

Optical Fiber Lightening for Fluorescence Signal Detection with Thermal Stability in Dentistry

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Abstract

Dental caries diagnosis system has been made with a fiber lighting, camera module and band pass filter. By simply aligning a 405 nm LED (Light Emitting diode) chips directly connected polymer fibers, a compact lighting for dental fluorescence imaging could be implemented. Special designed fiber holder with proper hole diameter was fabricated to directly connect polymer fibers with 1 mm fiber diameter and increased coupling efficiency between fibers and LEDs. Fibers connected to fiber holder were polished by polishing machine to reduce insertion loss of the fiber. Experimentally, an optical insertion loss of the fiber bundle of up to 0.8 dB was achieved. Further, LED array module was packaged with equally spaced LED chips with fiber holder on metal. Fiber lightening was fabricated with directly coupled between LED array module and fiber bundle by UV epoxy without focusing lens in order to lower the lightening temperature of intraoral camera in the human mouth. The measured temperature of fabricated fiber lightening was about 25 degree celcius. To achieve a fluorescence image and dental caries diagnosis, the proper optical filter, camera module, 405 nm fiber bundle lighting and software were investigated. The performance of the fluorescence intraoral camera with fiber lightening is confirmed by fluorescence image of human tooth.

Keywords

Fluorescence, LEDs, Dental Caries, Fiber Lightening

1. Introduction

Dental caries are an important public health problem worldwide, and the detection at early stage is key in pre-

venting and treating dental caries [1] [2]. Recently, new technologies for detection of dental decay at early stage of formation have been developed in order to provide health and economic benefits ranging from timely preventive interventions to reduction of the time required for clinical trial of anti-carries agents [3] [4]. Dental caries diagnosis systems are based on the measurement of a physical signal. Examples of the physical signals include X-rays, visible light, near infrared light, laser light, electronic current, ultra sound [5]. For dental caries detection, these methods are capable of launching and receiving signals. However, radiographs are limited in their ability to identify early dental caries. Accurate diagnosis and localization of the caries can be a real aid not only for early detection, for enhanced patient care as well. One of the developed diagnostic procedures employs fluorescence diagnostics with low-intensity lasers [6] [7] and LED light source [8] [9]. Fluorescence diagnostics, in dentistry, are widely used to diagnose caries of enamel and dentine and non-contact, non-destructive probing technique, which has received increasing attention due to its high sensitivity and specificity. Based on the results obtained, high sensitivity spectroscopic systems (Quantitative Light-Induced Fluorescence (QLF)) were developed. These systems are capable to perform early dental caries detection and monitor the treatment and prevention of hard dental tissues aimed at increasing enamel resistance and stimulating remineralization processes. Strong fluorescence of teeth under blue light irradiation has been reported [10]. Diode laser based systems emitting red light in the range of 633 - 655 nm were used to detect subgingival calculus by measuring characteristic fluorescence radiation around 700 nm, where health teeth tissue is not fluorescing [11]. Recently, light emitting diode (LED) radiation reflected from the tooth surface was also used to detect calculus. Investigated the calculus fluorescence spectra under different excitation wavelengths ranging from 360 to 580 nm and found great fluorescence increase at 570 - 640 nm when irradiating with 400 - 420 nm light [12] [13]. Considering the need of a robust quantitative detection method for dental calculus, and the possibility of improvement by utilizing more favorable excitation wavelength and cheaper light source, LED lights has been used for dental fluorescence detection and intraoral camera with fluorescence function. Intraoral camera has 405 nm blue-violet LEDs surrounding the camera lens and filter. However, because intraoral camera insert in mouth to detection dental caries for long time, heat during LED operating might be capable bring displeasure to patient. In order to resolve this problem, new lightening system without heat problem is necessary. In this paper, we report the fiber bundle lighting without heat problem and present the performance of the dental caries fluorescence detection with fiber bundle lighting. The fabrication process of the fiber bundle lighting with blue-violet LEDs are presented and discussed. To confirm the operation of the proposed fiber bundle lighting, we present fluorescence images.

