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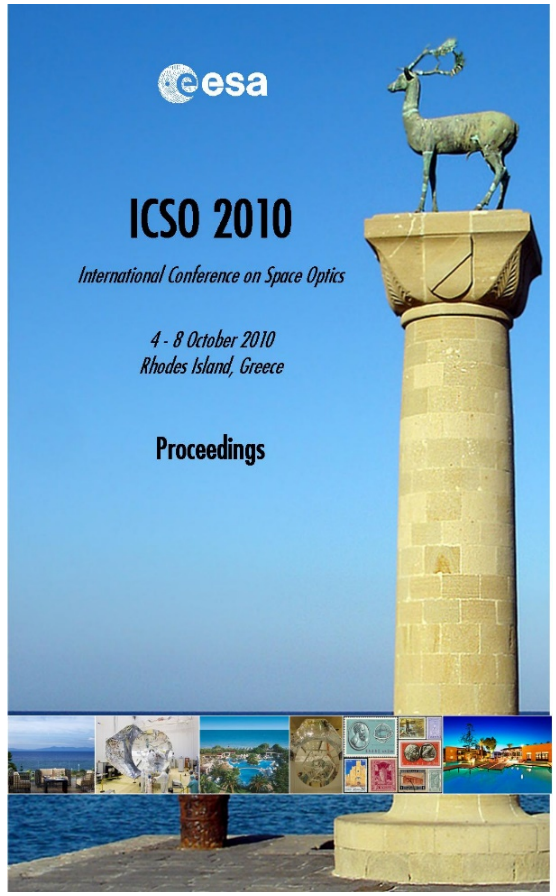

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400-1000 NM ALL-DIELECTRIC LINEAR VARIABLE FILTERS FOR ULTRA COMPACT SPECTROMETERS

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I. INTRODUCTION

A linear variable filter is a multilayer band-pass coating deposited with a thickness gradient that gives a significant wavelength shift of the transmission peak along the corresponding direction. In the perpendicular direction the thickness should be as uniform as possible, corresponding to a stable centring wavelength. Such components, associated with matrix detectors are of great interest for the design of compact and light weight spectro-imagers.

For such a filter, each of the rejection bands must be able to cover the whole spectral range that must be swept by the transmission peak. When this spectral range is rather large, extending for example from 400 to 1000 nm as in the case we studied, this rejection requirement rapidly becomes the most demanding one.

In that case, the standard approach consists to use a metal dielectric band-pass structure, known as induced transmission filter [1]: A metallic layer is embedded in a symmetrical dielectric stacks to form a two-cavity Fabry-Perot filter, each cavity being closed with a metallic and a dielectric mirror. The major advantage of the metallic layer is to provide the wide rejection bands that are required, while the dielectric surrounding stacks are designed to minimize the absorption in the metallic layer at the peak wavelength. However, the reflectance of this metallic layer, obviously linked with its thickness, is not only responsible for the transmission level in the rejection bands, but has also a direct impact on the filter's band-width and maximum peak transmission. As a result, these three main characteristics of the filter cannot be designed separately.

The only way to overcome this major drawback is to avoid the use of any metallic layer. In that case, rejection bands must be formed with the help of broad-band dielectric mirrors which requires a high number of layers. Instead of a few tens layers for a metal-dielectric structure, several hundreds are necessary for an all-dielectric solution.

This paper aims to describe the major steps of the work performed at Institut Fresnel to develop such a solution. We will first describe the design of the component and coatings, then the masking mechanism we developed to manufacture the coatings with the right thickness gradient. At last, we will give some partial results that prove the feasibility of this new concept.

II. COATING DESIGN

Using dielectric layers, a band-pass coating is basically designed with two quarter-wave mirrors surrounding a half-wave cavity layer in order to form a Fabry-Perot structure. In case sharp transitions are required between the band-pass and the rejection bands, several cavities can be deposited one on each other to form a classical multi-cavity structure. In that way, according to the layer-count used for mirrors, the thicknesses used for cavities and the number of cavities, it is possible to adjust separately the major characteristics that are the band-width and the rejection level. However, the spectral width of the rejections bands are limited to the high reflectivity spectral range of the quarter-wave mirrors used to form the cavity, typically ±100 nm for a peak wavelength at about 700 nm. For this reason, such a band-pass structure must be completed with both long and short-wavelength pass structures that will extend the rejection bands on both sides. Classically, these structures are formed with several quarter wave mirrors, with gradually increasing centring wavelengths in order to obtain a continuous high reflection band. In order to cover a spectral range as large as 400-1000 nm, five quarter-wave mirrors are required. Consequently, both the long and the short wavelength pass structures used to extend the rejection bands of the band-pass filter must be formed with 4 quarter wave mirrors, the fifth one being provided by the band-pass filter itself, as illustrated in figure 1.

