

ON A COMPARATIVE STUDY OF THE REFLECTIVITIES OF ALUMINIUM AND SILVER FILMS

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Plates I, II

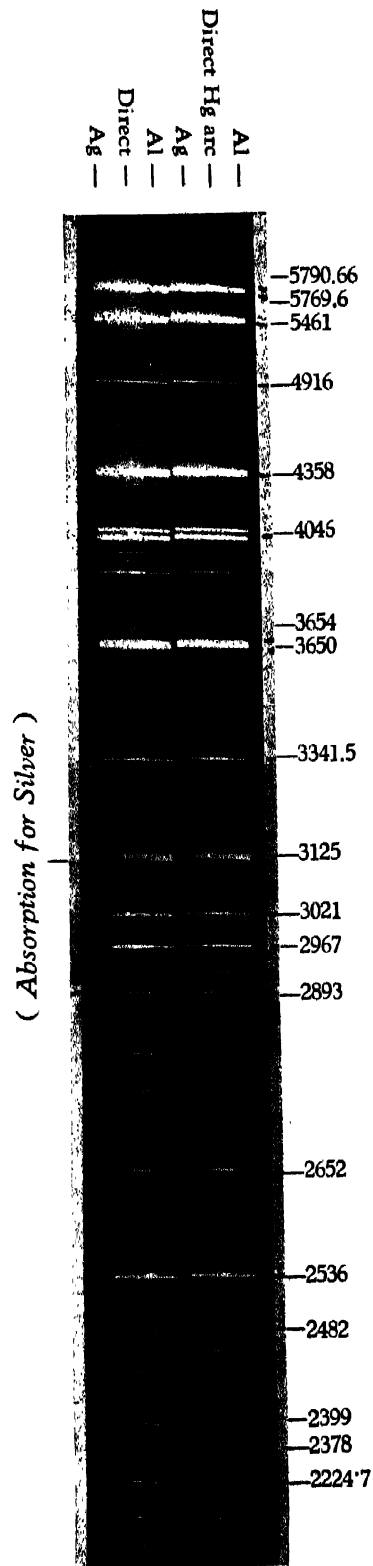
ABSTRACT. A comparative study of evaporated aluminium films with that of chemically deposited and sputtered silver films is given. The reflectivity of the films in the visible, near infra-red and ultra-violet part of the spectrum is discussed at length and the deterioration of silver films with time is shown. Methods of preparing the respective films are also given.

INTRODUCTION

A study of metallic reflecting surfaces is engaging the attention of many physicists in recent years in view of its importance to various optical instruments, such as Reflectors in Telescopes, Interferometers, Coeleostats, etc. There are three well-known methods of obtaining thin films of metals on to surfaces namely, chemical deposition, cathode sputtering and evaporation.

Each of these is characterised by certain restrictions and advantages. Chemical deposition cannot be applied to surfaces like rock-salt which are attacked by water; sputtering is particularly suitable for preparing films of the platinum metals, and the evaporation process is suited to the application of aluminium films.

Of the metals useful for reflection of light in the visible spectrum, the three most important are aluminium, speculum and silver. The mirrors in astronomical reflecting telescopes were formerly made of speculum metal—a hard alloy of copper and tin capable of taking a fine polish and having a fairly high reflecting power. But on account of the low reflecting power of speculum¹ they have been entirely replaced by glass mirrors coated on the figured surface with a thin film of silver. The silvered surface, when fresh, has a high reflecting power for wavelengths greater than 3750 A.U. But the reflecting power diminishes with time, owing to the gradual oxidation or to tarnishing due to the action of sulphur dioxide in the atmosphere. Where such atmospheric contamination is intense, the reflecting power falls rapidly, and, even under the most favourable conditions, there is a gradual fall in the reflecting power. Hence the mirrors have to be periodically dismounted and resilvered. Mirrors coated with aluminium, on the other hand, have been found to have the remarkable property of withstanding the deleterious effect of atmospheric contamination for long periods of time. A



