Citation: Proceedings of SPIE, vol: 7018, pp. 70182W1 - 70182W9 (2008)

https://doi.org/10.1117/12.2017482

Narrowband filters and broadband mirrors for the spectral range from 50 to 200 nm

M. Fernández-Perea*, M. Vidal-Dasilva, J. I. Larruquert, J. A. Méndez, J. A. Aznárez
GOLD, Instituto de Física Aplicada-Consejo Superior de Investigaciones Científicas (CSIC)
Serrano 144, 28006 Madrid, Spain

ABSTRACT

A summary of the optical coatings for the spectral range from 50 to 200 nm that can be prepared at GOLD is presented. This spectral range, named here far and extreme ultraviolet (FUV/EUV), is characterized by the high absorption of almost all materials and the strong dependence of their optical properties on the deposition parameters and on the exposure of the samples to the atmosphere. Broadband mirrors and narrowband filters were prepared in an ultra high vacuum system where in situ FUV/EUV reflectometry is available. In this work we summarize the main aspects concerning in situ performance and ageing of these coatings. Broadband mirrors composed of Al/MgF$_2$, SiC, B and Al/MgF$_2$/SiC cover the FUV/EUV spectral range from 50 to 200 nm. Above the transparency cutoff of MgF$_2$ (115 nm), transmittance filters based on Al/MgF$_2$ multilayers have been developed peaked at wavelengths as short as 120 nm. An example is shown centered at 124 nm with a peak transmittance of 27% and a FWHM of 12 nm for a fresh coating. Below 115 nm, a research on reflectance filters has recently started with very promising results on filters peaked at ~83 nm, close to the OII spectral line. Fresh filters with 27% peak reflectance at normal incidence and a FWHM of 14 nm have been obtained. These novel reflectance filters based on Al, Yb and SiO must still demonstrate stability over time. The developed coatings have a potential application in the field of astronomical observations.

Keywords: far ultraviolet, extreme ultraviolet, optical coatings, mirrors, filters, optical constants, thin films: optical properties

1. INTRODUCTION

Recent activity of Grupo de Óptica de Láminas Delgadas (GOLD) has been focused on the preparation of optical coatings for the spectral range from 50 to 200 nm, that will be designated here as far and extreme ultraviolet (FUV/EUV). One important application of FUV/EUV optical coatings is the development of space-based astronomical instrumentation. An improvement on the efficiency of optical coatings for this scarcely explored spectral range would contribute to obtain a wealth of key information that has not been accessible so far because of a lack of efficient optical devices.

The optical properties of materials in the FUV/EUV are characterized by the fact that transparency decreases progressively as the LiF cutoff wavelength (105 nm) is approached, both from longer and shorter wavelengths. When approaching it from longer wavelengths, the cutoff abruptly separates transparency from strong absorption, whereas absorption decreases slowly shortwards of the LiF cutoff. This edge will be considered here as the separation between far ultraviolet (FUV, 105 – 200 nm) and extreme ultraviolet (EUV, 50 – 105 nm). The limited transparency of materials near the LiF cutoff implies that the performance of optical coatings is less efficient than it is far above this edge, where there is a wealth of transparent materials with refractive indices almost at choice, but also far below this same edge, where low absorbing materials are available to alternate in multilayers well tuned at the desired wavelength. Additionally, the strong absorption of adsorbed air molecules and of the thin layers of compounds formed on the surface of many materials after air exposure makes necessary the in situ characterization of the optical properties of materials (before any exposure to the atmosphere takes place) and a thorough study of coating ageing.

The research performed at GOLD has been addressed in several directions: the search and optical characterization of new materials, the preparation of standard coatings with the aim of reproducing and improving their performance, the design and preparation of novel coatings, and the study of ageing behaviour. Few coatings can be considered as standard

in this spectral range, and most of them have been developed several decades ago. This is the case for reflective coatings of Al protected with MgF_2, transmittance filtering coatings alternating Al and MgF_2 for wavelengths longer than 115 nm, reflective single coatings of SiC and transmittance coatings of In or Sn for wavelengths somewhat shorter than ~105 nm. GOLD has been reproducing standard EUV/FUV coatings and developing novel ones, and the purpose of this proceeding is to display a catalogue of these coatings.

Section 2 describes the experimental equipment at GOLD. Section 3 addresses the different sorts of coatings that are deposited nowadays at GOLD: (1) Al/MgF_2 reflective coatings, (2) SiC and B reflective coatings, (3) Al/MgF_2/SiC reflective coatings, (4) (Al/MgF_2)$_n$ transmittance filters and (5) reflection filtering coatings peaked at ~83 nm composed of Al, Yb and SiO layers.

