Broadband Antireflection Coatings on High Index Substrates

Ronald R. Willey
Opto Mechanik, Inc.
425 North Drive
Melbourne, Florida 32935

ABSTRACT

We describe the concept, design, and application of simple broadband antireflection coatings for high index materials such as germanium, zinc sulfide, zinc selenide, etc. The object of the work was to develop a broad band antireflection coating from 8 to 11.5 micrometers for germanium and other high index infrared materials. However, the work is generally applicable where a substrate is to be AR coated with materials including a low index lower than the square root of the index of the substrate. The design concept and method which we describe is very simple, graphic, and suited to "back of the envelope" design. Further refinement by computer optimization only provides a minor tuning change. The actual application on Germanium has been quite successful.

INTRODUCTION

In a previous paper(1), we described the use of circle or admittance diagrams to easily visualize coating reflectance versus layer thickness. We showed how they can help the designer gain insight into monitoring sensitivity and other coating effects. These diagrams also lead to some very simple concepts the design of broadband antireflection coatings on high index materials. Figure 1 shows the locus on a reflectance diagram of a low index layer such as thorium flouride coated on a germanium substrate. This starts at the reflectance of the germanium and proceeds to a minimum reflectance which is not zero at the quarter wave optical thickness (QWOT) and then increases to the half wave point before repeating its path. Figure 1 also shows the reflectance locus of a similar low index layer which passes through the admittance equal to 1.0 point or zero reflectance point in air or vacuum. These two locii are the key elements of this discussion. If only two materials are to be used in the AR coating of the substrate and this is the low material, there is a class of three layer coatings where the first and last layers of the AR will lie on these two locii. The only remaining task in the design of an AR will be to find the proper second layer to connect these two locii and optimize the broadband characteristics to suit the requirements.

Figure 2 shows the locii of a range of possible high index second layers which connect the two low index locii. It has been found that the proper choice of the connecting second layer gives a good achromatizing effect similar to that of the half wave second layer in the usual quarter-half-quarter wave (QHQ) designs for broadband AR's on glass. The use of the concept for coating germanium, zinc selenide, zinc sulfide, and high index glass will be shown.

Figures 3 and 4 show the admittance diagrams of the same layers as in Figures 1 and 2. We will use admittance diagrams in the remainder of this paper.

ANTIREFLECTION COATING DESIGNS

The circle/admittance diagrams like Figures 1, 2, 3, and 4 were used to select approximate layer thicknesses near the center of the desired AR band for an automatic optimization of layer thicknesses with respect to the coating requirements. Figure 5 shows the results of such an optimization of a ThF4-Ge-ThF4 coating on germanium. The solid line is the admittance locus for a wavelength near the center of the band, and the dotted lines are the circles for the two extreme wavelengths in the band. It will be seen that all of the circles terminate near the unity admittance or zero reflectance point. It can be seen that as the wavelength gets shorter or the layers appear to be longer, the end of the first layer moves the circle further toward the reflectance minimum point. The longer second layer moves its end point further from the real axis. Finally, the last layer must be longer (which it naturally is) to bring the final termination near the zero reflection point. The converse is true as the wavelength gets longer and the layers appear shorter. This compensation effect is what gives the achromatizing broadband performance desired. Figure 6 shows the reflection of the design over the required band.

The same techniques were applied to an AR on zinc selenide (ZnSe) using the same coating materials. Figures 7 and 8 show the results. We then used ZnSe instead of germanium in the coating and acheived similar performance with different layer thicknesses as shown in Figures 9 and 10. There is almost no difference in the performance, which leaves the choice to the coater for physical properties of production convenience.

The same can be done with zinc sulfide (ZnS) substrates as shown in Figures 11 and 12.

APPLICATION TO HIGH INDEX GLASS

The technique is not as promising for glass substrates because the low index materials available are not lower than approximately the square root of the substrate index. Figure 13 shows the calculated reflectance of three layer coatings of this type on glass of index 1.74 where the second layer is of 2.25 index and the first and third are of 1.2, 1.3, and 1.35 respectively. A classical four layer AR is also shown for comparison. This four layer is an approximation of the QHQ design with appropriate indices. It can be seen that the three layer design with low index layers of 1.2 would be quite superior to the four layer. A three layer with 1.3 index would be more or less comparable to the four layer, and the 1.35 version is inferior to the four layer over the broad band. Figure 14 shows the admittance diagram of the 1.2 low index design which is so desirable but currently unobtainable. Figure 15 shows the diagram for the 1.35 low index version which may be acheivable but is not as desirable.