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freshly deposited film on exposure to the air immediately oxidises, and the oxide coating forms a protective layer which prevents the film from tarnishing. Sulphur dioxide in the atmosphere does not tarnish an aluminium film, or if at all, it does at a very slow rate.² This observation is based on an experiment³ conducted in Greenwich with a small mirror partly coated with silver and partly with aluminium. By the time the silver film had completely become yellow, the aluminium film was found unchanged. Dr. Strong mentions that the mirrors of a telescope aluminized in October, 1932, and in constant use since then, show no signs of tarnish.⁴ In addition, aluminized surfaces have been reported to have higher reflectivity in the ultra-violet than silvered surfaces, and this paper deals with a comparative study of the reflectivities of aluminium films with those of silver obtained by sputtering and chemical deposition.

EXPERIMENTAL ARRANGEMENT

*Previous Work.*⁵—Dr. Strong has described an apparatus for measuring the reflectivities of metal films for small angles of incidence. His apparatus is shown in fig. 1(a). Light from a powerful source falls on one of the comparison mirrors B and the light is made to fall on a photometer and the reading is recorded. As shown in fig. 1(b) the mirror to be tested is placed between the two comparison

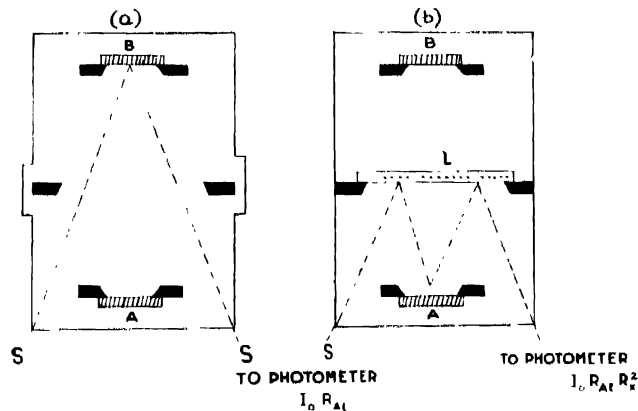


FIG. 1

mirrors so that light is reflected from that and then falls on the photometer. The apparatus therefore measures the square of the reflectivity. Measurements are made with monochromatic light obtained with a Müller-Hilger double quartz monochromator. A Nernst-filament as well as the Sun is used as light sources and quartz sodium or potassium cells as receivers. The photo-current is measured by an electrometer by a null method as well as with an amplifier and galvanometer.

The author has used a simple apparatus as described below for the visible and the near infra-red region of the spectrum. The method of procedure has been

to measure the intensity of a light beam falling on a photo-cell directly, and after reflection from the test surface, and the ratio of these intensities, as measured by the respective photo-electric currents, gives a measure of the reflectivity of the surface.

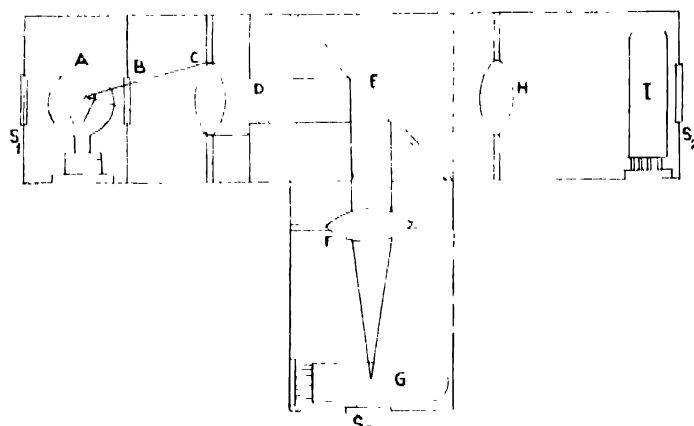


FIG. 2

Description. The apparatus as shown in fig. 2 consists of a T-shaped box. An incandescent 100-watts *frosted* tungsten-filament lamp A is used as the light source for the reflectivity measurements. For selecting various spectral ranges for the measurements, Wallace colour filters are used. The transmission band of the colour filter is determined using Hilger's constant-deviation spectrograph. Sunlight is used as a source and the drumhead of the spectrograph is adjusted by reference to the Fraunhofer's lines. The various colour filters are introduced in front of the slit of the spectrograph and the transmission band in the visible region of the spectrum is obtained for the different filters from the drumhead.

