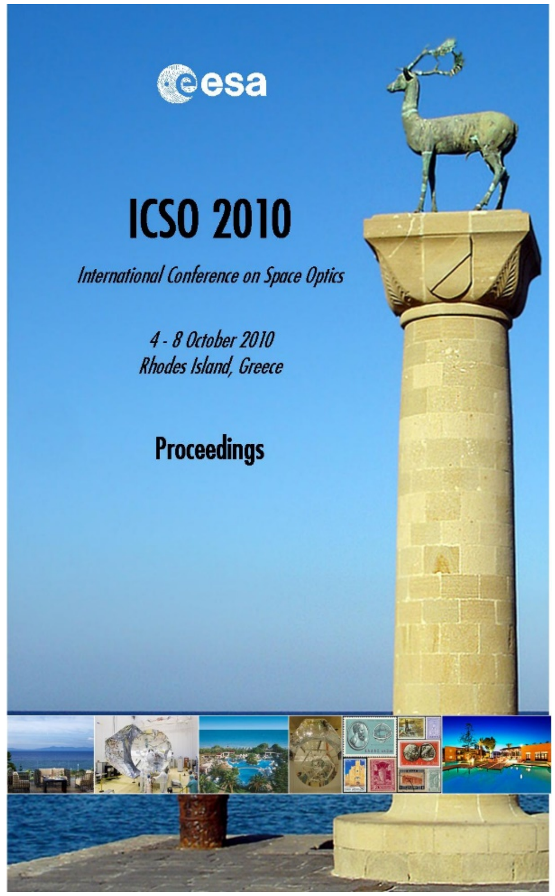
International Conference on Space Optics—ICSO 2010

Rhodes Island, Greece

4–8 October 2010

Edited by Errico Armandillo, Bruno Cugny, and Nikos Karafolas



Multilayer coatings for METIS instrument

A. J. Corso, P. Zuppella, G. Monaco, M. Suman, et al.

International Conference on Space Optics — ICSO 2010, edited by Errico Armandillo, Bruno Cugny, Nikos Karafolas, Proc. of SPIE Vol. 10565, 105655G · © 2010 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2552596

MULTILAYER COATINGS FOR METIS INSTRUMENT

A. J. Corso[1], P. Zuppella[1], G. Monaco[1,2], M. Suman[1], P. Nicolosi[1,2], D. L. Windt[3] and M. G. Pelizzo[1].
[1]*CNR – IFN, LUXOR Laboratory, Via Trasea 7 – Padova, Italy.*
[2]*Information Engineering Department, Padua University, Via Gradenigo 6B, Padova, Italy.*
[3]*Reflective X-ray Optics LLC, 1361 Amsterdam Ave., Suite 3B, New York, NY 10027, USA.*

ABSTRACT

The Multi Element Telescope for Imaging and Spectroscopy (METIS) is a coronagraph onboard of Solar Orbiter. It will perform simultaneous observations at HeII Lyman-α line, HI Lyman-α line and in visible. To achieve such capability, instrument mirrors need to be coated by multilayer (ML) structures with high efficiency at all three spectral ranges. Coatings with higher performances with respect standard Mo/Si are desirable. An instrument prototype of METIS has just flown onboard of a NASA sounding rocket: in this case, optics were coated with Mg/SiC MLs. Better performances have been obtained in terms of reflectivity, but long term stability of this coating is an open problem. Moreover the harsh conditions of the environment met during the Solar Orbiter mission given by plasma particles and high temperature could affect the lifetime of the optical components on the long term. We present the design and reflectivity tests of multilayer structures in which performances improvement is obtained by the use of novel capping layers. All multilayers are tuned at 30.4nm line but the design also maximize the performances at 121.6nm and 500 – 650 nm visible range. Analysis of Solar Orbiter environment have been carried on in order to point out the main damaging sources for the nanostructures. Computer simulations with a devoted software have been performed to preliminary evaluation of the possible instabilities in multilayers. Experimental tests for investigating the effects of the thermal heating and particles bombardments in the reflectivity performances have been planned.