2. EXPERIMENTAL SYSTEM

The experimental system used in this work was designed at GOLD and consists of an ultra high vacuum (UHV) coating system connected in vacuum to an UHV far-extreme ultraviolet reflectometer. In this multi-task equipment both thin film single-layer and multilayer coatings can be prepared by means of three different deposition techniques. Samples can be transferred without breaking vacuum to the reflectometry chamber. In situ transmittance and reflectance measurements can be performed at incidence angles from 3º to ~87º in two perpendicular planes.

Fig. 1 shows a schematic view of the equipment, where two different areas can be distinguished. One of them is devoted to sample insertion, deposition and treatment (chambers LLC, TDC and SC) and the other one to radiation propagation, wavelength selection and reflectometry measurements (chambers L, M, MC and RC). The more relevant features of the experimental system are pointed out below.
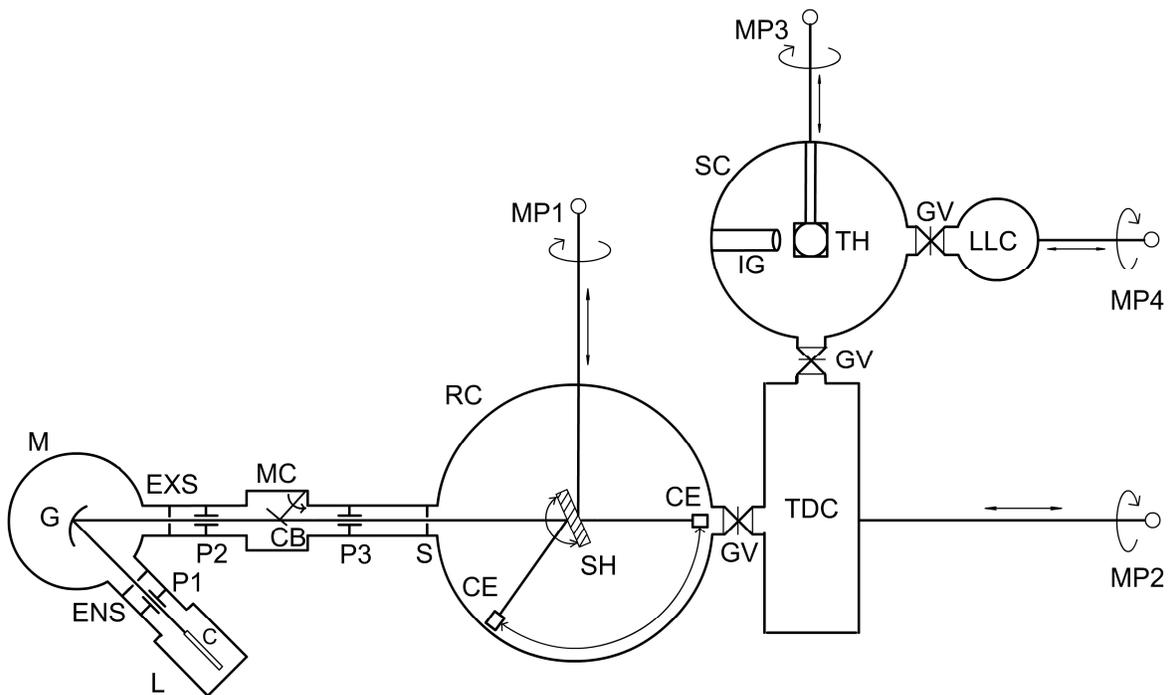

Fig. 1. Schematic view of the experimental equipment. C: capillary, L: lamp, M: monochromator, G: diffraction grating, ENS: entrance slit, EXS: exit slit, MC: modulation chamber, CB: chopper blade, S: aperture, RC: reflectometry chamber, CE: channel electron multiplier, MP1, MP2, MP3 and MP4: sample manipulators, SH: sample holder, P1, P2 and P3: small conductance pipes, TDC: thermal deposition chamber, SC: sputtering chamber, TH: target holder, IG: ion gun, LLC: load-lock chamber, GV: gate valve.

Sample deposition is performed in the thermal deposition chamber (TDC) and in the sputtering chamber (SC), that are UHV systems evacuated with ion and sublimation pumps and a turbomolecular pump, respectively. Base pressure after baking at 470 K is 1×10^{-8} Pa in TDC and 1×10^{-7} Pa in SC.

