Design, Simulation and Fabrication Techniques of Optical Filters for NBI

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ABSTRACT

This paper aims the design, simulation and fabrication techniques of two optical filters. The thin-film optical filters were designed for two specific spectral regions, -blue centered at 415nm and green, centered at 540nm-. The optical filters will be placed on top of two illuminants, which are in this case, an ultra-violet LED (light emitting diode), and a green LED, respectively. The optical filters are composed by seven layers using titanium dioxide (TiO_2) and silicon dioxide (SiO_2) alternately.

KEYWORDS

narrow-band imaging, medical devices, optical filters

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1 INTRODUCTION

The Narrow-Band Imaging (NBI) technology emerged from the need of detecting lesions not identified with white light. Thus, the NBI is used to enhance the endoscopic image contrast by capturing real-time images using an image sensor, light sources and optical filters. The optical filters are meant to be positioned under the endoscope light to create narrow-band wavelengths in the blue range (400-430nm) and green range (530-550nm) [1].

Medical studies revealed that the wavelengths 415nm and 540nm of the electromagnetic spectrum correspond to the peaks of hemoglobin absorption's band. The structures containing hemoglobin, such as blood vessels can be assessed by adjusting the color of the reflected light that penetrates the mucosa [2–4]. In such a way, the blood vessels appear darker, creating a better contrast between the mucosa in the surrounding area, which appears brighter when it reflects the light.

The wavelength of 415nm is located in the blue region of the electromagnetic spectrum, allowing the visualization enhancement of superficial veins. Moreover, the wavelength of 540nm is located in the green region of the spectrum, and is related to the visualization of sub-epithelial vessels, because it allows a deeper penetration in the skin [5–7].

The NBI system requires an attachment to a medical device with a light source and a monochromator system to be able to switch between the white LEDs (the broadband light), and the LEDs with NBI technology. Figure 1 shows a schematic of a NBI system, which is composed by the illumination system and the image recorder system. The illumination system is composed by two white LEDs, one blue/violet LED and one green LED.

This paper reports on the design, simulation and fabrication techniques for two optical filters, incorporating NBI technology on the purpose of enhance the quality of clinical diagnosis when coupled with capsule endoscopy or conventional endoscopy.

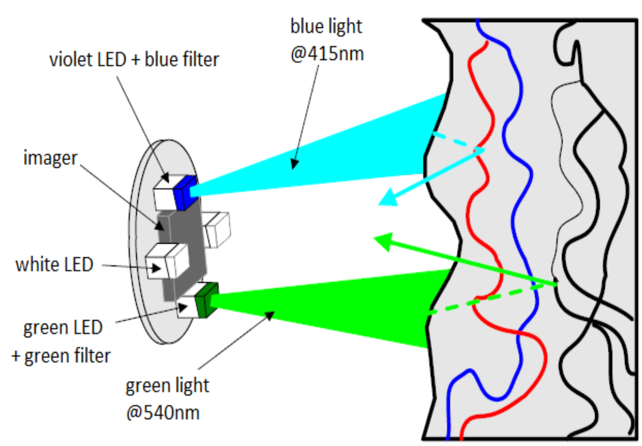

Figure 1: NBI system with LEDs along with blue and green filters and a CMOS image sensor.

2 METHODOLOGY

2.1 Optical Filters Design

The first step for designing optical filters is to choose the materials they will be made of, as well as the light sources that will be placed prior to the filters, and the substrate on which they will be fabricated. Once all the components involved in the process are selected, it is important to know the optical properties of the substrate, the thin-film materials, and the spectral signature of the light source. All the processes before the optical filter fabrication are shown in the following section, such as substrate preparation and deposition and characterization of the thin-films of TiO_2 and SiO_2.

As light sources, two colors of LEDs were chosen. The blue LED from Lumex presents a transmittance peak arund 410nm and was chosen because it comprehends the wavelength of 415nm. The green LED from DualCom presents a transmittance peak at 530nm and also comprehends the wavelength of interest 540nm. Both spectrum signatures of the green and blue LEDs are showed in the Figure 2 and Figure 3, respectively.