APPLICATION OF THE DESIGNS

We have produced satisfactory coatings of the Th-Ge-Th on Ge type. It was found that careful attention had to be given to temperatures, rates, and pressures to keep stress, absorption, and durability under control. Because neither Ge nor ThF4 seemed to pass severe abrasion and salt fog tests in our experience to date, small modifications of the basic design have been tried. A thin overcoat of almost any index can be added as part of the last layer where its optical thickness is substituted for an equal optical thickness of the last layer. If the layer is thin enough, its absorption in the pass band may be tolerable even if thick layers would absorb too much to be useful in the overcoating material. The compromise of "thick enough to protect" but "thin enough to transmit" is a key issue in producing a high durability versions of the designed coating. We have chosen to call these very thin layers ALMOST ACHROMATIC ABSENTEE (AAA) layers. Some other applications of such layers were described previously(2). Figures 16 and 17 show the application of a thin isolating layer of Ge over the last ThF4 layer and then a thin layer for hardness on top of that. Note that the effects on the circle diagram and spectral performance are small.

CONCLUSIONS

The concept of the design of a three layer AR on high index substrates has been shown and is amenable to "back of the envelope" design, and it lends insight to what is happening in the design. The technique has proved useful to us in producing practical coatings on germanium for the 8 to 11.5 micron band.

REFERENCES

(1) R. R. Willey, "Sensitivity of Monitoring Strategies for Periodic Multilayers", Proceedings of the SVC April 1987 meeting in Boston.

(2) R. R. Willey, "Optical Monitoring Scheme for Narrow Bandpass Filters", Optical Society of Americal Thin Films Meeting, April 1988, Tucson

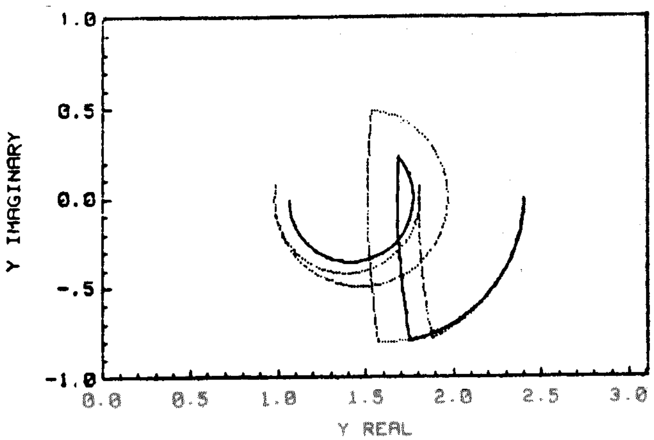

Fig. 7. Admittance of an optimized three layer AR of ThF4-Ge-ThF4 on zinc selenide in same format as Figure 5.

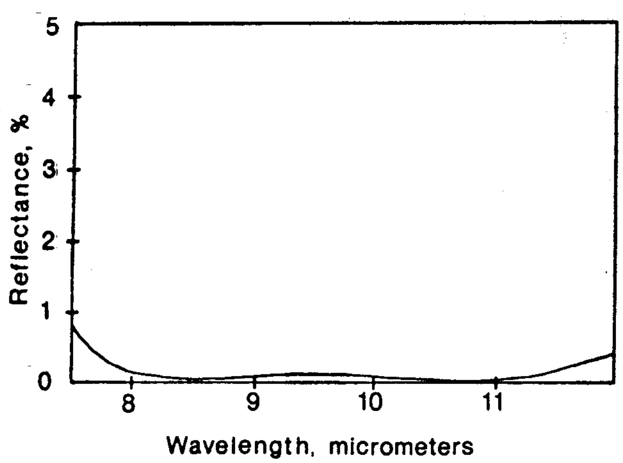

Fig. 8. Reflectance versus wavelength of the optimized three layer on ZnSe in Figure 7.

