

Design of the Optical Dual-Band Filter for Emission of Dual Fluorescein Through the Irradiation of Single Optical Source

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Abstract

In this study, a dual-band band-pass filter (BPF) is designed to separate the dual-wavelength emissions of 5-aminolevulinic acid (5-ALA) and fluorescence sodium (yellow dye). The dual-band BPF was investigated experimentally to improve its accuracy, speed, and energy efficiency in clinical settings. The possibility of dual fluorescence emissions with a single irradiation is proposed, which saves energy by producing 2 fluorescence diagnostic effects using a single piece of equipment.

Keywords

brain malignancy, surgical microscopy, fluorescence dye, dual-band filter, phantom test

Introduction

A surgical fluorescence microscope was used to assess the condition of a tumor excision using 5-aminolevulinic acid (5-ALA) and fluorescence sodium (yellow dye)-based contrast agents.¹ When irradiated at 405 nm, the fluorescence wavelengths of 520 nm (yellow dye) and 620 nm (5-ALA) were emitted, which were captured by a camera that provided the images through a monitor. However, because 2 fluorescence wavelengths were mixed and photographed, it is difficult to visually identify the status of the tumor.^{2,3} Therefore, it is necessary to design an appropriate filter capable of providing an image by separating the 2 fluorescence wavelengths.^{4–8} In this study, a glass-based dual-band band-pass filter (BPF) was used to separate the wavelengths of 5-ALA and yellow dye.

Analysis of the Fluorescence Emission by Surgical Microscope

Surgical microscopy consists of an optical source module and a camera. The surgical microscope uses a single excitation wavelength (λ_{ext} : 405 nm) and dual-emission wavelength (λ_{em1} : 520 nm, λ_{em2} : 620 nm) for the 5-ALA and yellow dye, as shown in Figure 1.^{5–8} However, if 2 emission wavelengths and fluorescein colors are photographed with one camera, then the colors of 5-ALA and yellow dye will appear mixed on the monitor, making diagnosis difficult (see Figure 1). Therefore, it is necessary to design a dual-band BPF to pass only the desired band and enable the monitoring of 5-ALA and yellow dye separately.

Design of a Band-Pass Filter

Figure 2 shows a dual-band BPF designed for individual monitoring of simultaneous fluorescence emissions of 5-ALA and yellow dye using the irradiation wavelength of a single optical source. The filter consists of lithium fluoride (LiF), silicon dioxide (SiO_2), and titanium oxide (TiO_2). Between SiO_2 and TiO_2 , the band-gap of zinc oxide (ZnO) is coated to separate the passband. t , z , and s are the thickness of SiO_2 , ZnO , and TiO_2 , respectively, p is the thickness of LiF , and d is the dimension of the filter. The values of t , z , s , p , and d are 1.2 μm , 4.0 μm , 1.0 μm , 26.05 μm , and 1.96 μm , respectively.

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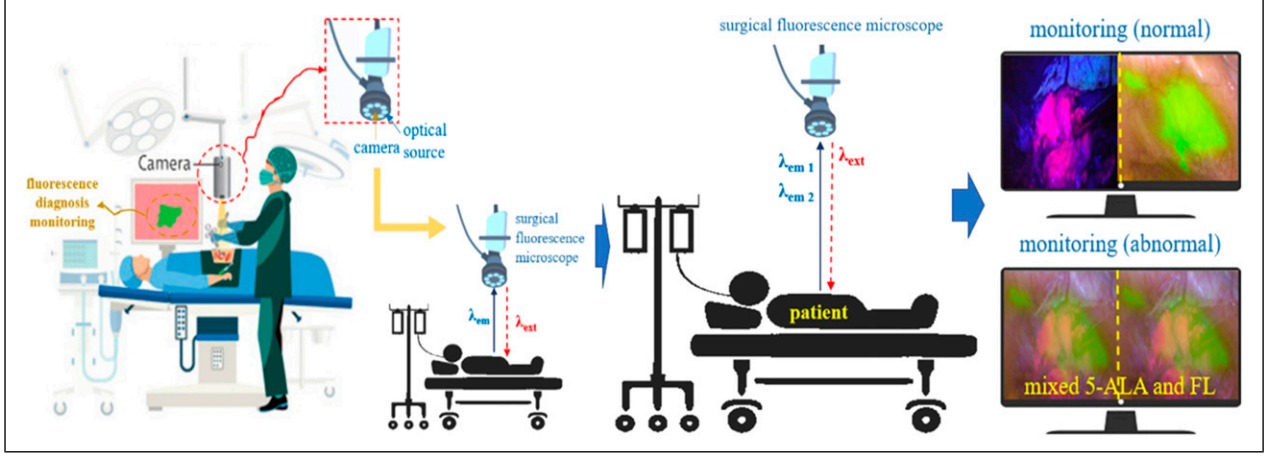


Figure 1. Fluorescence surgical microscope.