The optical filter structure consists of a multilayer of seven layers on top of the glass substrate. This light filtering system is based on the physical principle of Fabry-Perot resonators, which consists of two parallel mirrors (composed by layers of a high refractive index material and a low refractive index material, alternately) and they are separated by the ressonance cavity. The specific central wavelength transmitted is determined by the thickness of the ressonance cavity.

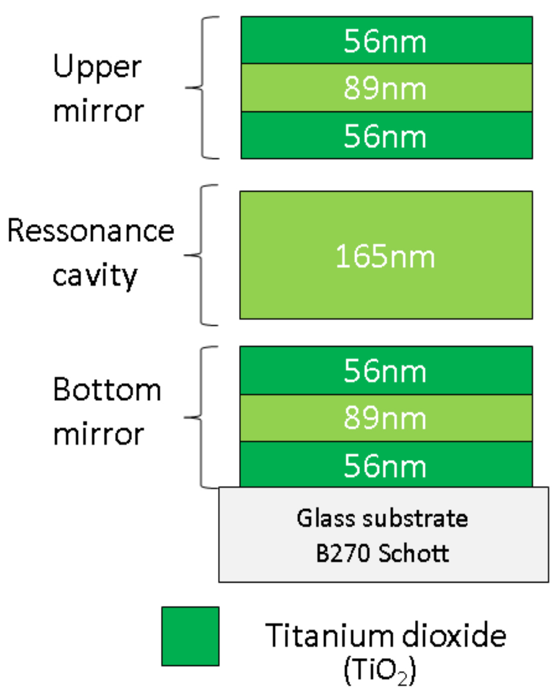

Figure 2: Structure of the green filter centered at the wavelength of 540nm.

T he top three layers correspond to the second mirror. The mirrors are composed by dieletric materials, such as TiO_2 and SiO_2, which have great optical characteristics, like high reflectivity and low absorption losses [8],[9]. The simulation of the optical filters was made using the software TFCalc^{TM} 3.5 (Software Spectra, Inc., Portland, OR), where is possible to set all properties of the materials that will be used for the fabrication of optical filters. The substrate chosen for the simulations was B270, from Schott North America, Inc., which presents great optical quality, with low surface roughness.

It is very important that the fabrication process be aligned with the simulations. Although the software simulations are reliable most of time, it is always better to adapt the process along the work. Figure 2 shows the layers of the green filter, within the respective thickness of each layer. The thickness of the layer are calculated taking in consideration the refractive index of the materials and the wavelength the filter should be centered. Figure 3 shows the calculated layers of the blue filter.

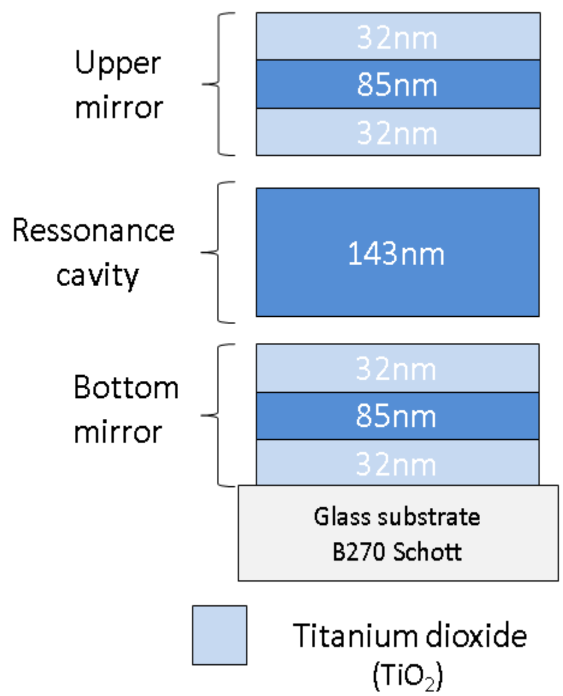

Figure 3: Structure of the blue filter centered at the wavelength of 413nm.

