Optical Monitoring Scheme for Narrow Bandpass Filters

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SUMMARY

We were presented with the problem of producing a series of narrow bandbass filters in the 8 to 12 micrometer spectral band of high durability with 1.0% tolerances on the edges and bandwidths. After some design study, it was decided to use germanium (Ge) and thorium fluoride (ThF2) as the coating materials and germanium for the substrates. The available coating chamber was equiped with an optical monitor using a photo-multiplier whose response was adequate to 1064 nanometers (nm) but not at much longer wavelengths. Germanium films absorb significantly at 1064nm but it is practical to deposit 15 or more quarter waves (QWOT,s) before the optical monitor signal becomes too attenuated to make reasonable layer terminations. Figure 1 shows a typical example of the monitor signal in reflection for a series of ThF4 and Ge layers. This structure could not be monitored directly in transmittance because the monitoring signal would be too severely attenuated after the first or second Ge layer. However, the whole layer system can be monitored directly in reflection if certain design conditions are satisfied. There is also some flexibility benefit to reflection monitoring in this case where each thick Ge layer masks the reflection characteristics of the underlying layers. Each low index layer has somewhat of a fresh start on the monitor. This approach cannot take advantage of error compensation features as described by Macleod and Pelletier(1) and Zhao(2), but the fact that the layers are being monitored at 1/10th the passband wavelength gives enough sensitivity for good spectral control.

Figure 2 shows the general behavior of a Ge layer of 13 QWOT's with 1-1/2 QWOT's of ThF4 on top in a reflectance circle diagram. The figure does not rigorously deal with the details after Apfel's(3) development, but it does illustrate the concept to a sufficient approximation. The magnitude of the swings of any subsequent Ge layer will depend greatly on where the low layer is terminated. If a low layer were to be an even number of QWOT's after starting from the point of convergence of the Ge spiral on the reflectance diagram, there would be very little modulation on the next Ge layer monitor signal. The Ge modulation is the greatest when the low layer terminates as far as possible from the convergence point of the Ge.

The general approach used to reach a satisfactory design and monitoring scheme has been as follows: 1) design the layer system to meet the passband and blocking requirements, 2) check and adjust the thicknesses of the low index layers so that the Ge

layers have reasonable modulation when monitored, 3) reoptimize the design to the requirements while holding the low layers fixed. This procedure results in a design which meets the requirments and can be monitored successfully.

Some of the specific designs had an additional problem that a few Ge layers had to be more than 25 QWOT's at 1064nm. The monitor signal would be attenuated in the last swings to the point that the cut points could not be determined. We found that we could solve this problem by splitting the thick Ge layer near the middle with a thin layer of low index. When properly chosen, this splitting layer restores the amplitude of the following Ge monitor swings to a relatively high level. Figure 3 shows an optical monitoring example of this splitting of a single thick high (H) layer to a HLH with a thin low (L) layer. Figure 4 shows generally what is happening on a reflectance diagram. It is desirable that the low layer be as thin as practical but have the maximum enhancing effect on the Ge swings. The greatest effect is when the low layer starts near where the swing is most positive on the imaginary axis of the reflectance circle diagram. Approximately 1/5th of a QWOT at 1064nm (1/50th at 10.6 micrometers) of low index material will bring the reflectance point out to where the next Ge layer will start again on the outside of a large spiral. In principle, this process could be repeated as often as necessary to handle even thicker layers of absorbing materials.

The introduction of the splitting layers causes a perturbation in the filter edges and shape of passband which must be corrected at the design stage. The splitting and adjustment of the design is as follows: 1) split the thick Ge layers with a thin (approx. 1/5th QWOT at 1064nm) layer of low index in the middle of the thick high layer, 2) check the monitor curve and shift the thin layer to the left until the start of the thin layer is just after the middle of the downward swing of the nearest Ge swing, 3) reoptimize the design by varying only the second part of the split high index layers and the first and last pair of layers in the entire stack. It has been found that the passband can be readjusted to the same performance as before the split. The edges and shape can be restored by lateral wavelength shifting of the edges and tuning of the outer layer pairs of the stack to clean up the band shape.

Actual filters have been produced using this scheme and seem to be well controlled to within 0.5% in edge position and bandwidt when directly monitored as described.

CONCLUSIONS

The monitoring scheme described has proved to be sufficiently sensitive and reproducible in design and practice to achieve edge control within 0.5% in the 8-12 micrometer spectral region. It allows the use of coating equipment of the more common visible spectrum configuration. The technique of inserting a thin splitting layer to enhance monitoring sensitivity in absorbing layers has been described graphically. It has been shown to be valuable in this application and should be generally useful in a broader range of applications.