Deposition chamber allows preparation of thin films by means of a 6-kW electron gun, when high temperatures are required, or by means of standard thermal sources (boats, baskets, filaments,…), when materials with lower evaporation or sublimation temperatures are involved. The sputtering chamber is provided with a rotatable target holder that hosts up to four different targets. A hollow cathode 3-cm Kauffman ion gun fed with Ar extracts atoms from the target, that finally reach the substrate at a distance of 150 mm. A flow of ~5 sccm of Ar through the ion gun and a secondary Ar flow of ~5 sccm through the hollow-cathode neutralizer result in a total pressure during ion beam sputtering (IBS) process of ~5×10^{-2} Pa. So far we have deposited C, Al, MgF_2 and SiC, but the material spectrum is much wider and we plan to try also other interesting materials as B_4C, Mo, etc. To monitor thickness during depositions we use a quartz crystal oscillator, that is previously calibrated through Tolansky interferometry. Considering that our system can be mounted with three different evaporation sources, and with four different sputtering targets, multilayers made of up to seven different materials could be deposited. This wide range of deposition possibilities in a system working in UHV conditions makes it suitable for the study of virtually any material of interest in the field of optical coatings in the range 50 – 200 nm, and also for the deposition and characterization of single layer or multilayer coatings for the FUV/EUV.

Several treatments can be performed in situ on the freshly deposited samples in order to simulate sample aging under different environments, such as exposure to gases (including atomic oxygen), heating, ion bombardment and UV irradiation.

UV radiation for reflectometry purposes is generated in a 500-W windowless capillary discharge lamp, fed with a continuous gas flow of nitrogen and/or noble gases. The result is a discrete spectrum with lines at wavelengths covering the range between 50 and 200 nm. The 0.2-m focal length monochromator (M) has an aperture of F/4.5 and a 64º angle between entrance and exit arms. The grating is holographic, with 1200 l/mm, and the reciprocal dispersion relation of the monochromator is 4 nm/mm, with entrance and exit slits width ranging from 0.05 to 3 mm. At the modulation chamber (MC), a 45º-tilted rotating cross stops simultaneously the monochromatic beam and a reference signal that is used to discriminate noise in a lock-in amplifier. Radiation gets to the UHV reflectometry chamber (RC), evacuated through ion and titanium sublimation pumps, with a base pressure of 1×10^{-8} Pa after baking at 470 K. This chamber is furnished with a precision sample manipulator and two detectors that respectively rotate in two perpendicular planes of incidence. These detectors are channel electron multipliers that have been coated with CsI to extend their sensitivity up to around 200 nm. More detailed information about the experimental system can be found elsewhere[1].

3. OPTICAL COATINGS: BROADBAND MIRRORS AND NARROWBAND FILTERS

This section shows the main characteristics of the FUV/EUV optical coatings developed at GOLD. Some of them reproduce standard FUV/EUV coatings. This is the case of Al/MgF_2 and SiC broadband mirrors, and of Al/MgF_2 narrowband filters. Furthermore, some novel coatings have also been developed. This is the case of Al/MgF_2/SiC and B broadband mirrors and of filters composed of Yb, Al and SiO.

3.1 Al/MgF$_2$ broadband mirrors

Reflective coatings of Al protected with MgF_2, both materials deposited by thermal evaporation, have been the best established coating in the FUV for over 40 years[2]. They can be prepared with a reflectance above 80% at wavelengths longer than 120 nm. Preparing best-performance Al/MgF_2 coatings is not straightforward, since Al is easily oxidized even under high vacuum so that it has to be protected readily, and MgF_2 must be free of impurities in order to keep its high transmittance down to 115 nm, the MgF_2 cutoff. Fig. 2 shows the near normal reflectance of an Al/MgF_2 coating prepared by thermal evaporation (TE) at GOLD and maintained under UHV. The reflectance of the coating after a short exposure to the atmosphere is also displayed in Fig. 2. The reflectance is close to the best results in the literature. A decay was observed after exposure to normal air that had not been reported previously; this reflectance decay was assigned to adsorption of atmospheric gases, such as water vapour and oxygen, on the MgF_2 film[3].

An attempt to improve the mirror performance at the shorter wavelengths was carried out by changing the deposition technique used to prepare the coatings from TE to IBS. We prepared coatings composed of sputtered MgF_2 and evaporated Al, evaporated MgF_2 and sputtered Al and all-sputtered coatings. The best result was obtained with the deposition of MgF_2 by IBS over Al deposited by evaporation. The reflectance of the latter combination is also displayed in Fig. 2 for both fresh and exposed samples. A reflectance increase at ~125 nm and below was measured for the IBS-MgF_2/TE-Al combination. The modified coatings display a reflectance decrease at wavelengths longer than ~125 nm, that was attributed to absorption on the sputtered MgF_2 probably due to the presence of F color centers[4]. Reflectometry measurements performed in the visible and near infrared spectral ranges showed, in agreement with reference 4, that the above mentioned reflectance decrease is maximum at ~550 nm.

