International Conference on Space Optics—ICSO 2014

La Caleta, Tenerife, Canary Islands

7–10 October 2014

Edited by Zoran Sodnik, Bruno Cugny, and Nikos Karafolas

Optical filters for UV to near IR space applications

T. Begou

H. Krol

Christophe Hecquet

C. Bondet

et al.

International Conference on Space Optics — ICSO 2014, edited by Zoran Sodnik, Nikos Karafolas,
Bruno Cugny, Proc. of SPIE Vol. 10563, 1056306 · © 2014 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2304155

OPTICAL FILTERS FOR UV TO NEAR IR SPACE APPLICATIONS

T. BEGOU[1], H. KROL[2], C. HECQUET[1], C.BONDET[2], J. LUMEAU[1], C. GREZES-BESSET[2] and M. LEQUIME[1].
[1] *Aix Marseille Université, CNRS, Centrale Marseille, Institut Fresnel, UMR 7249, 13013 Marseille – France,*
[2] *CILAS Etablissement de Marseille, 600 avenue de la Roche Fourcade, Pole ALPHA Sud - Saint Mitre, 13400 Aubagne – France.*
thomas.begou@fresnel.fr

I. INTRODUCTION

We present hereafter the results on the fabrication of complex optical filters within the Institut Fresnel in close collaboration with CILAS. Bandpass optical filters dedicated to astronomy and space applications, with central wavelengths ranging from ultraviolet to near infrared, were deposited on both sides of glass substrates with performances in very good congruence with theoretical designs. For these applications, the required functions are particularly complex as they must present a very narrow bandwidth as well as a high level of rejection over a broad spectral range. In addition to those severe optical performances, insensitivity to environmental conditions is necessary. For this purpose, robust solutions with particularly stable performances have to be proposed.

After presenting the coating process and the experimental set up for component characterization, we review the spectral responses of some devices with a focus on some specific parameters, i.e. uniformity, spectral transmission, spectral rejection and cosmetics.

II. EXPERIMENTAL SET UP

A. Deposition process

All the optical components are manufactured with the help of a LEYBOLD Optics HELIOS 4" machine, where low and high index materials are both deposited through Plasma Assisted Reactive Magnetron Sputtering (PARMS) [1] [2]. A seen in Fig. 1., the main chamber of the machine is subdivided in 4 deposition/treatment zones, two dedicated for dielectric materials (MF magnetron sputtering), one for metallic deposition (DC magnetron sputtering, not used here) and the last one for oxygen plasma assistance (PBS).

The substrates are set on a 12-position rotating sample holder (rotation at 240 rpm). According to the deposited material, either low or high index, the corresponding MF magnetron sputtering cathode is switched on; the oxygen plasma assistance is used for densification of the coating and also to respect the stoichiometry of the layers. Typical deposition rates of low and high index materials are respectively around 0.40-0.45 $nm.s^{-1}$ and 0.50-0.60 $nm.s^{-1}$, which means that less than an atomic layer of material is deposited at each turn of the sample holder. Thicknesses of the different deposited layers are optically controlled, in a transmission mode, at a precisely selected wavelength through the Optical Monitoring System OMS5000 developed by LEYBOLD Optics [3].

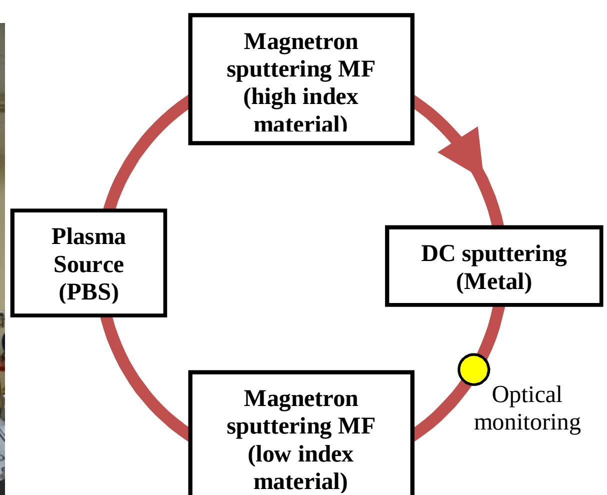

Fig. 1. HELIOS deposition process chamber.