I. INTRODUCTION

METIS is an instrument proposed to ESA for being part of the payload in Solar Orbiter Mission. This instrument implements a coronagraph which images the annular corona between 1.3 and 3 solar radii at minimum perihelion; it will observe the HeII Lyman-α line at 30,4nm, the HI Lyman-α line at 121,6nm and the visible wavelengths from 500 to 650nm. Therefore, the main mirrors require multilayer coatings to reflect the EUV wavelengths as well as high performances for UV and visible light.
Multilayers based on periodic Mo/a-Si structure have been used in many space experiments and they have always provided good long-term and thermal stability [1] which is a crucial point in a space mission such as Solar Orbiter. The reflectivity of these multilayers is usually less than 25% around 30.4nm line. As an alternative MLs Mg/SiC could be considered for METIS. Whereas their better reflectivity at 30.4 nm, they have been used in SCORE instrument on board of a sounding rocket. In addition, specific capping layers should be superposed in order to improve the reflectivities at 121.6 nm and in the visible spectral range [2]. Unfortunately, these coatings have not proved being stable over time and therefore it has to be carefully evaluated their usage in a long space mission. Others couples of materials could be used to enhance the throughputs of optical elements [3,4], but also for them there are not detailed studies investigating their stability in space applications. In particular, for Solar Orbiter it is also important the stability of these films to environmental components such as thermal annealing or particles bombardments. New designs based on a Mo/a-Si multilayer (very standard couple) overcoated by Iridium/Mo or Ir/Si capping layers are here proposed in order to improve the reflectance at 30,4nm line without degrading excessively the optical performances at 121,6nm line. The design is optimized using a technique based on the control of the standing wave distribution inside the ML [5,6]. Samples have been realized and tested for reflectivity performances. Experiments to evaluate their stability with respect to particle bombardment and thermal cycling are planned.

II. DESIGN AND EXPERIMENTAL DETAILS

All multilayer structures proposed here have been simulated by using IMD program which uses an algorithm based on recursive application of the Fresnel equations modified to account of interface imperfections [7]. The design has been performed for 5° of incidence with 0,5nm of roughness in each interface.
In the first step a Mo/Si multilayer coatings tuned to 30,4nm line has been designed; the structure obtained from optimizations is reported in Tab.1.

Period (nm)	Γ	Number of Periods
16,4	0,82	20

Tab.1: Design of multilayer coating tuned to 30,4nm line.

In top a 2nm Silicon layer is added and it foresees that half of which will oxidize. From simulations, reflectance is 26% at 30,4nm, 27% at 121,6nm and 35% at 600nm.
In order to improve the optical performances at 30,4nm without degrading reflectance at 121,6nm and visible wavelengths, new capping layer structures with Iridium layer on top have been studied: in Tab.2 these structures are reported with their simulated reflectances.

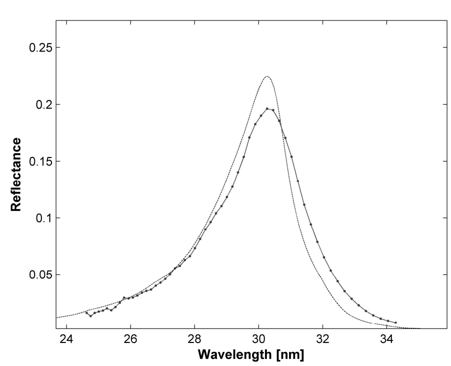
	Capping-layer structure	**Simulated Reflectance (%) at**		
		30,4 nm	**121,6 nm**	**600 nm**
CL1:	Ir(2nm)/Mo(2,2nm)	31	22	45
CL2:	Ir(2nm)/Si(15,4nm)/Mo(2,95nm)	26	28	40

Tab.2: Simulated reflectances for different capping layers used in top of Mo/Si multilayer

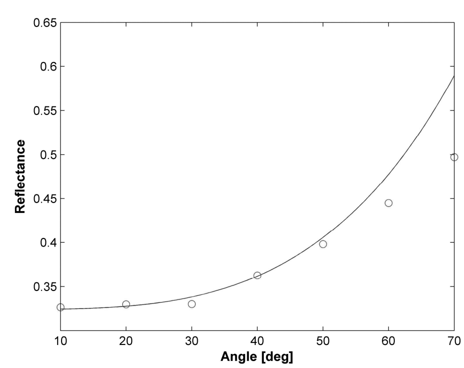
The films have been deposited from RXOLLC on a 16x16mm Silicon wafers taking the designs proposed into account. The reflectance at 30.4nm line has been measured in BEAR beam line at ELETTRA Synchrotron in Trieste (Italy) [8]. The measurements have been done at 5° of incidence in two different positions of the test chamber rotated 90° to each other and then averaged to obtain the reflectance to unpolarized light.
The reflectance at 121.6nm has been measured by using the normal incidence reflectometer at LUXOR (CNR – IFN, Padova). A monochromator mounted in Johnson-Onaka configuration selects the desired wavelength generated by a Deuterium lamp. The beam exiting from monochromator is focused in test chamber by a toroidal mirror working at 45° of incidence. Experimental chamber is placed with the $\theta - 2\theta$ plane parallel to the reflection plane of the sample; this facility allows only angular scan. Detection has been accomplished by a channel electron multiplier (CEM AMPTEK MD501). The polarization degree of the incident light at 121,6nm is known (0,89) [9] and then measurements have been performed only for one orientation of the chamber.
Reflectance at visible wavelengths have been measured by the Varian UV-Vis-NIR spectrophotometer "Cary 5000" [10] using an integrating sphere which performs the measurements at 8° of incidence; the geometry of the integrated sphere allows us to measure also only the stray light and then we can compute the specular reflectance. A polarizer at the entrance of the integrating sphere has been used for ensuring the measurements of the samples in s-condition and p-condition: the ordinary light reflectance is still estimated with the average of the two polarized components.

