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Report

OPTICAL TRANSMISSION DATA FOR THIN ALUMINIUM FILMS

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OPTICAL TRANSMISSION DATA FOR THIN ALUMINIUM FILMS

by

W.M. BURTON

ABSTRACT

The variation of the linear absorption coefficient of aluminium with wavelength between 1 Å and 6500 Å has been summarised using published data. Calculated transmission curves for typical aluminium filters are obtained with allowance for the additional absorption in an oxide layer. A filter of thickness 1000 Å gives a useful transmission waveband at wavelengths below 80 Å and also between 170 Å and 700 Å, but is almost opaque (density $\simeq$ 6) at visible wavelengths. A simple method is described for estimating the thickness of aluminium filters by measurements of the optical transmission in white light.

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CONTENTS

Page

1. INTRODUCTION

Thin aluminium films are useful as transmission filters in the soft x-ray and extreme ultraviolet (XUV) region. An unbacked aluminium film 1000 Å in thickness will provide good transmission in various wavebands below about 700 Å but is almost opaque at longer wavelengths, and can therefore be used to discriminate against near-ultraviolet and visible light. This technique has been used to obtain an important reduction of stray light intensity in instruments designed to record the extreme ultraviolet spectrum of sources with high visible intensity(1,2). Filters are prepared by vacuum evaporation of aluminium onto a glass substrate which has been coated with a water-soluble separating agent. The glass slide is then immersed in water to separate the aluminium film which is removed from the water surface directly onto the filter mount.

The choice of filter thickness depends on the particular application and requires an estimate of the transmission in various wavelength regions. This report collects together available information on the absorption coefficient of aluminium through the spectral region from x-rays to visible light (1 Å - 6500 Å). The absorption data is then used to calculate the transmission properties of aluminium filters of the type normally used in instrumentation for the XUV region. The final part of the report gives a description of a simple and convenient method developed for estimating the thickness of evaporated aluminium films intended for use as XUV filters. The filter thickness is estimated from a direct measurement of the transmission obtained using an intense white light source.

2. OPTICAL ABSORPTION PROPERTIES OF ALUMINIUM

If a beam of monochromatic radiation is attenuated from intensity I_0 to an intensity I when passing through an aluminium filter, then the transmission is given by the ratio (I/I_0). The transmission is related to the filter thickness t by the equation

$$(I/I_0) = e^{-\mu t}$$

where μ is the linear absorption coefficient which is given in units of cm^{-1} when t is measured in cm. Calculation of the transmission properties of a particular filter requires a knowledge of the value of μ as a function of wavelength and also a measurement of the thickness of the filter.

Transmission data for aluminium filters in the x-ray, ultraviolet and visible wavelength regions are readily available but the information is dispersed through many

