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Reflexions on Reflexions

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1 Angular Dependence of Reflectivity

Several materials are being evaluated as candidate optical surfaces for light concentrators. Their optical properties have been compared, mostly by measuring their reflectivity at normal incidence as a function of wavelength. As can be seen in an adjoining report by Guy Ouellette, this is not a very representative test. In operation, most of the reflexions from the concentrators will be much closer to grazing than normal incidence. The angular distribution is broad, and the peak lies at about 60 degrees (from normal).

As can be seen from the following graphs, the differences in reflectivity between normal incidence and larger angles are, for the most part, small. However, when considering the behaviour of dielectric-coated aluminum at low wavelengths (<400nm), this is not true. The integrated reflectivity (300-600nm) of these materials is several percent better at realistic angles than at normal incidence.

2 Omega Mirror

The measured performance of Omega Mirror at normal incidence, in air, is shown in fig.1. The data are compared with a model calculation by Fang Ho at NRC in which the material was simulated by a two layers on bare Al:

- Inner layer: 1160nm magnesium fluoride (n=1.434 at 450nm)
- Outer layer: 1100nm titanium/praeseodymium oxide. (n=1.973 at 450nm)

The refractive index of the oxide layer was difficult to determine as it depended critically on evaporation conditions, so it was fitted to simulate the data at normal incidence. The value obtained was rather lower than can be obtained by other means of evaporation.

Compare this with fig.2, where the light is incident at 45 degrees. Here the drop off at low wavelength is much less dramatic, and indeed, rather better than the model prediction. Measured angular distributions at several wavelengths in air are shown in figure 3.

If one integrates these reflectances at 45-60 degrees over the expected distribution of wavelengths, then the overall performance is only 0.4% less than the peak value of 94% (91% in water). At normal incidence the value is 6% less than the peak.

The model predictions for Omega at 45 degrees in air and water are shown in figure 4. Two things are clear:

- The peak response is 2-3% less in water than in air due to the smaller mismatch in refractive indices.
- The interference minimum below 300nm is a lot shallower in water than in air, presumably for the same reason.

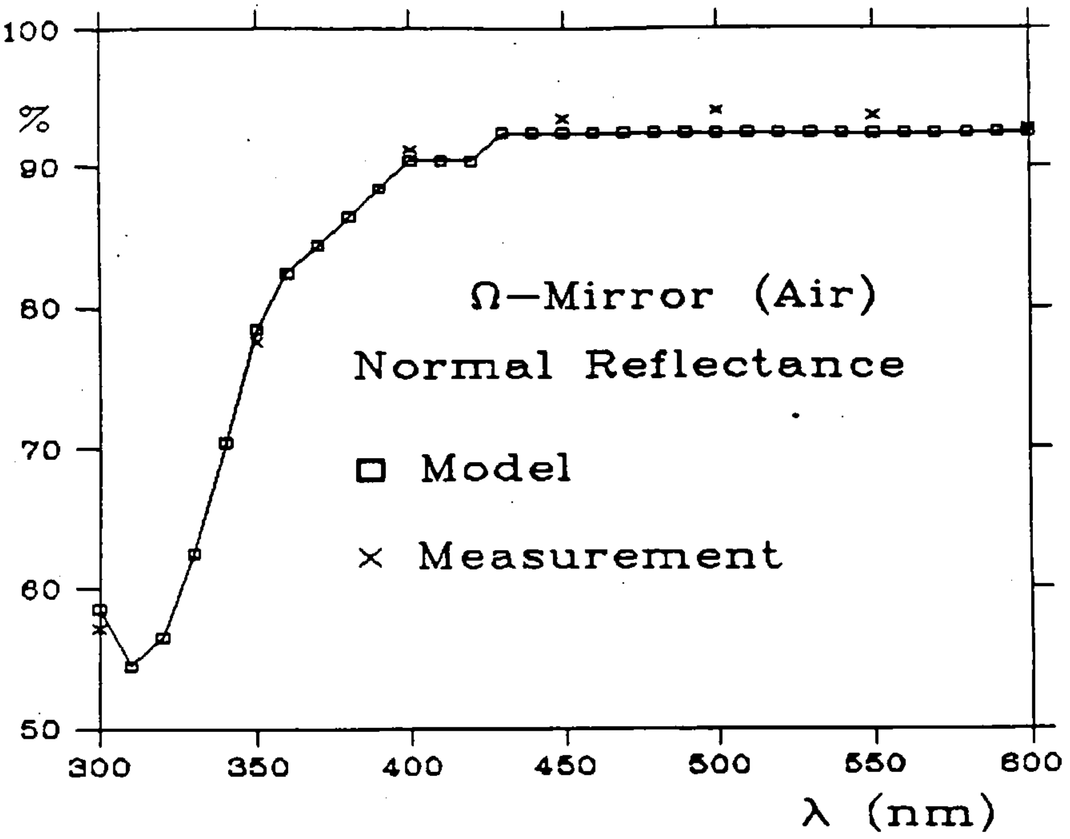
The average reflectance of Omega-coated cones in water is thus expected to be about 90.5%.

