Polarizing and non-polarizing mirrors in far UV for the Hydrogen Lyman-α radiation ($\lambda = 121.6$ nm)

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UVX 2010 (2011) 169–173
DOI: 10.1051/uvx/2011023

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Abstract. We demonstrate the feasibility of efficient polarizing and non-polarizing mirrors at $\lambda = 121.6$ nm designed within the framework of the Lyman α Lyot Coronograph Imager project. We have designed, realized and characterized such mirrors. Optical constants of the materials involved in the thin film coatings are determined experimentally. Reflectivity measurements in the VUV wavelength domain have been performed at PTB (Synchrotron at BESSY II, Berlin). A s-polarized reflectivity R_s as high as 68% is experimentally obtained with a coating made of a Fabry-Pérot resonator. To our knowledge this value is the highest ever reported for a polarizing mirror at this wavelength.

1. INTRODUCTION

The 80–130 nm vacuum-ultraviolet (VUV) spectral range is a key wavelength range to understand the processes acting in the upper solar chromosphere and the low solar transition region. Particularly, the Hanle effect which affects the Hydrogen Lyman-α radiation ($\lambda = 121.6$ nm) provides a means of investigating the coronal magnetic field, The term "Hanle effect" refers to the effect of a magnetic field on the direction and degree of a scattering linear polarization. Its detection implies polarization-dependent measurements. The rotation of polarization induced by the Hanle effect may be deduced from the comparison between the two monochromatic images obtained by reflection on a polarizing mirror and on a non-polarizing mirror.

In the VUV spectral domain where both transmittance and reflectance of most materials are very low, the realization of optical components is specifically difficult. For this reason, optical constant values are often either unknown or very dependent on the measurement conditions [1,2], thus making it difficult to design a desired component. We have developed a method particularly suited to the determination of optical constants in the VUV region [3,4] which enabled us to model and optimize reliably polarizing and non polarizing mirrors to be used at $\lambda = 121.6$ nm.

The materials involved in the fabrication of the mirrors are Al, which is the best material in terms of reflectivity, and fluorides (MgF_2, AlF_3), which are the best materials in terms of transparency, at this wavelength. Contrary to the other usual metals, pure aluminium maintains a reflectivity close to 80% down to $\lambda \approx 90$ nm, but the spontaneous formation of alumina upon air contact causes the actual reflectivity to collapse, as shown in Figure 1. Oxidization can be prevented by depositing on Al a transparent fluoride capping layer, which extends the range of high reflectivity from alumina to fluoride bandgap, thus including $\lambda = 121.6$ nm. Fluorides can also be used to form a polarizing anti-reflection coating or a non-polarizing coating.

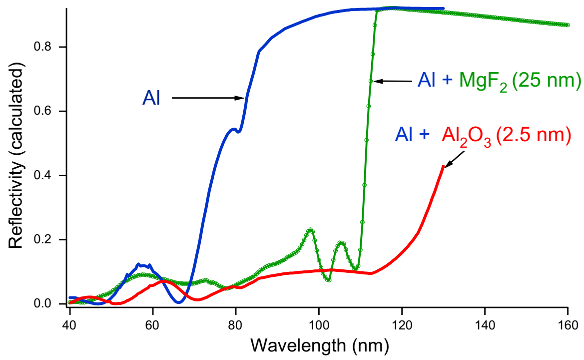

Figure 1. Calculated reflectivity under normal incidence of Al-based mirrors in the range 40 – 160 nm. Under oxidization, the reflectivity of pure Al collapses. A capping layer made of MgF_2 extends the high reflectivity spectral range down to $\lambda \approx 110$ nm.