2. Fabrications and Results

2.1. Design and Fabrication of the Fiber Bundle Lightening

We choose the polymer fiber which was commercially used to communication fiber of the car network and has low bending radius in order to solve heat problem of LED lightening. Polymer fiber with low bending radius is suitable for vertical illumination of intraoral camera. Polymer fiber used for experiment has 0.8 mm core diameter and buffer diameter of 1 mm. To uniformly illuminate lightening at human teeth, several polymer fibers needed and were well arranged around camera. Special fiber holder was designed to directly connect LED chip and hold polymer fibers shown in **Figure 1(a)**. The fiber holder was design for holding eight fibers with diameter of 1 mm, and had hole size of 1 mm and pitch of 0.5 mm.

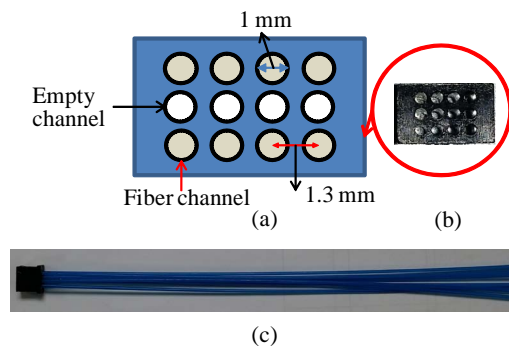


Figure 1. Pictures of (a) the array of LEDs and (b) the mirror for the array of LEDs.

Figure 1(b) is picture of the fabricated fiber holder to connect with LED chip. 8 polymer fibers were placed in the fiber holder. To secure the fixation, UV epoxy was applied between polymer fibers and fiber holder. The end faces of the fiber holder and end faces of each fiber were polished with fabricated polishing jig for decreasing insertion loss. After polishing process, the insertion loss was about 0.8 dB. **Figure 1(c)** is the picture of the fiber bundle with 8 polymer fibers.

The LED light array module (Gwangju, Korea, OE-H405LT1, OPTOENG) consists of eight blue-violet LEDs with power of 1.5 W, wavelength of 405 nm and continuous forward current of 350 mA. The distance between LED chips is about equal to the pitch of the fiber holder to improve coupling efficiency between LED chips and polymer fibers shown in **Figure 2(a)**. LED chip size was about 1.1 mm. We choose eight LED chips and proper resistor to fabricate LED module. The circuit of LED module was designed to be operated by voltage (5 V) of USB (Universal Serial Bus) port. LED array module (**Figure 2(b)**) without optical lens and fiber bundle were directly coupled by UV epoxy shown in **Figure 2(c)**. The transmission spectrum of the fabricated LED module was measured by using optical spectrometer (San Jose, CA, USA, UV-NIR, Bayspec) and optical fiber. **Figure 3** shows the transmission spectrum of the LED module. The spectrum was measured by directing coupling between multimode fiber and LED module. Center wavelength of the fiber bundle lightening was about 405 nm.

2.2. Fluorescence Intraoral Camera System Based on Fiber Bundle Lightening

A schematic diagram and image of the fluorescence intraoral camera with fiber lightening is shown in **Figure 4**.