The blue filter transmits a band from 4000 to 5200 A.U.

The green filter transmits a band from 5800 to 6000 A.U.

The red filter transmits a band from 5800 to 7000 A.U.

The lamp is mounted on a holder fixed to the box and the switch for the lamp is also provided in the box. Light from the lamp passes through a 2" square diaphragm B, and then falls on the colour filter which can be slid in the groove cut on the other side of the same plank carrying the diaphragm.

A convex lens of 6" focus is placed 6" from the lamp so that the rays from the filter after emerging from the lens are rendered parallel. A 2" square diaphragm D is placed behind the lens so as to limit the beam falling on the test surface. The holder carrying the test surface is placed at 45° as shown in the diagram so that the angle of incidence of the beam is 45°. The reflected light falls on another convex lens of 6" focus placed at 2" from the T-joint as shown in

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the figure. The photo-cell used for the measurement is placed at 6" from the centre of the lens, so that all the light is brought to a focus at the concave cathode of the cell. The cell used is a vacuum cell, R.C.A. 917 and measurements are taken with a sensitive galvanometer using a lamp and scale arrangement. The experiment is so conducted, that the same identical conditions prevail both for direct light and reflected light measurements. So the same photo-cell is used for both positions.

For direct incidence on the photo-electric cell, the plate-holder can be removed easily so that light is allowed to pass directly and fall on a similar convex lens of 6" focus placed at 2" from the T-joint as shown in the figure. The photo-cell is placed at 6" from the centre of the lens in a 4-pin base already fixed there.

PREPARATION OF THE FILMS

Chemical Deposition.—The well-known Brashear process and the Rochelle salt process are used for obtaining the desired films. The first is used to obtain thick coats on front-silvered mirrors. The Rochelle salt method, because its action is slower, is used for partially silvered mirrors such as interferometer plates, which require a uniform thin film with a specified ratio of reflection and transmission.

Evaporation Process. The process of obtaining evaporated films is described in the author's paper on "A Simple Method of Coating Optical Surfaces with Aluminium." ⁶ The high vacuum equipment necessary for the process is given in figure 3.

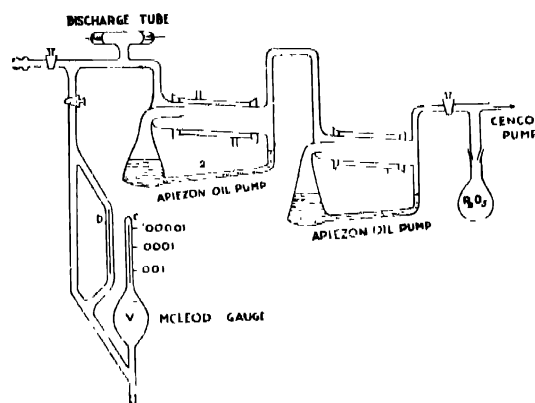


FIG. 3

Cathode Sputtering.—The sputtering chamber is the same bell jar used for the evaporation process with a hole in the top for the cathode connection. A cast-iron plate which is carefully machined in the lathe and lapped well with the bell jar is used as the base plate, so that it forms the anode. A terminal is provided in the base plate for connection to the secondary of the transformer.

The cathode is a rectangular silver plate $5'' \times 4''$ which is suspended from the top. The glow discharge is produced with an alternating potential of 25,000 volts from a Transformer working from 110 volts A.C. A milliammeter is used to measure the discharge current. The pressure is adjusted to be about .01 mm. The cathode is placed 5 cms. from the plate to be sputtered so that the boundary of the dark space is parallel to the surface to be coated. The same vacuum equipment as for aluminizing purposes is used but only the Cenco-Hyvac pump is worked. The pressure is indicated by the McLeod Gauge placed in the circuit.

