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TRANSMISSION AND REFLECTION STUDIES OF THIN FILMS IN THE VACUUM ULTRAVIOLET

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ABSTRACT

Both the transmittance and reflectance of 2 mm thick MgF_2 substrates and of thin films of BaF_2, CaF_2, LaF_3, MgF_2, Al_2O_3, HfO_2, and SiO_2 deposited on these substrates have been measured for the wavelength range 120 nm to 230 nm. Results for BaF_2, LaF_2 and MgF_2 show promise as being good materials from which interference filters can be made. The software and related hardware needed to take large amounts of data automatically in future measurements of the transmittance and reflectance has been developed.

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LIST OF FIGURES

Figure 1 - The Vacuum Ultraviolet Calibration Facility

Figure 2 - Transmittance and Reflectance Measurements of 2 mm Thick Parallel (for T) and Wedged (for R) Substrates of MgF_2

Figure 3 - Transmittance and Reflectance Measurements of a 53 nm Film of BaF_2 on an MgF_2 substrate

Figure 4 - Transmittance and Reflectance Measurements of a 51 nm Film of LaF_3 on an MgF_2 substrate

Figure 5 - Transmittance and Reflectance Measurements of a 68 nm Film of MgF_2 on an MgF_2 substrate

INTRODUCTION

The theory and understanding of thin-film optics has a long and honored history[1,2]. In addition, the use of thin-film interference effects to design high reflectivity mirrors and narrow band-pass filters is a well established technology, especially at the visible wavelengths. Not so well established at present, however, is the extension of this technology down to the vacuum ultraviolet (120 nm - 230 nm). Because of the shorter wavelengths of UV compared to visible light (by factors of 1/3 or 1/4), the required film thicknesses must not only be thinner but also must be more carefully controlled. Furthermore, values of the refractive indices n and the extinction coefficients k are poorly known at these wavelengths for materials likely to be useful as film materials.

In the face of the extensive work that needs to be done in the vacuum UV, there is also a natural and growing need to improve optical instrumentation designed for use in the UV. For example, satellite UV imaging of auroral and other emissions from Earth has distinct advantages over visible and IR imaging. Since the earth's atmosphere does not backscatter solar UV efficiently and is also highly absorptive of UV, satellite UV images of Earth allow for a reasonably direct viewing of auroral and airglow emissions, day or night, uncontaminated by the earth's albedo.

Determination of the wavelength-dependent optical constants n and k in the range 120 nm to 230 nm for a variety of materials is crucial. In particular, these values are necessary to the design of narrow band-pass filters needed for the UV Imager to be flown on the POLAR satellite of the ISTP Program. This satellite, scheduled for launch in 1993, will be in an eccentric polar orbit at heights ranging from about 2 Re to 9 Re and will provide an ideal platform for imaging the aurora. The emissions of interest are the strong H-Lyman alpha line at 1216 Angstroms, the 1304 and 1356 atomic oxygen lines, the weaker LBH N_2 bands between 1400-1700 and 1700-2300, and the atomic nitrogen lines at 1493 and 1744.

OBJECTIVES

The focus of this research study then is to determine the transmittance and reflectance of films having known thicknesses and composition. The materials are 2mm thick high quality commercially made MgF_2 substrates and thin films of BaF_2, CaF_2, LaF_3, MgF_2, Al_2O_3, HfO_2, and SiO_2 deposited on these substrates by the Optical Aeronomy Laboratory at the University of Alabama in Huntsville. The measured values of transmittance (T) and reflectance (R) are sufficient for calculation of the more fundamental quantities n and k as functions of wavelength. The actual process of obtaining n and k from the reported T and R data is to be carried out by Zukic, et. al.[3,4]. These results are part of the program to design and construct five narrow band-pass filters for the UV Imager on satellite POLAR, including band-pass windows centered on the wavelengths 1216, 1304, 1356, 1500 and 1800 Angstroms.

Because of the time-consuming nature of taking large quantities of data under high-vacuum conditions, there is also a need for as much automation of data acquisition as is practical. Thus, a useful task is to interface the existing hardware and software with upgraded versions. An existing computer program will be modified and enhanced to accomplish these tasks.