Hass (J. Opt. Soc. Am. 45, p945, 1955) gives formulae to calculate the maximum reflectances obtainable from two-layer dielectric stacks on a metal. For Omega the values are 95.0% in air and 93.5% in water (for quarter-wave thicknesses). The reflectances obtained in practice are close to these ideals.

3 Anodized Aluminum

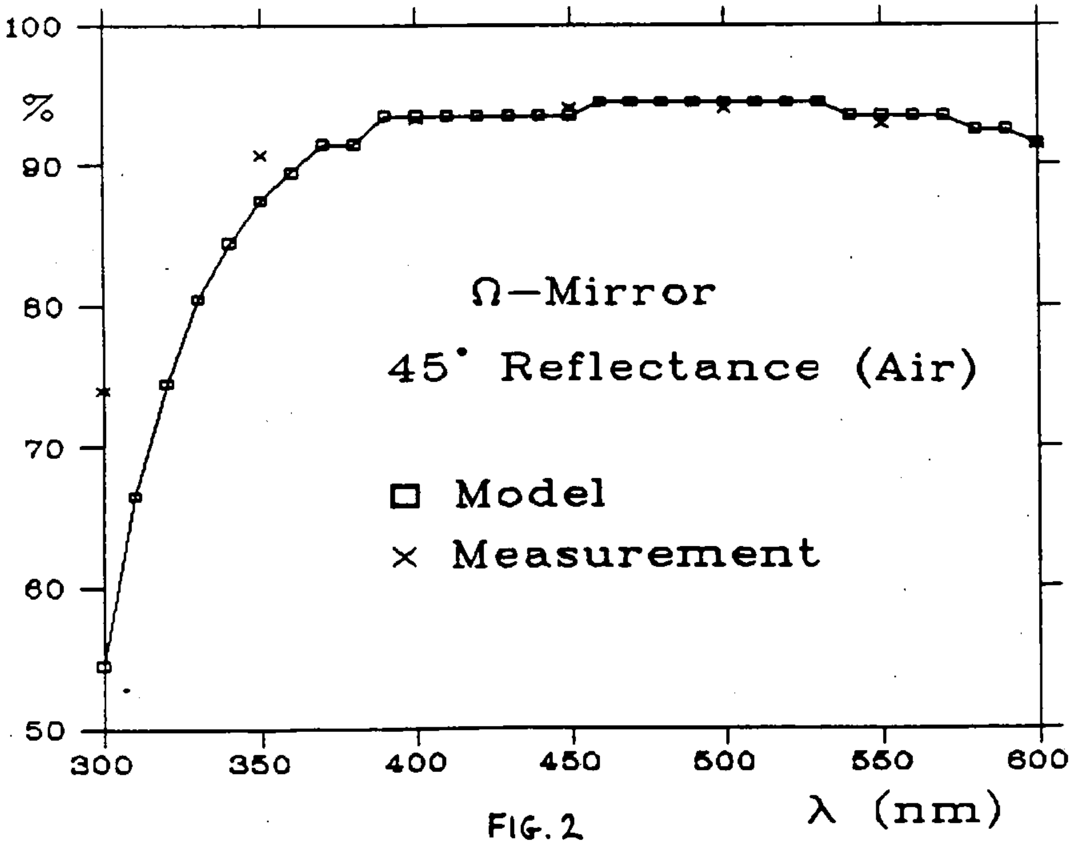
Similar calculations were made for anodized aluminum. Fang Ho modelled the performance assuming a 2900nm thick layer of oxide (n=1.405 at 450nm), and the results at 45 degrees are shown in figure 5 (together with a measurement using a red laser). The angular distributions at various wavelengths - with the interference ripples smoothed out - are shown in fig.6. They are much flatter than for Omega mirror and so the evaluation at normal incidence was a good approximation.