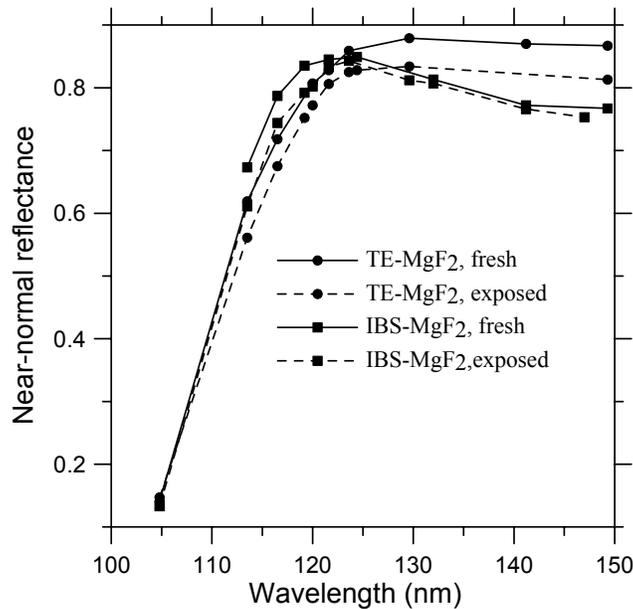Fig. 2. Near normal incidence reflectance of MgF_2-overcoated Al films. Two different deposition techniques were used: Thermal evaporation (TE) and ion beam sputtering (IBS). Curves show reflectances before and after a 15-minutes exposure to the atmosphere in both cases.

3.2 SiC and B broadband mirrors

Mirrors for the spectral region below the LiF cutoff wavelength (105 nm) are burdened with the relatively low normal reflectance of all known stable materials. Al is the material with the largest reflectance above ~83 nm, but Al films are degraded upon exposure to atmosphere and no protective coating that is transparent below 105 nm is available to prevent this degradation. Besides, standard multilayers are hindered by the strong absorption of all materials in the ~50-105 nm range, so that single layer coatings are mostly used in this range.

A small set of reflective materials is available for single layer mirror coatings in the EUV. Chemical vapor deposited SiC[5] is the stable material with the highest reflectance in the EUV spectral region above ~60 nm, with values around or above 40%. Bulk hot-pressed B_4C[6] extends the relatively high reflectance in the EUV down to 49 nm. Thin films of various materials deposited by physical vapor deposition, such as SiC prepared by magnetron sputtering[7] and by IBS[8], IBS-B_4C[9], and evaporated Ir[10] have somewhat lower reflectance than the above, but present the advantage of being also low-temperature and cost-effective processes.

In spite of the common use of IBS-SiC coatings, they are known to degrade to a limited extent by surface oxidation after exposure to atmosphere. So far, no in situ reflectance measurements have been reported. Fig. 3(a) displays the in situ reflectance from 58.6 to 149.3 nm of IBS-deposited SiC thin films prepared at GOLD. We found that the freshly deposited single SiC films have a higher reflectance than the available data obtained for thin film coatings that had been exposed to the atmosphere[11] for a short period of a few minutes, as can be seen in Fig. 3(a). A near-normal incidence reflectance of around 41% was obtained at 92 nm for a 41-nm thick SiC film deposited onto a glass substrate.

Our search for materials with high reflectance found single B films as an interesting coating for the EUV. We prepared and characterized e-beam evaporated B films with near normal reflectance similar to those of IBS-SiC and IBS-B_4C. Fig. 3(b) displays the experimental reflectance values of a B film 11-nm thick. A preliminary ageing test of B films showed results ranging from a moderate degradation close to that of IBS-SiC films for some B sample, to a larger degradation suffered by another aged B sample.
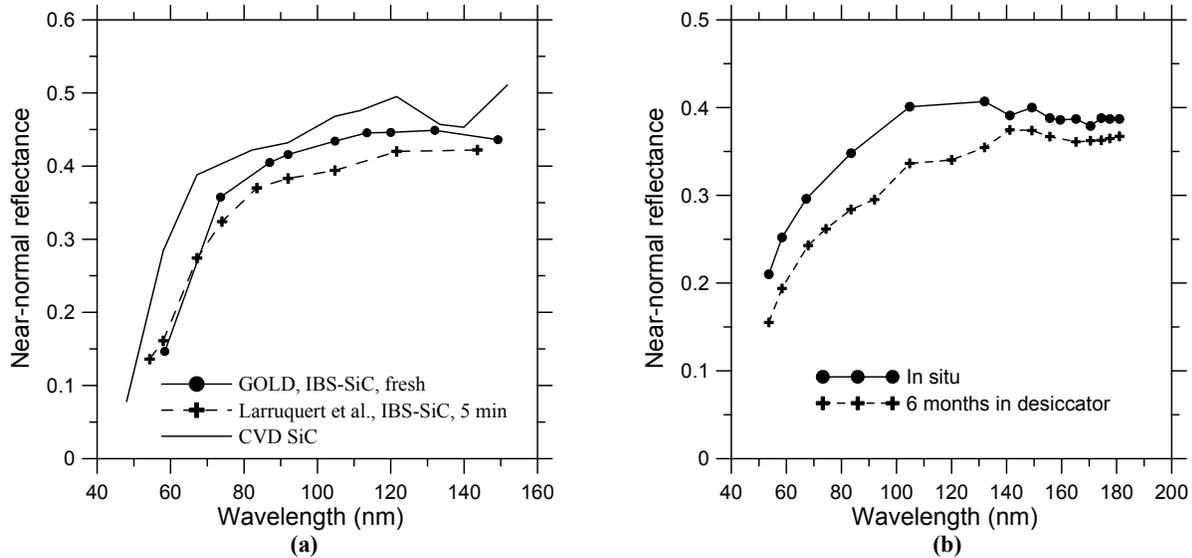