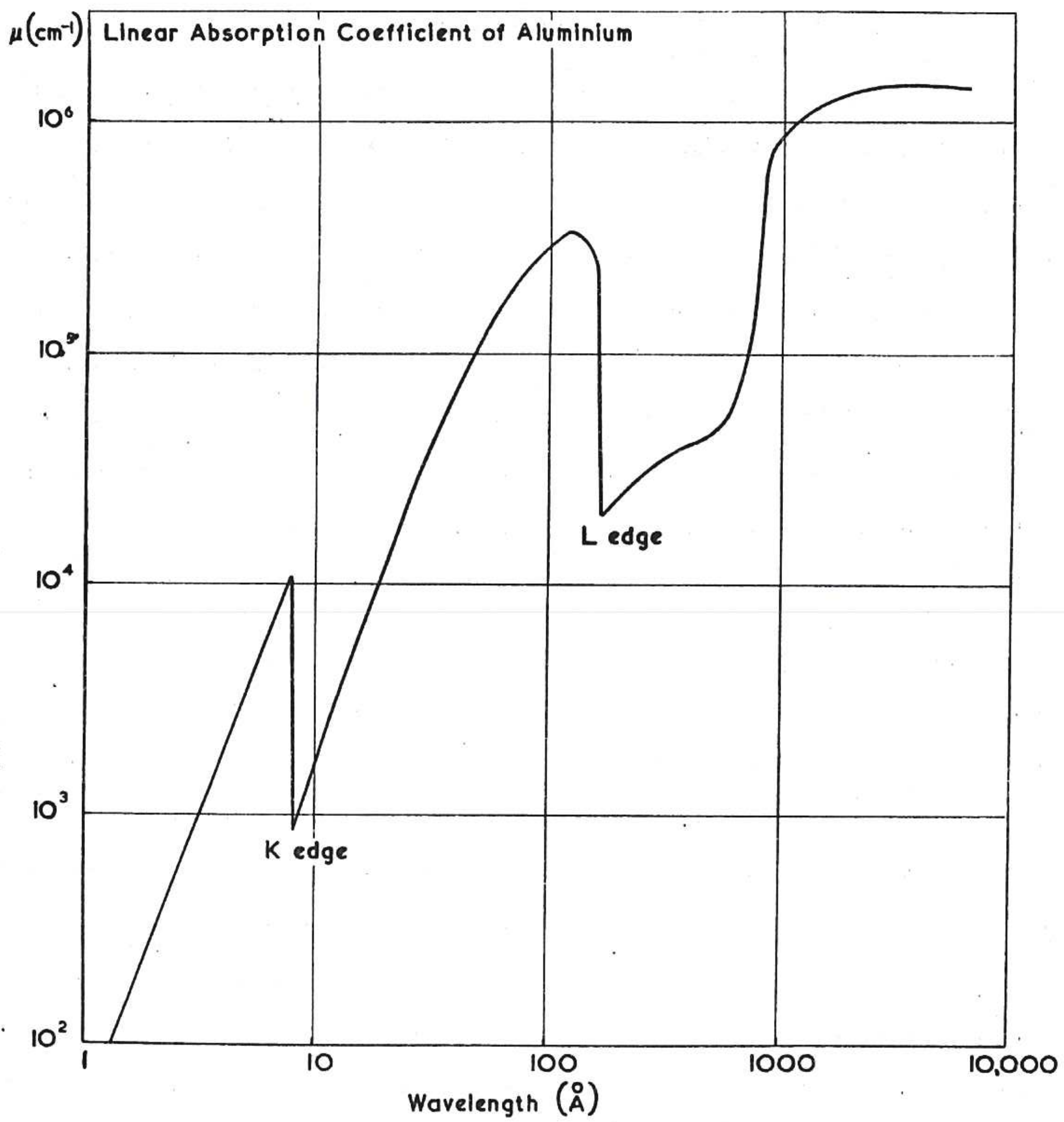

Fig. 1 (CLM-R64)
Linear absorption coefficient of aluminium (μ cm^{-1}) as a function of wavelength between 1 Å and 6500 Å. The data have been taken from the following papers (see references at end of text): (2) 170-800 Å; (3) 250-900 Å; (4) 1-8 Å; (5) 7-17 Å; (6) 25-110 Å; (7) 80-600 Å; (8) 50-500 Å; (9) 2200-6500 Å

published papers. Selected data$^{(2-9)}$ have been collected together in Fig. 1 to provide one graph giving the variation of μ as a function of wavelength. The results have been averaged and smoothed to provide a continuous curve giving mean values of the linear absorption coefficient for wavelengths between 1 Å and 6500 Å.

The thickness of filter materials is often expressed in units of mass per unit area (e.g. mg cm^{-2}) and consequently the mass absorption coefficient (μ/ρ) is normally used. The density ρ of evaporated aluminium is similar to the bulk density value of 2.7 gm cm^{-3}. This value of ρ has been used in converting published mass absorption coefficients into the linear absorption coefficient data given in Fig. 1.

The absorption coefficient is low for x-rays ($\lambda < 1$ Å) where aluminium is relatively transparent. Towards longer wavelengths the value of μ increases and the transmission decreases to a very low value at visible wavelengths. The smooth curve is broken by discontinuities at the K edge (8 Å) and the L edge (170 Å) where the absorption coefficient decreases by approximately a factor of ten over a very small increase in wavelength. Some fine structure has been reported in the region of these absorption edges but the detailed form of the curve appears to depend on the physical properties of the thin film and on the exact method of preparation(7). This structure has been smoothed out in preparing the data for Fig.1.