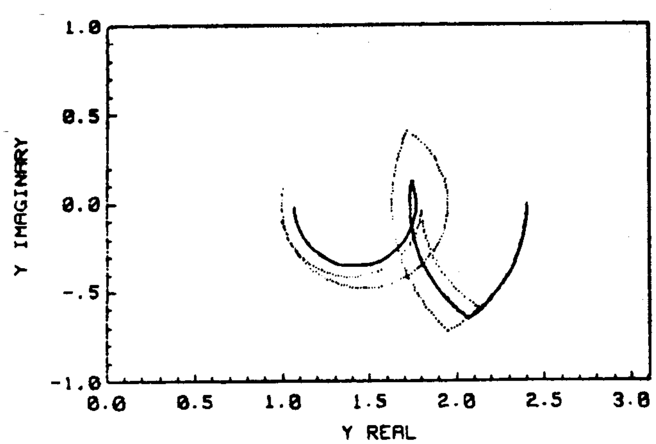

Fig. 9. Admittance of optimized three layer AR of ThF4-ZnSe-ThF4 on ZnSe.

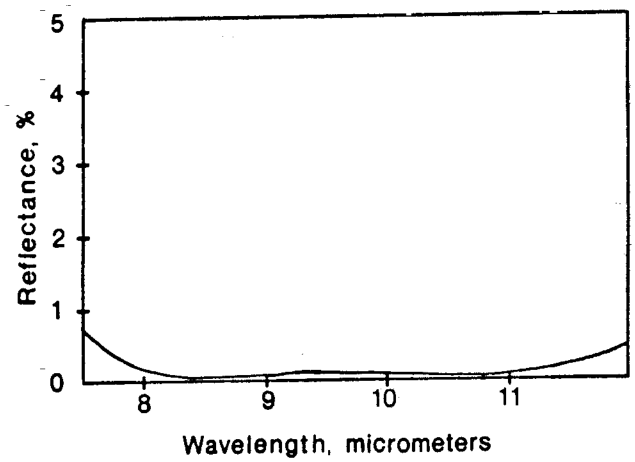

Fig. 10. Reflectance vs. wavelength of the ZnSe AR in Figure 9.

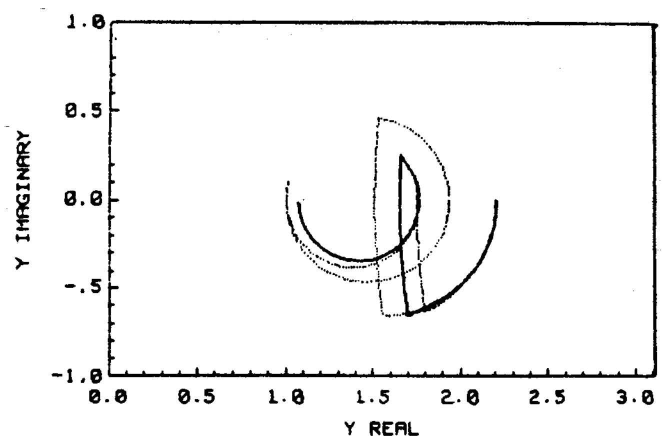

Fig. 11. Admittance of optimized three layer AR of ThF4-Ge-ThF4 on zinc sulfide.

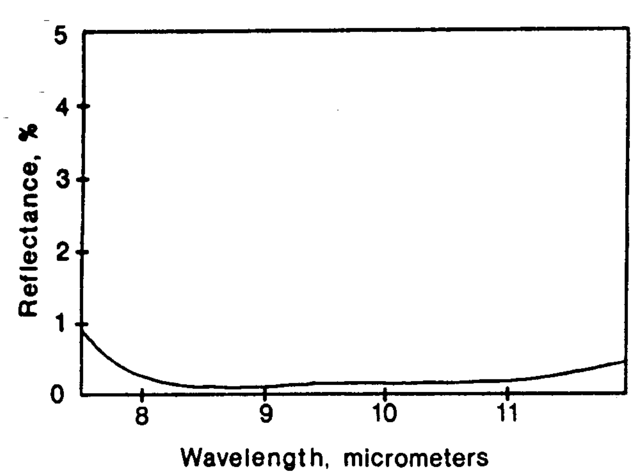

Fig. 12. Reflectance vs. wavelength of the ZnS AR in Figure 11.