Fig. 3. (a) Near-normal incidence reflectance of current IBS-SiC thin films measured in situ, compared with data from Ref. 11 for ex situ IBS-SiC thin films and from Ref. 8 for CVD-SiC. (b) Reflectance of an 11-nm thick B film both freshly deposited and after a storage of 6 months in a desiccator.

3.3 Al/MgF$_2$/SiC broadband mirrors

One of the few multilayer designs that have been proposed in the literature[12] to obtain a high normal incidence reflectance at wavelengths from ~50 to 105 nm consists on three layers of Al, MgF$_2$ and SiC (from the substrate to the topmost layer). These multilayers exhibited higher normal incidence reflectance than the single IBS-SiC films for wavelengths longer than 49 nm. An additional advantage of these mirrors when compared to the IBS-SiC single films is that the reflectance remains relatively high at wavelengths above 105 nm.

We have started the preparation of this type of multilayers in order to perform the necessary tests that might enable the substitution of single IBS-SiC coatings by these novel multilayers in the future. Our input so far in the preparation of Al/MgF$_2$/SiC mirrors has been the deposition of all layers in UHV and in the same vacuum system, along with the in situ characterization. More tests will be performed in the near future. In situ near normal reflectance of the coatings is plotted in Fig. 4. These multilayers presented a reflectance enhancement with respect to the single IBS-SiC layers prepared at GOLD in the spectral range from ~87 to 125 nm. The reflectance of the coating after 2 months of exposure to the atmosphere, also plotted in Fig. 4 along with data coming from reference 12, was higher than the reflectance of multilayers from the literature exposed during a similar period from 73.6 to 127.5 nm.

3.4 Narrowband transmittance filters tuned at λ > 115 nm

Transmittance filters with a narrow spectral response peaked at wavelengths in the FUV have been prepared at GOLD; these filters consist of multilayers composed of Al and MgF$_2$. This structure corresponds to a Fabry-Perot interference filter with MgF$_2$ layers used both as resonance cavity and protective layer. Calculations of the filters transmittance for cavity layers made of LiF and MgF$_2$ showed that the latter is the material that provide the highest and narrowest peak response. Al is used because of its high index contrast with respect to MgF$_2$ at the peak wavelengths (and therefore its high reflectance) and its increasing absorption towards longer wavelengths. The multilayer is deposited onto a crystalline MgF$_2$ substrate, transparent for wavelengths longer than the MgF$_2$ cutoff at 115 nm, that provides mechanical support

and complete rejection below the MgF_2 cutoff. These substrates were preferred to LiF substrates, with a shorter cutoff wavelength, because the former are more efficient at rejecting radiation shorter than ~116 nm, and they have a larger transmittance than LiF at the filter peak wavelengths. FUV transmittance filters are preferred versus reflectance filters due to the larger out-of-band rejection of the former ones.
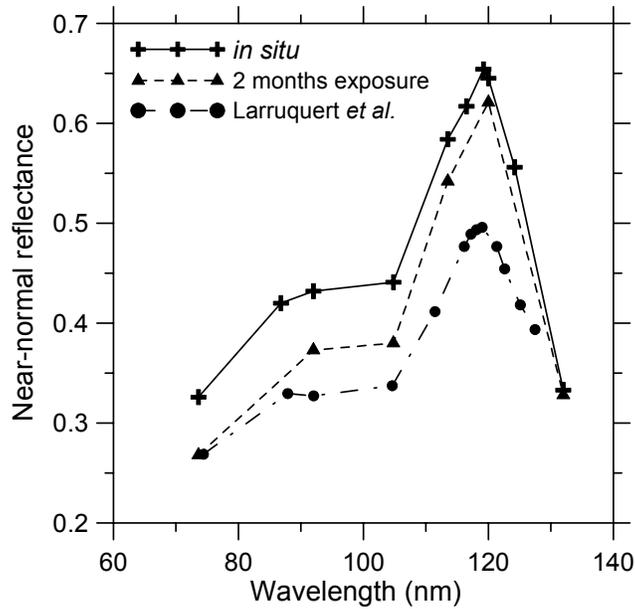