Transmission values calculated from the absorption coefficient data given in Fig.1 are in good agreement with observed values except in the wavelength region 170–800 Å where the measured transmission is much lower than the calculated values. The excess absorption has been attributed to the oxide film ($A\ell_2O_3$) which is rapidly formed when a filter is exposed to the air. An estimate of the thickness of the oxide layers was made by comparing measured transmission data with calculated values corresponding to various oxide layer thicknesses(2). The results indicated that a typical aluminium filter has an oxide coating about 40 Å thick on each surface of the metal film. The calculated transmission of this typical oxide coating is given in Fig.2 as a correction factor to be used after calculating the aluminium transmission from the filter thickness and the absorption coefficient data of Fig.1. The oxide layers also give rise to interference effects which slightly modify the spectral variation of the observed transmission but this is less important than absorption in the oxide layer which limits the transmission seriously in the 500–800 Å region.

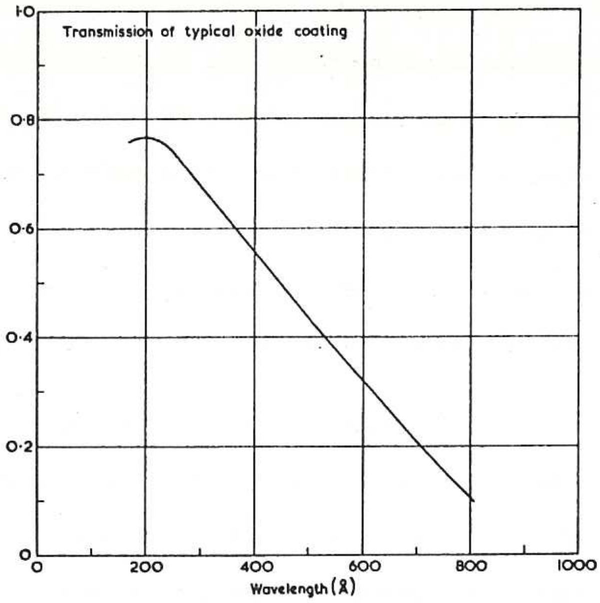

Fig. 2 (CLM-R64)
Transmission of a typical oxide coating (170-800 Å)

The averaged data contained in Figs. 1 and 2 have been used to calculate the transmission curves for unbacked aluminium

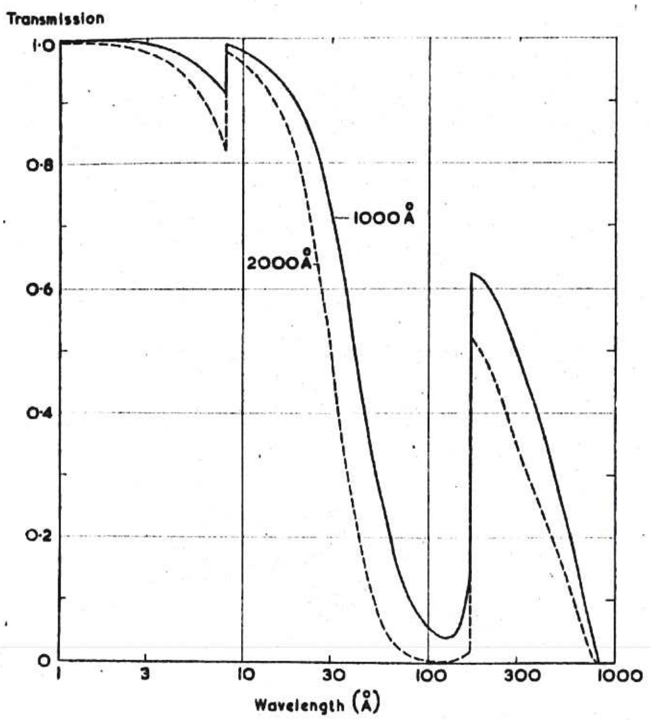

Fig.3 (CLM-R64)
Calculated transmission of aluminium filters 1000 Å and 2000 Å thick

filters of various thickness and the results are shown in Fig.3.

The useful waveband of a filter can be defined as the wavelength region in which the transmission exceeds some specified level. For an aluminium filter of 1000 Å thickness the useful transmission waveband defined by $T \geqslant 0.1$ extends from the x-ray region up to about 80 Å and again from the L edge at 170 Å up to 700 Å. The transmission of this filter in the near ultra-violet and visible region is just below 10^{-6} and it therefore behaves as a neutral filter (Density $D = \log 1/T \simeq 6$). The discrimination factor against visible light is consequently better than 10^5 throughout the useful waveband of the filter.

