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DESIGN NOTE

Simple UV–VUV beamsplitter coatings for Fourier transform spectrometers

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Abstract. In order to manufacture the UV–VUV Fourier transform spectrometer (FTS) beamsplitter, we present the experimental investigation of Al+MgF_2 as a beamsplitter coating in the UV and VUV wavelength ranges, based on the technical requirements of the UV–VUV FTS beamsplitter during development. The effects of film layers, material selection and structure design have been analysed by means of some numerical calculations. We have developed a UV–VUV reflectometer employing a Seya–Namioka monochromator, mainly for measuring the spectral properties of beamsplitter coatings covered on the ultraviolet-fused silica base at an incident angle of 5°. The results of the measurements are discussed. This work extends the area of application of Al+MgF_2 coatings.

Keywords: UV, VUV, beamsplitter coatings, Al+MgF_2, Fourier transform spectrometer, Seya–Namioka monochromator

1. Introduction

The significant advantages of the Fourier transform spectrometer (FTS) in determining absolute values of emission and absorption spectra in IR–FIR are well known. Progress in this area means that the technique now has advantages over dispersive grating spectrometry even in the short-wavelength region (UV–VUV and soft x-ray) [1, 2]. In IR–FIR, the film beamsplitters are often based on a free-standing stretched uncoated plastic membrane, called a pellicle [3]. But membranes cannot satisfy the high optical flatness required in the UV–VUV region, and there are still some spectral limits when multilayer coatings are used. It is therefore necessary to employ coated film on the transparent substrate to produce a reasonable beamsplitter for use in the UV–VUV FTS.

In this note, we offer a simple way to obtain beamsplitter film for use in the UV–VUV wavelength region. First, the performance of MgF_2-coated aluminium film is investigated theoretically by means of some numerical calculations. We have prepared MgF_2-coated aluminium film based on a substrate made from UV-fused silica and measured its spectral performance from 170 nm to 410 nm spectral regions. The spectral measurements show that the area in which Al+MgF_2 coatings can be applied extends to partially reflecting coatings for UV–VUV FTS.

2. Design approach and numerical analyses

In metals, on account of their very high conductivity, the absorption of electromagnetic energy is so large that they are practically opaque. In spite of this, metals play an important part in optics. Strong absorption is accompanied by high reflectivity, so that metallic surfaces act as excellent reflective mirrors. The absorption of metals is so large that we can only consider transmission below $\lambda/4$ in optical wavelengths. Transmission should be taken into account if the metal coating is thin enough. The transmissivity decreases exponentially with the thickness of the metal film, and the reflectivity of the film increases. It is possible to obtain the required capabilities when the absorption of the metal film is not dominant. High-reflectivity metal films are therefore suitable materials for use in beamsplitter coatings. Evaporated aluminium films are the most frequently used coatings for reflecting mirrors. Coatings of this type have been used in a variety of optical instruments because of the high reflectance of aluminium film in the wavelength region from 100 nm to infrared, and its good adherence to optical glass. MgF_2 film is used for preventing the formation of a layer of Al_2O_3, which absorbs strongly in the UV and VUV regions, and then maintains high reflectance in the short-wavelength range. The reflectance of an MgF_2-coated aluminium mirror is better than 80% at wavelengths longer than 170 nm.

A small angle of incidence is often chosen in the FTS in order to reduce polarizing effects [4]. Effects will be not

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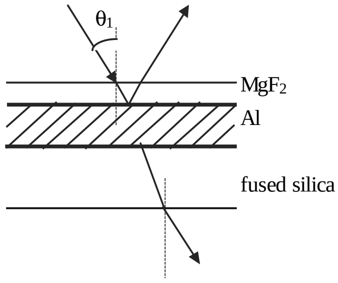


Figure 1. The structure of the beamsplitter film. θ_1 is the angle of incidence.

critical when the angle of incidence is less than 20°, so we chose an incident angle of 5° in the design of the beamsplitter coating (figure 1).