III. RESULTS OF REFLECTANCE MEASUREMENTS

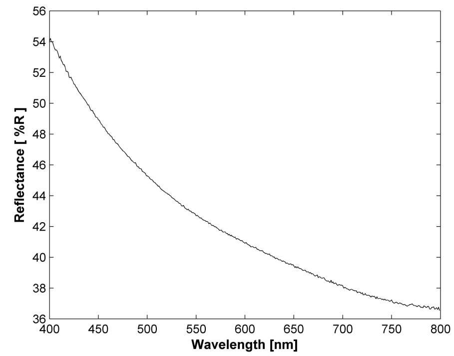
This section is devoted to results of reflectance measurements. The experimental data have been compared with the simulations. A better fit is obtained using the optical constants of Tarrio [11] for Molybdenum [3], although the accuracy of optical constants available in this range is poor and the validity of Fresnel’s coefficients approach used is critical.
Fig. 1 refers to classical Si/Mo multilayer coatings: reflectance is 19,6% at 30,4nm, 33% at 121,6nm and 40% at 600nm.



a)



b)

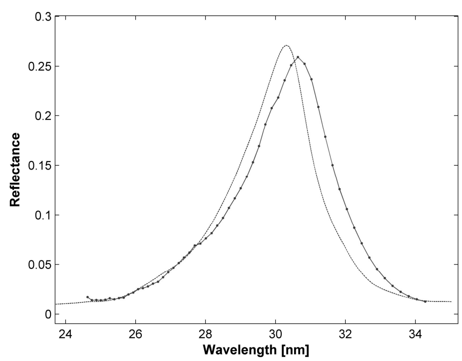


c)

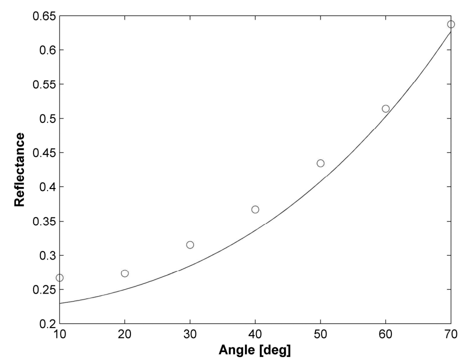
Fig.1: Si/Mo multilayer coatings - Reflectance measurements. a) Reflectance around 30,4nm line (interpolated line) compared with simulation (solid line); b) Reflectance measurements at 121,6nm line (circles) versus incidence angle compared with simulation (solid line); c) Reflectance measurements in visible range.

The reflectance measured at 121,6nm is higher than the theoretical value. The simulations have been conceived with 1nm of oxide in the topmost of stack. A better fitting is obtained considering 0,7nm of oxide: the optical performances at this wavelength ~~seems~~ very dependent on the oxide thickness and then a capping-layer which does not oxidize such as Iridium is required.

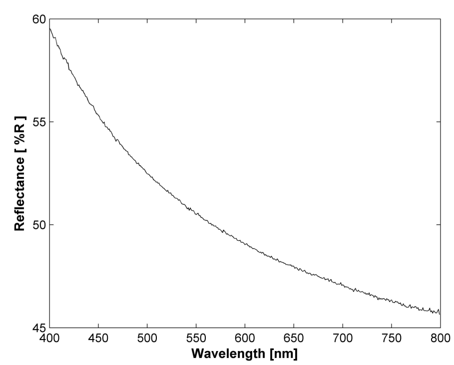
Fig.2 shows the measurements results for the classical Si/Mo with CL1: with this capping layer, the reflectance at 30,4nm line and at visible range is improved but at 121,6nm is degraded. The reflectance measured is 25% at 30,4nm, 26% at 121,6nm and 48% at 600nm.



a)



b)



c)

Fig.2: Reflectance measurements for Si/Mo multilayer coatings with Iridium CL1 capping layer. a) Reflectance around 30,4nm line (interpolated line) compared with simulation (solid line); b) Reflectance measurements at 121,6nm line (circles) versus incidence angle compared with simulation (solid line); c) Reflectance measurements in visible range.

The CL2 and CL1 capping layers show similar performances. The CL2 guarantees 25% at 30,4nm, 26% at 121,6nm and 55% at 600nm of reflectance.