2.2 Preparing the substrate

A cleaning step was performed prior to any thin-film deposition to prevent any external dirt to enter the sputtering, ECR (Electron Cyclotron Resonance) and PECVD (Plasma Enhanced Chemical Vapor Deposition) chambers, as well as to ensure a surface completely free of impurities. Two kind of cleaning processes were tested to discover which one was better for the thin-film adhesion and cleanness of the samples. The first one was a RCA clean, and the second one an simple organic clean.

RCA clean - The first step consisted in a piranha etch, which is a mixture of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) meant to clean organic residues off substrate. The second step consists in removing the silicon dioxide formed in the first step using a solution of hydrofluoric acid (HF) and water (H_2O). The last step consists in the removal of ionic contamination using a mixture of hydrochloric acid (HCl), H_2O_2 and H_2O.
Organic clean - The first step is to clean the samples with detergent. The second step is wash the samples with acetone for about 10 minutes in ultrasonic bath. The third step is to wash the samples with isoproponal for another 10 minutes in ultrasonic bath. Finally, the substrate is dried with nitrogen. The isopropanol evaporates from the surface and leaves no rest. This simple organic clean was found the better cleaning technique for the glass sample, once it does not etch the sample, leaving a flatter surface when compared to RCA clean.

2.3 Thin-film deposition

After the proper cleaning of the glass substrate, it is necessary to deposit thin-films of TiO_2 and SiO_2 separately to measure the specific characteristics of each material. This step and the characterization should be also aligned, in order to set a great control of thickness and refractive index. Three technologies were used for the thin-film deposition. The SiO_2 films were deposited by ECR and PECVD processes, and the TiO_2 were deposited by a DC sputtering. The ideal scenario would be depositing both films using the same process and the same machine, in a way that all the layers would be deposited without leaving the chambers and get air contamination. Unfortunately was not possible to deposit the SiO_2 thin-films by sputtering.
For this purpouse, four kinds of samples for both dieletric materials were deposited on a silicon wafer, with variation of thickness (40, 60, 80 and 100nm). The process was to deposit a thin-film, measure the characteristics and adjust the deposition rate. This is calculated in nm/s and once it is set, it is possible to know the realiability of the ECR, PECVD or sputtering machine, which means that every time the machine deposits the same thickness, with the same refractie index and deposition duration. The deposition rate used for sputtering was set to 0.082nm/s, for ECR was set to 0.095nm/s and for PECVD was set to 1.33nm/s.
The PECVD technique was chosen for the SiO_2 thin-films deposition, , because it offered a better film quality, in the sense of the optical properties (refractive index closer to the values in the literature), and also the duration of the process using PECVD was faster. The sputtering was the only technique avaiable for the TiO_2 thin-films deposition, but it showed a great process parameters control, reliability, and a satisfactory film quality.

2.4 Thin-film characterization

Before the deposition of the stack of thin-films layers, it is necessary to characterize both thin-films of TiO_2 and SiO_2 to know their refractive index and thickness. Most of sputtering, PECVD and ECR machines have a quartz crystal to guarantee the right thickness being deposited, but once the machines avaiable did not have it, it was decided to ensure the right thickness by measuring the samples. The thin-films were characterized by ellipsometry using a laser @6320Å. Although the substrate used for the optical filters is glass, there is a need to use a silicon wafer for ellipsometry technique. The thin-films of SiO_2 deposited by ECR presented a refractive index around 1.5, whilete the SiO_2 deposited by PECVD showed a refractive index around 1.462, which corresponds better to the values found on literature. The thin-films of TiO_2 deposited by sputtering showed a refractive index variation from 2.4 to 2.5.