From metals theory, we know that the reflection and transmission characteristics of a metal film can be calculated from known optical properties and a knowledge of its thickness. When we consider a natural light source without polarizing radiation, the reflectance and transmittance of beamsplitter coatings may be defined as

$$R = \frac{1}{2}(R_S + R_P) \qquad T = \frac{1}{2}(T_S + T_P). \qquad (1)$$

Here, R_S, R_P, T_S and T_P are the reflectance and transmittance of the electric vectors parallel and perpendicular to the plane of incidence. The relative efficiency of beamsplitter coatings in a Michelson interferometer is defined as [5]

$$E = 2RT/(2R_0T_0)_{ideal} = RT/0.25 = 4RT \qquad (2)$$

where R_0 and T_0 are the ideal reflectance and transmittance of the beamsplitter, respectively. The central wavelength is selected as 236.2 nm on the basis of the design of VUV FTS for the 170–320 nm spectral region. All the numerical simulations in this work were performed using a computer program developed on the basis of the metals optics theory of Max Born [6]. The effects of varying the thickness of magnesium fluoride film become very appreciable when the optical wavelength is lower than 130 nm. To simplify the calculation, we assumed that the multiple beam interference effect in MgF_2 film could be ignored, and supposed that MgF_2 and UV-fused silica were transparent over the entire spectral range of interest here. Figure 2 shows calculated values of R, T and E versus aluminium film thickness by using the optical constants of evaporated metallic aluminium films at room temperature [7]. The 5° incident angle is assumed, and the selected incidence wavelength is 263.2 nm in the program. The value of R increases from zero continuously and tends to be smooth as it reaches about 0.9. In contrast, the value of T descends from 1 to 0. They intersect each other once, at R and T values of 0.45, corresponding with an aluminium thickness of 10 nm. We also find that the corresponding point of thickness of aluminium film about the relative efficiency peak value 0.82 is 9.8 nm. From our simulated calculations, we found that the choice of aluminium film thickness in the course of film structure design is the key factor affecting the beamsplitter efficiency. Calculated results of R, T and E versus different light wavelengths are shown in figure 3, with

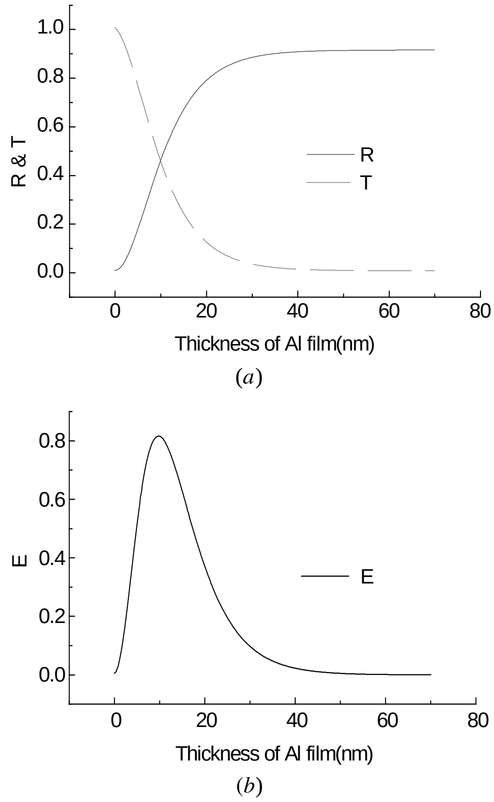
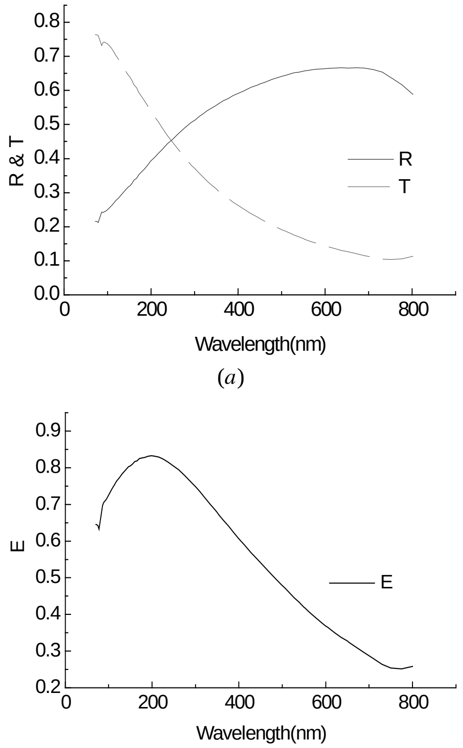


Figure 2. Numerical simulations of (a) R, T and (b) E for beamsplitter coatings versus the thickness of aluminium film for 5° incident angle of radiation at 263.2 nm.