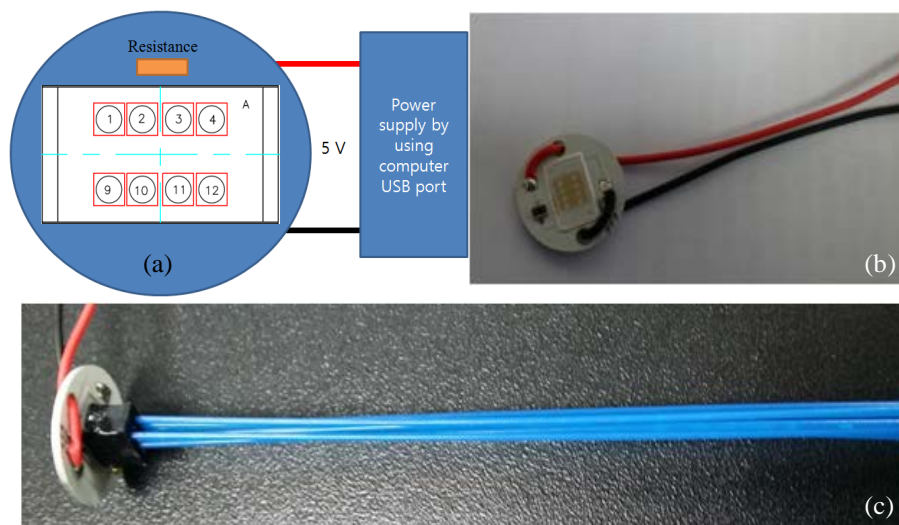


Figure 2. Schematic of the LED array module (a), picture of LED array module (b) and fiber lightening directly coupled LED array and fiber bundle (c).

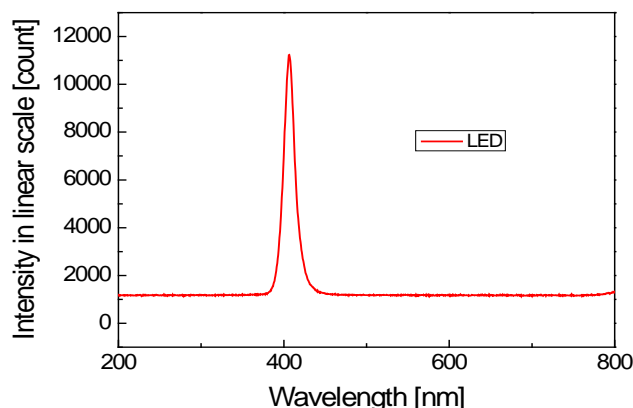


Figure 3. Transmission spectra of a LED module: Center wavelength was about 405 nm.

The fluorescence intraoral camera consisted of fiber lightening, camera module with lens and band pass filter. As fiber lightening of the intraoral camera had low temperature, discomfort of the patients due to high temperature of LED lightening could be solved.

Temperature of the conventional intraoral camera with LED module and implemented fluorescence intraoral camera with fiber lightening were measured by using IR camera. **Figure 5** is the IR camera images of conventional intraoral camera with the LEDs (a) and implemented fluorescence intraoral camera with fiber lightening (b) after 10 minutes operating. The temperature of the conventional intraoral camera surroundings LED module was about 50 - 65 degree celcius. On the contrary, the temperature of fiber lightening was about 25 degree celcius and was maintained at room temperature without a change in temperature.

After a fiber lightening as an excitation light source lighted up tooth, the fluorescence signal is directed to the fluorescence detector (camera module or Spectrometer), after being band pass filtered at center wavelength of 510 nm. We measured the fluorescence spectrum of the human tooth and the main fluorescence peak of the human tooth was about 510 nm wavelength shown in **Figure 6**.

Camera module (Gwangju, Korea, USB 2M-HU-201, Huentek) used for experiments had CMOS (Complementary Metal Oxide Semiconductor) image sensor, maximum resolution of 1632×1232 , pixels of 2 Mega pixels and frame rate of 5 fps. Lens with focal length of 10 mm was placed in the camera module for close-up of the human teeth. Fluorescence intraoral camera with fiber lightening has 8 channel fiber lightening emitting 405 nm wavelength surrounding camera module with lens and filter and connects to the operator computer via a USB port and is operatory by made software using Matlab. **Figure 7(a)** shows the fluorescence image of the human tooth which got through the proposed fluorescence intraoral camera with fiber lightening. Areas of the tooth are seen as bright green depicted regions of healthy tooth. While dark areas depicting loss of fluorescence is areas of concentrations of caries or demineralization status of tooth. The image-processing software quantifies the black and green components of the fluorescence. After green channel image was extracted from image taken by fluorescence intraoral camera shown in **Figure 7(b)**, edge was extracted from green channel image