IV. ENVIRONMENTAL SPECIFICATION

The study of the environmental components which can degrade the properties of the multilayer mirrors inside METIS is useful to determine a test plan for the optical coatings. In particular, for a multilayer coating which works in the range of the heliospheric distances of Solar Orbiter, it is important to consider the effects induced by Solar flux thermal irradiation, Solar Wind Plasma and Energetic Particles [12].
The maximum solar irradiation at perihelion will be 27000 W/m^2 which can increase the mirrors temperature up to about 70°C: for a safe stability the coatings should withstand working temperatures about twice of it.
Solar wind plasma is another potential damaging source and it is predominantly composed by protons and alpha particles and its description at mission average distance is reported in Tab.3; bombing tests should be carry out in order to investigate its effects in optical performances of the films.

Particle	Densities (cm^{-3})	Speed (km/s)	Energy (keV)
H^+	25	468	1
He^{2+}	1,175	468	4

Tab.3: Solar wind plasma description at Solar Orbiter average distance

Finally, energetic particles with energy about some MeV may be encountered during the mission and a stability test must be performed also for these cases; a good estimation of this phenomena is still reported in [12].

V. CONCLUSIONS

The multilayers presented here are based on a standard couple of materials used many times in space missions and its stability in these applications is already investigated. Using Iridium based capping layers the low reflectance at 30,4nm is improved without degrading excessively the optical performance at 121,6nm and visible lines. Furthermore, Iridium does not oxidize and then a good stability in reflectance at 121,6nm line is expected.
The good results obtained from reflectance measurements have been confirmed the improvements and films seems suitable for METIS. However, the stability to aging and environment is not investigated yet and an adequate test plan devoted to study these aspects is currently undergoing development.

VI. REFERENCES

[1] M.-F. Ravet, F. Bridou, X. Z. Song, A. Jerome, F. Delmotte, R. Mercier, M. Bougnet, P. Bouyries, and J.-P. Delaboudiniere, "*Ion beam deposited Mo/Si multilayers for EUV imaging applications in astrophysics*" Proc. SPIE 5250, 99–108 (2004).
[2] S. Zuccon, D. Garoli, M.G. Pelizzo, P. Nicolosi, S. Fineschi, D. Windt, "*Multilayer coatings for multiband spectral observations*", Proc. '6th Internat. Conf. on Space Optics', ESTEC, Noordwijk, The Netherlands, 2006 (ESA SP-621, June 2006).
[3] Windt D. L., Donguy S., Seely J., and Kjornrattanawanich B., "*Experimental comparison of extreme-ultraviolet multilayers for solar physics*" Appl. Opt. 43, 1835–1848 (2004).
[4] J. Zhu, Z. Wang, Z. Zhang, F. Wang, H. Wang, W. Wu, S. Zhang, D. Xu, L. Chen, H. Zhou, T. Huo, M.Cui and Y. Zhao, "*High reflectivity multilayer for He-II radiation at 30.4 nm*" Appl. Opt. 47, No. 13 (2008).
[5] M. G. Pelizzo, M. Suman, D. L. Windt, G. Monaco, P. Nicolosi, "*Innovative methods for optimization and characterization of multilayer coatings*" Proceedings Vol. 7360, EUV and X-Ray Optics: Synergy between Laboratory and Space, René Hudec; Ladislav Pina, Editors, 73600Q (2009).
[6] M. G. Pelizzo, M. Suman,G. Monaco, P. Nicolosi, D. L. Windt, "*High performance EUV multilayer structures insensitive to capping layer optical parameters*" Optics Express 16 Issue19 (2008), pp. 15228-15237
[7] D. Windt, "*IMD — software for modeling the optical properties of multilayer films*" Comput. Phys. 12, 360 –370, (1998).
[8] ELETTRA - Bending magnet for Emission Absorption and Reflectivity (BEAR) beam-line , on-line http://www.elettra.trieste.it/experiments/beamlines/bear/index.html (2010).
[9] D. Garoli, F. Frassetto, G. Monaco, P. Nicolosi, M. G. Pelizzo, F. Rigato, V. Rigato, A. Giglia, S. Nannarone, "*Reflectance measurements and optical constants in the extreme ultraviolet – vacuum ultraviolet region for SiC with a different C/Si ratio*" Appl. Opt., vol. 45, pp. 5642 – 5650 (2006).
[10] Cary 5000 UV-Vis-NIR spectrophotometer, on-line http://www.varianinc.com/cgi-bin/nav?products/spectr/uv/cary5000/cary_5000 (2010).

[11] C. Tarrio, R. N. Watts, T. B. Lucatorto, J. M. Slaughter and C. M. Falco, "*Optical constants of in situ deposited films of important extreme-ultraviolet multilayer mirror materials*", Appl. Opt., vol. 37, pp. 4100 – 4104 (1998).

[12] ESA, "*Solar Orbiter environmental specification*", Issue 2.0 (2008).