9.8 nm thick aluminium film. R increases from 0.3 to 0.62 and T falls from 0.64 to 0.25 in the 150 nm to 410 nm spectral region. The curve of relative efficiency indicates that the values of E are higher than 0.7 in the spectral range between 110 nm and 350 nm, and peak value is 0.82 at 236.2 nm wavelength. The degree of fluctuation is acceptable in this region. The desired performance of beamsplitter coatings will be met when a little light radiation energy loss is allowed. A frequency-stabilized HeNe laser is often used to assist with the data sampling of white light interferograms for FTS, so we should consider the performance of beamsplitter coatings for a wavelength of 632.8 nm. Because the calculated value of relative efficiency is 0.36 at 632.8 nm, we concluded that this kind of coating would not affect the detection of the high spectral intensity laser interferogram signal.

3. Experiment and result

We prepared MgF_2-coated high-purity aluminium film on polished UV-fused silica with a thickness of 2 mm, using a high-vacuum evaporator under precisely controlled conditions. The pressure in the evaporator during the deposition was held at 2×10^{-5} mm Hg and the substrate temperature was not higher than 50 °C [8]. Aluminium of 99.999% purity in wire form is used for evaporating, and is wound onto the helical tungsten filament. A tungsten boat is used for premelting and evaporating the MgF_2 powder. The substrates have been cleaned beforehand with a detergent. Two shutters made of metal leaves are used to



(*b*)

Figure 3. Numerical simulations of (*a*) *R*, *T* and (*b*) *E* for beamsplitter coatings versus light wavelengths for 5° incident angle of radiation.

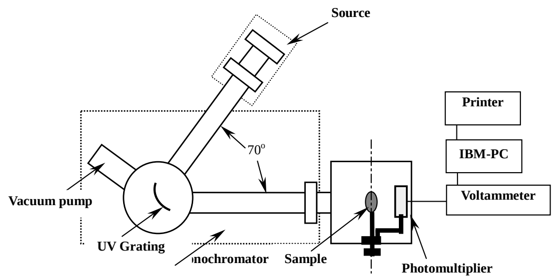


Figure 4. Schematic of the apparatus used for the optical performance testing of the beamsplitter coatings.

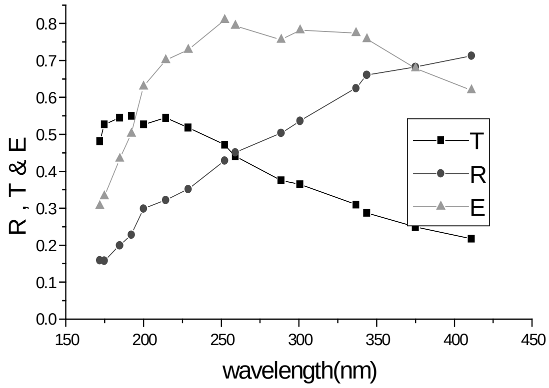


Figure 5. Experimentally determined spectral characteristics of beamsplitter coatings.

avoid contamination of the substrate during the premelting and evaporating of the MgF_2 and aluminium. The shutter on the tungsten filament is opened when the evaporation reaches constant speed, and it is closed when a desired film thickness is reached. Then the shutter on the tungsten boat filled with premelted MgF_2 is opened, and it is closed when evaporation is complete. The MgF_2 coating and aluminium thicknesses are monitored by a quartz oscillator calibrated during the deposition. The spectral performances of samples had been tested from 170 nm to 410 nm used a UV–VUV reflectometer consisting of a hollow cathode light source, a Seya–Namioka monochromator, sample chamber, detector, data sampling and processing system. The sample's position can be adjusted accurately.