B. Spectral uniformity set up

In order to define the spectral uniformity of the processed optical component, we use a dedicated set up elaborated few years ago [4]. The principle used to obtain a precisely localized analysis surface is to form on the sample the geometrical image of a calibrated aperture stop, as is shown in Fig. 2. Following the propagation of light, this aperture stop is placed in front of the sample, which allows us to control visually the probing-zone location on the sample. Several aperture stops of different diameters, all located on a wheel, are available, permitting the adaptation of the spatial resolution according to the kind of measurement we want to perform. Obviously, selecting a small analysis surface to improve the spatial resolution decreases the flux level and consequently the signal-to-noise ratio.

At the entrance of the system, the light source is imaged on the aperture stop while, at the exit of the system, the sample is imaged on the entrance slit of a monochromator either by way of the transmitted beam.

Now both the light source (High Brightness Xenon Arc lamp) and the monochromator (optical spectrum analyzer ANDO AQ 6315-A) are connected to the bench by means of optical fibers.

A horizontal sample holder is used to allow the positioning of the sample and a reference glass side by side. The transmission measurement is thus performed vertically. The substrate holder is motorized along two axes in the horizontal plane so that we can perform 2D mappings of the samples.

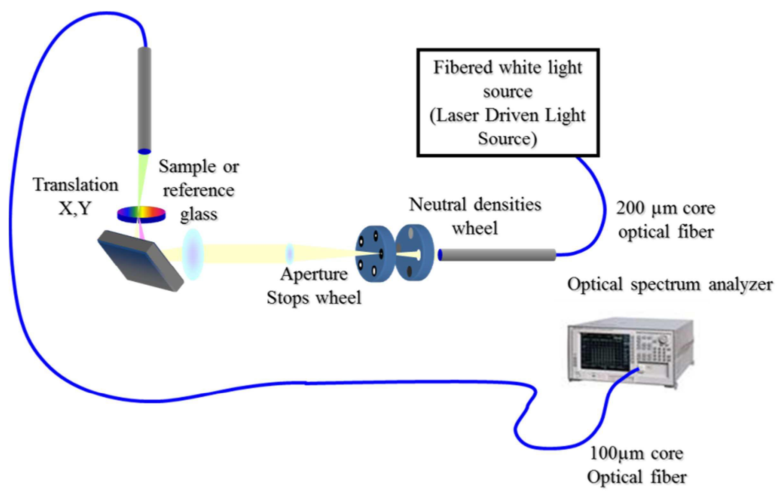

Fig. 2. Spectral uniformity measurements set up.

C. Cosmetic measurements

As for the spectral uniformity, the cosmetics of the realized optical device are analyzed through a homemade experimental set up [5]. To perform the measure, a sample is illuminated with a collimated LED (M470L2-C1 – Thorlabs) with 400 mW output power, centered at 470 nm, with 29 nm spectral bandwidth. The angle of incidence of the incoming beam is fixed at 45°. A CMOS camera (DCC145M – Thorlabs) is placed at normal incidence to the sample in order to collect the light scattered by all the surface defects. Finally a ×2 telecentric objective (63-741 - Edmund Optics) is added in the system in order to image the sample surface on the CMOS camera. Due to the telecentric objective the entrance pupil is rejected at infinity, which guarantees that the angular coordinates of the chief ray defining the direction of scattered light are the same at all points on the sample surface. Samples are fixed on custom sample holders that allow fixing either 25 mm- or 100 mm-diameter samples. These sample holders are designed in order to minimize the contact with the glass and therefore limit parasitic scattering from holder. Moreover, the distance between the sample and the surface underneath is designed such as the camera does not collect any light scattered from this rear surface. The sample holders are finally fixed on two wide range translation stages (150 mm) that permit to scan the whole sample's surface. We have developed custom Labview® programs in order to make the camera acquisition and precisely translate the sample in X and Y-directions.

