Optical interference filters technology for space applications

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RCMO Team

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Optical Thin Film Research Team

Of Institut Fresnel

<u>The Team:</u>

3 Ass. Prof., 1 Emeritus Pr., 1 Research Scientist, 2 Engineers

2 Ph.D. Students

<u>1 Technological platform</u>: *Espace Photonique*

<u>Projects:</u>

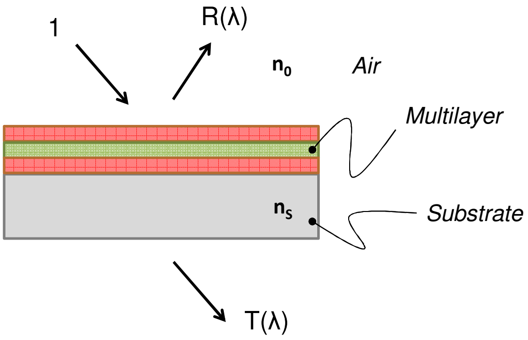
Various projects with Public and Private entities.

- 1/3 of our projects are with private companies.
- 1/3 of our projects are with CNES
- 1/3 of our projects are with academic projects

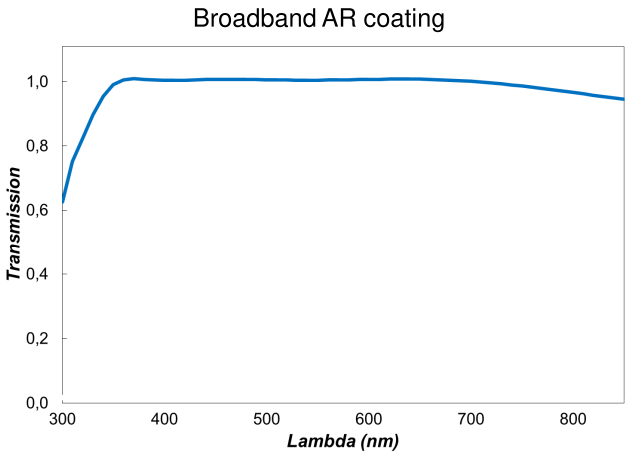
Partners and clients

Optical interference filter

Thin-film multilayer stack for the control of the spectral properties of the light transmitted by the substrate on top of which it has been deposited.

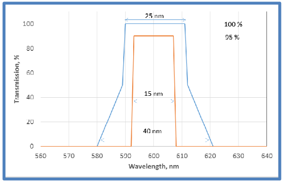


Optical filtering functions



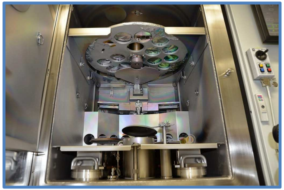
Optical filters design and fabrication

Design



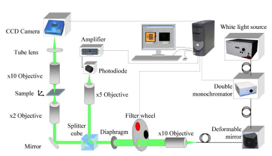
Stack formula

Fabrication



Component/ prototype

Characterization



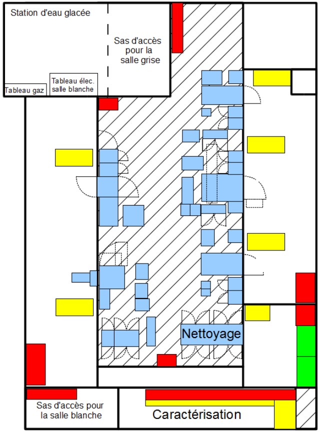
Performances

The Espace Photonique Platform

Sputtering

DIBS

HELIOS



Characterization

Evaporation

BAK 600

SYRUSpro 710 – 1 & 2

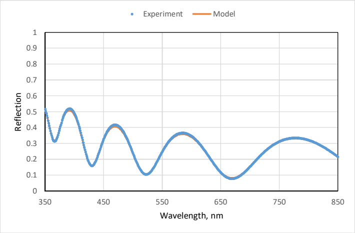
Thin film filter design

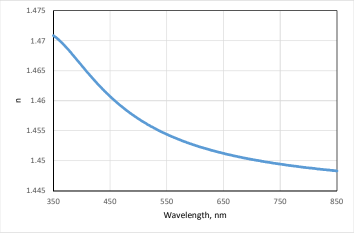
Material optical properties

- Spectrophotometric measurements (**Optical measurements**)
  - Different incidences, polarizations…
  - Different substrates
  - Multilayers
- Various dispersion models
  - Cauchy, Sellmeier
  - Tauc Lorentz
- Various optimization methods

N = n - ik

Precision on n and k is within 0.001 or better over a broad spectral range from 1 to several octaves.





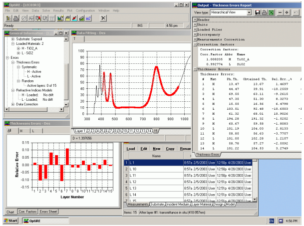
L. Gao et al., Opt. Express 20, 15734-15751 (2012)