The vacuum apparatus of the reflectometer used for testing the spectral performance of Al+MgF_2 film is shown in figure 4. Ray radiation of different wavelengths can be divided by rotating the grating appropriately. The radius of curvature of the UV concave diffraction grating ruled with 1200 lines mm^{-1} is 1 m, the ruled area is 30×50 mm^2, and the width of the incident slit is about 2 mm. The sample can be rotated at any incident angle in the sample chamber, and the angle can be read from a dial outside the sample chamber. The shifts of incident and reflective measurements were controlled by repeatedly stretching out and drawing back the sample stand. The detector is connected with a bearing which can be rotated along with the rotation of the sample on the same axis by a mechanical device consisting of worm gearing. Sodium salicylate dissolved in methyl alcohol had been sprayed onto the glass envelope of a Hamamatsu R928 photomultiplier for the detection of ultraviolet and vacuum ultraviolet radiation. The operating current of a water-cooled hollow cathode light source (working gas: nitrogen) was maintained at 250 mA, and the operating voltage of the photomultiplier was controlled at −800 V. The vacuum system was adapted to maintain the pressure at 2×10^{-2} mm Hg during the course of the experiment. The data sampling and processing system consisted of an 8250 digital voltammeter, an IEEE 488/GP-IB interface processing unit, an IBM personal computer, real-time processing software and a printer.

Reflectance *R* and transmittance *T* are determined by formulating as following expressions after sampling:

$$R = (V_r - V_0)/(V_i - V_0) \qquad T = (V_t - V_0)/(V_i - V_0) \tag{3}$$

where V_i, V_r and V_t are output voltage values from the 8250 digital voltammeter when the photomultiplier receives the light radiation of different wavelengths from the direct incidence, reflection and transmission of the sample separately. V_0 represents the output voltage value of stray light when the incident slit is closed. Data processing is performed by a personal computer. The measured results are stored on the hard disk after analogue-to-digital conversion, and are printed out subsequently. To reduce accidental errors due to radiation fluctuations of light source, *R* and *T* can be corrected by co-adding ten times of output voltage values in a short period and dividing equally before calculating with formula (3).

The measured values of *R*, *T* and *E* are shown in figure 5. The reflectivity is about 0.15 and the transmittance is about

0.5 at 170 nm. They are all lower than the theoretical values shown in figure 3 because we have not considered the absorption by the MgF_2 film and UV-fused silica substrate of vacuum ultraviolet radiation. The values are similar to the theoretical values above 200 nm because of the absorption is reduced in that region. The reflectivity is 0.46 and the transmittance is 0.45 at 250 nm. From the curve of relative efficiencies, we find that the value of E drops sharply from about 0.6 to 0.3 over the spectral region 200–170 nm.

4. Conclusion

We have obtained Al+MgF_2 beamsplitter coatings on a UV-fused silica substrate. From the spectral measurements, the average relative efficiency increases sharply from 0.3 to 0.6 in the region from 170 nm to 200 nm, and the average value is about 0.45. E is higher than 0.7 between 200 nm and 350 nm, and the peak value is greater than 0.8. The feasibility of its use in UV–VUV beamsplitters in FTS is illustrated. This kind of beamsplitter coating has a broad spectral range. The thickness of the aluminium film is a crucial part of the design. The thicker the aluminium film produced, the shorter the achievable central operating wavelength. But the loss of optical radiation energy will increase following a rise in absorption of the aluminium film. The influence of the thicknesses of the protective film and the substrate should be carefully considered in the design procedure for UV and VUV FTS beamsplitters.

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References

[1] Thorne A P, Harris C J, Wynne-Jones I, Learner R C M and Cox G 1987 A Fourier transform spectrometer for the vacuum ultraviolet: design and performance *J. Phys. E: Sci. Instrum.* **20** 54

[2] Howells M R, Frank K, Hussain Z, Moler E J, Reich T, Moller D and Shirley D A 1994 Toward a soft x-ray Fourier- tranform spectrometer *Nucl. Instrum. Methods* A **347** 182–91

[3] Dobrowolsk J A and Traub W A 1996 Numerical study of the design of beamsplitters for the far-IR for use in Fourier transform spectrometers *Proc. SPIE* **2776** 231–5

[4] Li Zhigang, Qi Wenzong and Li Futian 1998 Soft x-ray and VUV Fourier transform spectrometer and spectral resolution *Opt. Precision Engng (China)* **6** 84–90

[5] Bell R J 1972 Introductory Fourier Transform Spectroscopy (New York: Academic) 108–28

[6] Born M and Wolf E 1975 *Principles of Optics* (New York: Pergamon) pp 611–64

[7] Palik E D 1985 *Handbook of Optical Constants of Solids* (New York: Academic) 369–406

[8] Canfield L R, Hass G and Waylonis J E 1966 Further Studies on MgF_2-overcoated aluminium mirrors with highest reflectance in the vacuum ultraviolet *Appl. Optics* **5** 45–50