III. DEFINITION OF THE OPTICAL FILTERS

To define the design of the optical filters, refractive indices and extinction coefficients of the available materials are extracted from the transmission spectra of monolayer of each material [6]. According to the centering of the filters, either UV or visible/infrared range, two different couples of materials are used. As seen in Fig. 3., for UV filters, Nb_2O_5 became absorbing, so multilayer optics are designed with HfO_2 as high index material and SiO_2 as low index material. For filters dedicated to visible or infrared range, since Nb_2O_5 is no more absorbing and the contrast is higher between the refractive indices of SiO_2 and Nb_2O_5, filters are designed with this these two materials.

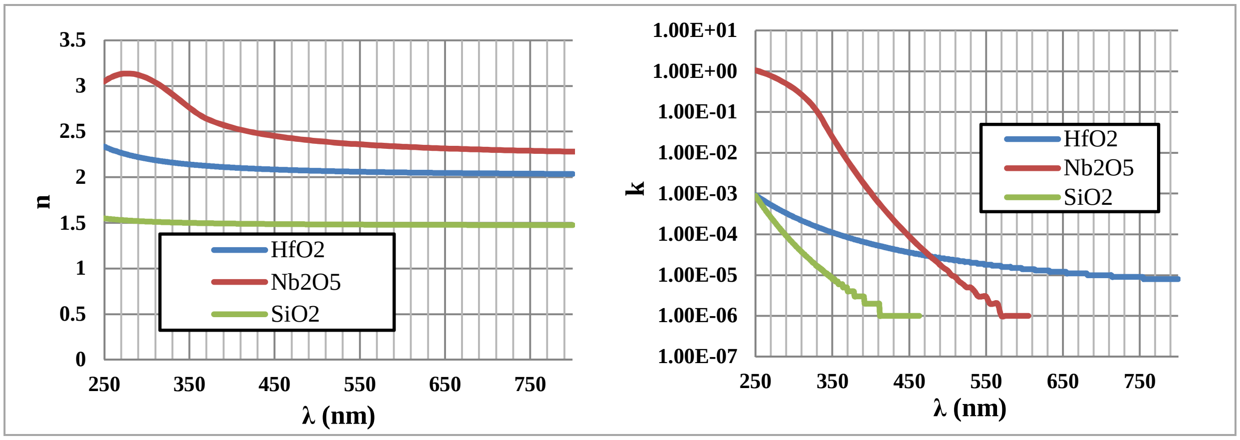

Fig. 3. Refractive indices (n) and extinction coefficients (k) of the materials deposited with the HELIOS System.

The design of the different filters is obtained from the combination of Fabry-Perot cavities and mirrors. Then the design is optimized using commercial software based on needle optimization method [7] in order to adapt the spectral transmission and to suppress very thin layers (i.e. < 10 nm).

All the filters presented in this paper are treated on both sides. The typical number of layers on each side ranges from 50 to 120. The maximum cumulated thickness on one side is around 26 µm (16 µm of SiO_2 and 10 µm of Nb_2O_5).

IV. RESULT

The realizations of 12 filters are demonstrated in this part: 1 filter in the UV range (named UV Filter), 2 filter in the visible range (named VIS Filter 1 and 2) and 9 filters in the near IR range (named IR Filter 1 to 9). As experimental results, we present the transmission spectra of all the filters, the result of an uniformity measurement for one filter and the result of a cosmetic analysis for another one.

A. Transmission spectra

The transmission spectra are acquired using a Perkin Elmer Lambda1050 spectrophotometer. The transmission spectra for optical filters working in UV or visible range are shown in Fig.4. and the transmission spectra for IR components in Fig.5..