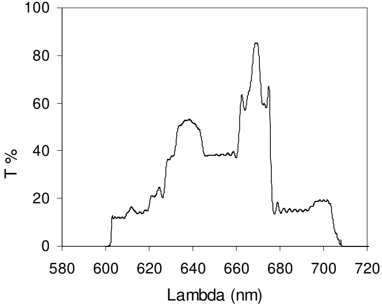
Thin film filter design

Design techniques

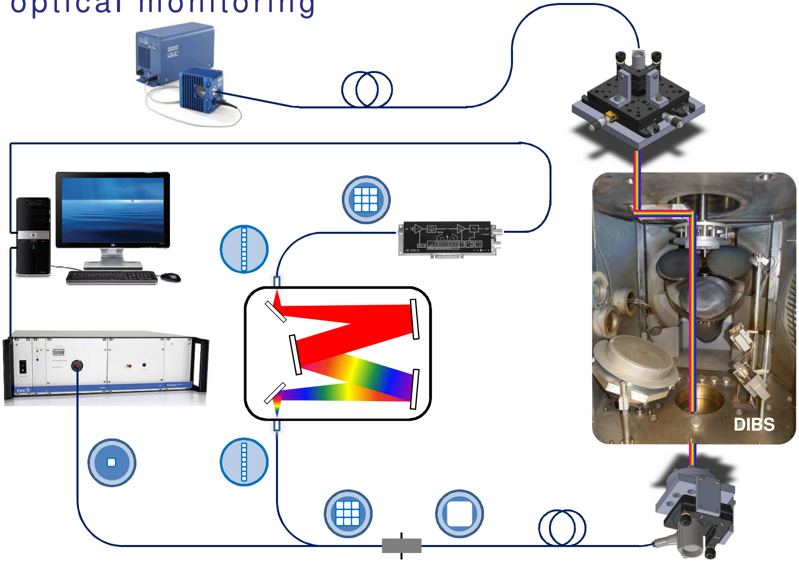
- <u>Goal</u>: determine the sequence of alternated H and L refractive index materials having resulting R(λ) and T(λ) meeting the specifications.

Commercial software (Optilayer)



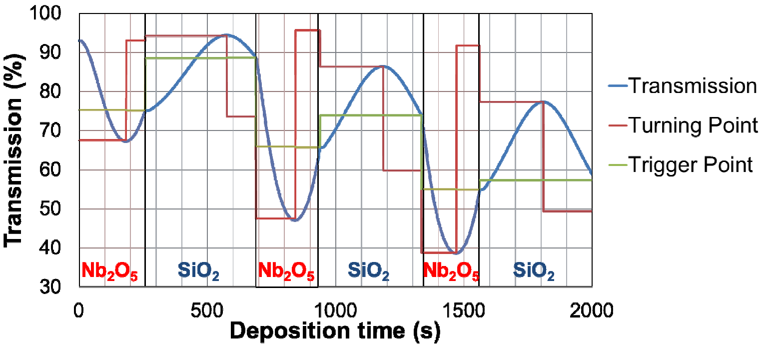


In-situ optical monitoring



In-situ Optical Monitoring

Objective:
Precision on the optical thickness of each layer within a few 0.1%



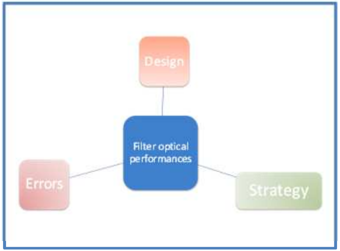
Optical monitoring : trigger point method (from the monochromatic transmission measurement of the sample during deposition, each layer is stopped at optimized transmission value

Thin film filter design

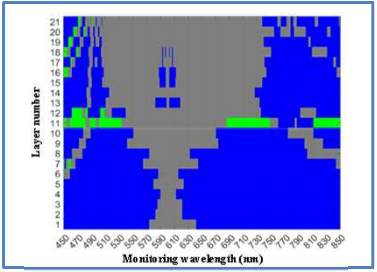
Virtual Deposition Process

- <u>Goal</u>: Determine the optimal monitoring strategy and predict the success rate of a deposition.

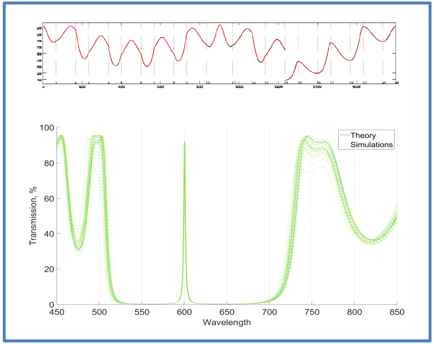
Custom VDP program



Strategy determination

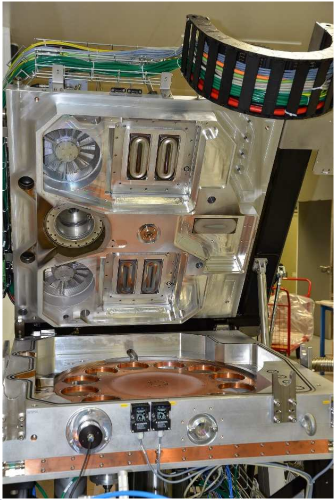


Deposition simulation



High performances deposition machine

Bühler/Leybold Optics HELIOS



LEYBOLD OPTICS
A part of Bühler
BÜHLER

High performances deposition machine

A few details

- 12 sample holders (1 dedicated to optical monitoring).
- Plate rotation at 240 rd.min-1.
- Load-lock.
- 4 process zones :

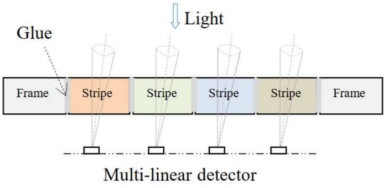
  - 1 assistance plasma source,

  - 2 MF magnetron sputtering sources (dielectric material deposition),

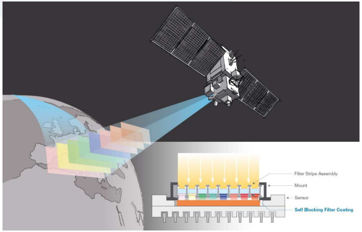
  - 1 DC sputtering source (metallic material deposition).
- Real time monochromatic optical monitoring of the deposition in transmission.
- Available targets : Si, Nb, Hf, Ta, Ag, Cr.
- Available Gas : Ar, O2, N2.

