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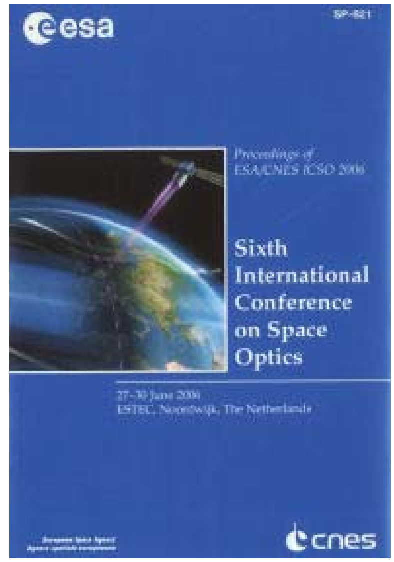

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MULTILAYER COATINGS FOR MULTIBAND SPECTRAL OBSERVATIONS

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ABSTRACT

Extreme UltraViolet instrumentation often requires the use of multilayer coated optics. Such coatings have a limited working bandwidth, and therefore are optimized to perform in correspondence of specific EUV spectral lines. Nevertheless, contemporary observations of the same target in other spectral region would strongly improve scientific knowledge. In this work we present a study on multilayers optimized to achieve high efficiency also in other spectral bands. These coatings would allow the realization of very compact instruments, such as UVCI on board of the Solar Orbiter.

1. INTRODUCTION

The new idea is the use in astronomical telescopes of multilayer optics that although is tuned for the extreme ultraviolet (EUV) wavelength band (i.e. 2-40nm), it can nevertheless operate also at the vacuum ultraviolet (VUV) and visible wavelength (i.e 90-200 nm and 500-700 nm respectively). This idea has been first proposed within the Solar Group of the Osservatorio Astronomico di Torino (OATo) of the National Institute for Astrophysics-INAF in application to the UVCI instrument and developed in collaborazione with [1,2].

Due to the quite different requirements, space optics for astronomical and solar physics instrumentation is classically specialized at the wavelength band in which the observations are carried out. Among many examples, we can mention the remote-sensing instrumentation aboard the European Space Agency (ESA) mission "Solar and Heliospheric Observatory" (SOHO) [3]. On SOHO there are different telescopes for solar disk observations in visible-light (Michelson Doppler Imager – MDI), UV (Solar Ultraviolet Measurements of Emitted Radiation – SUMER), EUV (Extreme-ultraviolet Imaging Telescope – EIT) and soft X-ray (Coronal Diagnostic Spectrometer – CDS). There are also different telescopes for observations of the solar corona in visible light (Large Angle and Spectrometric Coronagraph – LASCO) and UV (Ultra-Violet Coronagraph and Spectrometer – UVCS). For the coronagraphs, in particular, the requirements on the stray-light to disk-light rejection ratio are very different for the visible light (i.e. <1e-08) and the UV (i.e. <1e-05). This is the reason why the classical approach calls for designing and using separate coronagraphic instruments for the different wavelength bands [4,5].

However future solar missions proposed by ESA and NASA will have very challenging orbital profiles. The ESA "Solar Orbiter" for instance, will fly twice a year around the Sun with perihelion distance as close as 0.2 AU (Astronomical Units), that is about 40 solar radii from the solar surface [6,7]. The orbit of NASA "Solar Probe" mission will bring the spacecraft even closer to the Sun: up to 4 solar radii [8,9]. These missions will be more planetary type of missions than "great observatories" like SOHO or Hubble. Therefore the spacecraft resources available for the payload will be at a premium. For this reason, it is important to develop technologies that will allow combining in one instrument the remote-sensing of two or more telescopes operating at different wavelengths.

In Italy the solar group of INAF-OATo has proposed a coronagraph whose telescopes uses multilayer optics tuned for an EUV band centered at 30 nm, that can however also operate in the VUV (122 nm) and visible light (500-700 nm) [1]. The Italian team is developing a sounding-rocket prototype of such an Ultraviolet and Visible light Coronagraphic Imager (UVCI) [2]. The UVCI instrument for the Sounding-rocket Coronal Experiment (SCORE) is developed in collaboration with the Naval Research Laboratory (NRL), Washington D.C., as part of the HERSHEL payload scheduled for launch on a NASA rocket in 2007.