Figure 7 compares reflexions at 45 degrees in air and water. The overall reflectivity of an anodized aluminum concentrator in water will be no better than 80%.



100
%
90
80
70
60
50
300
350
400
450
500
550
600
λ (nm)
Ω—Mirror (Air)
Normal Reflectance
□ Model
× Measurement

FIG. 1



100
%
90
80
70
60
50
300
350
400
450
500
550
600
λ (nm)
Ω—Mirror
45° Reflectance (Air)
□ Model
× Measurement

FIG. 2

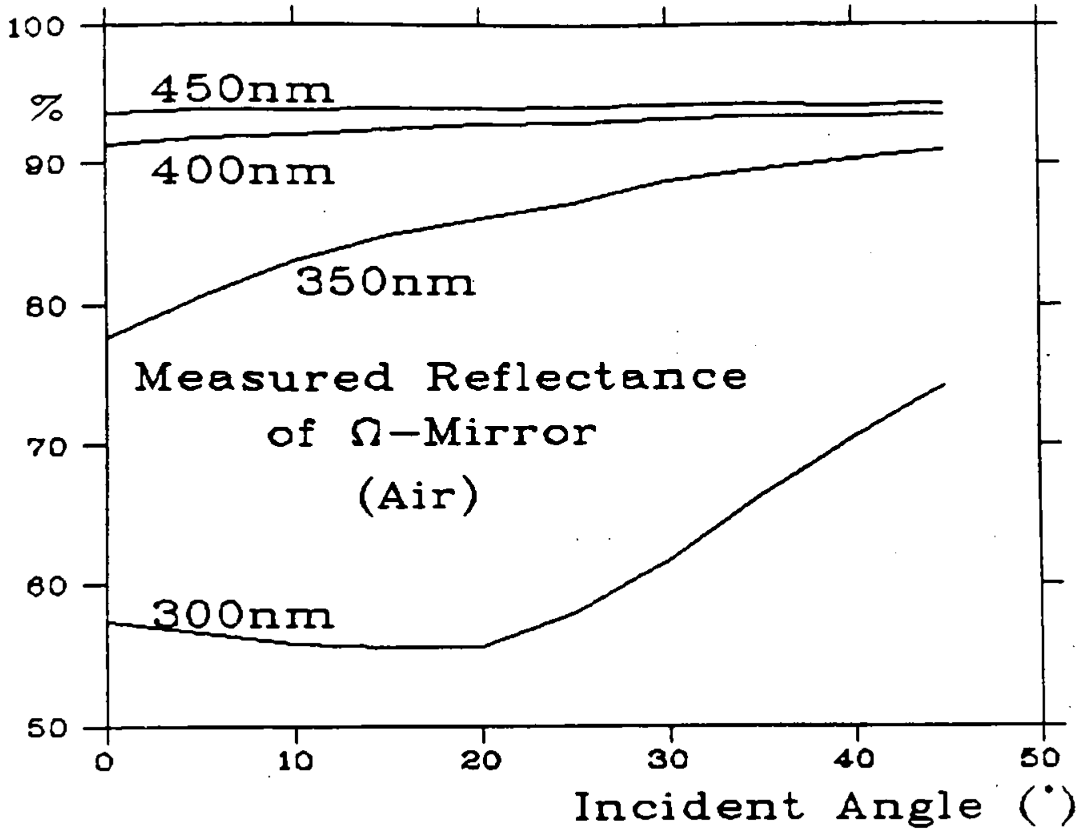

100
%
90
80
70
60
50
0
10
20
30
40
50
450nm
400nm
350nm
300nm
Measured Reflectance
of Ω–Mirror
(Air)
Incident Angle (°)