Multispectral filters

IDEFIX R&T CNES project

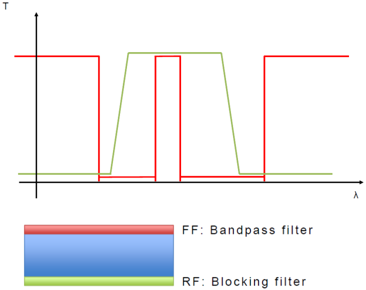


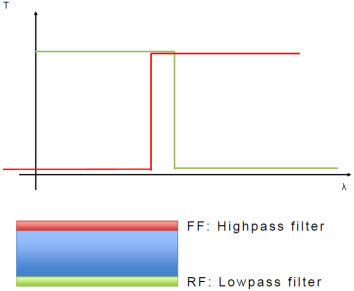
Bi	CWL λ_c (nm)	FWHM $\Delta\lambda$ (nm)	Mean T (%)	Rejection ratio (%)	Total integrated Scattering TIS (%)	Slope 10% 90% (nm)
B0	415 ± 3	40 ± 10%	> 80	< 0.3	< 0.3	< 5
B1	667 ± 2	30 ± 10%	> 80	< 0.3	< 0.3	< 5
B2	782 ± 1	16 ± 10%	> 80	< 0.3	< 0.3	< 5
B3	910± 2	20 ± 10%	> 80	< 0.3	< 0.3	< 5

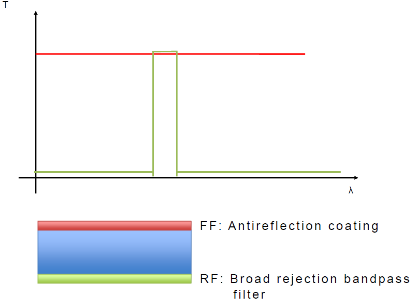


www.opticsbalzers.com

Bandpass filters design





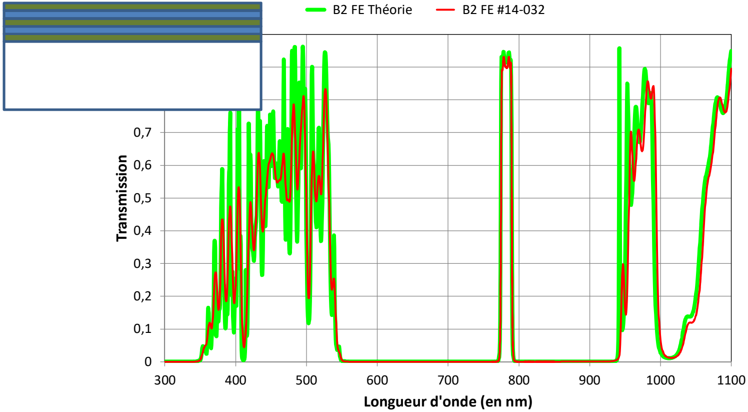


- Various possible approaches for the same type of optical functions.
- All are possible but they present various advantages and drawbacks.

Complex filter

Filters for space applications

Objective:
Error not exceeding a few percent over broad spectral range



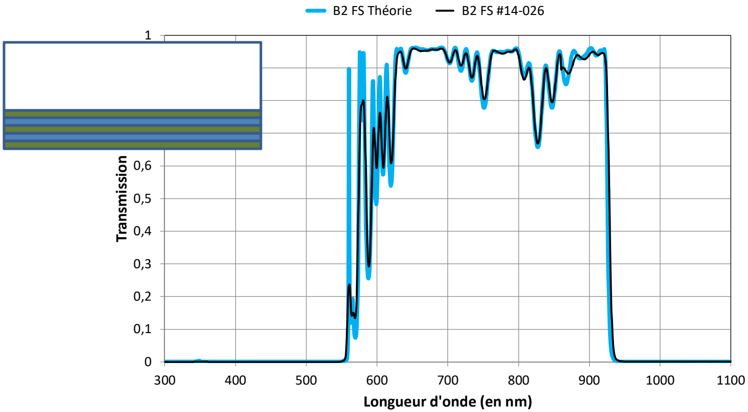
Filtering face (93 layers, 4600 nm Nb_2O_5 and 5500 nm SiO_2)

T. Begou et al., CEAS Space J 9(4), 441–449 (2017).

Complex filter

Filters for space applications

Objective:
Error not exceeding a few percent over broad spectral range

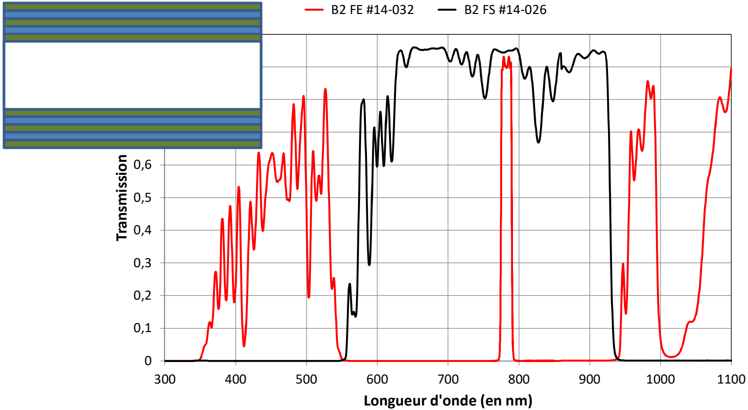


Blocking face (100 layers, 3800 nm Nb_2O_5 and 5800 nm SiO_2)