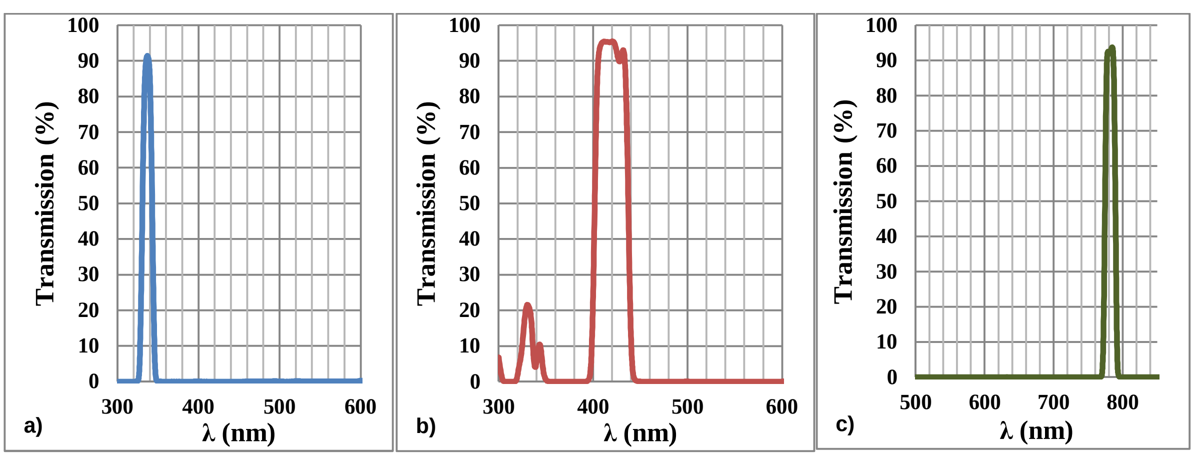

Fig. 4. Transmission spectra of the UV-VIS deposited filters: UV Filter (a), VIS Filter 1 (b) and VIS Filter 2 (c).

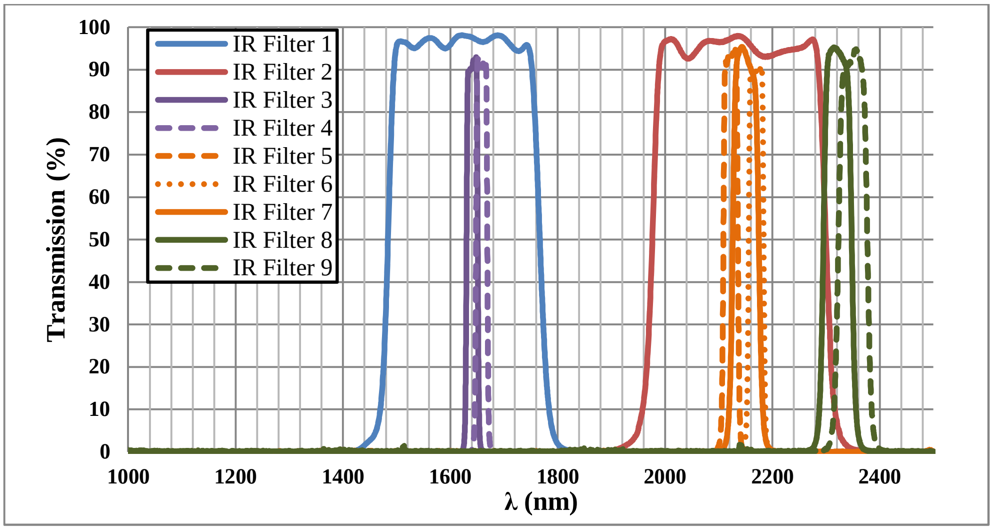

Fig. 5. Transmission spectra of the IR deposited filters.

As seen in Fig.4. and Fig.5., all the device are narrow bandpass filters with a transmission in the pass band above 90%. Moreover all filters exhibit a good rejection on a large spectral range in accordance with the device specification.

