Optical interference filters with controlled spectral and spatial properties

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Optical Thin Film Research Team
Of Institut Fresnel

The Team:
6 Scientists, 2 Engineers 3 Ph.D. Students

1 Technological platform: Espace Photonique
3 e-beam machines (including Bühler SYRUSpro 710)
Dual ion beam sputtering (Teer Coatings DIBS)
Plasma assisted reactive magnetron sputtering
(Bühler/Leybold Optics HELIOS)

Custom and commercial optical benches

Projects:
Various projects with Public (e.g. ESA, CNES) and Private entities.
Introduction

- Optical interference coatings provide an efficient way for the production of 1D structures

- Transmission is controlled by the optical thickness of each individual layer:

  \[ t(\lambda) = |t(\lambda)|e^{-i\phi(\lambda)} = f(n_1 t_1, n_2 t_2, n_3 t_3...) \]

- Both amplitude and phase can be changed by controlling the optical thickness of each individual layer.

- We will present:
  - Thickness structuring for control of transmitted/reflected amplitude and phase
  - Refractive index structuring for the control of transmitted/reflected phase and amplitude
Control of transmitted amplitude
Fabry-Perot filter tuning

Figure 3: A schematic representation of an integrated implementation of the Fabry-Perot optical filter on top of standard CMOS imager in a tiled layout (dimensions not to scale, left) and alignment of filters to tiles (right).


B. Portier, Optical Interference Coatings (OIC), MC.8 (2016)

www.silios.fr
Control of transmitted phase
Diffractive optical elements

\[ \Delta \varphi = \frac{2\pi \Delta nt}{\lambda} \]
Control of reflected amplitude and phase

Phase and amplitude micro-mirrors

- **Circular micro-mirrors** with size from 50 to 150 µm
- $R > 99\%$, $AOI = 0^\circ$, $\lambda = 1064$ nm
- $\phi_1 - \phi_2 = \pi/2$ @ $\lambda = 1064$ nm

\[
\phi_1 = \arctan \left( \frac{\text{Im}[\eta_0 (BC^* - CB^*)]}{\eta_0^2 BB^* + CC^*} \right)
\]
\[
\phi_2 = \pi \left( 1 - \frac{4}{\lambda} \left[ \left( \sum t_H + \sum t_L \right) + t_C \right] \right)
\]

J. Lumeau et al., Proc. OIC, paper FA.10 (2016)
Control of reflected amplitude and phase
Phase and amplitude micro-mirrors

Spectral characterizations

Spatial characterizations

J. Lumeau et al., Proc. OIC, paper FA.10 (2016)
Method to produce a phase/amplitude change

- Classical method for structuring thickness: etching of the substrate surface or the layer

- Alternative method consists in structuring the index of a layer using a photosensitive material

\[
\Delta \phi = \frac{2\pi \Delta n t}{\lambda}
\]
Photosensitive material specifications

- Use of non-oxide glass-based coating
- Commercial chalcogenide glass: AMTIR-1: Ge$_{33}$As$_{12}$Se$_{55}$
- Electron beam deposition of solid targets
- Transparent from ~900 nm up to ~15 µm and photosensitive.
- Compatible with other deposited materials: Ta$_2$O$_5$ and SiO$_2$.
- Layers with thickness from 200 nm up to 20+ µm and high transmission.

Chalcogenide layer photosensitivity

Exposure of the coating at 808 nm produces a change of the optical thickness of the layer.

- Spectrally dependent refractive index change
- Refractive index change as large as $4 \times 10^{-2}$ @ 1 µm.

Thin films stability
Unexposed/exposed samples

- Measurements after 3 different duration of storage: 0 days, 20 days, 60 days
- No measurable variations. Stable state.

Control of transmitted amplitude

Bandpass filter

Filtering face (93 layers, 4600 nm Nb$_2$O$_5$ and 5500 nm SiO$_2$)
Blocking face (100 layers, 3800 nm Nb$_2$O$_5$ and 5800 nm SiO$_2$)

If FWHM is lower than 0.2% of $\lambda_0$, i.e. 2 nm @ 1µm, transmission of the filter will be highly affected by the filter uniformity.
Control of transmitted amplitude
Fabry-Perot light trimming

\[ 2en_{sp} = m\lambda_0 \]

\[ \frac{\Delta \lambda}{\lambda_0} = \kappa \frac{\Delta n_{sp}}{n_{sp}} \]

Control of transmitted amplitude
Fabry-Perot light trimming

Simple cavity
$(HL)^4 \ 6P \ (LH)^4$
- ZnS $(n_H = 2,25)$
- Cryolite $(n_L = 1,3)$
- $Ge_{15}Sb_{20}S_{65} \ (n_P = 2,4)$
- Silica substrate

EBD deposition
Control of transmitted amplitude
Fabry-Perot light trimming

3 nm
Uniformity 0.2%

0.05 nm
Uniformity 0.003%

DOE fabrication

Procedure

1. Deposition of a multilayer structure:
   \[ \text{Substrate} / \text{AR2} / \text{AMTIR} - 1 / \text{AR1} / \text{air} \]

2. Design of the proper pattern to record and produce the required far-field intensity.

3. Recording of the designed pattern within the multilayer structure and in-situ optical monitoring

4. Ex situ optical characterization of the component final performances
Binary DOE fabrication
Designed structures

Design: 4 quadrants

Pitch size

Design: Circular
Top Hat

Design: Square top-hat

Design: 2×2 dots matrix

0

π
Control of transmitted Phase
Diffractive optical elements

1. Exposure system:
   1. 808 nm high energy LD
   2. DMD
   3. Imaging system

**Control of transmitted Phase**

Diffractive optical elements

1. **Exposure system:**
   - 1. 808 nm high energy LD
   - 2. DMD
   - 3. Imaging system

2. **Optical monitoring system:**
   - 1. 976 nm low energy LD
   - 2. CCD camera

Binary DOE fabrication
In-situ monitoring
Binary DOE fabrication
Examples: square top-hat

**Binary DOE fabrication**

Examples: Beam converter

Binary DOE fabrication
Examples: circular top-hat

Measured Intensity Profile

Theoretical Intensity Profile

Binary DOE fabrication
Examples: dots matrix

Measured Intensity Profile

Theoretical Intensity Profile

Multilevel DOE Fabrication
4-level DOE design

Multilevel DOE Fabrication

4-level DOE ex situ characterization

Conclusions

\[ |t(\lambda)|e^{-i\varphi(\lambda)} = f(n_i t_i) \]

Control of transmitted and reflected phase has been investigated using change of thickness or refractive index.

Example of the tuning of the transmitted wavelength of a Fabry-Perot filter has been demonstrated.

Complex DOEs based on multilayer structures and photoinduced refractive index change have been fabricated.