Complex filter

Filters for space applications

Objective:
Error not exceeding a few percent over broad spectral range

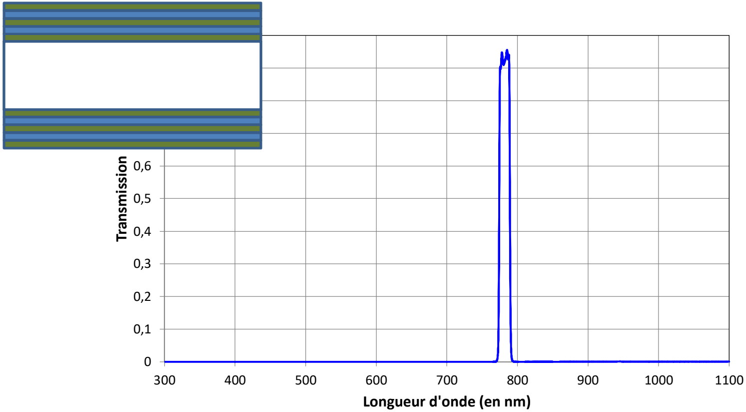


Narrowband filter with broad rejection band

Complex filter

Filters for space applications

Objective:
Error not exceeding a few percent over broad spectral range



Narrowband filter with broad rejection band

T. Begou et al., CEAS Space J 9(4), 441–449 (2017).

Complex filter

Filters for space applications

Objective:
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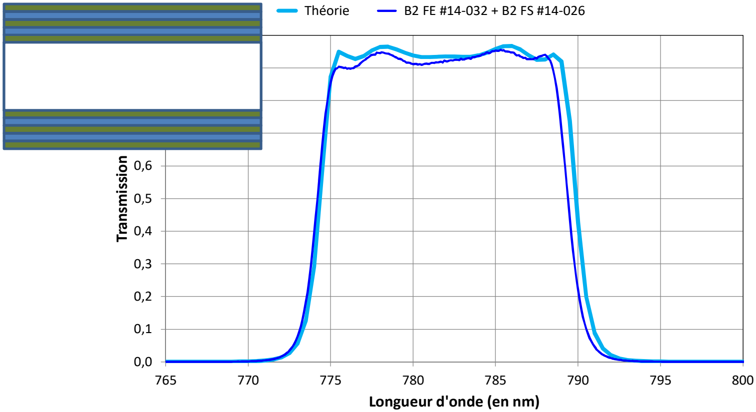


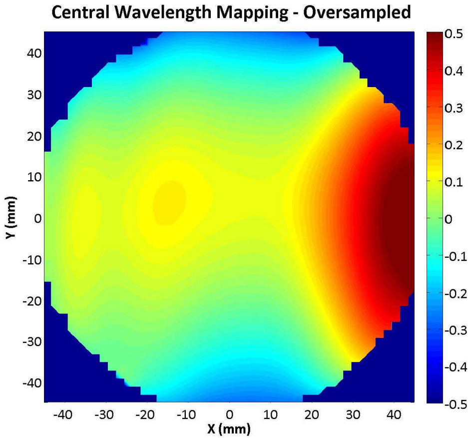
Excellent agreement between theory and experiment

T. Begou et al., CEAS Space J 9(4), 441–449 (2017).

Complex filter

Filters for space applications

Objective:
Error not exceeding a few percent over broad spectral range



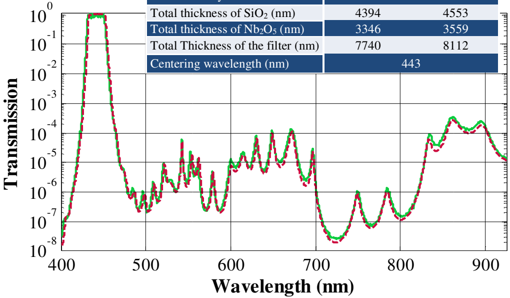
Uniformity better than 0.5% over 80 mm aperture

Complex filters – Other examples

Bleu and IR filters (3MI-mission)

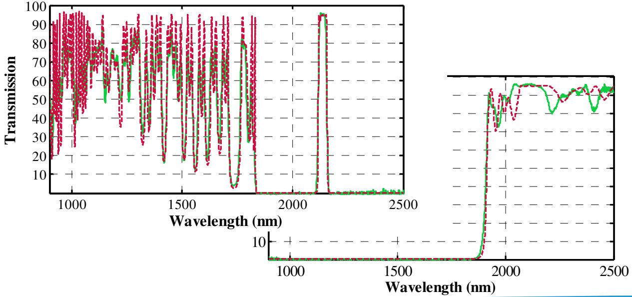
443 NM 3MI FILTER

	3MI-3 Filter	
	Front Face (FF)	Rear Face (RF)
Number of layers	87	76
Total thickness of SiO_2 (nm)	4394	4553
Total thickness of Nb_2O_5 (nm)	3346	3559
Total Thickness of the filter (nm)	7740	8112
Centering wavelength (nm)	443	



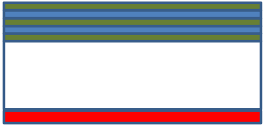
2132 NM 3MI FILTER

	3MI-12 Filter	
	Front Face (FF)	Rear Face (RF)
Number of layers	66	140
Total thickness of SiO_2 (nm)	14434	14700
Total thickness of Nb_2O_5 (nm)	11174	9905
Total Thickness of the filter (nm)	25608	24605
Centering wavelength (nm)	2132	



Stress in optical coatings

Fundamental studies



STONEY formula:

$$\sigma = \frac{E_s t_s^2}{6(1-\nu_s)t_f}\frac{1}{R}$$

Stress compensation is obtained if:

$$\left(\sum t_{Nb2O5}\sigma_{Nb2O5} + \sum t_{SiO2}\sigma_{SiO2}\right)_{back\ side} = \left(\sum t_{Nb2O5}\sigma_{Nb2O5} + \sum t_{SiO2}\sigma_{SiO2}\right)_{front\ side}$$

- Theoretical aspects: athermal structures
- Thorough experimental studies

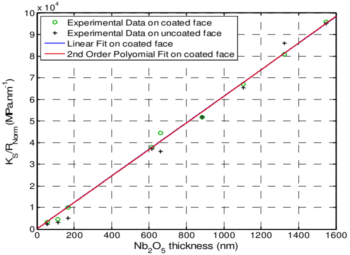
T. Begou and J. Lumeau, Optics Letters 42(16) (2017).