DESCRIPTION OF FILM SAMPLES

The film depositions are carried out by the Optical Aeronomy Laboratory at the University of Alabama in Huntsville. The film materials, BaF_2, CaF_2, LaF_3, MgF_2, Al_2O_3, HfO_2, and SiO_2 are deposited in vacuum on MgF_2 substrates 12.7 mm in diameter by 2 mm thick. When needed, a 3 degree wedged substrate is used to eliminate background contributions to reflectance coming from reflection off the backside surface of the substrate. Film thicknesses for samples measured vary from about 50 nm to 100 nm. The substrates have a surface roughness of about 2.5 nm, marginally smooth for the film thickness deposited. All handling, deposition and transportation of substrates is done under standard clean-room procedures to ensure a minimum of contamination.

DESCRIPTION OF THE VACUUM ULTRAVIOLET CALIBRATION FACILITY

The vacuum ultraviolet calibration facility is a 1000 liter hydrocarbon-free system currently being used to measure reflectance and transmittance. The configuration at present is shown in Figure 1. Briefly stated, the facility consists of a main chamber containing an instrument platform on which filter samples can be mounted. Mated to the main chamber is the smaller source chamber containing a .2 meter monochromator and an optical system capable of delivering a collimated UV beam having a 1 nm bandwidth and dimensions of approximately 2 cm square. The main chamber is a cylinder having diameter 1 m and length 1.25 m; the source chamber is also a cylinder but having a diameter .3 m and length 1 m. The light source is a sealed deuterium lamp with a MgF_2 window and provides continuous useful spectra from about 115 nm to 230 nm.

Samples are mounted on an 8-slot wheel in the main chamber, operated by with a small stepping motor controlled by means of electrical feedthroughs. Behind the filter wheel is a photometer fixed in a position to measure transmitted intensity. A second photometer is positioned to view reflected light under the condition that the filter wheel is oriented to a 4 degree incident angle with respect to the beam. The vacuum system provides a hydrocarbon-free environment at a pressure of order 10^{-5} Torr, maintained by a pair of cryo pumps.

In order to enable a means of monitoring the beam signal strength as well as of checking background at each wavelength, three of the eight filter-wheel positions are occupied. One of the three positions contains a calibrated UV enhanced aluminum mirror for use in determining the reference beam intensity for reflectance measurements. The other two positions are used to monitor the reference beam and background intensities for transmittance measurements. Thus, in any single run, 5 or fewer samples can be measured for both T and R at all wavelengths from 120nm to 230nm, consistent with the range of usefulness of the deuterium lamp. Measurements are made by setting the monochromator at a particular wavelength and then successively rotating the filter wheel to each of the required positions. When all positions for a given wavelength are complete, the computer, which has accumulated the photometer current data directly on-line, calculates the value of T (or R) along with statistical uncertainties.

Software has been developed which gives the user several levels of automatic operation. At the lowest level of automation, the monochromator is set by hand, the filter wheel is positioned manually by means of a vacuum rated stepping motor, and on command, the photometer current is sampled repeatedly by the computer. At the highest level of automation, the filter wheel and monochromator are set manually to the starting value, after which the computer guides the system through a complete set of specified input wavelengths and filter-wheel positions, both taking and processing data as obtained. Upon completion of a run, graphs and tables are produced of T and R as a function of wavelength.

The monochromator stepping motor (model PH296-01B, Vextra) has been interfaced with the parallel input/output port of the computer by means of a motor driver circuit (model 2D3128, Anaheim Automation). Two bit-positions of the eight-bit port are used for motor control. The in-vacuum filter wheel stepper motor (model C, Princeton Research Instruments) has similarly been interfaced using a motor driver circuit board (model ESH081/R2D23, Cyber-Research). An optoisolator (model ESH 085, CyberResearch) protects the computer system from electrical noise and potentially damaging voltages. Four additional bit-positions are used for the vacuum stepping motor operation.