2. EXPERIMENTAL PROCEDURES

Thin films of aluminium and fluorides have been successively evaporated on float glass substrates, 2 cm in diameter, in a UHV chamber equipped with a quartz thickness monitor controlled electron gun and different crucible charges. The initial pressure in the chamber was lower than 10^{-6} Pa. In order to control the thicknesses as precisely as possible, the deposition rates were calibrated by using grazing incidence X-ray reflectivity. This technique was then used to control the actual value of the thickness of each of the successive layers forming the mirror coating. Indices were determined by using the graphical method we developed [3,4]. It is briefly described in the next paragraph. Polarized reflectivity measurements at $\lambda = 121.6$ nm were performed at the PTB (Physikalisch-Technische Bundesanstalt), with synchrotron radiation from the electron storage ring MLS (Metrology Light Source) [5,6] in Berlin.

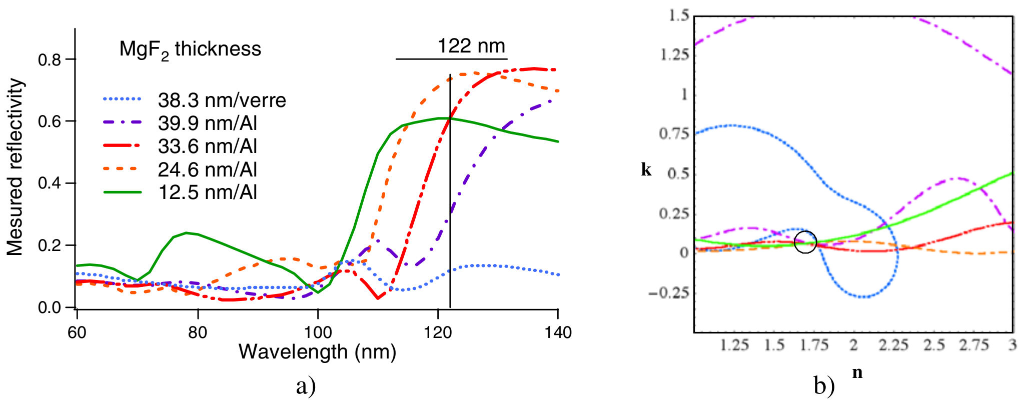

Figure 2. a) Measured reflectivity of MgF_2 layers deposited on Al; b) Corresponding iso-reflectivity curves drawn for $\lambda = 121.6$ nm and determination of n and k at the common point of intersection.

3. DETERMINATION OF THE OPTICAL INDICES FROM REFLECTIVITY MEASUREMENTS

The material of unknown index (n, k) is deposited on Al covered glass. Several samples are prepared, different only in the thickness (e) of the deposited layer. The reflectivity of these samples under normal incidence is then measured, particularly at $\lambda = 121.6$ nm (Fig. 2a). From these data, (n, k) iso-reflectivity curves can be drawn (Fig. 2b). The (n, k) unknown couple is determined as the coordinates of the common point of intersection in the (n, k) plane between the iso-reflectivity curves thus obtained. Three curves, that is three samples, are generally necessary to unambiguously determine the (n, k) solution at the considered wavelength. We obtained n = 1.73 and k = 0.04 for MgF_2 at $\lambda = 121.6$ nm (k = 0 in Palik's tables [1,2]).

4. POLARIZING MIRRORS AT $\lambda = 121.6$ nm

In the VUV, where most materials are highly absorbing, an efficient polarizing mirror cannot be achieved simply by using a Brewster incident angle on a bulk material, except with fluoride crystals. The reflectivity of the p-polarized light R_p must be minimized by depositing an appropriate antireflection (AR) coating. Different configurations have been optimized, realized, and compared [8]. In order to achieve a reliable modelling, the formation of alumina inside the deposition chamber has been taken into account and indices of fluorides are those we have beforehand measured by using the above mentioned method.