Stress in optical coatings

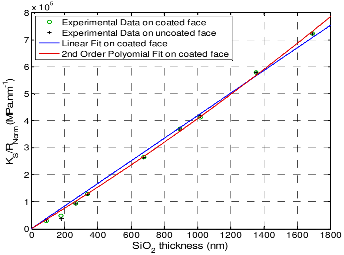
Fundamental studies

- **Linear Fit : $\sigma_i = K_i$** [5]
- **Second order polynomial Fit : $\sigma_i = A_i + B_i\, t_i$**

Material	**Linear Fit**		**2nd order polynomial fit**		
	K	***MF***	***A***	***B***	***MF***
Nb_2O_5	**61.4**	0.051	**61.0**	**0.0003**	0.050
SiO_2	**418.5**	0.061	**371.2**	**0.0360**	0.042



Stress determination for Nb_2O_5 film

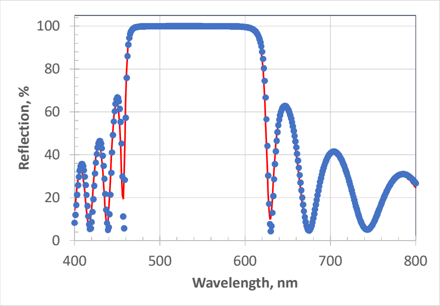


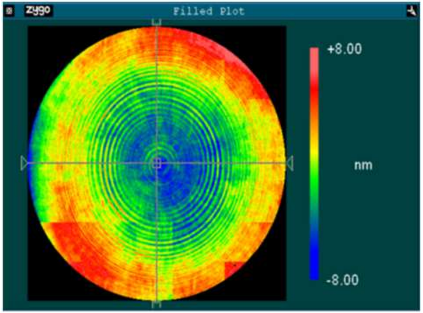
Stress determination for SiO_2 film

T. Begou and J. Lumeau, Optics Letters 42(16) (2017).

High performances mirrors

ELI-NP project





- R_S/R_P > 99.95% @ 515nm, AOI = 25°
- Flatness λ/30 @ 515 nm
- Ultra precise characterization of stress in coatings
- **Stress compensation using bi-facets deposition**

High performances mirrors

ELI-NP project

eli Nuclear Physics

LAL LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

ALSYOM ALCEN

- July-September 2016: delivery of **80 mirrors** to ALSYOM.
- October-December 2016: delivery of **42 mirrors** to LAL.

- 60 mirrors Φ30 mm and 42 miroirs Φ50/75 mm with perfectly compensated flatness
- 20 mirrors Φ30 mm with an addition +2 nm PtV curvature on the front face.

	Flatness in λ/30	Rs, %	Rp, %
Average	0.858	99.9648	99.9590
STDEV	0.173	0.0082	0.0107

T. Begou and J. Lumeau, Optics Letters 42(16) (2017).

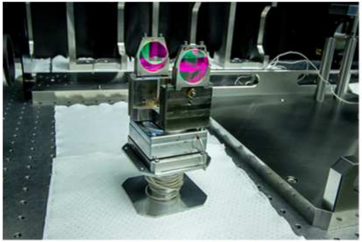
High performances mirrors

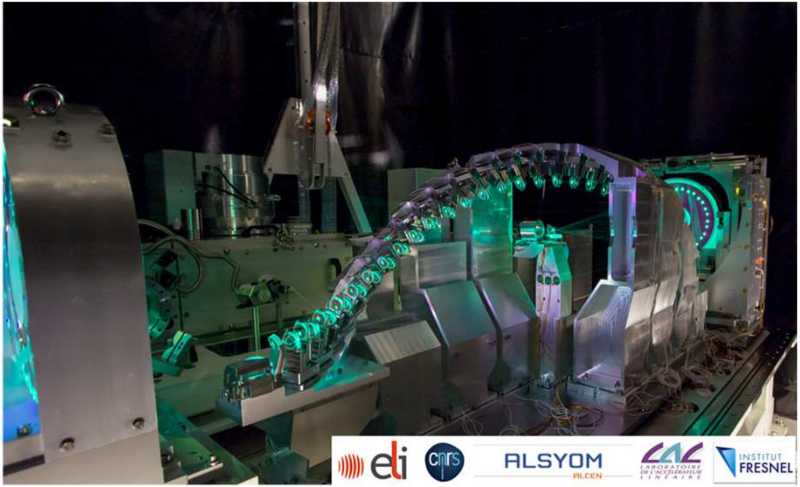
ELI-NP project

eli Nuclear Physics

LAL LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

ALSYOM ALCEN

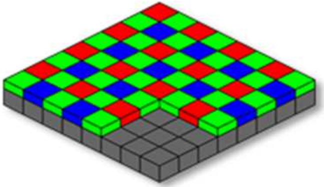




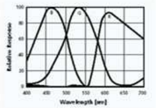
Courtesy of Nicolas Beaugerard ALSYOM/SEIV/CNRS