The UVCI instrument design consists of an externally occulted, off-axis Gregorian telescope with multilayer-coated optics. The design has been optimized for a sounding-rocket flight at 1 AU as compared to the solar Orbiter platform at 0.2-0.3 AU. The UVCI is designed to obtain monochromatic images in the Lyman-α lines of neutral hydrogen, HI 121.6 nm, and of the singly-ionized helium, HeII 30.4 nm lines and measure the polarized brightness (pB) of the visible K-corona. An external coronagraph is essential due to the scattering properties of the mirrors. The idea is to realize the UVCI instrument with just one channel optimized for the HeII Lyman-α with a 30.4 nm multilayer coating, which also provides high reflectivity in other spectral

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bands. The off-band rejection at 121.6 nm and visible is insured by an Al filter. When observing in these two wavelengths bands an Al/MgF_2 interference filter will be inserted in front of the detector in place of the EUV Al filter. In this way the same multilayer optics is used for different spectral bands (EUV, VUV and visible light).

2. Mo/Si

In the UVCI there are two channels: channel He II for observation at 30.4 nm and channel H I for observation at 121.6 nm. The two telescope mirrors of the He II channel are covered with multilayer coatings, whereas those of the H I channel with standard Al/MgF_2 to enhance 121.6 nm reflectivity. However the objective is to have in the He II channel a multilayer mirror which can provide a discrete reflectivity level also at 121.6 nm and in the visible band.

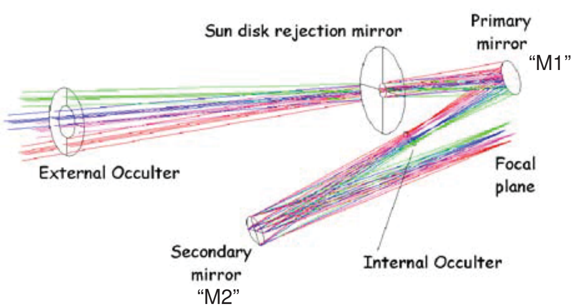

Fig. 1. Optical design of a single HERSCHEL-UVCI channel.

Preliminary multilayer samples for UVCI-HERSCHEL (Fig.1) have been deposited by RF-Magnetron sputtering and fully characterized in terms of period d, Γ ratio and interface quality and final performances. They consist of 15 periods of Mo and Si layers deposited on a Si wafer; an additional Si layer of about 2 nm is deposited on the top of the stack in order to act as a protective cap-layer after oxidation in air [9].
Mo/Si provides long term stability which is essential for successfulness of the space mission.
In Fig.2 theoretical performances of Mo/si ML are presented. It is evident the presence of a non-negligible second order at about 15nm. The presence of multi-orders reflectivity can cause a reduction of the instrumental signal to noise (S/N) ratio. In space instruments working with low levels of S/N, as for coronagraphs, this reduction has to be carefully considered because it can affect the acquired signal.

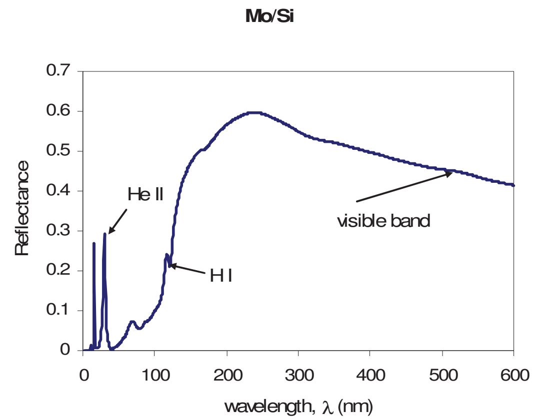

Fig. 2. ML reflectivity versus wavelength.

3. Si/B_4C

A Si/B_4C consisting of 15 periods has been also considered. The structure is protected by 20Å of additional Si, of which 10Å have been considered naturally oxidized, as in the case of Mo/Si. Si/B_4C multilayer structure theoretically has a better spectral purity and second order reduction compared to Mo/Si structure (Fig.3) [10]. In Table 1 we report some experimental results for a Mo/Si and a Si/B_4C ML.