Fig. 4. Near-normal reflectance of freshly deposited $Al/MgF_2/SiC$ multilayers before atmospheric exposure and after storage in a desiccator during two months. Data from reference 12 corresponding to a 2 – 3 months exposure are also included.
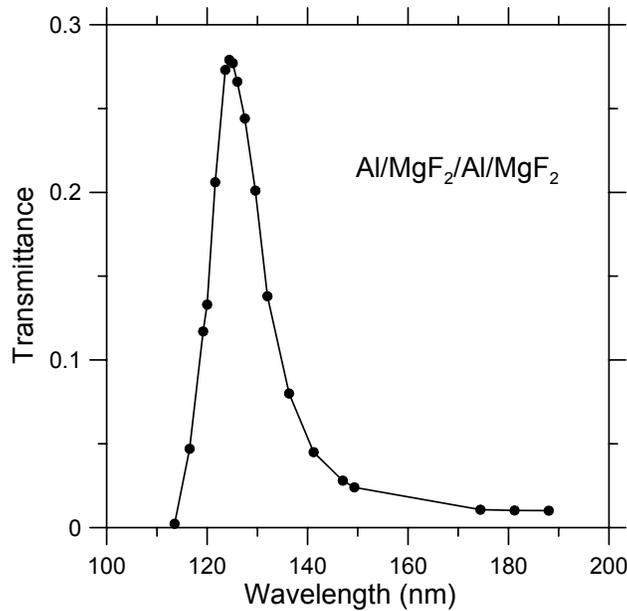

Fig. 5. Transmittance of a MgF_2 substrate/$Al/MgF_2/Al/MgF_2$ filter.

A primary application of these narrowband filters can be found on space telescopes devoted to the exploration of the universe in the FUV. An example of one of these telescopes is the World Space Observatory (WSO) project, to be launched in ~2012, that is conceived to contain instruments both for UV imaging and UV spectrometry. In particular, FUV imaging will require the use of narrowband filters centered at wavelengths of 120 nm and above.

Variations on the number and thickness of the filter layers can be used to modify the filter characteristics: peak wavelength, maximum transmittance, FWHM and out-of-band rejection. Multilayers may alternate 2, 3 or more (Al/MgF$_2$) bilayers. As the number of bilayers increases, a larger out-of-band rejection is obtained, along with a more restrictive thickness tolerance.

Fig. 5 displays the in situ transmittance of an example filter prepared at GOLD. In this case the filter is composed of four evaporated layers (MgF$_2$ substrate/Al/MgF$_2$/Al/MgF$_2$), with values of maximum transmittance and FWHM of 0.27 and 12 nm, respectively. Some work has been performed on filters based on IBS-MgF$_2$ films. The preliminary results show somewhat shorter peak transmittance than for all-evaporated films.

3.5 Narrowband reflective filters tuned at λ ~ 83 nm

Coatings with narrowband reflection properties have become available in most spectral ranges. However, the ~50-105-nm spectral range has been lacking such coatings because the materials in this range have a strong absorption; this turns inefficient the accumulation of layers in a multilayer, because radiation is mostly absorbed in the outermost layer. Recently, new narrowband multilayers tuned at 60 and 92 nm have been developed based on Tb and Si[13] and on La and B$_4$C[14], respectively.
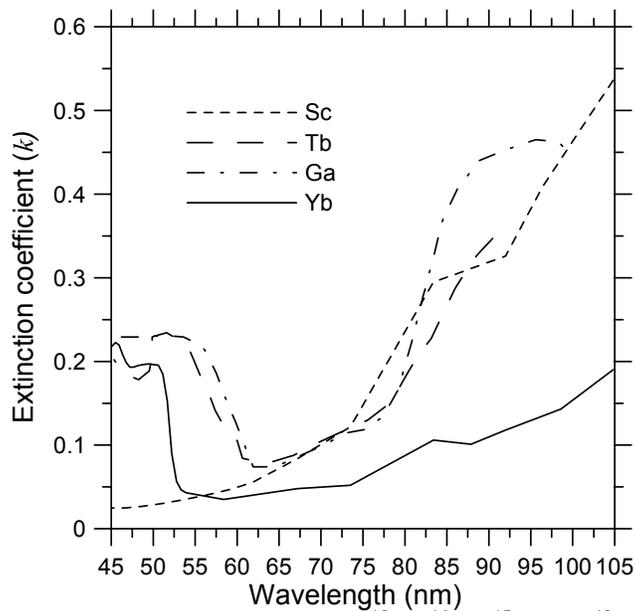

Fig. 6. Experimental extinction coefficient values of the lanthanides Sc[15], Tb[16], Gd[17] and Yb[18] in the spectral range from 45 to 105 nm.

