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IMPROVED ALUMINUM COATINGS FOR THE ULTRAVIOLET

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ABSTRACT

Highly reflective aluminum coatings or aluminum coatings with dielectric overcoats are frequently used in the ultraviolet. The reflectance values published by Hass and his group are generally accepted for this uv region. We have produced evaporated aluminum coatings for a wide range of deposition conditions and none of our coatings exhibit the Hass reflectance characteristics. The reflectance of our coatings appear to be independent of the evaporation pressure and deposition time or rate. Our coatings do not have the characteristic decrease in reflectance with decreasing wavelength. Our main attention has been focused on the origin of a reflectance dip for each of our coatings near 300 nm. This dip has apparently not been reported before and does not appear to be due to adsorbed layers on the film or due to trapped impurities within the film.

INTRODUCTION

The published reflectance values of Hass (1) and his group (2) for aluminum films are widely accepted and repeated in many handbooks. They stress that the uv reflectance values are sensitively dependent on the evaporation pressures and deposition times or rates. The purity of the starting material is also important. Figure 1 is a reproduction of the reflectance data of Hass for pure aluminum deposited at a chamber initial pressure of $1-2 \times 10^{-4}$ torr and several deposition times from 5 to 180 seconds. These curves are characteristic for other pressures and times; the lower the pressures the higher the reflectance. The reflectance decreases monotonically with decreasing wavelength and with increasing deposition time. Their physical model is that impurities are trapped in the film during deposition and thus rapid evaporations will minimize this adsorption and yield higher reflectances. They associate the uv falloff of reflectance to impurities.

We have produced a number of aluminum films from a wide range of deposition conditions overlapping the conditions used by Hass and his group. None of our films have the reflectance properties displayed by the Hass films. The purpose of this paper is to give a brief report of our results and to show the significant differences between our films and theirs (3).

EXPERIMENTAL RESULTS

Our data are shown in Figs. 2-4 for aluminum films deposited for various pressures and deposition rates or times. For comparison, the data of Hass and his group are shown for films prepared under conditions similar to ours. In Fig. 2 the reflectance for one of our mirrors is

shown as curve (2). This mirror was prepared at a chamber operating pressure of $3-5 \times 10^{-6}$ torr and a deposition rate of 30 Å/sec resulting in a film 1500 Å thick. Curves (1) and (2) are data of Hutcheson et al. (2) for pressures of 3×10^{-6} torr and deposition rates of 10-20 Å/sec and 500 Å/sec, respectively. Their films were 600-700 Å thick. The Hutcheson et al. deposition rates bracket ours but our films do not show the uv reflectance decrease. The higher reflectance value of curve (3) relative to curve (1) is consistent with Hass theorem, "higher deposition rate the higher reflectance." The low reflectance values of our film is also consistent with Hass' statement regarding thickness. In Fig. 3 we compare our films with those of Hass (1) for operation pressures of $1-2 \times 10^{-5}$ torr and different deposition times. For each of our mirrors a shutter was used over the evaporation source to give a uniform deposition temporal profile. The data of Hass were interpolated from curves such as Fig. 1 to correspond to deposition times equivalent to ours. From the reports it is not clear whether Hass used a shutter. The data of Hass, Fig. 3, shows the monotonically increasing reflectance with shorter deposition time and the increased uv falloff with time. Our data show neither of these characteristics. In Fig. 4, the interpolated data of Hass [curves (1) and (3)], show the same pressure and deposition time characteristics as his other data, Figs. (1 & 3). The reflectance of our mirrors, curves (2) and (4), do not have this same pressure-time dependence but do have enhanced reflectance at the shorter wavelengths.

In addition to the pressure-time dependence, each of our films has a reflectance dip near 300 nm. The majority of our attention has been focused on the possible origin of this dip. Several films were prepared under conditions that might enhance or temper this reflectance dip. The

results are shown in Fig. 5. For the film shown as curve (a), the dip is about 10% compared with about 1% or less for Figs. 2-4. This is the largest dip measured, it is stable in time but we could not reproduce these results in other films. We are not aware of any unusual deposition conditions and thus consider this film to be anomalous.

Curve (b) is the reflectance of diamond-turned aluminum. This metal mirror was then exposed to fluorine for an extended period. The action of the fluorine is to remove the oxide and hydrate layers always present on aluminum and replace them with AlF_3 . From the fluorine exposure time-temperature we estimate the AlF_3 to be about 30-40 Å. The reflectance spectrum of this fluorinated mirror is identical to that of curve (b). In an effort to increase the number of atoms and molecules adsorbed in the film during deposition several aluminum films were deposited by sputtering. The results are shown as curve (c). Several reflectance dips are evident, in addition to the lower average reflectance compared with the evaporated films of Figs. (2-4). Finally, curve (d) is for an off-the-shelf commercial aluminum mirror with an SiO_2 overlayer. In addition to the deep dip near 300 nm there is one near 440 nm.

CONCLUSION

Using a wide range of deposition conditions, we have produced aluminum films that do not exhibit the uv falloff characteristics of the films produced by the Hass group. We have found no correlation between uv reflectance and deposition properties. This is inconsistent with the previous reports (1,2). Our films show a reflectance dip near 300 nm that has not been reported before. The origin of this dip is uncertain

but it does not appear to be due to adsorbed layers or increased impurities in the film. Similar reflectance dips are observed for diamond-turned metallic (not evaporated) aluminum mirrors.

References

1. G. Hass, J. Opt. Soc. Am. 45 (11), 945 (1955).
2. E. T. Hutcheson, G. Hass, and J. K. Coulten, Opt. Comm. 3(4) 213 (1971).
3. The unabridged version of this paper has been submitted for publication in Applied Optics under the title, "Evaporated Aluminum Films with Improved UV Reflectance." The reader is referred to this paper for details.

Figure Captions

- Figure 1. Reproduction of reflectance data of Hass (1) for chamber pressure of $1-2 \times 10^{-4}$ torr and several deposition times.
- Figure 2. Curves 1 and 3 are reproductions of Hutcheson et al. data at 3×10^{-6} torr, 10-20 Å/sec and 500 Å/sec, respectively, resulting in film thicknesses of 600-700 Å each. Curve 2 reported here for chamber pressure $3-5 \times 10^{-6}$ torr, and 30 Å/sec deposition rate resulting in a film thickness of about 1500 Å.
- Figure 3. Comparisons of reflectance dates of Hass (1) and that reported here for chamber pressures of $1-2 \times 10^{-5}$ torr and several deposition times. The Hass data were interpolated to the listed deposition times t . For our films a shutter over the source was used to control the deposition time. Curves 1 & 2: $t = 60$ sec. Curves 3 & 4: $t = 30$ sec. Curves 5 & 6: $t = 15$ sec.
- Figure 4. Comparison of the reflectance data of Hass (curves 1 and 3) to that reported here (curves 2 and 4) for two chamber pressures and deposition times. The Hass values have been interpolated from Figs. 1 and 2. For the data reported here no shutter was used and the deposition times were determined by the input power to the evaporation boat. Curves 1 & 2: $p = 1-2 \times 10^{-4}$ torr, $t = 57$ sec. Curves 3 & 4: $p = 1-1 \times 10^{-5}$ torr, $t = 25$ sec.
- Figure 5. Reflectance of several mirrors prepared under various conditions. (a) aluminum film showing anomalously large decrease in reflectance near 300 nm, (b) diamond turned aluminum mirror before and after exposure to fluorine, (c) sputtered Al film, (d) off-the-shelf commercial Al film with SiO protective overcoat.