REFERENCES

(1) H. A. Macleod and E. Pelletier, "Error Compensation Mechanisms in Some Thin-Film Monitoring Systems," Opt. Acta 24, 907 (1977).
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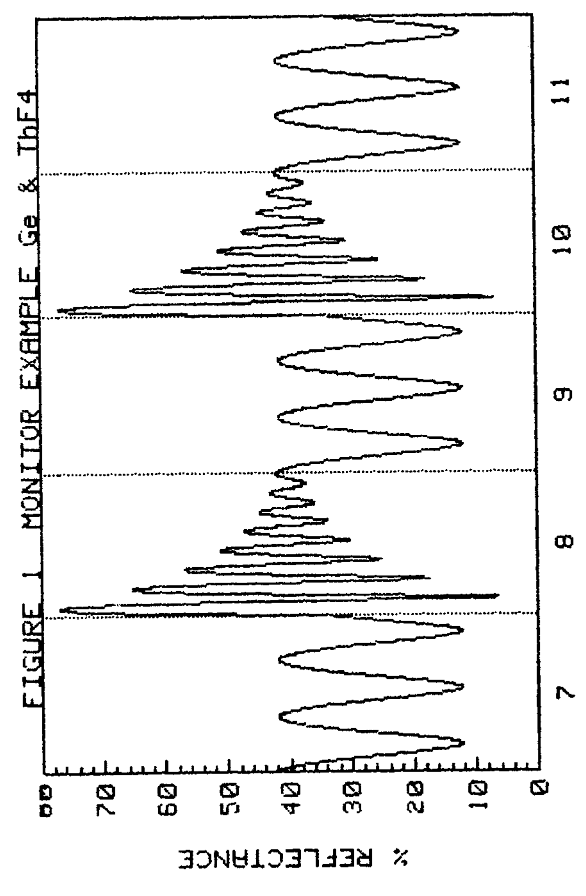


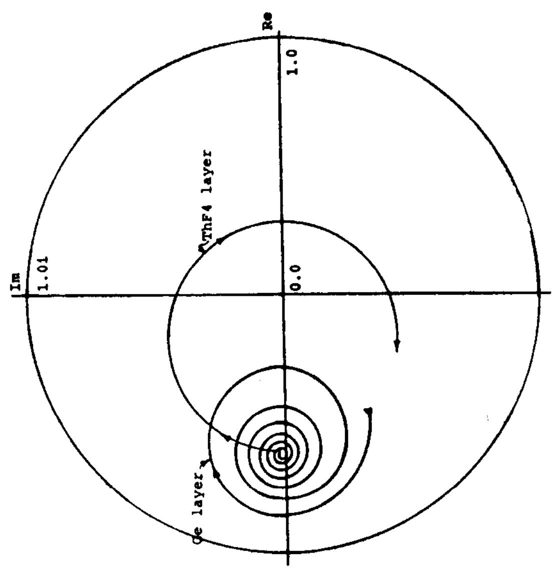
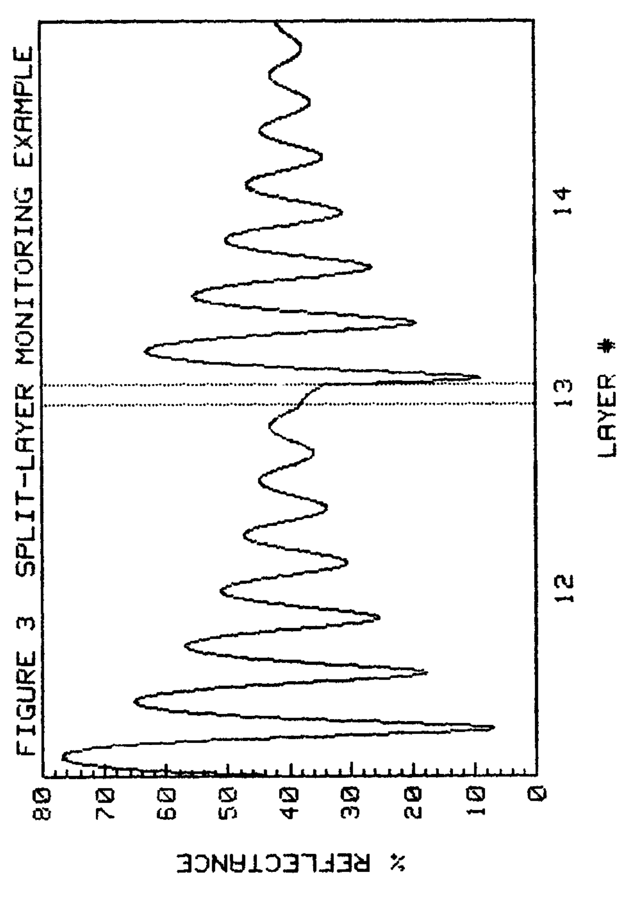


Fig. 2. Reflectance circle diagram of 13 QWOT's of germanium followed by 1-1/2 QWOT's of ThF4.



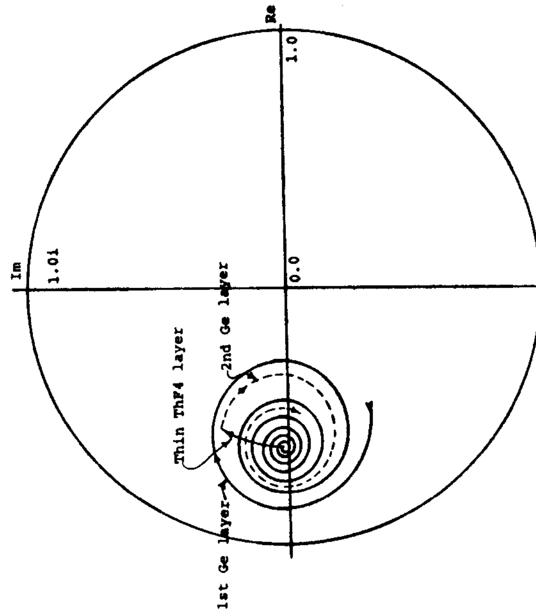


Fig. 4. Reflectance circle diagram of 13 QWOT's of germanium followed by a thin layer (1/5·QWOT) of ThF4 to increase the amplitude of the monitor oscillations on the second germanium layer.