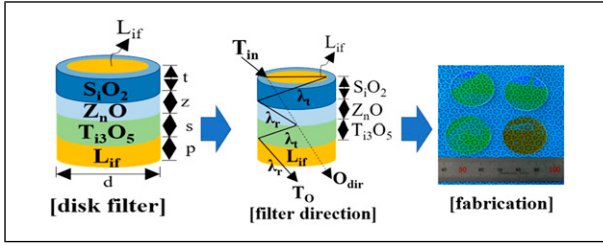


Figure 2. Design method and fabrication of BPF.

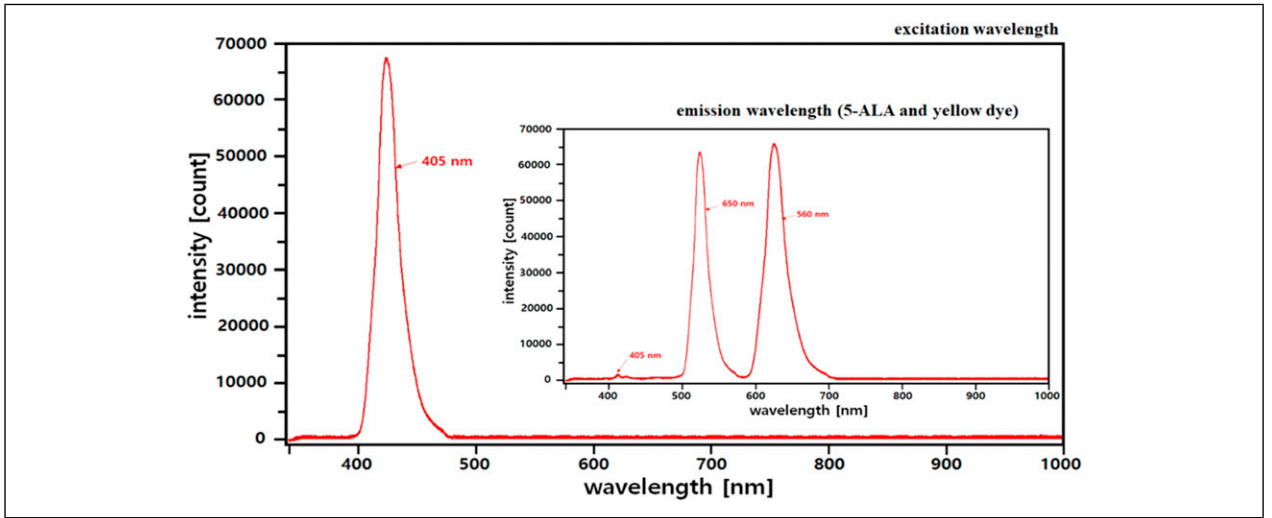


Figure 3. Measurement results of the BPF.

Figure 2 shows the optical source transmission direction of the filter, where T_{in} and T_o are the optical sources of the incident and transmission, and λ_t and λ_r are the wavelengths corresponding to the transmission and reflection, respectively. If the transmission optical source (T_{in}) is incident at the surface of L_{if} , then the optical source is refracted by Snell's law given as

$$T_o = \lambda_t - \lambda_r \sum_{n=0}^{\infty} (-\lambda_t \lambda_r)^n \quad (1)$$

The transmission band λ_t is generated when the characteristics of the material and material boundary are discussed. λ_r is obtained through the material and thickness of ZnO by reverse refraction, which can suppress the spurious.

The λ_r of SiO_2 is the passband of 5-ALA owing to the characteristics of matter, and T_{13}O_5 passes the yellow dye wavelength. Figure 2 shows the fabrication of the filter with a diameter and thickness of 26.05 mm and 1.96 mm, respectively.

Experimental Results

Figure 3 shows the experimental results of the proposed filter. The measured excitation wavelength is 405 nm. The emission wavelengths of 5-ALA and yellow dye are 650 nm and 560 nm, respectively. The transmission (T) and optical density are above 98.6% and below .11%, respectively.

Conclusion

In this study, a dual-band BPF capable of separating the simultaneous fluorescence emissions of fluorescence sodium (yellow dye) and 5-ALA was designed for improved accuracy, speed, and energy efficiency in clinical settings. In the designed BPF, the fluorescence diagnosis method using a 405 nm single wavelength was very helpful for tumor restationing because the distinction between blood vessels and tumors becomes clear.

Author Contributions

Study concept and design: So Yoon Kwon Analysis and interpretation: Ki-Cheol Yoon Study supervision: Kwang Gi Kim

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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