As an example, in Fig.6. and Fig.7. a comparison between the theoretical transmission extracted from the design of the filters and the experimental result are performed for the VIS Filter 2.

In the transmitting band, a very strong agreement is observed between the design predictions and the measurement results (transmission maximum and shape of the band).

To compare also the theoretical and experimental rejection, a measurement with an optical spectrum analyzer ANDO AQ 6315-A is performed using our high brightness Xenon Arc Lamp. Although a limitation of the measurement for very low rejection zone due to limitation of the equipment (for optical densities > 5-6), an excellent agreement is exhibited between theoretical and experimental curves.

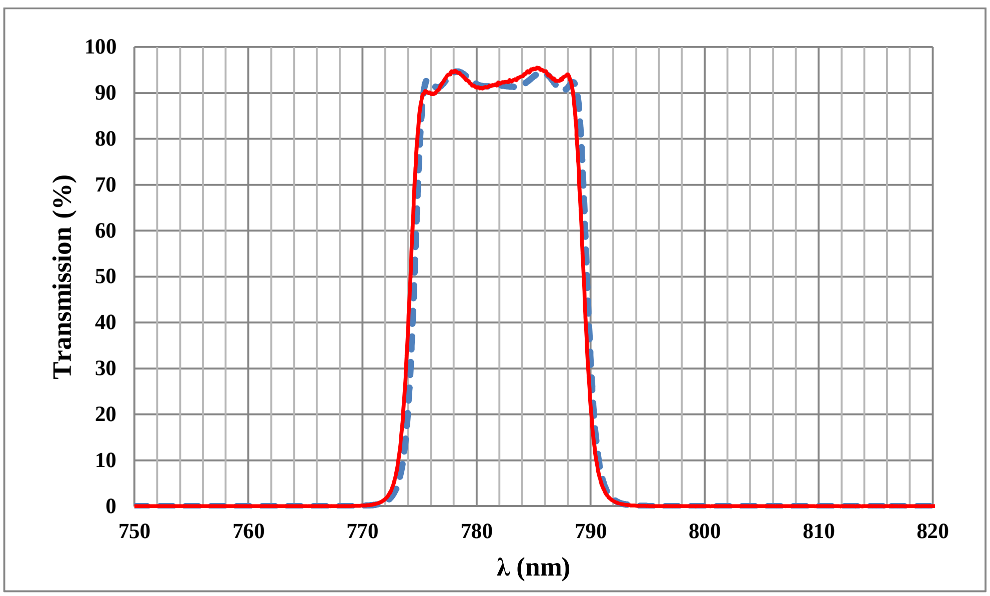

Fig. 6. Comparison between theoretical (dashed line) and experimental (solid line) transmission of the VIS Filter 2.