3 RESULTS

The blue light source is centered @411nm and exhibits a transmittance of 90.51%, and the green light source is centered @533nm, with transmittance peak of 91.43%. After the simulations using the software TFCalc^{TM}, there were obtained the transmittance spectrum of both filters. The simulations took in consideration the thickness of the layers calculated in the section II. A slight change in the thickness of the resonance cavity has a huge modification capacity in the final transmittance peak and FWHM. In that way, it is important to test a variety of thickness in order to achieve the best result.
The green filter is centered @540nm with 72.83% of transmittance peak (wich showed better centered wavelength, because the bandwidth of the illuminant was wider), and FWHM of 27nm. The spectral transmittance of the green LED and the green filter with the LED as illuminant is showed on Figure 4, as well as the FWHM range.

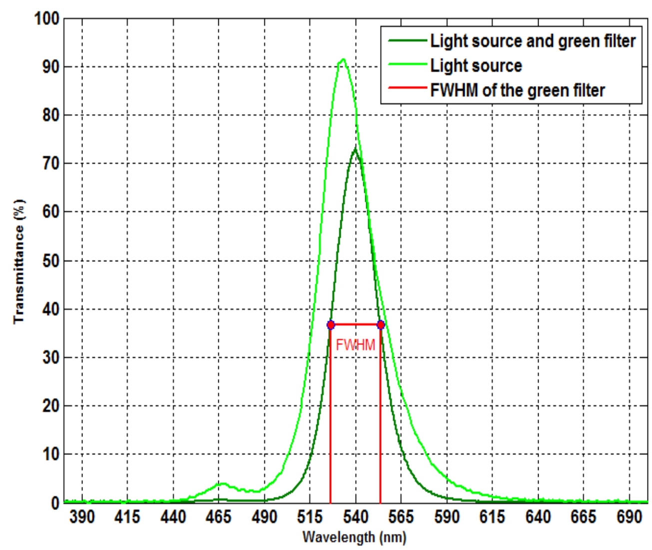

Figure 4: Simulated spectral transmittance of the green Fabry-Perot optical filter and the light source for this filter.

The blue filter is centered @413nm with 58.54% of transmittance (that was the better result, considering that the bandwidth of this illuminant was very narrow) and FWHM of 14nm. The spectral transmittance of the blue LED and the blue filter with the blue LED as illuminant is showed on Figure 5.

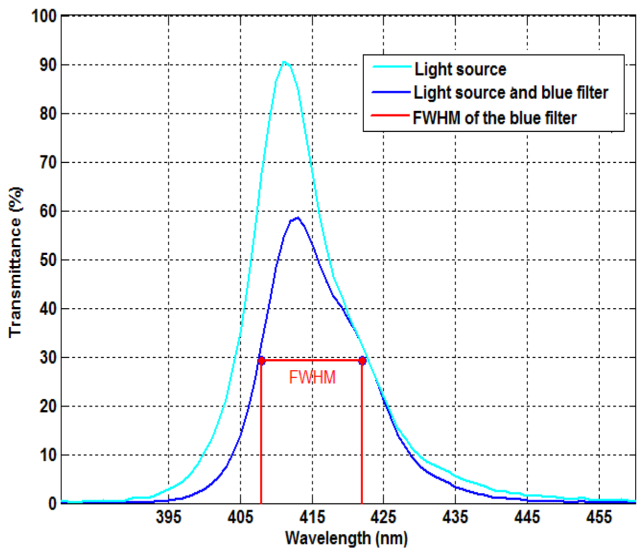

Figure 5: Simulated spectral transmittance of the blue Fabry-Perot optical filter and the light source for this filter.

4 CONCLUSIONS

Two optical filters were designed and simulated. Two dielectric material (TiO_2 and SiO_2) were characterized by ellipsometry, and deposited by sputtering, PECVD and ECR machines. The optical filters were designed for specific spectral ranges of blue and green regions of the electromagnetic spectrum. The blue filter was designed centered at around 415nm and the green filter, centered at 540nm. The calculated FWHM of both filters is within the range of the NBI technology.

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