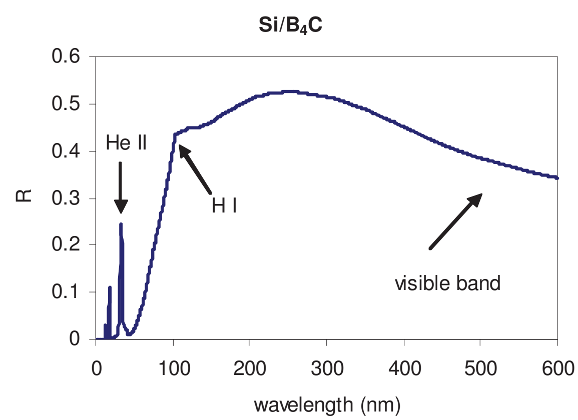

Fig. 3 Reflectivity of Si/B_4C versus wavelength.

Mo/Si		Si/B4C	
d (A)	Γ	d (A)	Γ
164.5	0.81	185.2	0.73
R_{max} 1st order	R_{max} 2nd order	R_{max} 1st order	R_{max} 2nd order
0.28	0.55	0.31	0.06

Table 1. Experimental parameters and reflectivities of Mo/Si and Si/B4C ML.

Respect to a Mo/Si ML, a Si/B_4C ML offers a R_{max} increment of about 11% joined to a second order reduction of about 89%. Furthermore the first order FWHM is reduced of approximately 15%.
Anyway this kind of multilayer shows rather weak long term stability. Measures acquired in a time interval of about 10 months evidence no degradation in the first 4 months, while a reflectivity peak reduction of about 10% at 30.4 nm has been observed after 10 months (Fig. 4).
This degradation is probably due possible internal stresses.

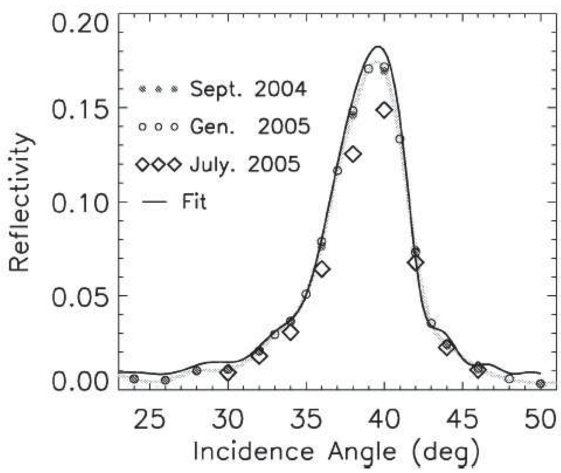

Fig. 4. Si/B_4C reflectivity data for λ=30.4 nm.

4. SiC/Mg

The SiC/Mg structure could be another possible structure for multilayers working at 30.4nm [11]. As can be seen in figure 5 this kind of multilayer shows a better reflectivity than the standard Mo/Si and the Si/B_4C structure.

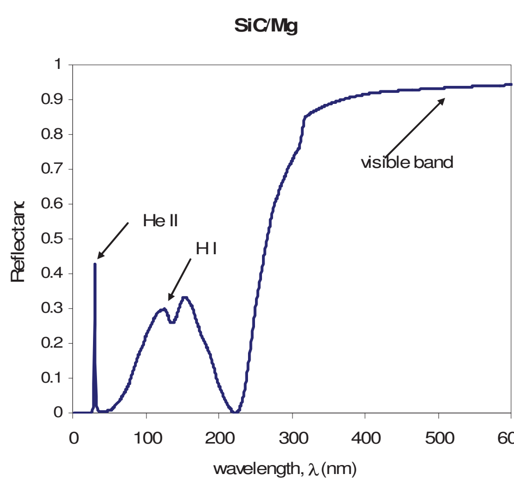

Fig. 5. Reflectivity of SiC/Mg ML versus wavelength.