To reach the rejection level that was specified in our study, about 25 layers were necessary for each of these mirrors. The total number of layers was consequently about 240: One hundred for the long wavelength pass structure, as many for the short wavelength pass structure, and about forty for a 3-cavity band pass structure.

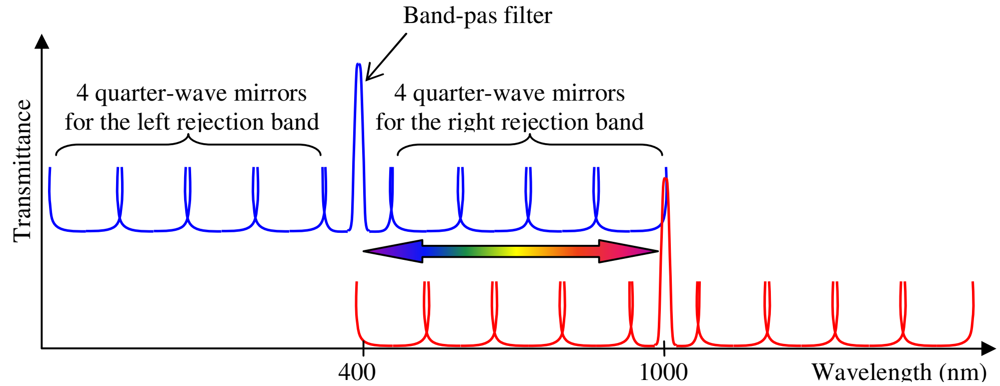

Fig. 1. Schematic spectral profile of the coating split in its elementary stacks

In order to simplify the manufacturing of such a complex coating, keeping in mind that the thickness gradient will add some extra difficulties related to the masking mechanism, we decided to split this design in three basic stacks deposited on separated substrates, namely the band pass coating and its two long and short blocking filters. These three variable coatings will be finally bonded together to form the complete component.

III. MASKING MECHANISM

For a dielectric coating, multiplying the thicknesses of all layers with a constant factor directly results in a proportional wavelength shift of the spectral response. As a consequence, manufacturing a 400-1000 nm variable coating simply requires depositing the coating with a thickness ratio of 2.5 along the few millimetres of the component in the spectral direction (7 mm in our case). To reach such a high thickness gradient, a masking mechanism is necessary, and among the possible solutions, figure 2 illustrates the principle of the mechanism we used [2].

The substrate, located in the substrate-holder, is given an alternative translation movement over a mask blade in which a trapezoid window is open. The distance between the substrate and the mask should be as low as possible to minimize shadowing effect (0.2 mm in our case). The deposited thickness being proportional to the exposure time and consequently to the length of the window in the translation direction, the coating is finally deposited with a thickness gradient that is perpendicular to the translation axis.

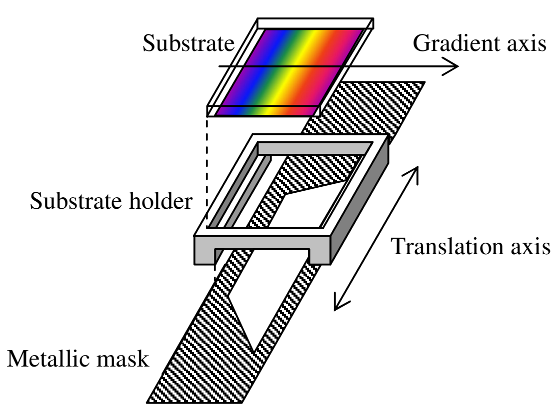

Fig. 2. Principle of the masking mechanism

In case the mask is static in the deposition machine, and the motion applied to the substrate, the thickness is perfectly uniform perpendicularly to the gradient axis as any point along this axis follows the same trajectory. This result, which is true even if the natural thickness distribution of the machine is not uniform, is the great advantage of this solution. The counterpart is that the deposition rate is rather low since the substrate is hidden behind the mask at the extremities of the translation movement. In our case, for a 20 mm-long substrate, using a 20 mm-long window in the mask and a 40 mm translation length, the deposition rate was about 1/4 of its nominal value. A stepper motion, mounted outside the vacuum chamber, has been used to operate the mechanism.

Among the difficulties we had to face, the major one was related to a problem of differential thermal expansion between the mask (steel) and the mechanism structure (aluminium alloy). Due to the very long deposition time, day after day, the mechanism experienced several thermal cycles, heating during deposition, cooling during the night, which resulted in a bending of the mask inducing friction with the substrate.

This difficulty has been overcome with the manufacturing of a new mechanism completely made in stainless steel.

IV. MANUFACTURING AND MEASUREMENTS

The coating deposition was performed with a Dual Ion Beam Sputtering machine using SiO_2 and Ta_2O_5 as layer materials. Layers manufactured with this deposition technique are known to be compliant with space environment requirements. Due to the lower deposition rate resulting from the masking mechanism, the deposition time was about one week for the band-pass filter, two weeks for the long-wavelength pass filter, and three weeks for the short-wavelength pass filter. The thickness monitoring was performed optically on a dedicated substrate, located in the same substrate holder as the variable coating but translating in front of a rectangular mask to obtain a uniform thickness distribution.

