DESIGN, SIMULATION AND FABRICATION OF OPTICAL FILTERS FOR NARROW BAND IMAGING IN ENDOSCOPIC CAPSULES

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***Abstract* — This paper presents the design, simulation and fabrication of two optical filters that could be integrated in endoscopic capsules (EC) to perform narrow band imaging (NBI) analysis. The thin-film optical filters were designed for two specific spectral regions (blue, centered at 415 nm, and green, centered at 540 nm) and will be placed on top of current EC white light emitting diodes (LEDs). The filters are composed by 7 thin-film layers of titanium dioxide (TiO_2) and silicon dioxide (SiO_2) and will be deposited using RF-sputtering technique. The integration of NBI functions in EC represents an important clinical and technological advance, since it will improve the EC diagnostic functions, e.g. enhanced visibility of capillaries and veins for the diagnosis of dysplasia, as a complement to the current capsule vision based in white light.**

***Keywords :* Optical filters, Endoscopic capsule, Narrow band imaging.**

I - Introduction

The developments in endoscopic capsules (EC) have been grown in the past years since these devices are able to perform diagnosis in a less invasive way, when compared with traditional exams, such as gastroscopy and colonoscopy. Also, using EC it is possible to access new areas of the gastrointestinal (GI) tract that were previously accessed only by surgery, such as some parts of the small intestine. Unlike conventional endoscopy, no drugs are administered to the patient and air insufflation is not necessary. Cessation of anticoagulant therapy is unnecessary, in contrast to conventional endoscopy during which scope trauma, perforation of the bowel or biopsies can cause excessive bleeding that might require surgery. Moreover, it doesn't require the continuous presence of a physician, and it is disposable, which minimizes the risk of infection [1-3]. However, its diagnosis depends mainly on white-light images taken during its travel through the GI tract, and even in a high-resolution image, some lesions are still missed.

Nowadays, the diagnostic capability of standard endoscopy is improved by using narrow band imaging (NBI). This technique uses spectral characteristics of endoscopic light to enhance the mucosa, including vascular structures, in greater details without dyes [4]. The use of NBI has been proven to enhance the diagnosis of: inflammatory disorders of the GI mucosa [4]; dysplasia in patients with Barrett's esophagus and ulcerative colitis [5-6]; colorectal cancer [7]; polyps [8]; among others. In these studies, NBI was integrated in conventional endoscopes using band-pass filters that narrow white-light to wavelengths around 415 nm (blue region of the spectrum) and 540 nm (green spectral region).

This paper proposes the development of a NBI system to be incorporated in an EC. Such a system would have a huge clinical utility, since it would take not only advantage of all the benefits associated with the use of an EC, but also it would add important diagnostic functions to current capsule white-light imaging functions.

In Figure 1 it is presented the EC with the NBI system. This is based on thin-film optical filters that will be placed on top of 2 of the 4 capsule white LEDs (light-emitting diodes) to select the two specific spectral bands: blue and green. The blue light penetrates the mucosa only superficiality and is mainly absorbed by hemoglobin, enhancing surface and capillary details. The green light penetrates more deeply in the tissue, displaying sub-epithelial vessels. When the two images are combined, an extremely high contrast image of the tissue surface is shown. This way, combining the capsule endoscopy and the NBI technique a more accurate diagnostic can be obtained.

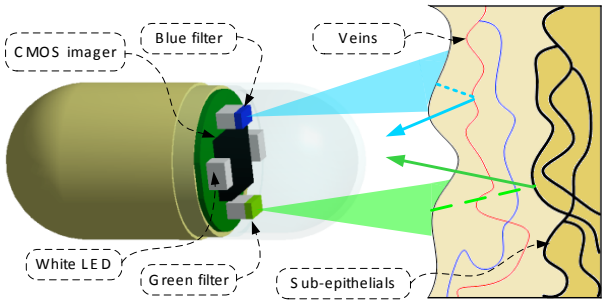

Figure 1: *EC with an integrated NBI system.*

II – Optical filters design

Thin-film optical filters are designed for the selection of two particular spectral bands that will be used for tissue illumination: one band centered at 415 nm (blue filter) and another band centered at 540 nm (green filter). This light filtering system is based on Fabry-Perot thin-film resonators, which consist of two parallel mirrors separated by a resonance cavity (Figure 2). The thickness of the resonance cavity, or the distance between the mirrors, determines the specific central wavelength that is transmitted, i.e., each filter can be easily tuned to a different central wavelength by adjusting only the thickness of one layer.

The filter structure is a multilayer composed by 7 layers: the top 3 layers correspond to the first mirror, whereas the bottom 3 layers correspond to the second mirror (see Figure 2). The mirrors are composed by dielectric materials with high and low-refractive indexes (titanium dioxide, TiO_2, and silicon dioxide, SiO_2, respectively) which provide good optical performance characteristics (high reflectivity and low absorption losses) [9-10]. These optical filters should be designed to yield a band-pass around the specific central wavelength, with FWHM (Full-Width-Half-Maximum) less than 25 nm.