A SiC/Mg multilayer without any cap-layer has been prepared by Refractive X-Ray Optics (D.Windt) and tested at LUXOR laboratory at Padova. The reflectance measurements were performed with two different facilities [9, 12] working in the 1-40 nm and 40-150 nm spectral range respectively. In Fig.6 we compare the measured reflectivities for the three multilayer structures considered, to evidence the better reflectivity of SiC/Mg.

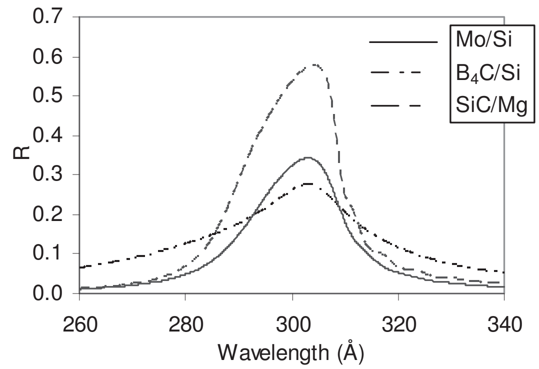

Fig. 6. Experimental comparison of multilayers for λ=30.4nm.

In Fig. 7 and Fig. 8 the reflectance values at 30.4 nm and 121.6 nm versus the angle of incidence are reported, while in the visible band we measure a reflectance of about 70% at only one angle of incidence (six degrees from the normal incidence).

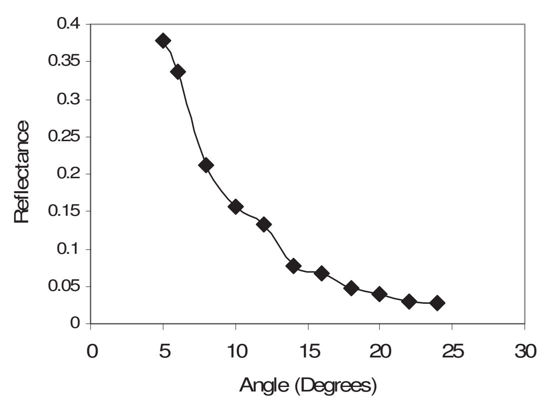

Fig. 7. Measurements at 30.4 nm versus incidence angle.

At 30.4 nm we found a good accordance with the reflectivity expected theoretically. Instead reflectivity at 121.6 nm (Fig.8) is lower than the one expected from the simulation (Fig.5) probably because of optical constants.

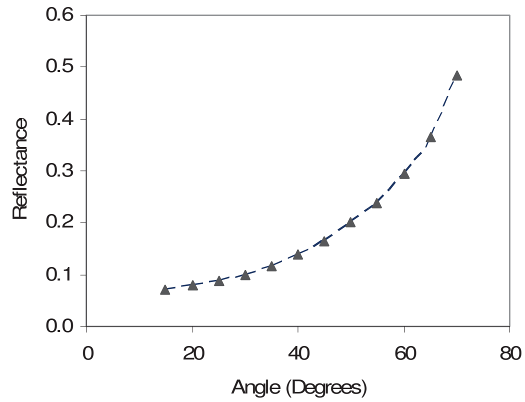

Fig. 8. Measurements at 121.6 nm versus incidence angle.

In order to improve the multilayer performances several samples of SiC/Mg have been deposited with different kinds of cap-layers and varying the structure parameters (i.e. d, Γ) with the same aim as before: to get a bright peak at 30.4 nm and a good reflectivity as well at 121.6 nm and in the visible band. The samples reflectivity has been measured at LUXOR lab. and at the BEAR beamline at the Elettra synchrotron (Trieste). As an example, the results at 30.4 nm on some sample are shown in Fig. 9 and 10, while in Fig.11 measurements at 121.6 nm are reported

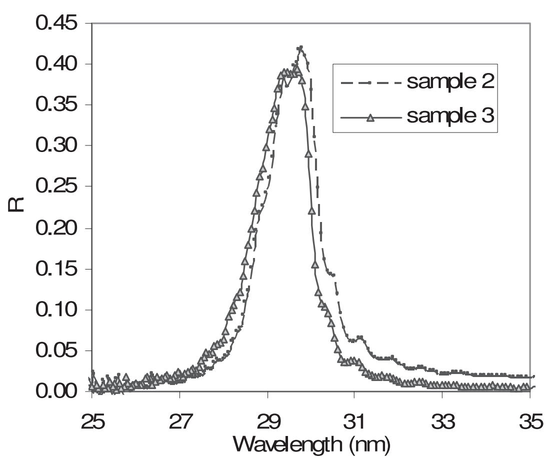

Fig. 9. Measured reflectivities for Mg/SiC samples at λ=30.4 nm for different incidence angles.