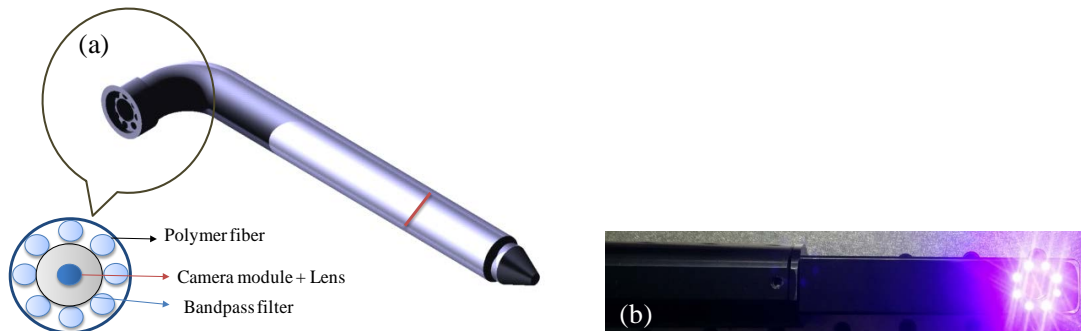


Figure 4. Schematic of fluorescence intraoral camera with fiber lightening (a) and picture of implemented fluorescence intraoral camera (b).

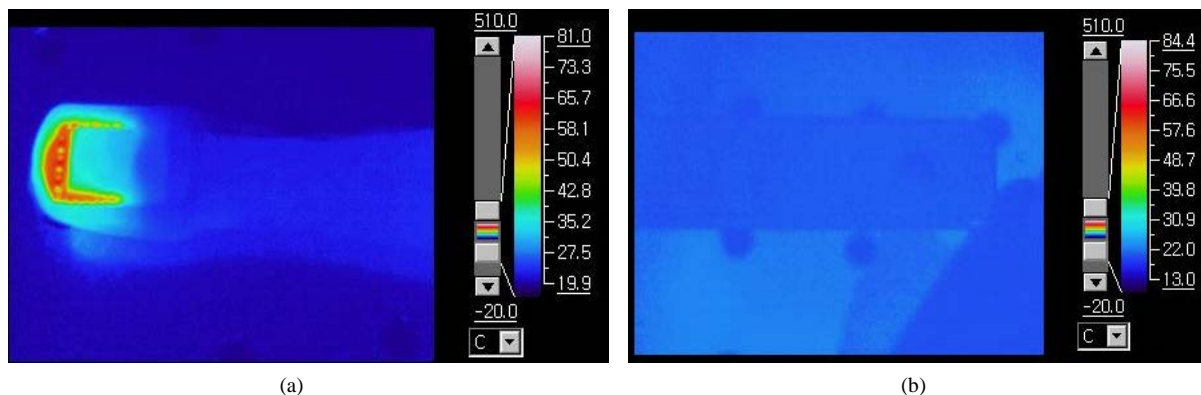


Figure 5. IR camera images of conventional intraoral camera and fabricated fluorescence intraoral camera with fiber lightening.

shown in **Figure 7(c)**. Edge clearly was made by using line mask shown in **Figure 7(d)** and generated hole due to extracting edge was filled shown in **Figure 7(e)**. Finally, as due to extracting, generated noises and border were removed by imaging process software shown in **Figure 7(f)**, we could identify potential caries in the earliest stages by using fluorescence intraoral camera with fiber lightening. **Figure 8** is fluorescence diagnosis real time image and white light image with on screen orange color after image processing.