FIG. 3

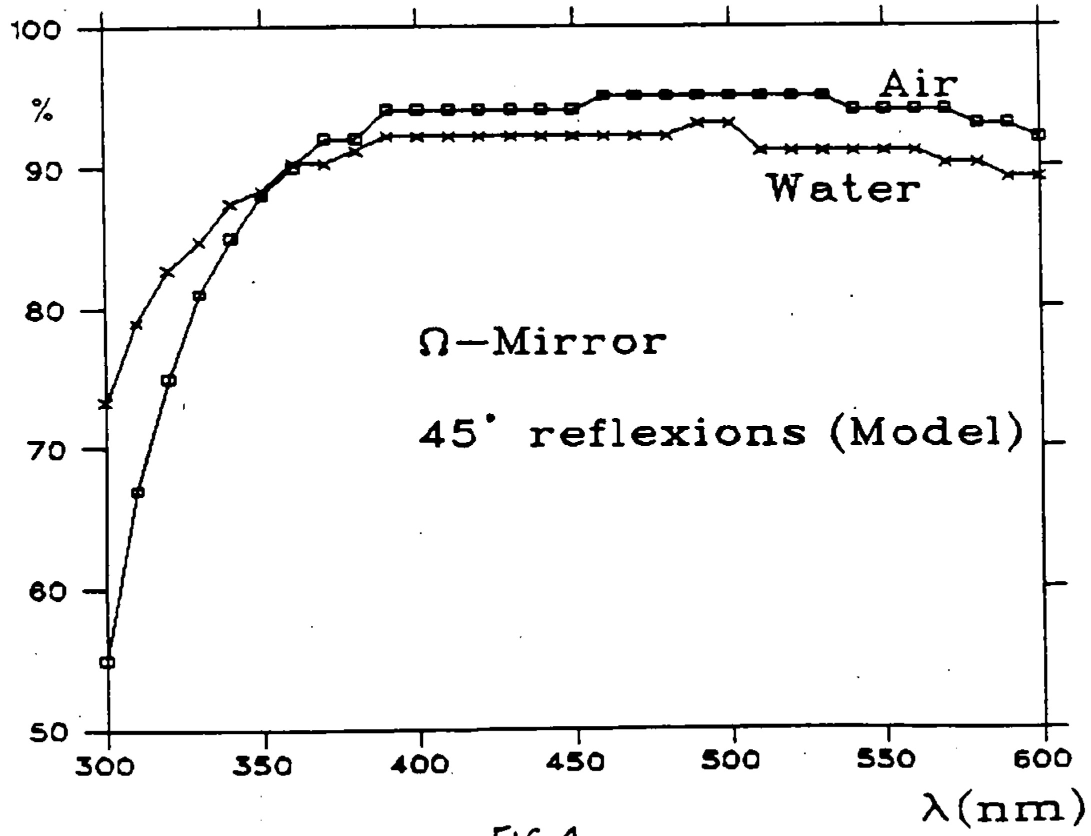

100
%
90
80
70
60
50
300
350
400
450
500
550
600
Air
Water
Ω–Mirror
45° reflexions (Model)
λ(nm)