The response of multilayers for the spectral range ~50-105 is severely compromised by the lack of transparent materials. Until recently the only known materials with relatively high transparency in this spectral range were In and Sn, that have been used as transmittance filters based upon their intrinsic transparency bands. A new source of low-absorption materials in this range was found recently among lanthanides; some of them have been thoroughly studied in recent times: Sc[15], La[16], Tb[16], Gd[17], Nd[17], Yb[18], Ce[19] and Pr[20] present a low-absorption band centered in the ~50-105 nm. Sc is not strictly a lanthanide, but it is usually considered as one of them because its similar chemical properties. In Fig. 6 we have gathered the available information on the extinction coefficient k (related to the absorption coefficient through $\alpha = 4\pi k/\lambda$) of those materials with the lowest extinction coefficient in the vicinity of 83 nm. As can be seen in Fig. 6, Yb displays the lowest k values among all the considered materials for wavelengths longer than about 56 nm.

In this proceeding we present results on the preparation of multilayers based on the transparency of Yb, that also use Al as a contrasting material. The extremely high reactivity of both materials makes the protection of the structure mandatory. We selected SiO as the protective material taking into account that this material has been reported to be

relatively inert and its absorption is not extreme (optical constants were previously measured). SiO is also used here as a barrier layer.

Narrowband filters were prepared with two different structures: Al/Yb/SiO and Yb/Al/Yb/SiO (starting with the innermost layer). All the materials were deposited by means of thermal evaporation. Fig. 7 shows the experimental reflectance of an Yb/Al/Yb/SiO filter. Reflectance was measured both in situ and after 7 months of storage in air. A decrease in reflectance was observed after air exposure, but the filtering properties of the coating remained very promising after this long storage period. Observation of aged samples under the microscope showed that a dendritic structure had developed on the coating, presumably because of diffusion or reaction between Yb and Al. SiO barrier layers were deposited to prevent this phenomenon with thicknesses ranging from 0.7 to 1.2 nm. A SiO barrier layer of 1.2 nm prevented the formation of the dendritic structures, which resulted in a moderate decrease of the reflectance peak.
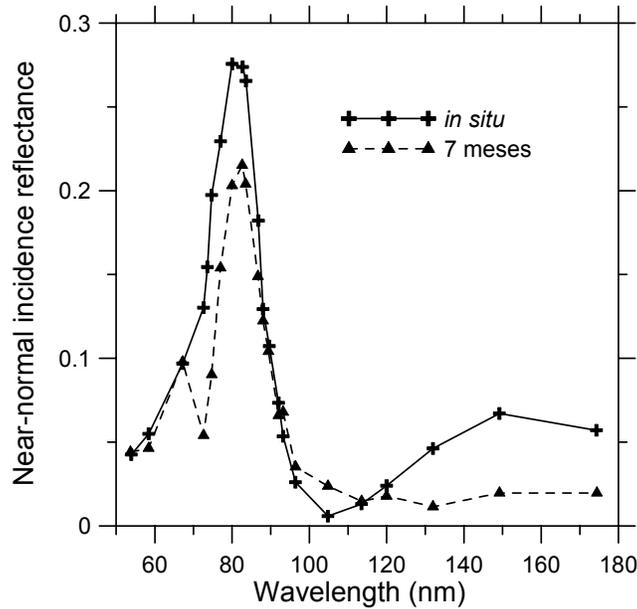

Fig. 7. Experimental near-normal reflectance of a filtering multilayer based on Al, Yb and SiO for both a fresh and an aged sample.

CONCLUSIONS

We have presented a catalogue of coatings for the spectral range from 50 to 200 nm that are prepared nowadays at GOLD. These coatings are prepared by means of evaporation and ion beam sputtering techniques in an UHV system that allows in situ characterization of the prepared samples. Astronomical instrumentation development is among the primary applications of these optical devices.

We show experimental results for both broadband mirrors and narrowband filters. FUV broadband mirrors are composed of Al/MgF$_2$ bilayers, and EUV broadband mirrors are composed of single layers of SiC or B and of a multilayers composed of Al/MgF$_2$/SiC. FUV narrowband mirrors are Fabry-Perot interference filters composed of layers of Al and MgF$_2$. EUV narrowband filters are made of alternating layers of Al, Yb and SiO.

ACKNOWLEDGMENTS

REFERENCES

1. J. A. Aznárez, J. I. Larruquert, J. A. Méndez, "Far ultraviolet absolute reflectometer for optical constants determination of ultra high vacuum prepared thin films", Rev. Sci. Instr. **67**, 497-502 (1996).

2. G. Hass, R. Tousey, "Reflecting coatings for the extreme ultraviolet", JOSA **49**, 593-602 (1959).

3. M. Fernández-Perea, J. A. Aznárez, J. Calvo-Angós, J. I. Larruquert, J. A. Méndez, "Far ultraviolet reflectance variation of MgF_2-protected aluminum films under controlled exposure to the main components of the atmosphere", Thin Solid Films **497**, 249-253 (2006).