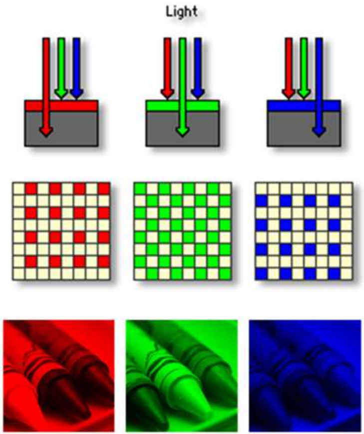
Mono-chip color camera

Bayer-type filter



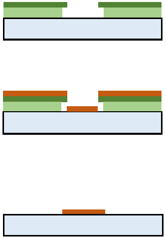
Color Filter Array Sensor





Fabrication technology

Lift-off using 2 photoresists



(a) Spin coating

(b) Deposition

(c) Photoresist removal

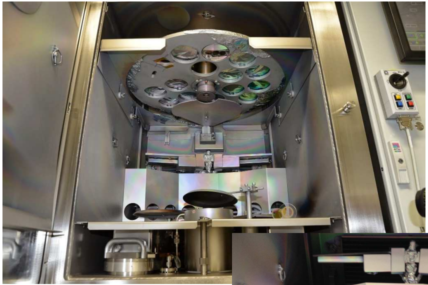
<u>Lift-off technique using 2 photoresists</u>

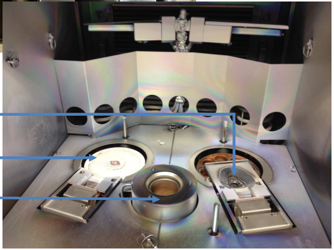
- Use of small caps to prevent walls formation.
- Precise positioning of the masks.
- Low temperature deposition of the multilayer layer (80-100°C).
- Removal of the photoresists.

M. Lequime et al., Proc. SPIE 9627, paper 96270V (2015)

Bühler SYRUSpro 710

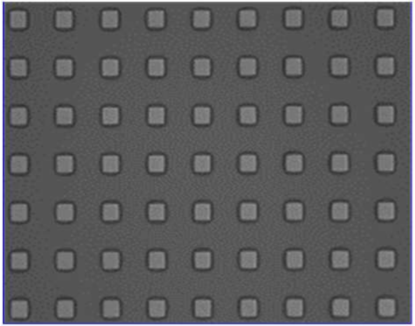
Deposition of structured filters



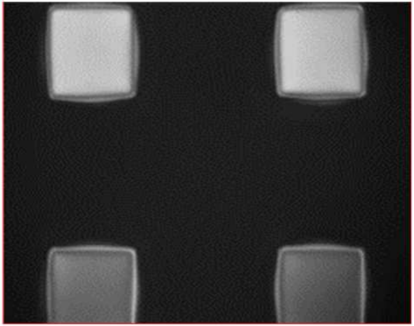


Geometrical characterization

Zygo NewView 7300 – 1 pixel



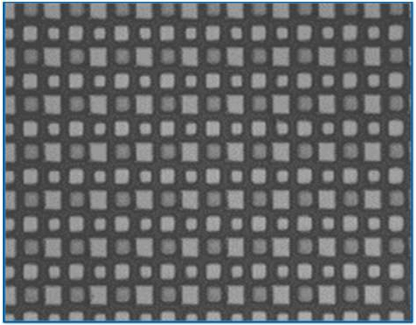
X10 objective – Zoom x1



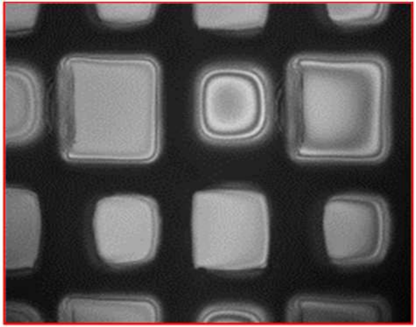
X100 objective – Zoom x0,5

Geometrical characterization

Zygo NewView 7300 – 4 pixels



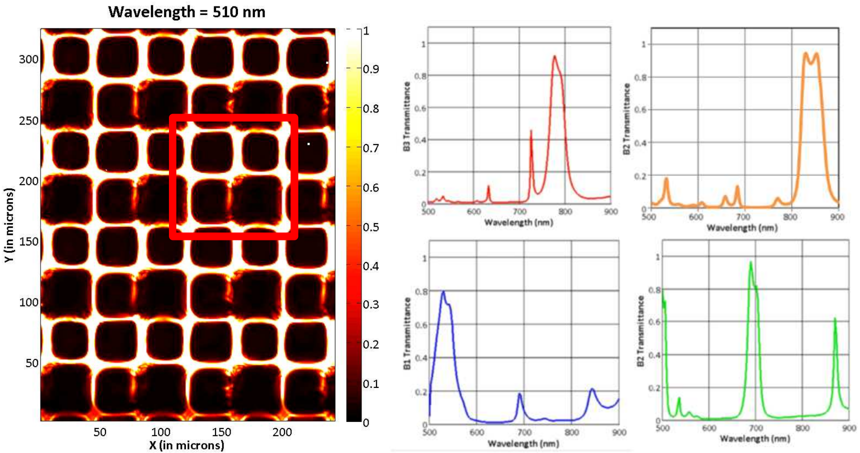
X10 objective – Zoom x1



X100 objective – Zoom x0,5

Spectral characterizations

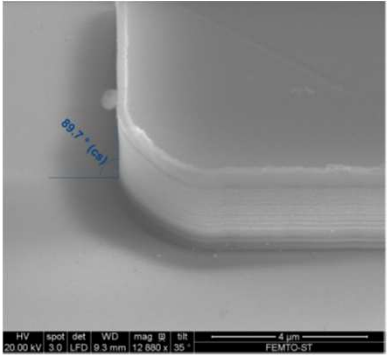
Resolution: spatial 2 mm, spectral 0.5 nm