RESULTS AND CONCLUSIONS

Examples of transmittance and reflectance measurements are shown in Figures 2, 3, 4 and 5. As a result of the measurements, optical constants for these and other film materials have been determined and will be used in the design of UV narrowband filters[4]. Indications from these calculations are that high values of the refractive index make LaF_3 and BaF_2 good for use with MgF_2, having lower refractive index, in making narrowband transmission filters. Because the measurement process is now automated, more accurate and consistent measurements are able to be obtained than previously, without the stress and tedium imposed on the operator.

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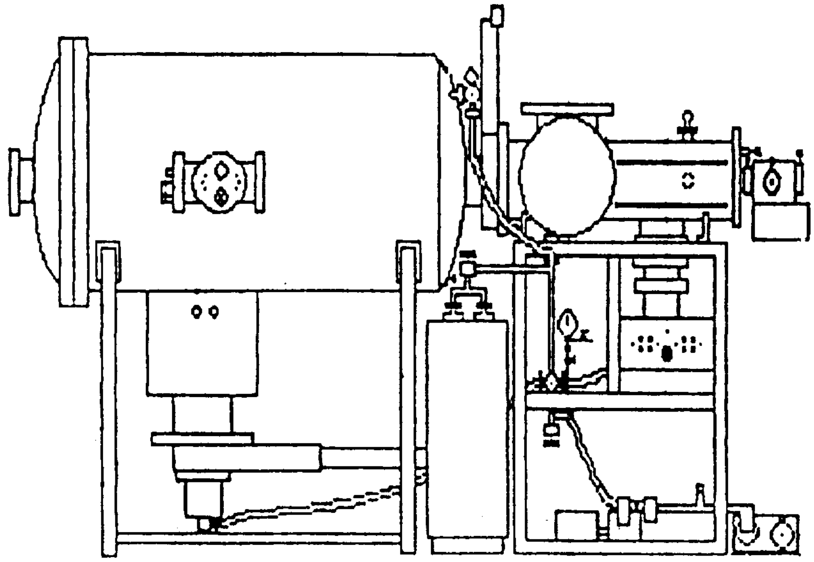