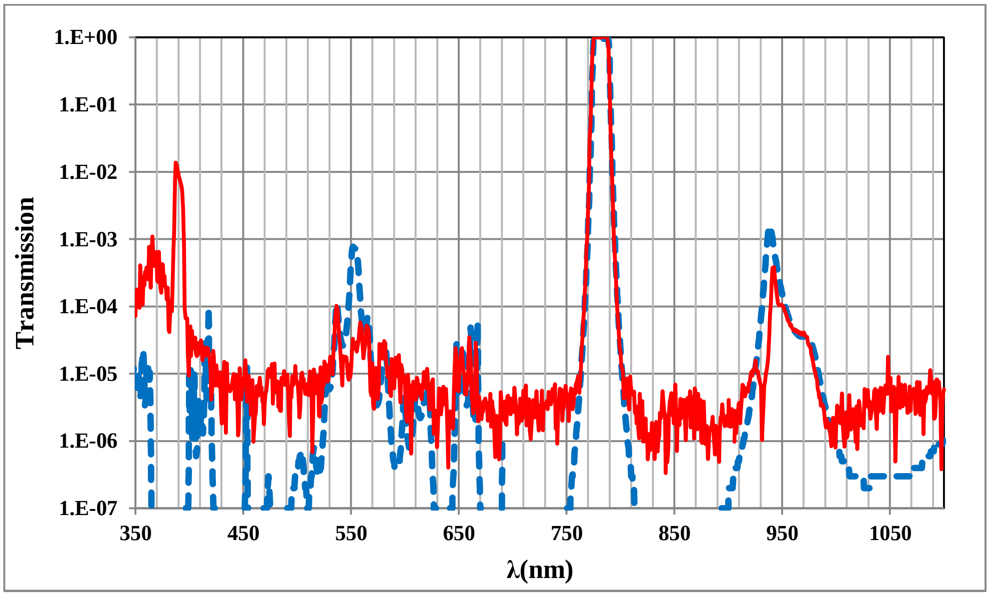

Fig. 7. Comparison between theoretical (dashed line) and experimental (solid line) transmission of the VIS Filter 2 in logarithmic scale.

B. Optical uniformity measurements

The optical uniformity is measured on a 100 mm diameter glass substrate. In Fig.8., the VIS Filter 2 uniformity, only treated on one side, exhibits a very low shift of the central wavelength. As seen in the cartography, the central wavelength varies from -0.2% to 0.5% over the surface of the substrate. Same results are observed for the other filters.

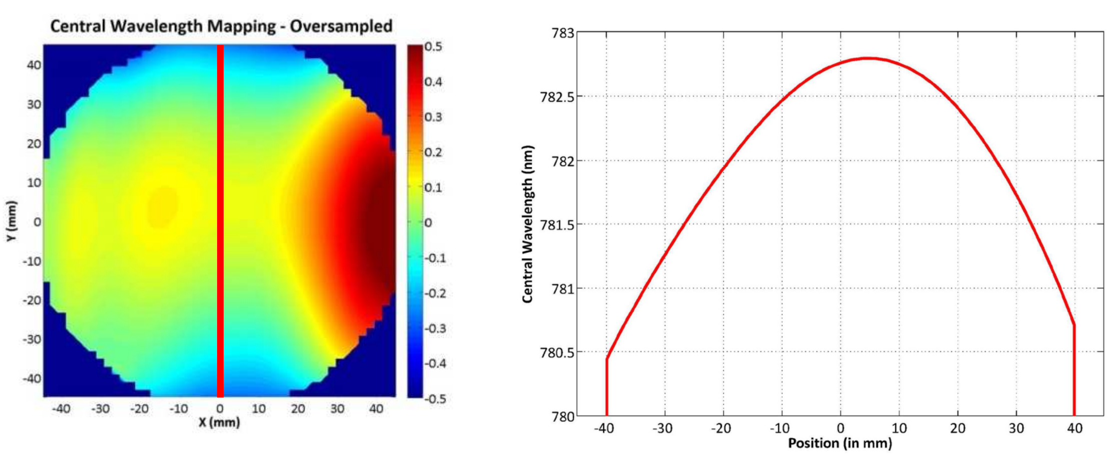

Fig. 8. Result of the spectral uniformity measurement on the filter side of the VIS Filter 3 (Cartography and shape of the central wavelength of the filter along the red line).

C. Cosmetics of the filters

The measurement of the cosmetics, shown in Fig.9., has been performed to help us improve our cleaning procedure of the HELIOS machine before the deposition of a filter. On the left image of Fig.9., the measure, done in uncleaned machine, exhibits the presence of lots of cosmetics that could lead to degradation of the performance of the filter. In order to improve these characteristics, we develop an optimized strategy of cleaning that leads to the better results of the right image of Fig.9..