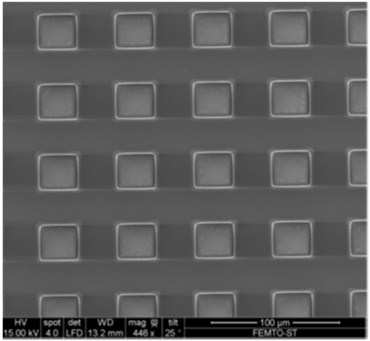
New developments

RIE on multilayer structures

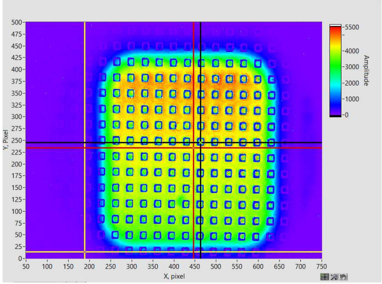
- ➢ DRIE of multilayer structures



- ➢ Deposition and liftoff



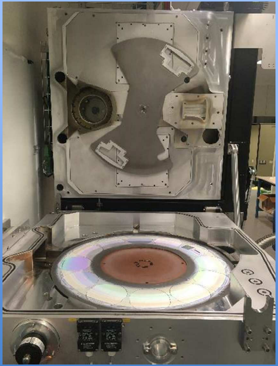
- ➢ Optical characterization



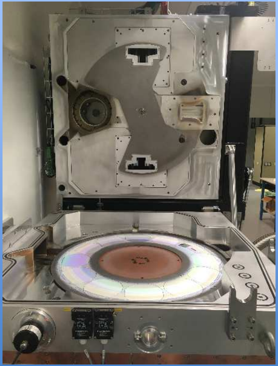
Linearly variable filters

The approach

Modification of the shutter in order to insert non uniformity mask that will be closer to the substrate (few mm)



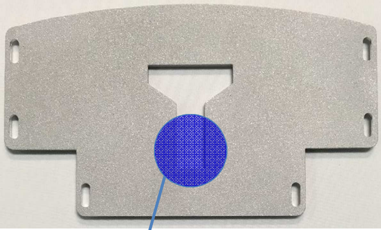
Shutter closed



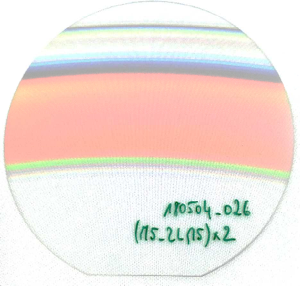
Shutter opened

Linearly variable filters

Illustration



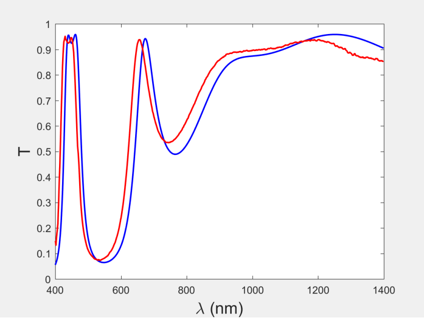
Optical monitoring performed for **thinner** part of the component

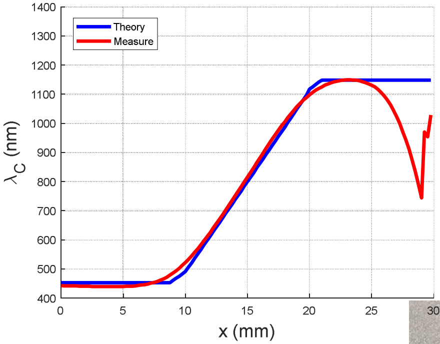


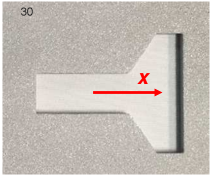
- **Dimensions** of the non uniformity mask
- **Linear thickness gradient** on a **10 mm zone**
- **Thickness ratio** of **3** between the extreme part of the mask

Linearly variable filters

Double cavity bandpass filter





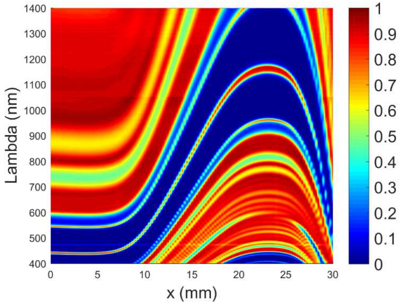


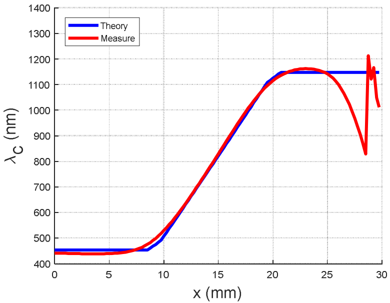
- Dynamic evolution of the transmission as a function of the ***x*** position
- Theoretical and measured curves

Linearly variable filters

Narrow bandpass filter

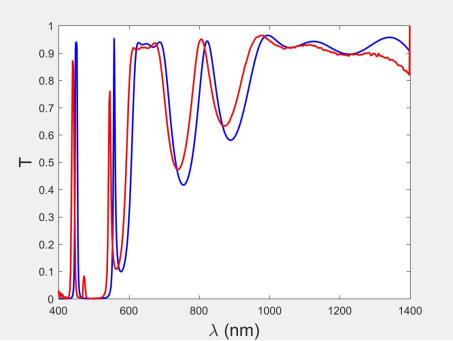
- 23-layer **double cavity** Fabry Perot : **[(H L)² H 2L H (L H)²] L [(H L)² H 2L H (L H)²]**
- **H** and **L** are respectively **quarter wavelength** thicknesses for **Nb_2O_5** and **SiO_2** @ **450 nm**
- **All the layers** are deposited under the **non uniformity mask** described in the upper part

