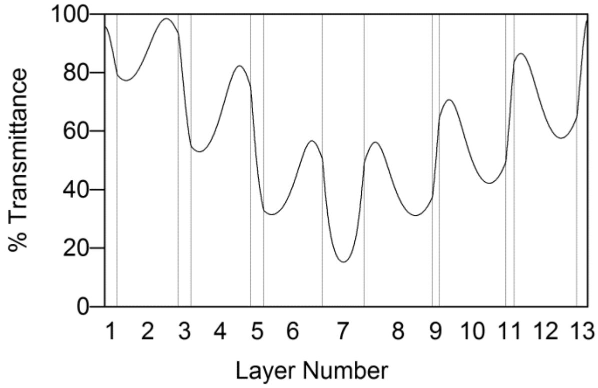

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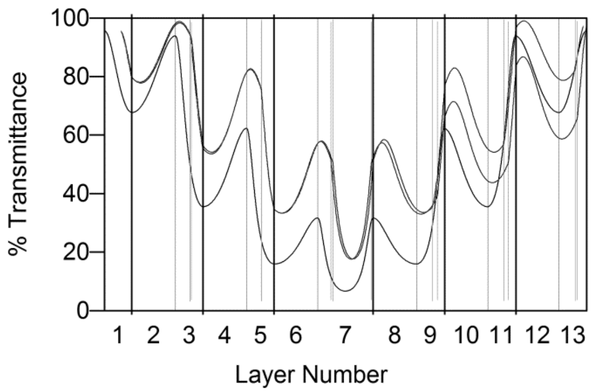

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