FIGURE 1

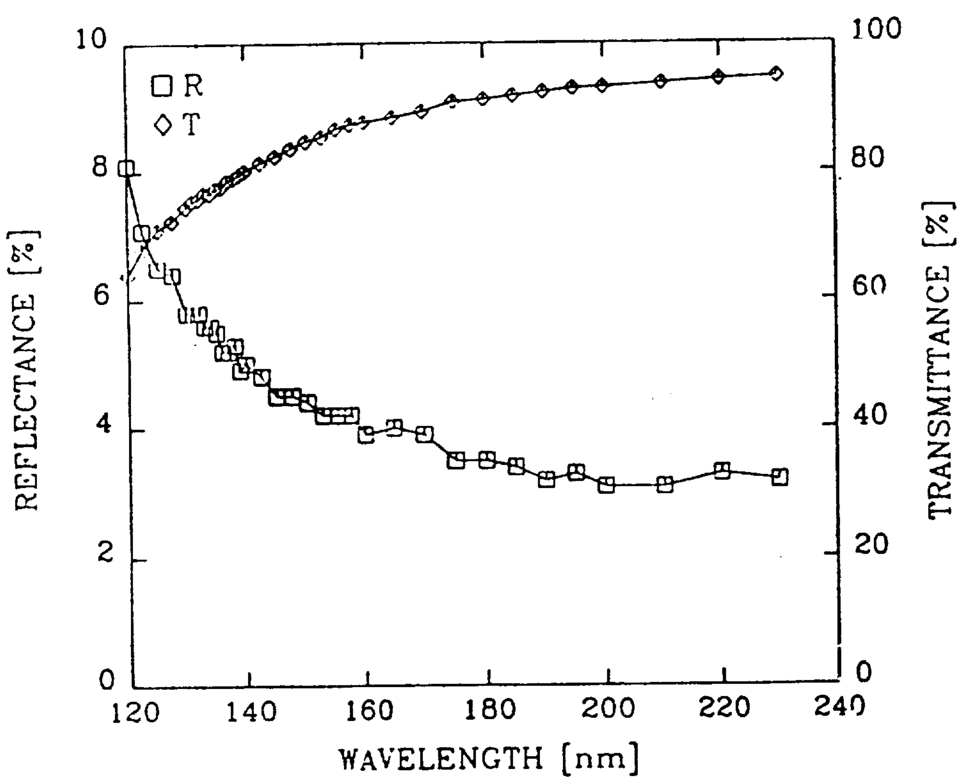


FIGURE 2

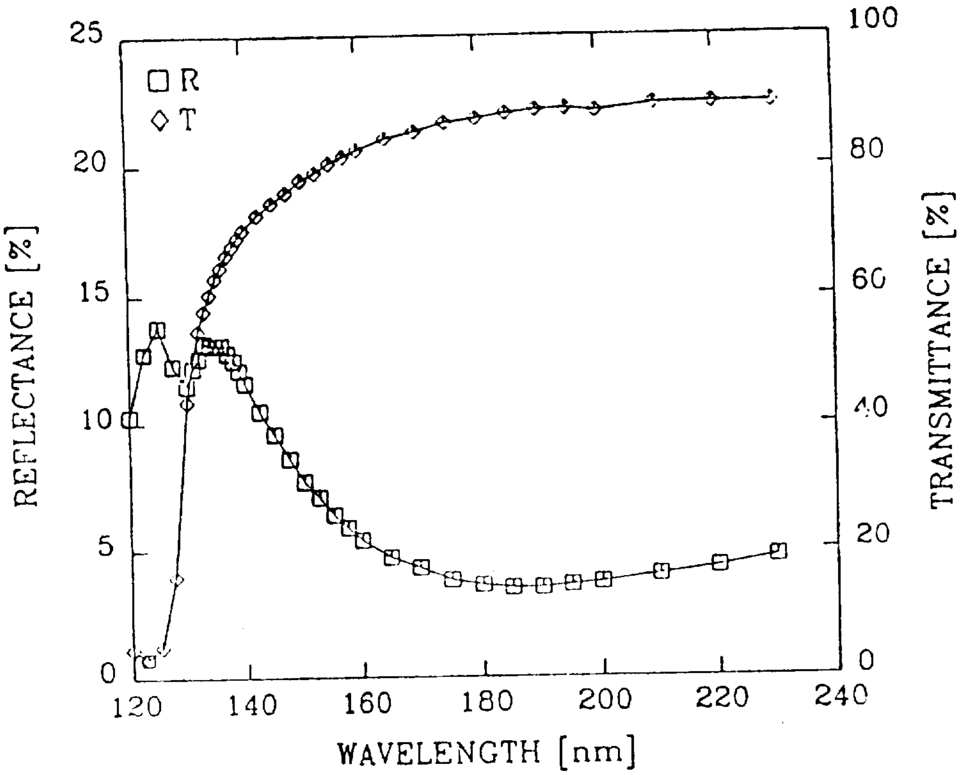
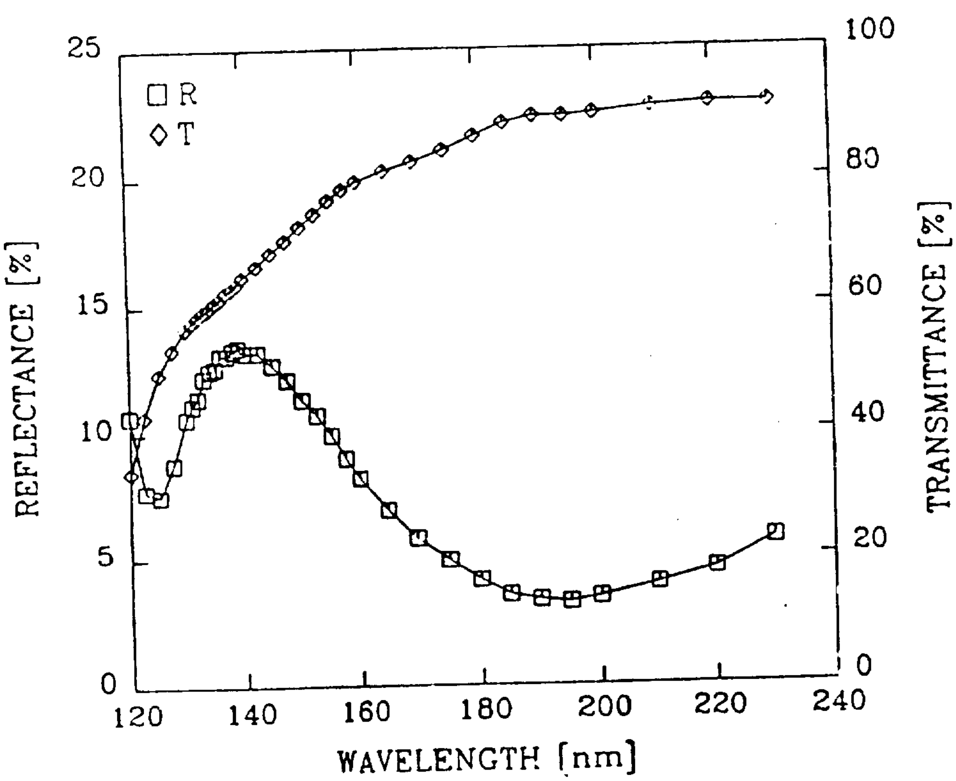


