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Optical Filter for Providing the Required Illumination to Enable Narrow Band Imaging

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Abstract

This paper presents the design, fabrication and characterization of two Fabry Perot type optical filters (415 nm and 540 nm) for enabling Narrow Band Imaging (NBI) in medical devices (MD). The two-colour illumination should satisfy a highly specific optical design, which is composed of a thin-film optical filter stack of titanium dioxide (TiO_2) and silicon dioxide (SiO_2) thin-films and commercially available light-emitting diodes (LEDs). The short-wavelength design is the most critical and simulations show a maximum relative optical output of 21 % at 415 nm with Full-Width-Half-Maximum (FWHM) of 13 nm for a blue LED with the designed optical filter, which is confirmed by experiment. The green light simulations show a maximum relative optical output of 34 % with FWHM 36 nm at 540 nm. The TiO_2 and SiO_2 thin films were fully characterized.

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Keywords: Medical devices, narrowband imaging, thin-film optical filter.

1. Introduction

The introduction of medical devices (MD) the endoscopy [1] gave the exciting prospective of video endoscopy in the parts of the gastrointestinal tract (GI) that were previously accessible only by surgery, such as some parts of the small bowel. However, the functionality of the MD can be increased beyond imaging.

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The American Gastroenterological Association (AGA) has already pointed at the use of Image Enhanced Endoscopy (IEE) using Narrow Band Imaging (NBI) for diagnosis of early diagnosis of oropharyngeal and gastrointestinal cancer [2]. The NBI is a high-resolution imaging technique that uses narrow bandwidths of 30 nm and central wavelengths at 415 nm (blue) and 540 nm (green). The optimized hemoglobin absorption in these shorter wavelengths of light permit focused visualization of micro vessels of the superficial layer of the mucosa (415 nm) and submucosa (540 nm). Fig. 1 shows a solution to introduce the NBI in MDs. Available MDs are equipped with white light-emitting diodes (LEDs), which have very limited spectral power at 415 nm (blue) and 540 nm (green). For NBI technique, the MD must be immobilized [3-5].

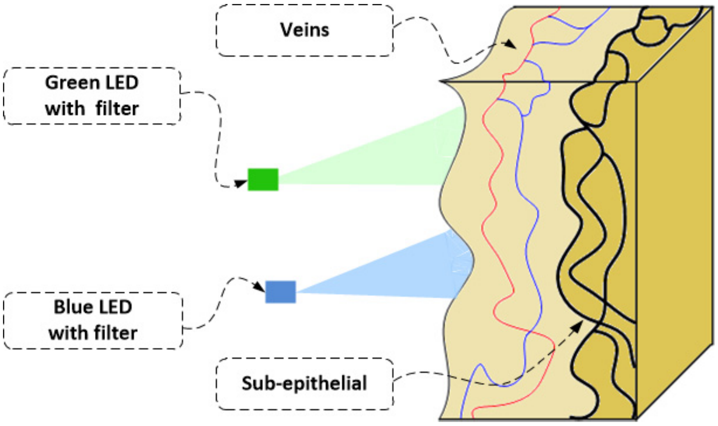
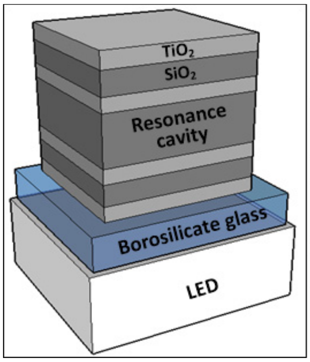


Fig. 1. Medical device with the NBI.

2. Architecture

Therefore, in this work a blue LED is used with spectral emission peak at 404 nm and a FWHM of 20 nm and a green LED at 522 nm and a FWHM of 41 nm. The blue and green optical filters were designed and simulated using the software *TFCalc*^{TM} to provide the matching with the NBI blue and green light specifications. The refractive index (n) and extinction coefficient (k) of the sputtered titanium dioxide (TiO_2) and silicon dioxide (SiO_2) thin-films were obtained by ellipsometry measurements and introduced in the software's database. Fig. 2 shows the structure of the NBI spectral filtering system for the blue and green.



Material	Blue light Thin-film thicknesses	Green light Thin-film thicknesses
TiO_2	35 nm	40 nm
SiO_2	80 nm	81 nm
TiO_2	35 nm	40 nm
Resonance cavity	430 nm	437 nm
TiO_2	35 nm	40 nm
SiO_2	80 nm	81 nm
TiO_2	35 nm	40 nm

Fig. 2. Structure of the NBI spectral filtering system for medical devices.

Fig. 3 shows the simulation results of NBI light filtering for the EC. The simulated blue optical filter transmittance peak is at 415 nm, with a FWHM of 13 nm and 21 % of maximum peak transmittance. The green optical filter simulation shows a peak at 540 nm with a FWHM of 36 nm and maximum transmittance peak of 34 %.

The reactively sputtered TiO_2 thin-films were obtained at 200 W of RF power and a controlled argon/oxygen gas flow ratio of 5:1. A high-purity Ti-metal target with a thickness of 6.35 mm and a diameter of 50 mm was used. The total operating pressure was 3×10^{-3} mbar. The deposition rate of the TiO_2 thin-films is 0.2 Å/s. The SiO_2 thin-films were deposited at room temperature by non-reactive RF magnetron sputtering with Ar flow rate of 15 sccm.

The SiO_2 target presents is of very high purity (99.9995 %) with a diameter of 50 mm and 6.35 mm thickness. The total operating pressure was 8.5×10^{-4} mbar. The resonance cavity layer was deposited with an RF power of 200 W and a deposition rate of 1.2 Å/s. The other SiO_2 thin-films were deposited at a RF power of 150 W with a deposition rate of 0.9 Å/s. Fig. 4 shows the deposition scheme for the fabrication the TiO_2 and SiO_2 thin-films.