The mirrors thicknesses are the same for both filters: 38 nm for the TiO_2 layers and 82 nm for the SiO_2 layers. This procedure enables the simultaneously fabrication of both filters, minimizing the global deposition time. The resonance cavity thickness is equal to 122 and 208 nm for the blue and green filter, respectively.

The use of these filters takes advantage of the currently available capsule white LEDs thus avoiding the integration of new light-sources on the EC.

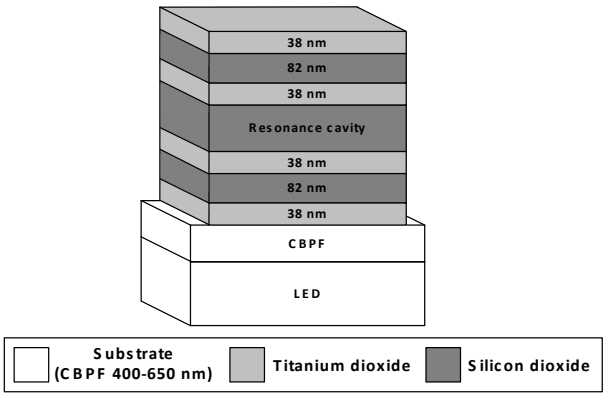

Figure 2: *Structure of the Fabry-perot optical filter on the commercial optical band-pass filter (CBPF).*

II – Simulation results

The structure of both filters was optimized and simulated using the optics software TFCalc™ 3.5.

In Figure 3 and Figure 4 it is presented the simulated transmittance for the two designed Fabry-Perot optical filters, together with the spectral transmittance of a commercial band-pass filter (CBPF) [11] on top of which the filters are deposited. In Figure 3 and Figure 4 it is shown that each filter is sensitive to its specific spectral band, with FWHM < 25 nm, and a ratio of maximum transmittance to background noise greater than 90/20 (enough for this application in terms of optical characteristics).

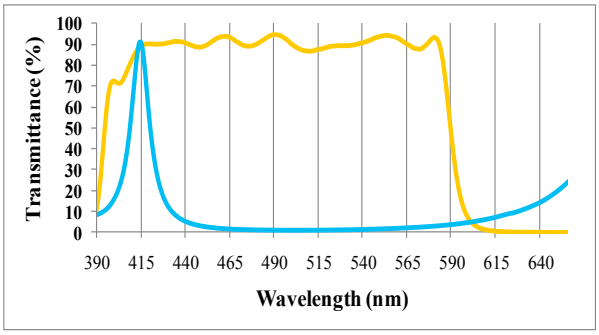

Figure 3: *Simulated spectral transmittance of the blue Fabry-Perot optical filters, together with the spectral transmittance of a CBPF between 400-650 nm.*

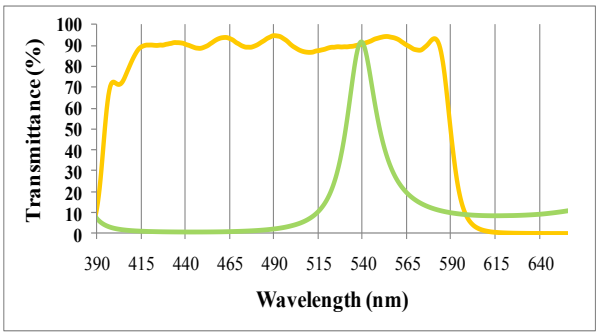

Figure 4: *Simulated spectral transmittance of the green Fabry-Perot optical filters, together with the spectral transmittance of a CBPF between 400-650 nm.*

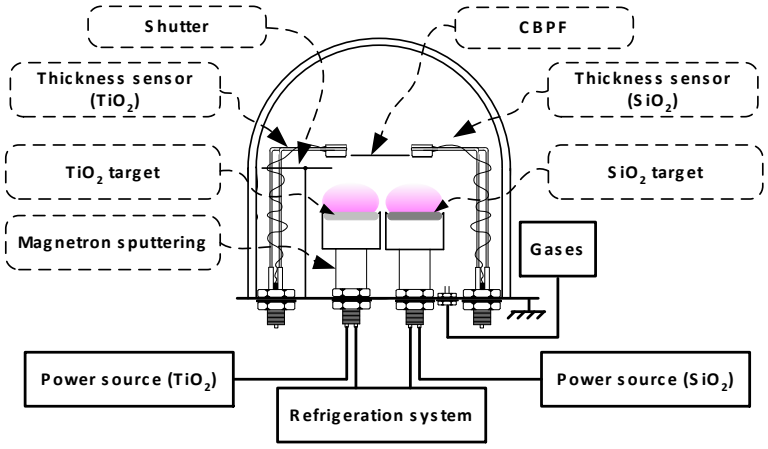

Figure 5*: Deposition scheme for the fabrication of the two optical filters using a twin RF-sputtering system.*

III – Optical filters fabrication

The deposition scheme to fabricate the optical filters is shown in Figure 5. Each layer of TiO_2 and SiO_2 is deposited by using a twin RF-sputtering system. With this deposition scheme the seven layers of the optical filters are deposited in the same vacuum process, which provides a better adhesion between the different thin-film layers, and obviates the oxidation of the thin-films. Moreover, the fabrication process is maskless.