FIGURE 3



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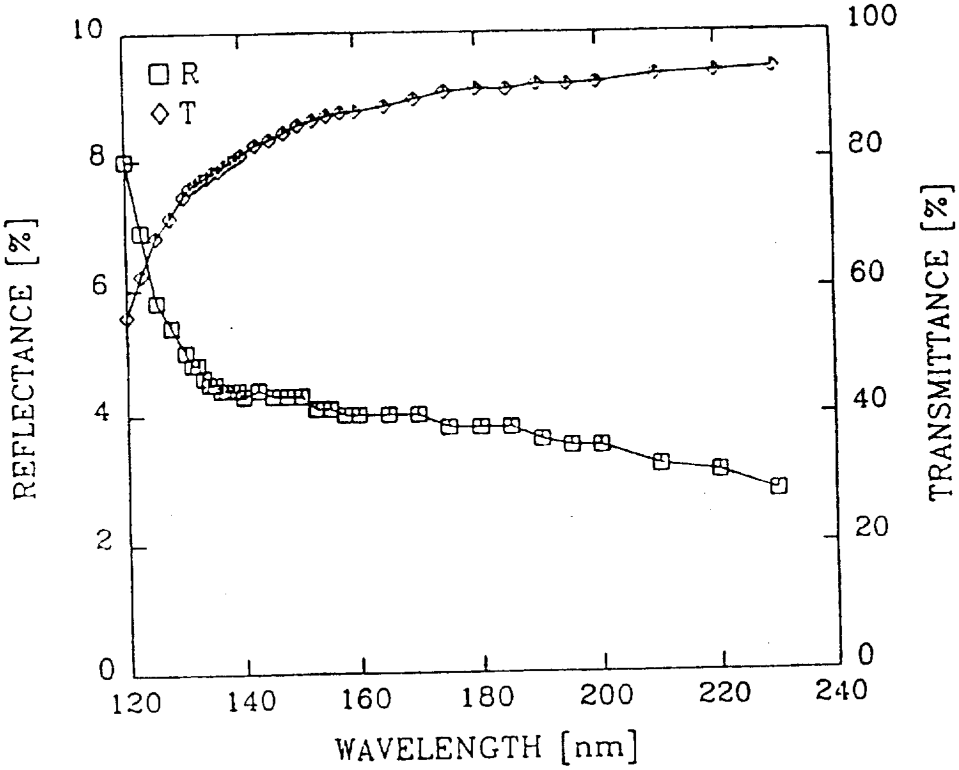

10
8
6
4
2
0
100
80
60
40
20
0
R
T
REFLECTANCE [%]
TRANSMITTANCE [%]
120
140
160
180
200
220
240
WAVELENGTH [nm]

FIGURE 5