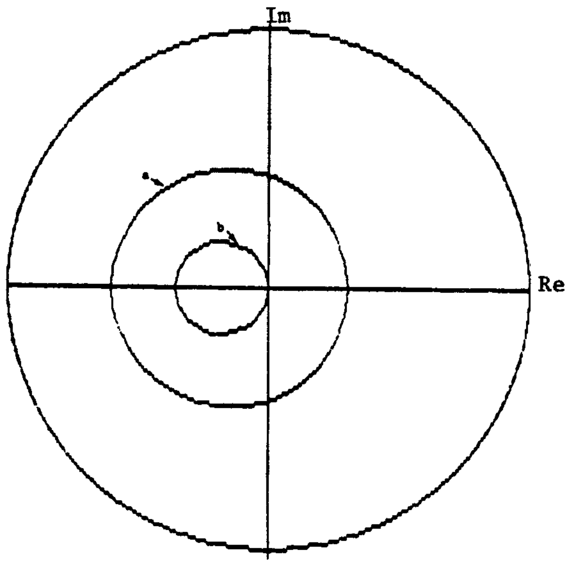

Fig. 1. Reflectance diagram with: a) the locus of reflectance versus thickness of a ThF_4 film on a germanium substrate, b) the locus for a ThF_4 film ending in air or vacuum.

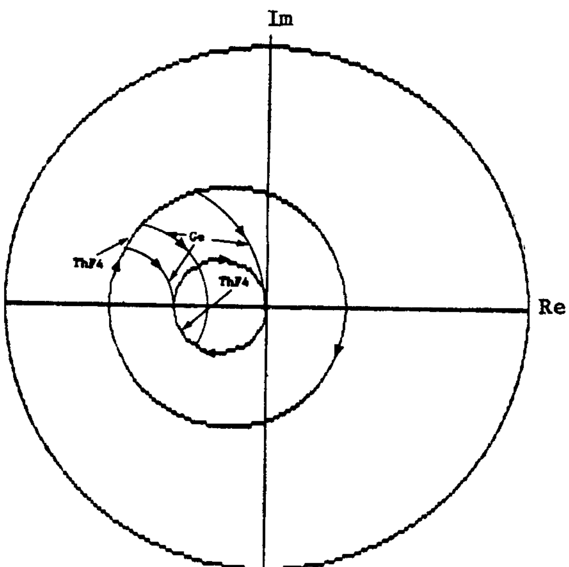

Fig. 2. Reflectance diagram of possible high index (germanium) layers which could connect the two low index layers that start at the germanuim substrate and end at the reflectance of a vacuum.

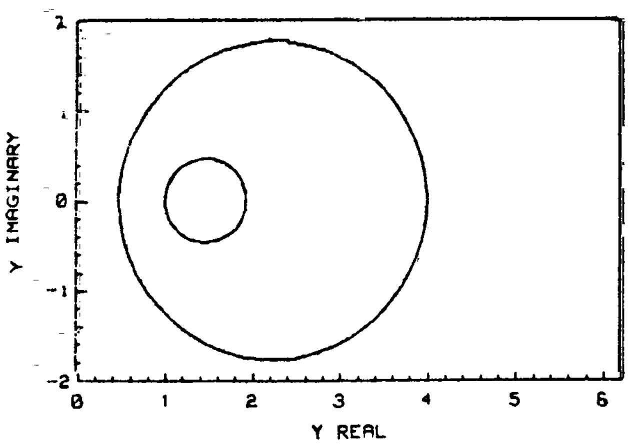

Fig. 3. Admittance diagram of the same films as Figure 1.