3. MEASUREMENT OF FILTER THICKNESS BY WHITE LIGHT TRANSMISSION

When evaporating thin aluminium films for use as filters some method is required to estimate the film thickness. Interference techniques are commonly used for this purpose but the measurements can become time consuming when many samples are prepared and when films of uneven thickness are produced. A method of thickness measurement was required which would allow rapid selection of films about 1000 Å thick. The transmission of such a film in the visible region is very low but is measurable and therefore can be used to estimate film thickness.

The absorption coefficient data contained in Fig.1 shows that μ for aluminium is almost constant in the wavelength region between 4000 Å and 6000 Å so that a single value of $\mu = 1.4 \times 10^6$ cm^{-1} can be taken as the white light absorption coefficient. Using this value the transmission and optical density of aluminium can be calculated for various thicknesses and the resulting curve is given in Fig.4. The white light optical density is a linear function of film thickness and increases by approximately one unit of density for each 160 Å of thickness, a 1000 Å thick film having an optical density of about six.

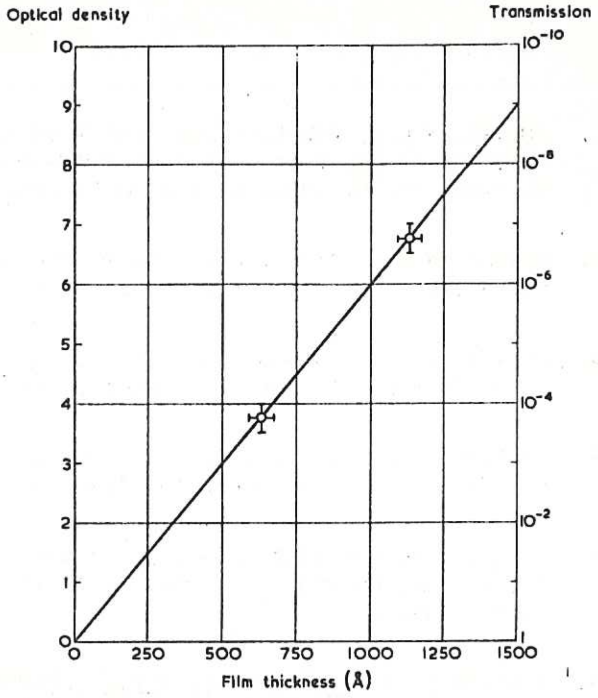

Fig.4 (CLM-R64)
Calculated white light transmission and optical density for aluminium films of various thickness, together with two measured points

The density of an evaporated aluminium film can be rapidly estimated by comparison with calibrated neutral density filters, using the sun as a bright source of white light and the eye as a null detector. A series of comparison filters covering the range 2.0 to 10.0 in steps of 0.5 was prepared by combining sheets of Kodak Wratten gelatine neutral density filter types ND05, ND10, ND20. Using a viewing system which screened the eye from direct sunlight, the sun was observed alternately through the aluminium film and through the various neutral density filters until the brightness of the solar disk could be matched by two similar densities. The eye is a good null-type detector and the density could be estimated rapidly to better than 0.5D which corresponds to an error of less than 100 Å in the thickness measurement. It was not possible to see the solar disk when filters more dense than D = 9 were used so the method is unsuitable for measuring films greater than about 1500 Å in thickness, but thicker filters could still be prepared by addition of two measured films of less than 1500 Å thickness.

To test the accuracy of this method of thickness measurement two aluminium films were prepared and measured by the simple procedure and also by the thin film interference fringe technique. The interference fringe method gave measured thickness values of 630 ± 40 Å and 1130 ± 40 Å for the two test films. Neutral density measurements of these films gave D(3.5-4.0) and D(6.5-7.0) respectively. These two points are included in Fig.4 and show good agreement with the calculated calibration curve confirming the reliability of the neutral density comparison method.

4. ACKNOWLEDGEMENTS

The aluminium films used in this work were prepared with the co-operation of Mr F.F. Freeman and Mr B.B. Jones. The thickness measurements were carried out by Mr A.T. Hatter.

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