FIG. 4

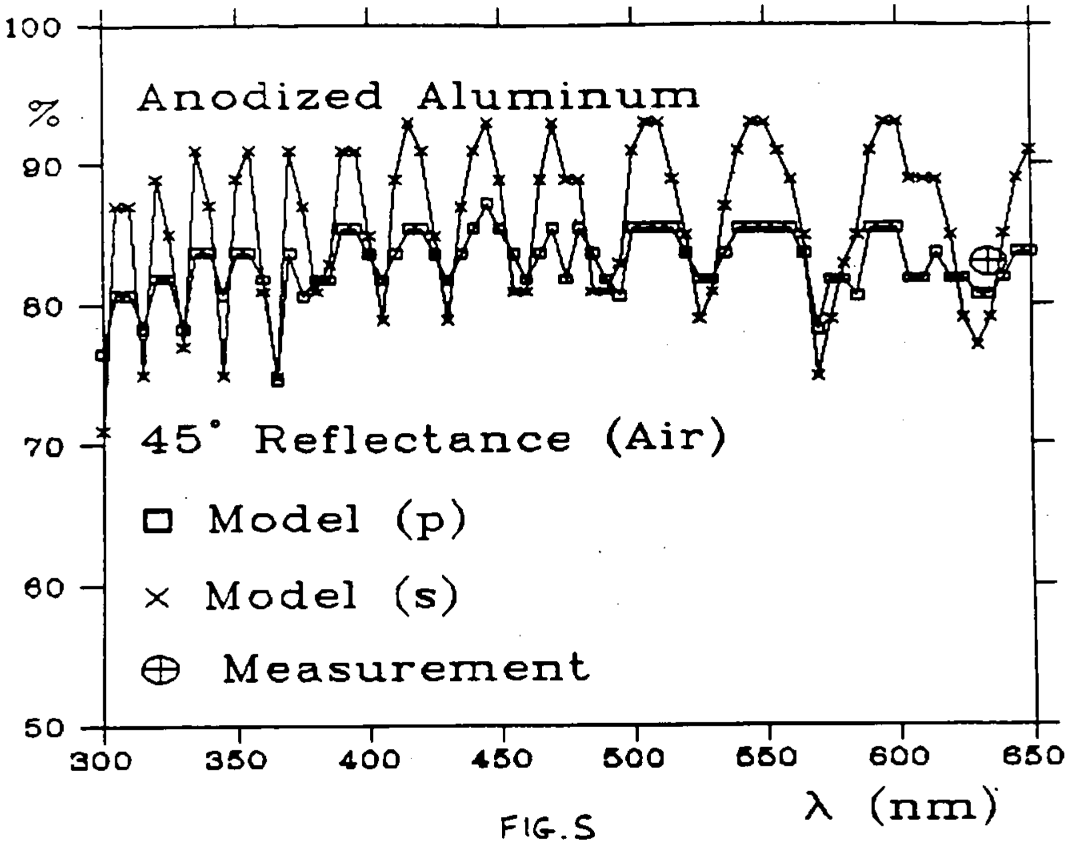

100
%
90
80
70
60
50
300
350
400
450
500
550
600
650
λ (nm)
Anodized Aluminum
45° Reflectance (Air)
□ Model (p)
× Model (s)
⊕ Measurement

FIG. 5

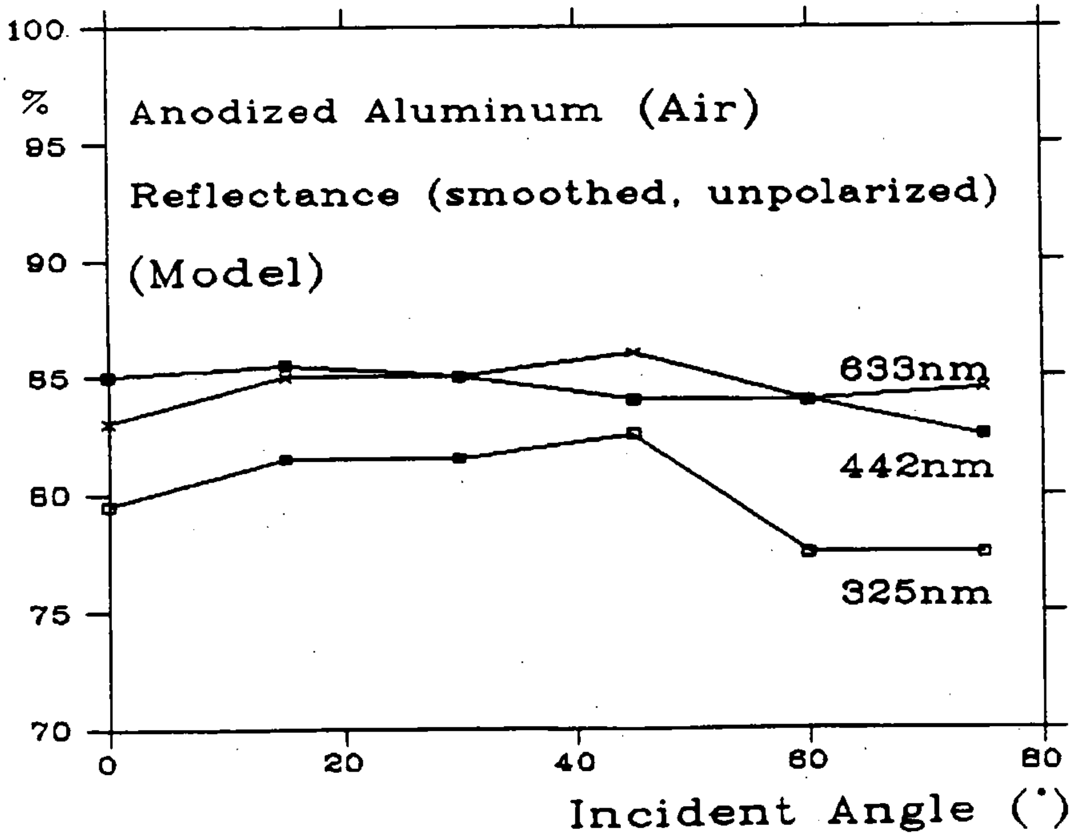

100
%
95
90
85
80
75
70
0
20
40
60
80
Incident Angle (°)
Anodized Aluminum (Air)
Reflectance (smoothed, unpolarized)
(Model)
633nm
442nm
325nm