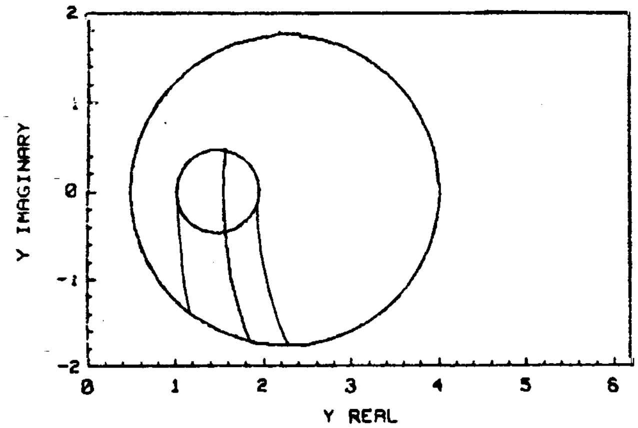

Fig. 4. Admittance diagram of the same films as Figure 2.

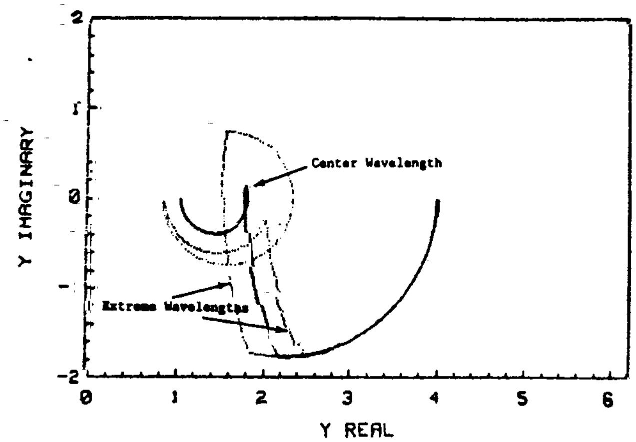

Fig. 5. Admittance of an optimized three layer AR of ThF_4-Ge-ThF_4 on germanium. Solid line is for a wavelength at the center of the band. Dotted lines are the long- and shortwave limits of the band.

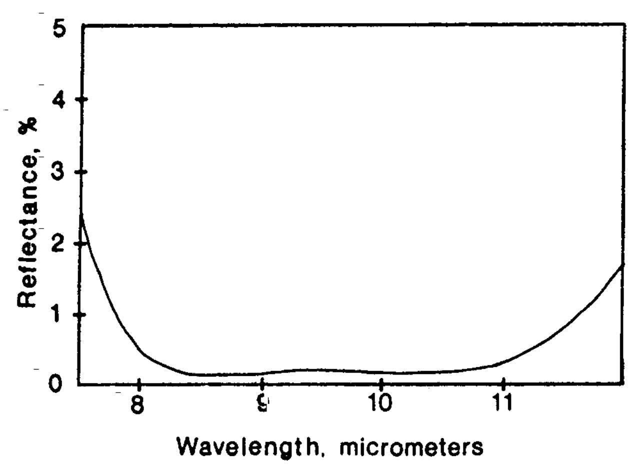

Fig. 6. Reflection versus wavelength of the optimized three layer design in Figure 5.

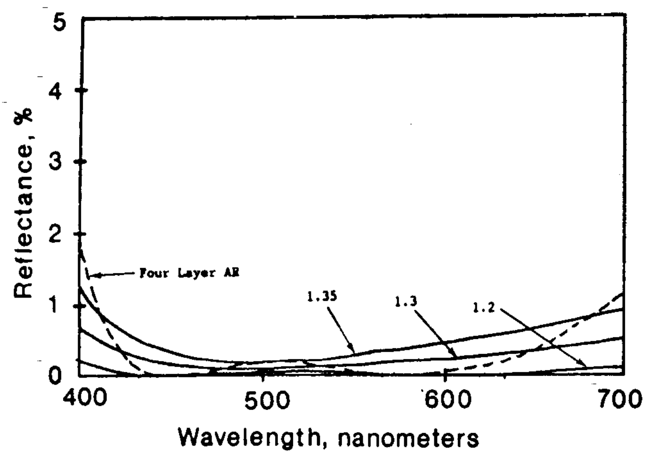

Fig. 13. Reflectance vs. wavelength of three layer AR's on 1.74 index glass with low index layers of 1.2, 1.3, and 1.35. A four layer broadband AR is shown for comparison.