3. Conclusions and Discussion

We have proposed and presented the fabrication of a fluorescence intraoral camera with fiber lightening for solving heat problem of the LED lightening. By placing 8 polymer fibers in the fiber holder and directly attaching

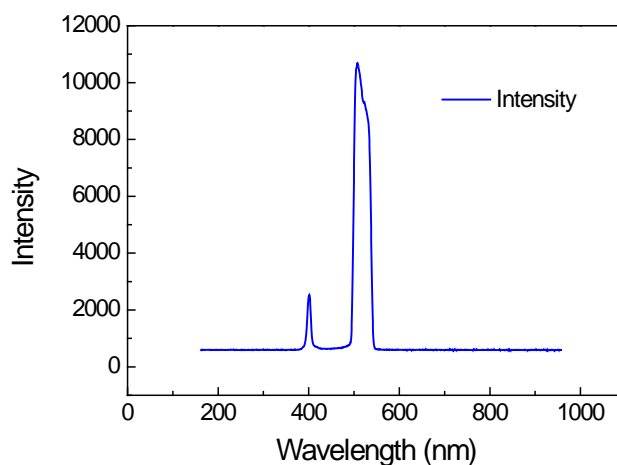


Figure 6. Fluorescence spectrum of the human tooth by using fiber lightening with center wavelength of 405 nm.

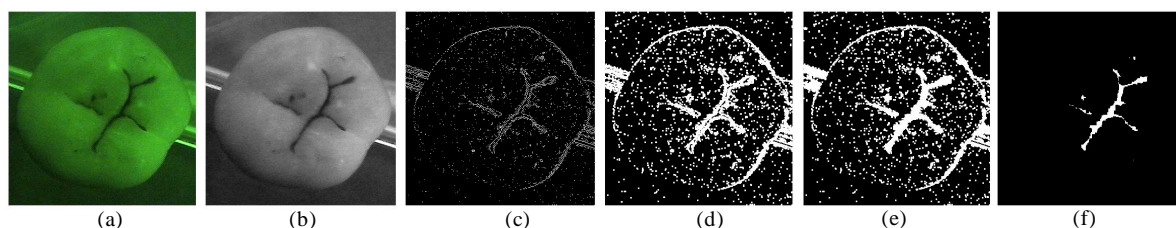


Figure 7. Dental GUI algorithm. Fluorescence image of human teeth (a); extracted green channel image from color image (b); edge extraction from green channel image (c); edge sharpening by using line mask (d); generated due to edge extraction hole filling (e); border and noise removing (f).

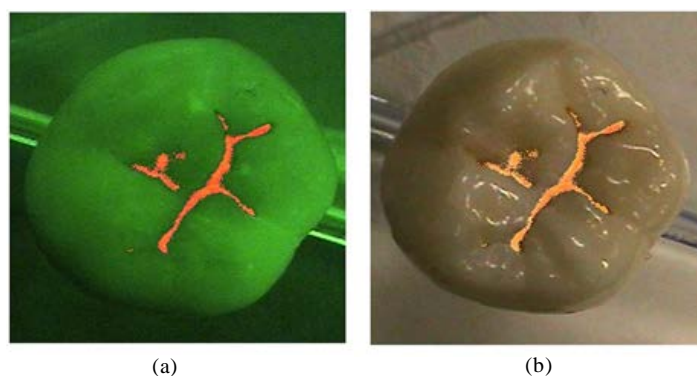


Figure 8. Fluorescence real time image (a) and white light image (b) of the human tooth after image processing. Fluorescence intraoral camera with fiber lightening could identify suspicious dental caries of human teeth through the different color.

fiber bundle and LED module with 405 nm LEDs, we could fabricate a fiber lightening for the fluorescence intraoral camera. In addition by using a band pass filter and lens, only the fluorescence image of the human teeth could be taken and identified dental caries through image processing in real time. By equipping the implemented fiber lightening, a fluorescence intraoral camera system was made and used to the dental diagnosis image of human tooth. Further, discomfort of the patients due to high temperature of LED lightening could be solved. Through the fluorescence images, we can say that the proposed fluorescence intraoral camera with fiber lightening has a great potential as a diagnosis system without heat problem in dentistry.

Since the coupling loss of the fiber lightening can be adjusted by controlling polishing condition of the polymer fiber and aligning between fiber bundle and LED module, we can expect an effective fiber lightening also. Therefore we might find good applications especially in the field of fluorescence based medical diagnostic equipment without heat problem.

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