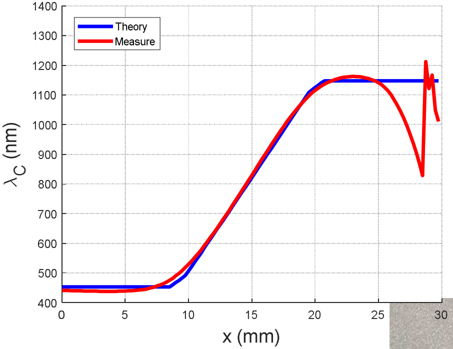


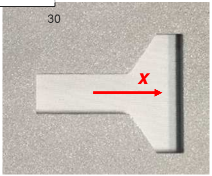


Linearly variable filters

Narrow bandpass filter







- Dynamic evolution of the transmission as a function of the ***x*** position
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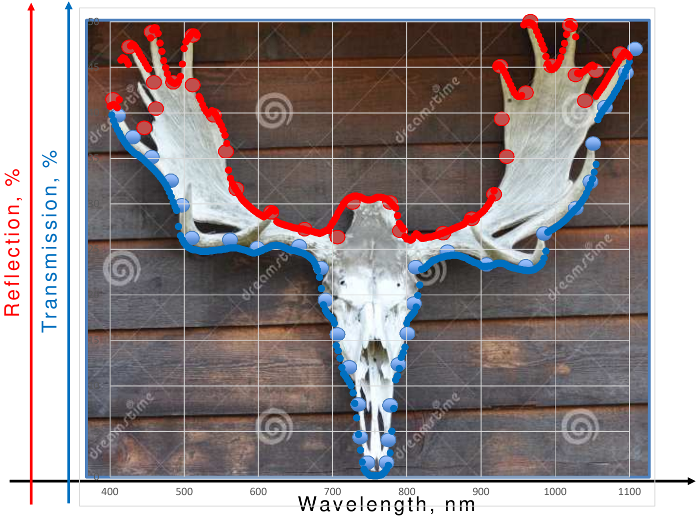
Metal-dielectric filters

OIC Manufacturing contest

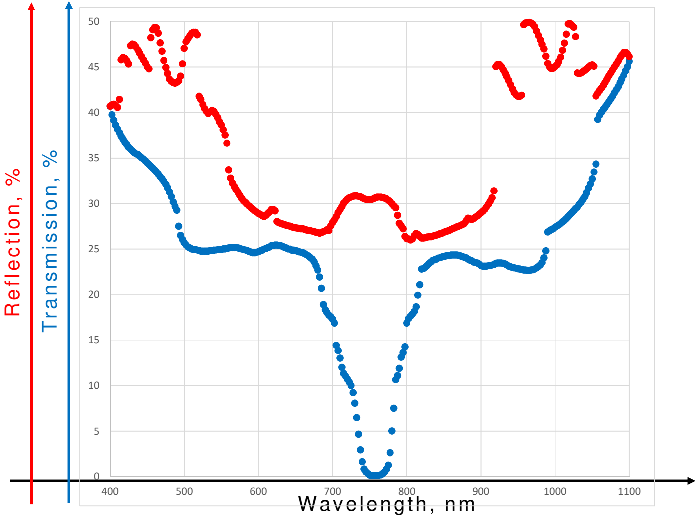


T. Begou et al., Optics Express 24(18), 20925–20937 (2016)

Metal-dielectric filters

OIC Manufacturing contest

Optical Interference Coatings



Metal-dielectric filters

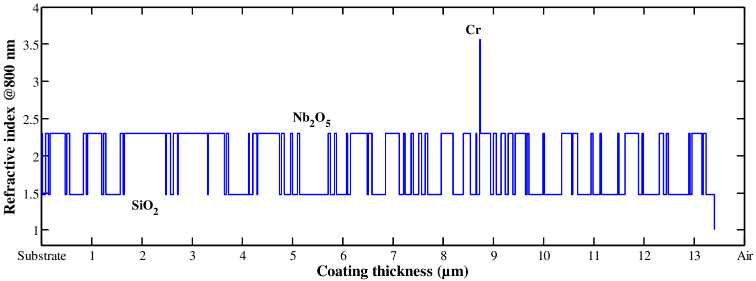
OIC Manufacturing contest


Research Article Vol. 24, No. 18 | 5 Sep 2016 | OPTICS EXPRESS 20925

Optics EXPRESS

Advanced optical interference filters based on metal and dielectric layers

THOMAS BEGOU, FABIEN LEMARCHAND, AND JULIEN LUMEAU*



- Alternated high and low index materials (Nb_2O_5/SiO_2) except for layer #67 made with chromium
- No periodicity, and layer thicknesses from 6 nm to 395 nm
- 8 different monitoring glasses

Optical Interference Coatings

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Advanced optical interference filters based on metal and dielectric layers

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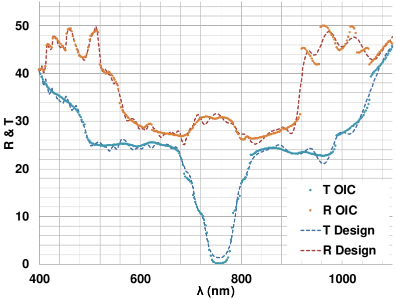

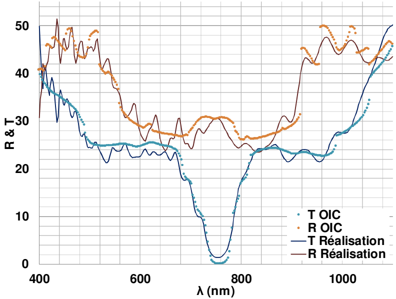

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Optical Interference Coatings

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