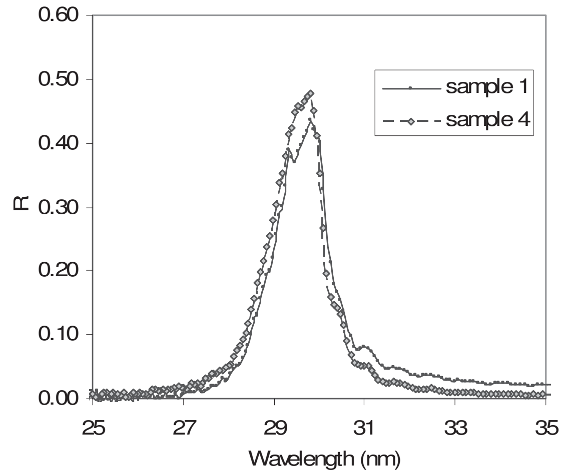

Fig. 10. Measured reflectivities for Mg/SiC samples at λ=30.4nm for different incidence angles.

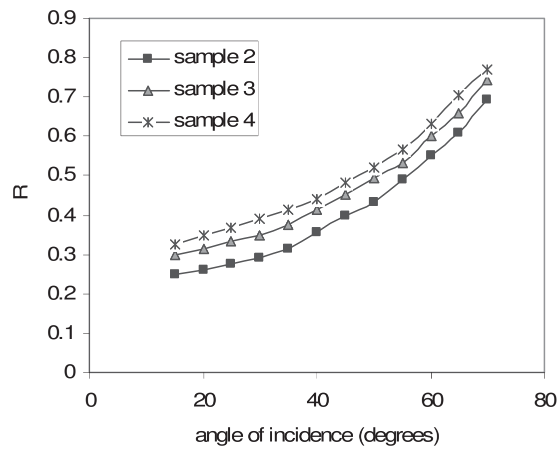

Fig. 11. Measured reflectivities for different Mg/SiC samples at λ=121.6nm for different incidence angles.

Results indicate a considerable increase of the reflectance at λ=121.6 nm with respect to ML without any cap-layer.

A final comparison of different ML samples as previously described is presented in Fig.12, where also the results in the in the visible band (633nm) have been taken into account.

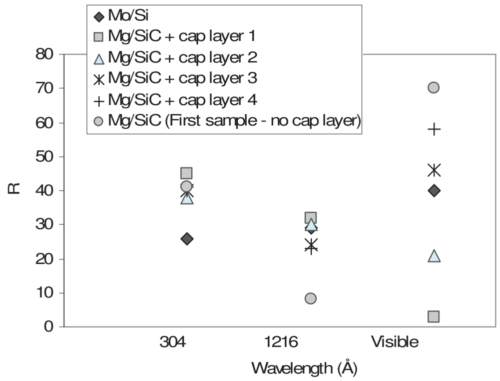

Fig. 12. Comparison of reflectivities of Mo/Si, Mg/SiC without cap-layer and othe Mg/Sic with different cap-layers.

5. CONCLUSIONS

Different candidate multilayer structures for solar physics have been taken into consideration. The well known Mo/Si structure is the most used in space missions because of its long term stability; however it doesn't provide a good spectral resolution (high FWHM and high second order peak).

The Si/B4C structure instead presents higher efficiency at He II, better spectral resolution and lower second order peak. Anyway measurements show that it is rather unstable in time. The new structure considered in this work is Mg/SiC; from the measurements done in Padova on the sample without any cap-layer we found a worse reflectance than the one expected from the simulations. However adding different kind of cap-layers higher reflectivities have been obtained. So the Mg/SiC multilayer structure with a cap-layer is demonstrated to be at the moment the best performing in the three spectral regions considered.

6. ACKNOWLEDGEMENTS

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