FIG. 6

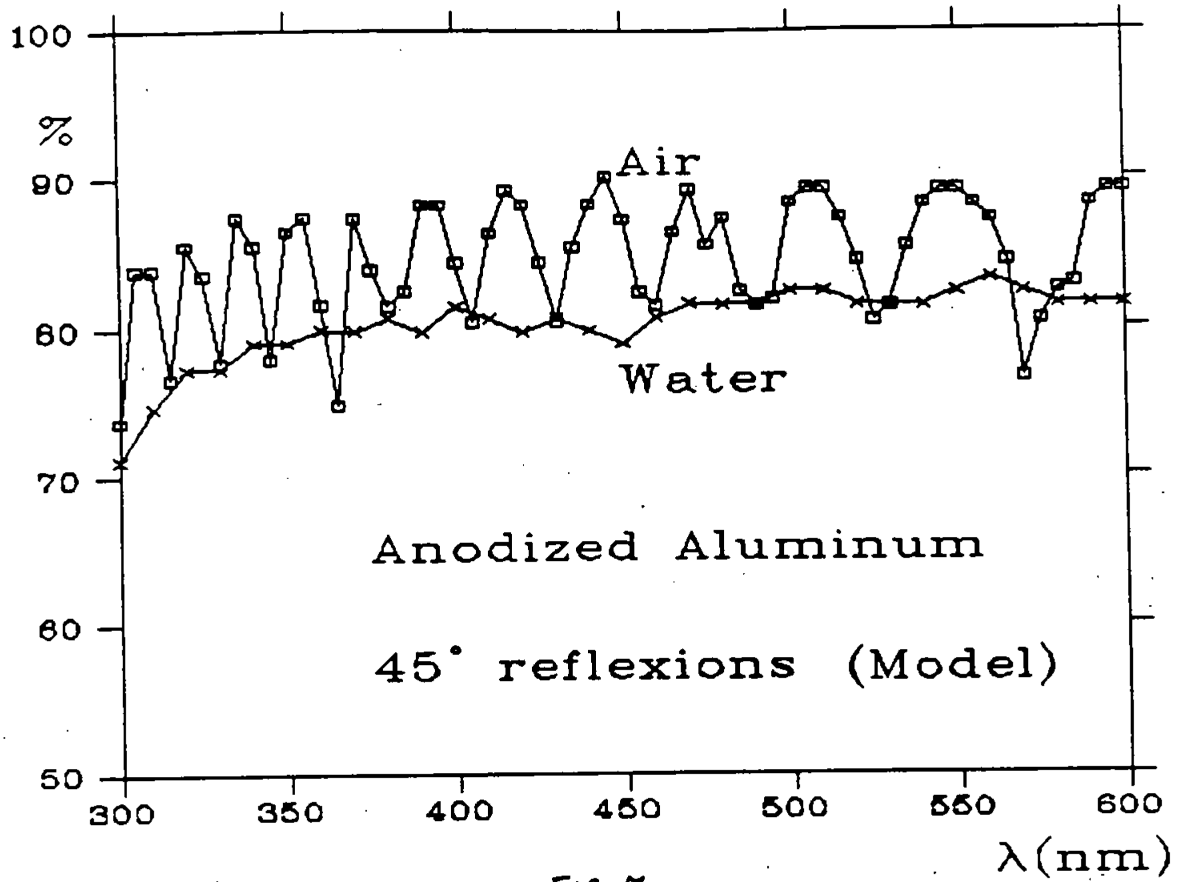

100
%
90
80
70
60
50
Air
Water
Anodized Aluminum
45° reflexions (Model)
300
350
400
450
500
550
600
λ(nm)

FIG. 7