4. E. Quesnel, L. Dumas, D. Jacob, F. Peiró, "Optical and microstructural properties of MgF_2 UV coatings grown by ion beam sputtering process", J. Vac. Sci. Technol. A **18**, 2869-2876 (2000).

5. W. J. Choyke, W. D. Partlow, E. P. Supertzi, F. J. Venskytis, G. B. Brandt, "Silicon-carbide diffraction grating for the vacuum ultraviolet: feasibility," Appl. Opt. **16,** 2013–2014 (1977).

6. J. I. Larruquert, R. A. M. Keski-Kuha, "Optical properties of hot-pressed B_4C in the extreme ultraviolet", Appl. Opt. **39**, 1537-1540 (2000).

7. J. B. Kortright, D. L. Windt, "Amorphous silicon carbide coatings for extreme ultraviolet optics", Appl. Opt. **27**, 2841-2846 (1988).

8. R. A. M. Keski-Kuha, John F. Osantowski, Howard Herzig, Jeffery S. Gum, and Albert R. Toft, "Normal incidence reflectance of ion beam deposited SiC films in the EUV", Appl. Opt. **27**, 2815-2816 (1988).

9. G. M. Blumenstock, R. A. M. Keski-Kuha, "Ion-beam-deposited boron carbide coatings for extreme ultraviolet", Appl. Opt. **33**, 5962-5963 (1994).

10. G. Hass, G. F. Jacobus, W. R. Hunter, "Optical properties of evaporated iridium in the vacuum ultraviolet from 500 Å to 2000 Å", J. Opt. Soc. Am. **57**, 758-762 (1967).

11. J. I. Larruquert, R. A. M. Keski-Kuha, "Reflectance measurements and optical constants in the extreme ultraviolet for thin films of ion-beam-deposited SiC, Mo, Mg_2Si, and InSb and of evaporated Cr", Appl. Opt. **39**, 2772-2781 (2000).

12. J. I. Larruquert, R. A. M. Keski-Kuha, "Multilayer coatings with high reflectance in the extreme-ultraviolet spectral range of 50 to 121.6 nm", Appl. Opt. **38**, 1231-1236 (1999).

13**.** D. L. Windt, J. F. Seely, B. Kjornrattanawanich, Yu. A. Uspenskii, "Terbium-based extreme ultraviolet multilayers", Opt. Lett. **30**, 3186-3188, (2005).

14. J. F. Seely, Y. A. Uspenski, B. Kjornrattanawanich, D. L. Windt, "Coated photodiode technique for the determination of the optical constants of reactive elements: La and Tb", Proc. SPIE **6317**, 63170T-1 (2005).

15. M.Fernández-Perea, J. I. Larruquert, J. A. Aznárez, .J. A. Méndez, L. Poletto, A. Marco Malvezzi, A. Giglia, S. Nannarone, "Determination of optical constants of scandium films in the 20–1000 eV range", J. Opt. Soc. Am. A **23**, 2880 - 2887 (2006).

16. Yu. Uspenski, J. Seely, N. Popov, I. Artioukov, A. Vinogradov, D. Windt, B. Kjornrattanawanich, "Extreme UV optical constants of rare-earth metals free from effects of air contamination", in Soft *X-Ray Lasers and Applications VI*, E. E. Fill, ed., Proc. SPIE **5919**, 213-220 (2005).

17. B. Kjornrattanawanich, D. L. Windt, Y. A. Uspenskii, J. F. Seely, "Optical constants determination of neodymium and gadolinium in the 3 nm to 100 nm wavelength range", in *Advances in X-ray/EUV optics, components, and applications*, A. M. Khounsary, C. Morawe, eds., Proc. of SPIE **6317**, 63170U (2006).

18. M. Fernández-Perea, J. I. Larruquert, J. A. Aznárez, J. A. Méndez, L. Poletto, D. Garoli, A. M. Malvezzi, A. Giglia, S. Nannarone "Determination of the transmittance and extinction coefficient of Yb films in the 23-1,700-eV range", J. Opt. Soc. Am. A **24**, 3691-3699 (2007).

19. M. Fernández-Perea, J. I. Larruquert, J. A. Aznárez, J. A. Méndez, L. Poletto, D. Garoli, A. M. Malvezzi, A. Giglia, S. Nannarone "Determination of the transmittance and extinction coefficient of Ce films in the 6-1,200-eV range", J. Appl. Phys. **103**, 073501-1-7 (2008).

20. M. Fernández-Perea, M. Vidal-Dasilva, , J. A. Aznárez, J. I. Larruquert, J. A. Méndez, L. Poletto, D. Garoli, A. M. Malvezzi, A. Giglia, S. Nannarone "Determination of the transmittance and extinction coefficient of Pr films in the 4-1,600-eV range", accepted for publication in Journal of Applied Physics.