EXPERIMENTAL PROCEDURE

The experiment consists in taking readings with the photo-cell and galvanometer for direct light and reflected light from the coated plate for a particular wavelength, using the proper filter. The reflection coefficients are calculated in each case and tabulated as shown in tables I to VII below.

Two 4-pin American bases are fixed one at G and another at I, so that the cell alone needs to be shifted from one position to another. The cell is worked with an anode voltage of 60 volts.

Readings are taken for the coated plates for different spectral regions choosing the proper filter and tabulated as shown in tables below.

The reflectivities of the following plates are compared :—

(1) Chemically silvered (polished)	...	...	Table I
(2) Chemically silvered (unpolished)	...	...	Table II
(3) Sputtered (polished)	...	...	Table III
(4) Sputtered (unpolished)	...	...	Table IV
(5) Chemically silvered (after 15 days' exposure in Laboratory)	...	...	Table V
(6) Chemically silvered (after 30 days' exposure in Laboratory)	...	...	Table VI
(7) Aluminized plate	...	...	Table VII

TABLE I

Silver Plate (polished)

Filter used	Wave-length in A.U.	Deflection for direct light	Deflection for reflected light	Reflection coefficient
Blue	4000—5200	25 mm	23.5 mm	94 %
Green	4800—6000	15 mm	14.5 mm.	96 %
Red	5800—7000	155 mm.	147.5 mm.	95 %

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TABLE II
Silver plate (unpolished)

Filter used	Wave-length in A.U.	Deflection for direct light	Deflection for reflected light	Reflection coefficient
Blue	4000—5200	25 mm	20.5 mm.	82 %
Green	4800—6000	15 mm	13.0 mm	87 %
Red	5800—7000	155 mm.	130.5 mm	90 %

TABLE III
Sputtered plate

Filter used	Wave-length in A.U.	Deflection for direct light	Deflection for reflected light	Reflection coefficient
Blue	4000—5200	25 mm	22.5 mm.	90 %
Green	4800—6000	15 mm.	14.0 mm.	93 %
Red	5800—7000	155 mm	147.5 mm.	95 %

TABLE IV
Sputtered plate (polished)

Filter used	Wave-length in A.U.	Deflection for direct light	Deflection for reflected light	Reflection coefficient
Blue	4000—5200	25 mm	23.5 mm.	94 %
Green	4800—6000	15 mm	14.5 mm.	96 %
Red	5800—7000	155 mm.	147.5 mm	95 %

TABLE V
Silver plate (after 15 days' exposure in laboratory)

Filter used	Wave-length in A.U.	Deflection for direct light	Deflection for reflected light	Reflection coefficient
Blue	4000—5200	21 mm	18 mm	75 %
Green	4800—6000	16 mm	13.5 mm.	84.4 %
Red	5800—7000	155 mm.	136.5 mm	89.8 %

TABLE VI

Silver plate (after 30 days' exposure in laboratory)

Filter used	Wave-length in A.U.	Deflection for direct light	Deflection for reflected light	Reflection coefficient
Blue	4000-5200	25 mm.	17.5 mm.	70 %
Green	4800-6000	16 mm.	12.5 mm.	83 %
Red	5800-7000	135 mm.	130.5 mm.	88 %

TABLE VII

Aluminised plate

Filter used	Wave-length in A.U.	Deflection for direct light	Deflection for reflected light	Reflection coefficient
Blue	4000-5200	25 mm.	22.5 mm.	90 %
Green	4800-6000	15 mm.	13.5 mm.	90 %
Red	5800-7000	155 mm.	139.5 mm.	90 %

TABLE VIII

Wave-length in A.U.	Reflection Coefficient						Al Plate
	Silvered polished	Silvered not polished	Sputtered Plate	Sputtered Plate (polished)	Ag, 15 days in the laboratory	Ag, 30 days in the laboratory	
4000-5200	94 %	82 %	90 %	94 %	75 %	70 %	90 %
4800-6000	96 %	87 %	93 %	97 %	84 %	83 %	90 %
5800-7000	95 %	90 %	95 %	95 %	90 %	88 %	90 %

DISCUSSION OF THE RESULT

Taking the case of silvered plate, the reflectivity of a polished plate is superior to that of an unpolished plate (Tables I to IV). The reflectivity of silver decreases with time (Tables V and VI). The reflectivity of evaporated and

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sputtered films are less than that of polished chemical silver, but the films on polishing give a better reflection. It is probable that chemical silver, sputtered and evaporated films require burnishing to form the metal into a compact film which exhibits a higher reflection coefficient.