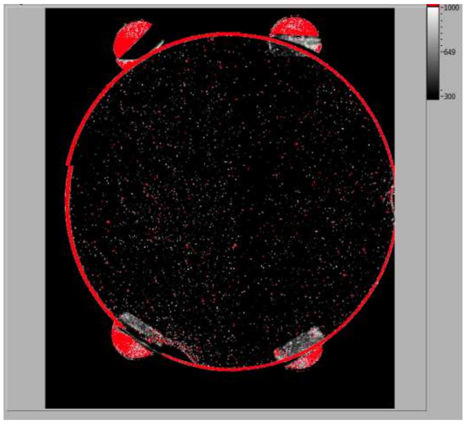
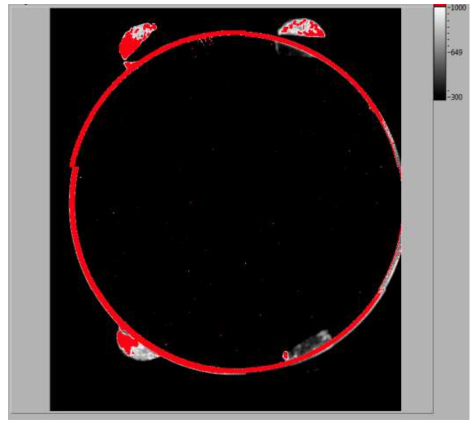

Fig. 9. Cosmetics measurement on the filter side of the VIS Filter 3 (before and after optimization of the cleaning procedure of the deposition machine).

D. Space qualification

The compatibility of the UV Filter 1 with space applications have been tested on LAT (Lot Acceptance Test) samples through environmental and durability qualification and acceptance tests (temperature, humidity, thermal vacuum, …) which revealed no deterioration of the optical performances.

V. CONCLUSIONS AND PERSPECTIVES:

We demonstrate in this paper the realization of narrow band pass filters elaborated by plasma assisted reactive magnetron sputtering.
Two dedicated optical setups, developed within the Institut Fresnel, were used in order to characterize accurately the spectral and cosmetic features. High transmission, i.e. very low absorption, is exhibited for all the filters even for UV filters. Uniformity better than ± 0.4% over 100 mm aperture is demonstrated resulting in low fluctuations of the spectral properties over the surface. To be in accordance with demanding requirements concerning cosmetics performances, improvement of the process were implemented and allowed decreasing the number of defects by several orders of magnitude.
To explore more deeply all the possibility of the HELIOS machine in future works studies on metal/dielectric filters or on pseudo-gradient index profile will be performed.

VI. ACKNOWLEDGEMENT

The Perkin Elmer 1050 and Leybold Optics HELIOS machine were acquired within the framework of the Espace Photonique facility and funded by the financial support of the French Department of Industry, CNRS, the local administrations (Provence-Alpes Côte d'Azur Regional council, Bouche du Rhône council, town of Marseille), and the European Community.

REFERENCES

[1] M. Scherer, J. Pistner and W. Lehnert, "UV- and VIS Filter Coatings by Plasma Assisted Reactive Magnetron Sputtering (PARMS)", *OIC 2010 Proceedings*.
[2] T. Begou, C. Hecquet, F. Lemarchand and M. Lequime, "All dielectric broadband mirror for Fabry-Perot interferometer" *OIC 2013 Proceedings*.
[3] A. Zoeller, M., H. Hagedorn, W. Klug and C. Schmitt, "High accurate in-situ optical thickness monitoring", *OIC 2004 Proceedings*.
[4] L. Abel-Tiberini, F. Lemarquis and M. Lequime, "Dedicated spectrophotometer for localized transmittance and reflectance measurements", *Appl. Opt.*, vol.45 (7), pp. 1386-1391, March 2006.
[5] A. Joerg, J. Lumeau, M. Zerrad and M. Lequime, "Low-cost automatic system for the control of the surface quality of coated and uncoated wafers" *OIC 2013 Proceedings*.
[6] L. Gao, F. Lemarchand and M. Lequime, "Reverse engineering from spectrophotometric measurements: performances and efficiency of different optimization algorithms" *Appl Phys A*, Vol. 108 (4), pp. 877-889, september 2012.
[7] Sh. Furman and A.V.Tikhonravov, "Basics of optics of multilayer systems", *Editions Frontiers*, Gif-sur Yvette, 1992.