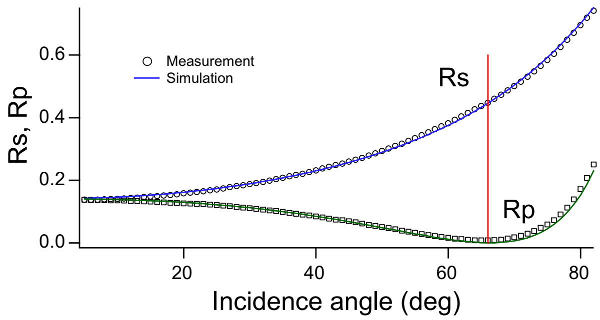

Figure 3. Polarization-dependent reflectivity of an optimized single MgF_2 layer deposited on float-glass. Measurement: $\alpha = 66°$ Rs = 0.446 P = 0.96 ± 0.04; Simulation: $\alpha = 66°$ Rs = 0.446 P = 0.9993.

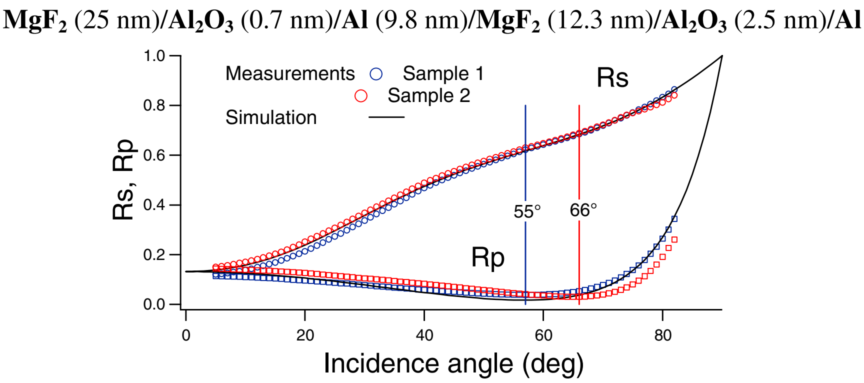

Figure 4. Polarization-dependent reflectivity of a polarizing mirror made of a Fabry-Pérot resonant cavity deposited on glass. Samples 1 and 2 have been prepared simultaneously onto neighbouring substrates. Measurements :1) $\alpha = 55°$ Rs = 0.622 P = 0.89 2) $\alpha = 66°$: Rs = 0.684 P = 0.92.

Two examples are given below: the simplest configuration (Fig. 3) and a more complicated one (Fig. 4). In the first, the AR coating is made of a single MgF_2 layer deposited on glass, in the second one it is made of a Fabry-Pérot resonant cavity ($Al/MgF_2/Al$) protected from oxidization by a top fluoride layer. In both cases, the optimization process aimed at reducing R_p to a minimum. A very good agreement is obtained between calculation and experiment (Fig. 3 and Fig. 4). This agreement is not achievable if the formation of a few Angstrom alumina on the aluminium surface in the vacuum chamber is not taken into account [7]. The polarizing power $P = (R_s - R_p)/(R_s + R_p)$ is affected by a 4% experimental relative uncertainty which does not enable us to confirm precisely its predicted high value. A s-polarized reflectivity R_s as high as 68% is experimentally obtained with a coating made of a Fabry-Pérot resonator. To our knowledge this value is the highest ever reported for a polarizing mirror at this wavelength.

5. NON-POLARIZING MIRRORS AT $\lambda = 121.6$ nm

In view of an investigation of the Hanle effect, a non-polarizing mirror, working at the same incidence angle as the polarizing mirror, is needed to form a reference image. The equality $R_s = R_p$ may be obtained with a mirror made of aluminium by adjusting the thickness of the MgF_2 layer which protects Al from oxidization [8]. Figure 5 shows the reflectivities calculated for such a simple mirror at an incident angle of 69° as a function of the MgF_2 thickness. Depending on the phase difference between interfering beams, which varies with the MgF_2 thickness, the mirror may be s-polarizing, p-polarizing, or non-polarizing. The three points of intersection between R_s and R_p indicate the values of the MgF_2 thickness that should yield non-polarizing mirrors at an incident angle of 69°.