We find aluminium films are inferior to freshly deposited silver for reflectivity in the visible region, but they have more or less uniform reflectivity from 4000 A.U. to 7000 A.U. which is very useful from the point of view of photography.

Reflectivity in the red and near infra-red.—For taking measurements in the red and near infra-red, Zeiss Ikon Infra-red filters, R-10, R-15, R-20 are used.

EXPERIMENTAL ARRANGEMENT

The same apparatus as used for the visible region is used for the measurements as the glass can transmit up to 2.2μ in the infra-red. The same photo-cell which is very sensitive in the infra-red, as shown in the special chart given by the makers, is used for the readings. Measurements are taken as before, first for direct light and then for reflected light, in the case of the chemically silvered plate and aluminized plate respectively.

TABLE IX

Aluminium (near Infra-red)

Filter used (Zeiss Ikon)	Deflection for direct light	Deflection for reflected light	Reflection coefficient
R-10	155 mm.	139.5 mm.	90 %
R-15	177 mm	161.0 mm.	86 %
R-20	122 mm	95.0 mm.	84 %

TABLE X

Silvered (polished) Plate

Filter used (Zeiss Ikon)	Deflection for direct light	Deflection for reflected light	Reflection coefficient
R-10	155 mm.	147.5 mm.	95 %
R-15	177 mm.	111.5 mm.	95 %
R-20	112 mm	107.5 mm.	96 %

Inference :—From the Tables IX and X one can easily see how the aluminium films are inferior to silver in reflectivity in the red and near infra-red.

The following table reveals to us a comparative percentage reflection in the visible and near infra-red region of the spectrum for the chemically silvered and aluminized plates.

TABLE XI

Wave-length in A.U.	Visible			Near infra-red	
	4000-5000 Blue	4800-6000 Green	5800-7000 Red	R-15 Zeiss Ikon filter	R-20 Zeiss Ikon filter
Percentage of reflection (Al)	90	90	90	86	84
(Ag)	94	97	95	95	96

On the superiority of Aluminium over Silver Films in the ultra-violet region of the spectrum—For investigating the reflectivity of aluminium films in the ultra-violet region of the spectrum, a quartz spectrograph and quartz mercury-arc are used. Following, in the main, the method of Ben Johnson⁷ and Sabine,⁸ the attempt has been to take photographs of the spectrum of mercury arc for direct light first and then after reflection from the test surface, the surface being placed here at 45° angle of incidence. The spectrograms show clearly the relative "density" of the lines

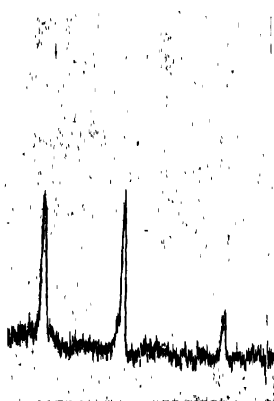
- (a) when photographed directly,
- (b) when photographed after reflection from the test surface.

Micro-photometer records are taken for wave-lengths below 2500 A.U. and the records clearly show how aluminium is superior to silver in that region of spectrum. The exact experimental details are given below.