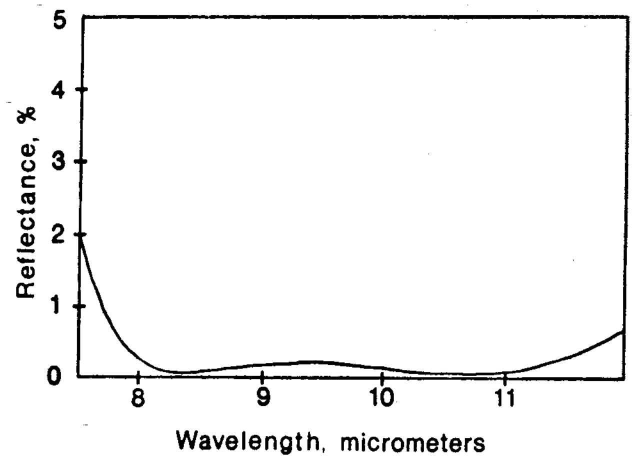

Fig. 16. Reflectance vs. wavelength of a three layer AR plus two thin AAA layers on top for environmental durability.

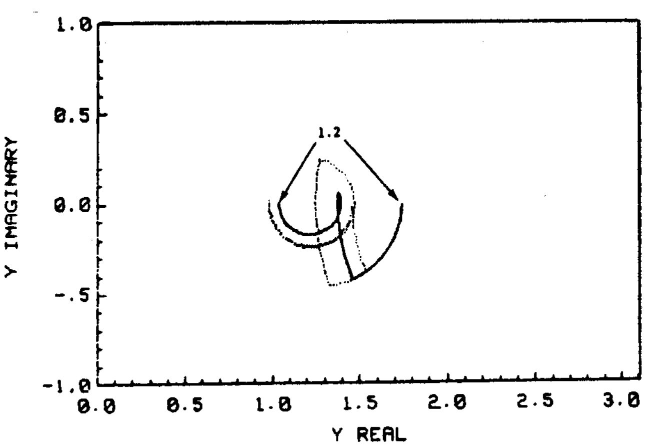

Fig. 14. Admittance diagram of the three layer AR on 1.74 glass with 1.2 index for the low layers.

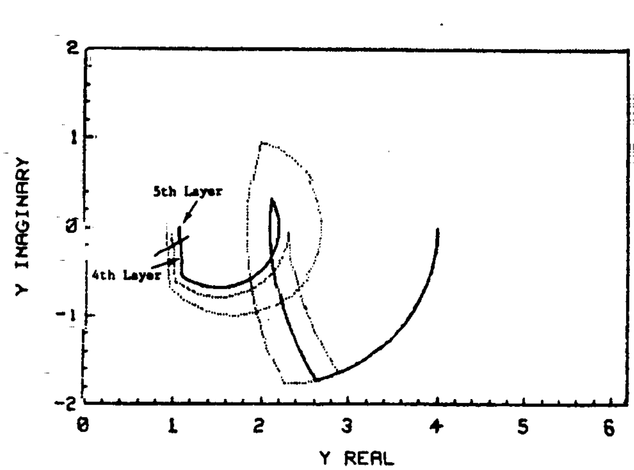

Fig. 17. Admittance diagram for the five layer AR of Figure 16. Note the small extent of the 4th and 5th layers.

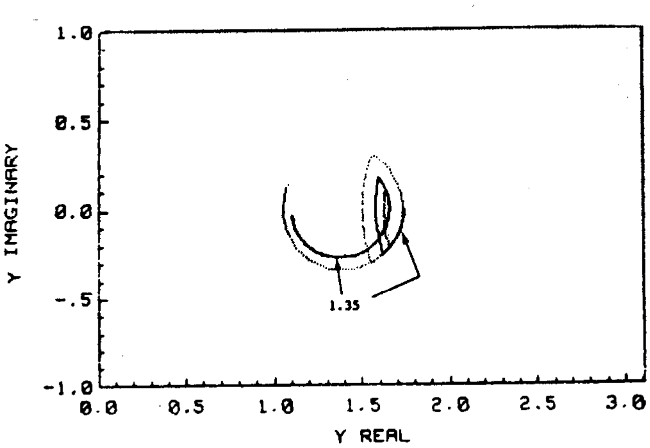

Fig. 15. Admittance diagram of the three layer AR on 1.74 glass with 1.35 index for the low layers.