The measurement of the variable coatings optical properties were performed on an optical bench specially developed in our team for localized measurements [3]. Typically the spot size was about 100 µm to limit the averaging effect due to the thickness gradient.

Figure 3 give some of the spectral profiles measured on the band-pass coating from which were extracted the gradient thickness and transverse uniformity.

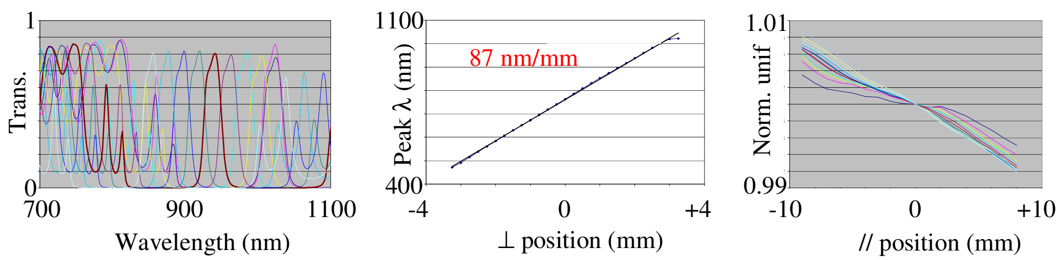

Fig. 3. Transmission profiles measured on the band pass variable coating (left), measured thickness gradient (middle), and normalized uniformity measured perpendicularly to the gradient (right)

All the characteristics measured on the band pass filter were in agreement with calculations. The ± 1% uniformity defect measured perpendicularly to the gradient can be due to a misalignment in the substrate holder during deposition or measurement. It can also be due to a non perfectly uniform translation movement in the masking mechanism. In any case, it can be corrected through a proper alignment with the detector.

Blocking filters manufactured with the initial mechanism suffered from friction problems with the mask, as mentioned in the previous section. Only the short-wavelength pass filter has been manufactured once again with the new mechanism, with very good results, as illustrated in figure 4.

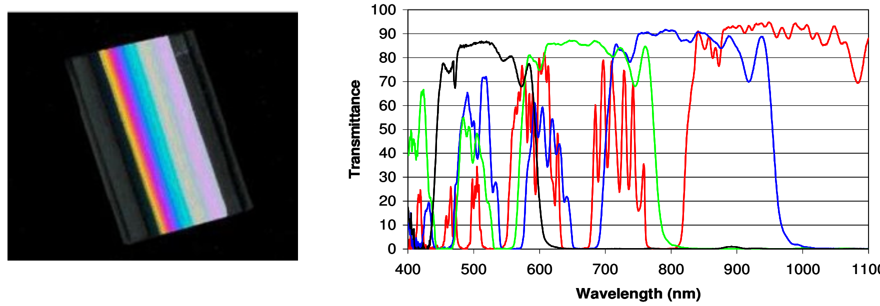

Fig. 4. Four measured transmittance profiles across the short-wavelength pass blocking filter with cut off wavelengths at 600 nm (black), 775 nm (green), 950 nm (blue), 1150 nm (red)

In addition to these manufacturing activities, some tests have been performed concerning the bonding of variable filters. Two identical single-cavity variable filters were manufactured and glued together. The transmittance measurement of the resulting component, in good agreement with calculations, did not reveal any misalignment. Notice that the alignment accuracy proven with this test is much higher than required by the association of the band pass filter with blocking filters.

V. CONCLUSION

The goal of this work was to study the feasibility of a wide-range (400-1000 nm) all-dielectric variable filter as an alternative solution to the more classical metal-dielectric approach. From the design point of view, this new approach is clearly more efficient, but at the price of much higher number of layers, not far from ten times more. An immediate consequence is a much longer deposition time, and since the masking mechanism reduces the deposition rate by a factor 4, the total time required for manufacturing could easily be regarded as prohibitive: approximately six weeks were necessary for us to deposit the 240 layers of the design.

Regarding concrete results of this work, due to some technical difficulties with the initial masking mechanism, and due to this excessive deposition time, we were not in position to successfully manufacture a set of three variable coatings with satisfactory properties. However, the feasibility of all critical steps has been demonstrated:

- deposition (with the new mechanism) of thick variable coatings with good cosmetic, and optical properties in agreement with theoretical results
- manufacturing of the right thickness gradient
- perpendicular uniformity in agreement with the requirements assuming a proper alignment with the detector
- validation of the alignment of coatings during the bonding step.

As a result, all-dielectric variable coatings can be regarded as a highly constraining but feasible alternative solution to metal-dielectric variable coatings.

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