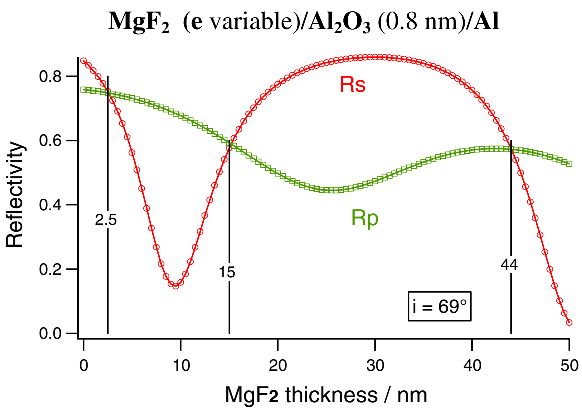

Figure 5. Polarization-dependent reflectivity calculated for a simple MgF_2 / Al / glass mirror at an incidence angle of 69° as a function of the MgF_2 thickness. The formation of an alumina layer is taken into account.

We have explored the two solutions: $e \approx 44$ nm and $e \approx 15$ nm. The experimental results are obtained in satisfactory agreement with predictions. The first mirror (Fig. 6a) is non-polarizing only at a given incidence angle ($i = 66°$, $R_s = R_p \approx 50\%$) and displays a negative polarizing power for $\theta < 66°$ ($R_s < R_p$). The second one (Fig. 6b) is non-polarizing in a broad range of incidence angles and displays a reflectivity higher than 55%.

6. CONCLUSION

A preliminary determination of indices in the wavelength range 80–140 nm was carried out which enabled us to model and optimize polarizing and non polarizing mirrors at $\lambda = 121.6$ nm. Mirrors

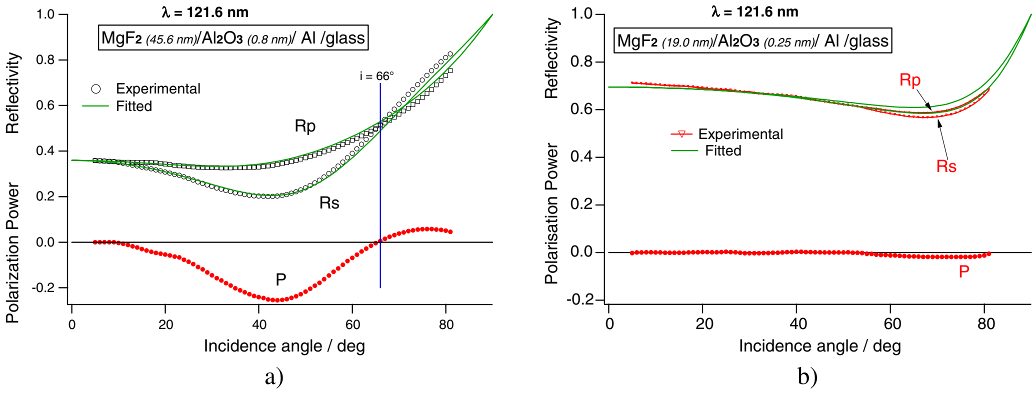

Figure 6. Polarization-dependent reflectivity of two non-polarizing mirrors: a) with e(MgF2) = 45.6 nm;

have been fabricated according to the modeling optimization and polarization-dependent reflectivity measurements have been performed at PTB synchrotron beam line. A very satisfactory agreement has been obtained between prediction and experiment. Efficient polarizing and non-polarizing mirrors at $\lambda = 121.6$ nm have been demonstrated that should enable the Hanle effect affecting the Hydrogen Lα radiation to be fruitfully exploited.

Acknowledgments

This work was supported by the CNES (Centre National d'Etudes Spatiales, France). We thank J.C. Vial, F. Auchère, A. Millard, F. Rouesnel (from Institut d'Astrophysique Spatiale, Orsay, France) for fruitful discussions, M. Richter, A. Gottwald, U. Kroth from PTB (Berlin) for polarization-dependent reflectivity measurements.

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