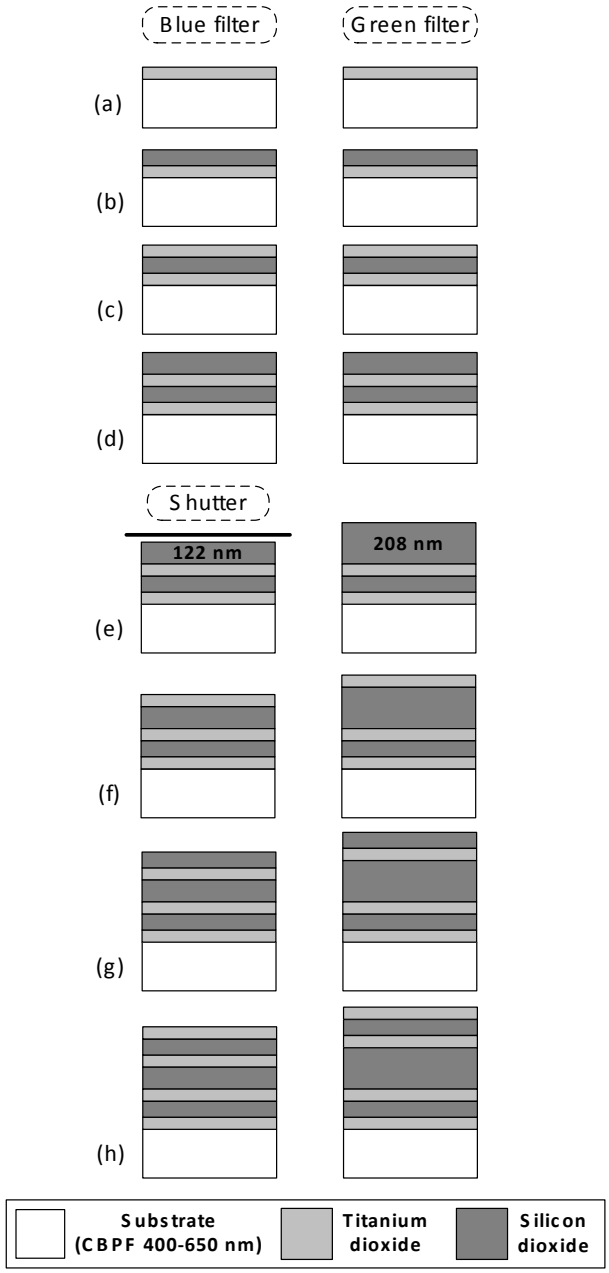

Figure 6: *Fabrication steps of the optical filters.*

As a substrate for the optical filters deposition, it will be used a CBPF, with a band between 400 nm and 650 nm, in order to avoid the transmission of wavelengths far outside the visible range. The fabrication steps for both filters are shown in Figure 6.

In Figure 6(a) a thin-film of TiO_2 is first deposited with the thickness of 38 nm. In step (b) it is deposited the SiO_2 thin-film, with the thickness equal to 82 nm. The second layer of 38 nm thick TiO_2 is deposited in step (c).

In step (d) the middle layer is deposited, to form the resonance cavity, until a thickness of 122 nm. As previously demonstrated, the blue filter requires a resonance cavity thickness of 122 nm while the green filter requires a thickness of 208 nm. In step (e) a shutter is activated to stop the deposition of the resonance cavity layer for the blue filter, while the resonance cavity layer of the green filter is continuously deposited until it reaches 208 nm. The steps (a), (b) and (c) are repeated on steps (f), (g) and (h). The total thickness of the blue filter is 438 nm and the green filter is 524 nm.

IV – Conclusions

In this work it is described the integration of NBI function in ECs. For the NBI system, two different thin-film optical filters are designed. Its fabrication process is also described using a twin RF-sputtering technique with 2 magnetrons. The targeted fabrication process enables a good adhesion of the thin-film layers and avoids the oxidation between the different layers. The NBI function in EC will improve the diagnosis capability of current available ECs. NBI uses two discrete bands of light: one blue at 415 nm and one green at 540 nm. Narrow band blue light displays superficial capillary network, while green light displays sub-epithelial vessels and when combined offer an extremely high-contrast image of the tissue surface.

Acknowledgements

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