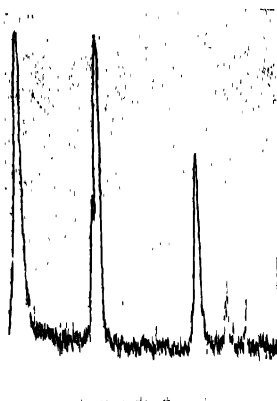
EXPERIMENTAL PROCEDURE

The same 'T' Box (Fig. 2) as previously used for finding the reflection coefficient in the visible region of the spectrum is used with all the lenses removed leaving the plate-holder alone. As shown in photograph the box is provided with slits at the three corners of the 'T' Box, so that light can pass through them freely. After making the preliminary adjustments of the quartz spectrograph such as the width of the slit, focus, tilt motion, the quartz arc is placed in a vertical position, so that a photograph of the spectrum of the direct light can be

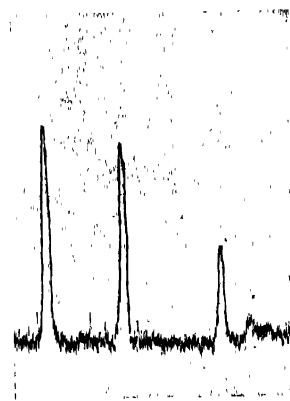
MICROPHOTOMETER RECORDS FOR WAVE LENGTHS 2482, 2399, 2378
OF MERCURY ARC



REFLECTED LIGHT
(Silver)



DIRECT LIGHT



REFLECTED LIGHT
(Aluminium)

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taken. Then the quartz arc is placed for the reflected light position, so that a photograph of the spectrum of the reflected light from the test surface can be taken. In order to get a comparison photograph of the direct light and reflected light for aluminium and silver films respectively, a wedge is used. The middle aperture is used for direct light, the top and bottom ones are used for aluminium and silver films respectively.

The plates used for the spectrograms are "Ilford special rapid panchromatic H.D. 700." Everything being kept at identical conditions, 3 minutes' exposures are given both for direct light and reflected light. The plates are developed and the photographs thus obtained are shown in the left page.

DISCUSSION OF THE RESULT

1. From the photograph we can easily see how the reflection is strong with the aluminized plate even down to $\lambda = 2200$. The lines do not suffer much in intensity by reflection from the aluminized surface.

Below 3340 A.U. the lines of the mercury are reflected from aluminium are definitely more intense than from silvered surfaces.

2. Silver as can be seen from the spectrograms shows clearly a strong absorption at 3123 A.U. unlike aluminium. That is, on the short wave-length side of 3750, the reflecting power of silver falls off rapidly owing to selective absorption. This is a serious disadvantage when observations are required in the ultra-violet region. In a reflecting telescope where the image is normally produced by reflection at two silvered mirrors this loss by the selective absorption is a serious handicap for photographic work. It has been decided therefore to coat the Presidency College 24" Reflector which has been correctly figured, polished and parabolised with aluminium instead of silver.

3. Below 2500 A.U. the microphotometer records taken show clearly how aluminium is superior to silver in that region of the spectrum. The microphotometer records are given in the left page.

4. For wave-lengths greater than 4000 the lines of mercury are for silver are more intense than for aluminium, showing the superiority of silver in the red region.

SUMMARY OF RESULTS

1. Chemical silver has better reflectivity when polished (Tables I to V).
2. Silver films get tarnished soon and so lose in reflectivity with time (Tables V and VI).
3. Sputtered films when polished have better reflectivity and they are very nearly equal in this respect to polished chemical silver (Tables III and IV).

4. Aluminium has uniform reflectivity in the visible region (Table VII).
5. Aluminium films are inferior to silver films in the red and near infra-red region of the spectrum (Tables IX and X).
6. Aluminium is found to be superior to silver in the ultra-violet region of the spectrum.
7. A freshly deposited film of aluminium on exposure to the air immediately oxidises and the oxide coating forms a protective layer which protects the film from tarnishing. Nevertheless the film can be dissolved by alkali or dilute Hydrochloric acid to which a trace of copper salt is added.
8. Aluminium films are more strongly adherent to glass than silver films. This tenacity makes it possible to clean the surface of dust or other contamination by washing with soap and water.
9. Aluminized mirror scatters less light than silver mirrors as the latter have to be polished and this process leaves many small scratches upon the silver.

I wish to express my thanks to Professor G. P. Krishnamoorthi Iyer for his interest in my work and to Sir C. V. Raman for allowing me facilities to take the microphotometer records in his Department at the Institute of Science, Bangalore.

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