Capability and limits of the technology of complex optical interference filters

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Abstract. Over the last 15 years, there have been tremendous progress in the technology of optical interference filters. Nowadays, it is more and more common to fabricate optical interference filters that can combine several tens to several hundreds of layers in order to produce more and more complex optical functions. These progresses are the result of improved multilayer structures modeling and design procedures, the introduction of Virtual Deposition Process, and the development of performant physical vapor deposition machines associated with in-situ optical monitoring. In this paper, we will present actual state-of-the-art of these technologies and some typical examples of filters. We will then present some of the actual challenges and outlook in order to produce more and more performant optical components.

1 Introduction

Optical filters that use the interference effect to obtain spectral transmission and reflection are very classical optical elements that are used in a wide variety of optical systems, e.g. in telecommunication, biophotonics, industry, buildings. These optical functions are obtained by combining thin layers with different refractive indices and thicknesses onto a substrate. They allow achieving an almost infinite number of spectral functions including bandpass filters (narrowband and broadband filters), edge filters (longpass and shortpass filters), notch filters (from single to multiple), beamsplitters (polarized or not), PLUURU FRDWLQJ. In this paper, we will present the recent developments that have been carried out at Institut Fresnel in the achievement of this class of filters, with particular focus on the design and fabrication.

2 Design and fabrication of optical interference filters

First of all, with the increase of computational capabilities associated with the development of more and more sophisticated design procedures and algorithms [1], it is now possible to find solutions to most of physical design problem using commercial software. However, one must always keep in mind that these designed multilayer stacks must also be in accordance with the fabrication capabilities. Therefore, in order to predict and perfectly adapt the monitoring strategy with the stack design, there have been large efforts toward the development of so called "Virtual Deposition Process" (VDP), i.e. software that enable to simulate a deposition, and therefore take into account all the fluctuations, errors, processing PHWKRG in order to predict the performances of a filter after fabrication without running the experiment [2]. While these VDPs have some limitations as it is hard to perfectly reproduce the exact experimental conditions within software, they have proven to be of prime interest as they provide a new way for the development of optimal monitoring strategies.

In addition to these theoretical developments, and thanks to the development of process automation, there also have been astonishing developments in the deposition and monitoring techniques. It is now possible to run full-automated depositions lasting several tens of hours and containing several hundreds of layers and with total stack thickness of several tens of microns [3]. While electron beam deposition is one of the most conventional techniques for the fabrication of optical interference filters, sputtering has proven to be a better choice for a large number of applications as it provides more stable and repeatable deposition rates. Among the various sputtering techniques that are available, plasma assisted reactive magnetron sputtering combined with a stable a repeatable optical monitoring system, has proven to be a very reliable technique when it comes to complex multilayer filters [4]. Various examples of complex filters, especially for space applications, where requirement are very strict, can be found in the literature [5].

For most of the applications that were just mentioned before, the spectral requirements are either on the transmission or on the reflection properties of the filters. These optical functions are achieved by using stacks only composed with dielectric layers. Thus, large efforts have been placed on minimizing the absorption and scattering losses in these filters. Actually, many developments have been carried out towards the decrease of absorption losses, especially for high energy and high power lasers and other efforts have been made in order to minimize

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scattering losses that can bring very large parasitic light especially in imaging systems for space or astronomy applications. By the combination of two dielectric materials, it is then possible to design and fabricate most of lossless optical functions. Then, the quality of the final filter relies on the precision that is achieved when controlling the thickness of each layer and this is highly dependent on the quality of the optical monitoring method and strategy that are implemented. Many efforts have recently been made within our team in order to generate new algorithms that calculate optimal optical monitoring strategies, both for monochromatic and broadband techniques [6]. That way it is possible to minimize the errors to a level that would correspond to average random errors of a few 0.1%. However, there is up to date no generic method and approaches for producing optical interference filters and the final results highly depend on the type of filters to be fabricated. In this presentation, we will review some of the typical performances that can be achieved with the previously described methods.

3 Examples of optical interference filters

The following examples of filters have been fabricated within the Espace Photonique platform using Plasma Assisted Electron Beam Deposition and Plasma Assisted Reactive Magnetron Sputtering. Three examples are provided hereafter. The first is highly reflective mirrors (R > 99.95%) at 515 nm and at 22° angle of incidence in s and p polarisations. These mirrors include 33 layers with alternated HfO_2 and SiO_2 materials with total thickness of 2.5 µm (Figure 1).

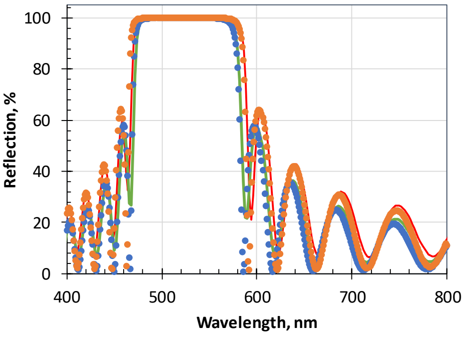

Fig. 1. Spectral dependence of reflection at 22° angle of incidence for s polarization (theory in orange and experimental in red) and p polarization (theory in blue and experimental in green) in case of single side coated mirrors.

Another example of filters that will be demonstrated are UV bandpass filters with central wavelength at 351 nm ± 2 nm, a FWHM of 20 nm ± 2 nm, an average transmission > 90% over the spectral range [344-358] nm and blocking wavelength range from 200 nm up to 1200 nm with OD ~ 3. These filters were obtained by depositing on both faces of a fused silica substrate. The materials that were used for this application are again HfO_2 and SiO_2. The front face includes 170 layers with a total thickness of 11.4 µm, while the second face is coated with 92 layers with a total thickness of 13.7 µm (Figure 2).

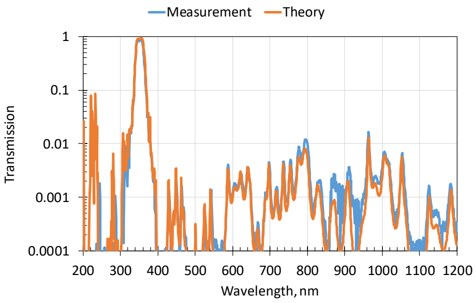

Fig. 2. Spectral dependence in log scale of the transmission of a UV-bandpass filter.

The last class of filters that we demonstrated are filters with broadband controlled spectrum. These filters are commonly combined with white light source in order to produce broadband illumination with constant spectral brightness. As a consequence, the transmission of these filters must reproduce the inverse of the intensity distribution of the broadband light source and eventually also take into account the spectral sensitivity of the detector that will be used for the measurement. This filter was achieved by depositing 30 layers with alternated HfO_2 and SiO_2 materials and a total thickness of 2.3 µm (Figure 3).

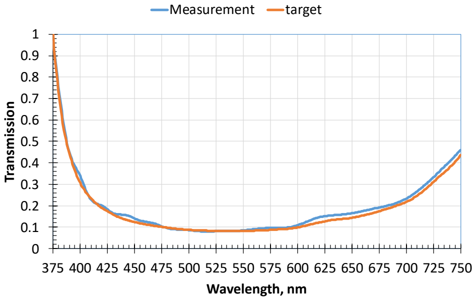

Fig. 3. Spectral dependence of the transmission the filter.

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