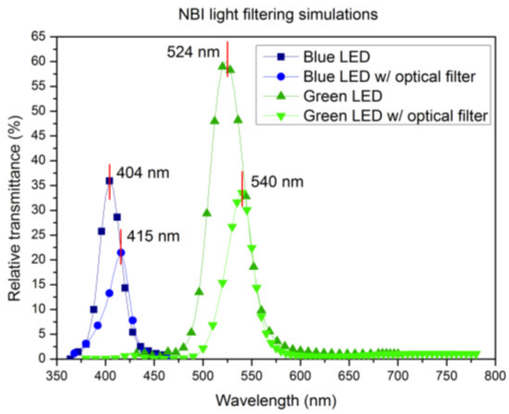


Fig. 3. Optical filters simulations for the blue and green.

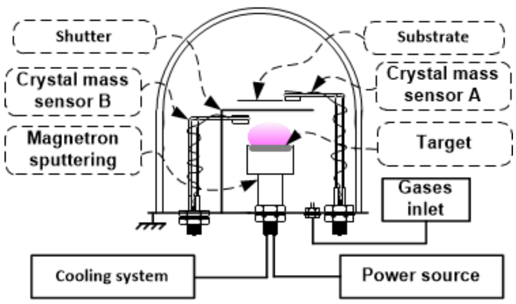


Fig. 4. Deposition scheme for the fabrication of the TiO_2 and SiO_2 thin-films using the RF sputtering system.

3. Results

Fig. 5(a) shows the measured refractive index of TiO_2 thin-film in comparison to literature, while Fig. 5(b) shows this information for SiO_2.

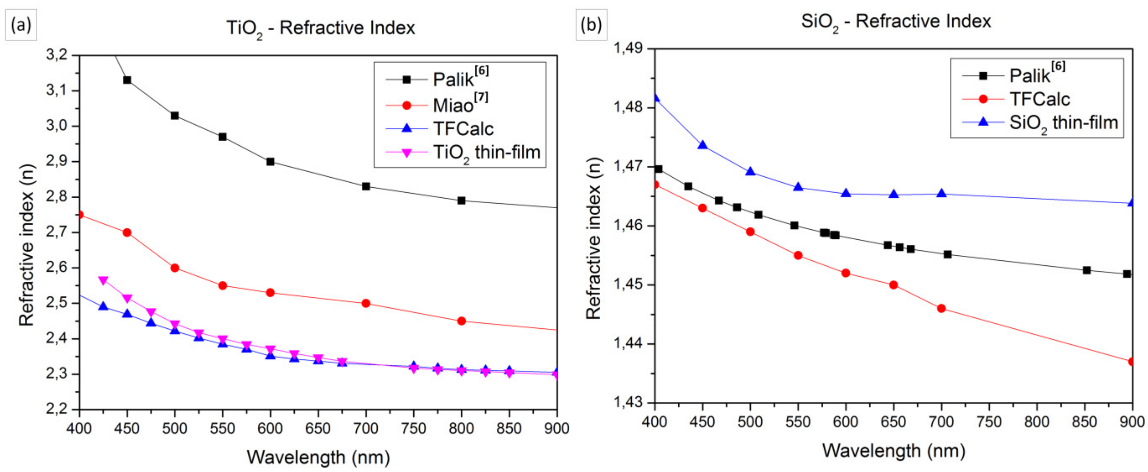


Fig. 5. Ellipsometry measurements of the refractive index in comparison with literature; (a) TiO_2; (b) SiO_2.

Fig. 6 shows the results of optical spectral transmittance for blue and green optical filters respectively.

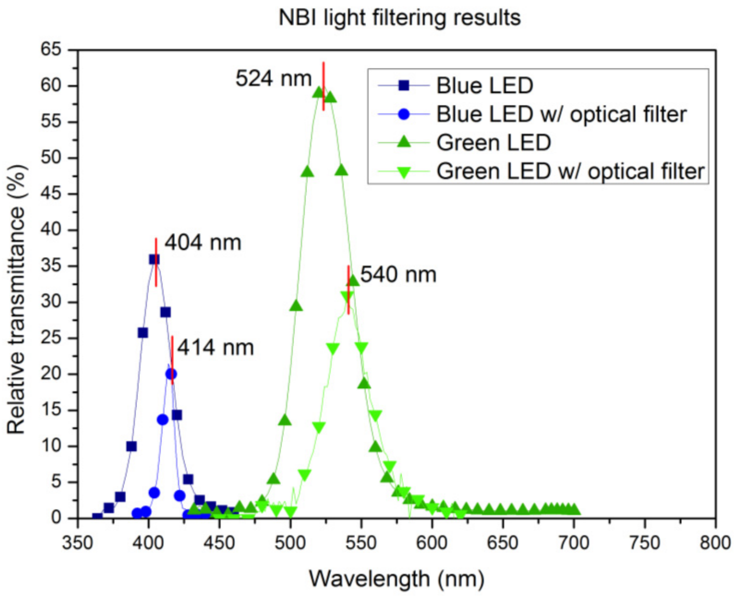


Fig. 6. NBI light filtering results of the blue and green optical filters.

The results on the blue light show a shift of the peak transmission to 414 nm, with a FWHM of 11 nm and maximum transmittance of 21 %. The green light results show a shift of the peak transmission to 540 nm with a FWHM of 34 nm and a maximum transmittance of 31 %, which is similar to the simulations. These results show that the actual shift in spectral transmittance of the blue and green LED with the optical filters applied is very close to the simulation results. Furthermore, the actual reduction in the transmittance is similar to the simulation result.

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