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# Feasibility study on a micro-size dosimeter using an optical fiber probe based on a photostimulable phosphorescence

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ABSTRACT

We propose a novel micro-size dosimeter using an optical fiber probe based on the PSL from the $BaFBr:Eu^{2+}$. Through basic experiments using the prototype dosimeter, the feasibility of the proposed dose monitoring method has been confirmed. We confirm that increasing the stimulus laser power is effective to improve the signal to noise ratio. The lower limit of detectable dose of the prototype dosimeter probe having sensitive region with the diameter of 200 μm is preliminarily estimated to be 11 mGy for a Co-60 gamma-rays. This value is much smaller than the typical irradiation dose (a few Gy per treatment) in the radiotherapy. We can measure the dose in a few hundred subdivisions during a treatment. We, therefore, conclude that the proposed micro-size dosimeter can be a promising candidate of in-vivo and on-line dose monitor in the radiotherapy.



## 1. Introduction

Radiotherapy utilizes a difference in the sensitivity between cancer cells and healthy tissue. Because cancer cells are generally more sensitive to radiation damage than healthy tissue, radiation irradiation can preferentially cause damage to cancer cells. Since the difference in their sensitivities is generally quite slight, the irradiation should be spatially concentrated into a tumor in practical radiotherapy. The effect of radiotherapy additionally has dose response with S-shaped curve and strongly depends on irradiation dose near the threshold dose. To verify quantitatively and spatially appropriate irradiation, we should precisely evaluate irradiation dose at or near a tumor. Recently, advanced irradiation methods, such as respiration-synchronous irradiation, have been developed (Starkschall, 2007). In these irradiation methods, more accurate, in-situ and on-line dose monitoring techniques are required.

In order to accurately estimate the irradiation dose into affected regions, dose monitors are required to be inserted into the affected region in a patient body. However, it is difficult to insert dosimeters into a patient body because general dosimeters have the size of a few millimeters at least and patients must have physical pain to be inserted them into their body. Therefore, in-vivo dose monitors are desired to be miniaturized as small as possible. In addition, because a dosimeter probe with large size perturbs dose distribution in a patient body, miniaturization of the dosimeter probe size makes the perturbation small (Das et al., 2008). But at the same time, miniaturization of the dosimeter probe size generally causes decrease of the detection sensitivity. In the case of the pulse mode operation, as the dosimeter probe size becomes smaller than range of charged particles directly depositing energy in a dosimeter probe, which is from sub- to a few millimeters for fast electrons produced by high energy photons, the signal intensity for each radiation event also becomes small because these charged particles can deposit little energy in the small probe. Also, in the current mode operation, miniaturization of probe size leads to deterioration of signal to noise ratio. For many radiation detectors, a pre-amplifier is located near the probe to preprocess signals before signal transmission. If the pre-amplifier is avoided, the noise causing in a signal line becomes significant, when especially downsizing the detector probe. On the other hands, an optical fiber probe used as a transmission line of an optical signal, such as scintillation photons, is generally free from electrical noise. However, in an intense gamma-ray and/or X-ray field, Cherenkov radiation can be a source of noise in the optical fiber. When downsizing the detector sensitive volume, the signal intensity decreases as compared with the noise causing in the signal line. When using small dosimeter probe of the successive signal readout type, we suffer from low signal to noise ratio in either the pulse mode or the current mode.

On the other hand, the integrating-type dosimeter probe can obtain larger signals than a noise level even if the dosimeter probe size is smaller than the charged particle range, because small

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energy depositions can be accumulated in the detector element until exceeding a noise level. We propose a novel micro-size dosimeter using a photostimulable storage phosphor (PSP) and an optical fiber. The PSP is one of the integrating-type detector elements and generally used in the plate form known as an imaging plate (IP) (Iwabuchi et al., 1994). The energy depositions accumulated in the PSP can be read out in the form of a photostimulated luminescence (PSL) after irradiating a stimulus light. In the proposed dose monitoring system, the both of stimulus and luminescence lights are conducted through an optical fiber. The signal of this system, therefore, can be read out remotely and on-line.

The concept utilizing the PSP as the in-vivo dose monitor was already proposed by some researchers (Marckmann et al., 2006), who used an $Al_2O_3$:C crystal as the PSP. The PSL intensity of the $Al_2O_3$:C crystal is relatively low, so that a large crystal and/or long accumulation time are required to acquire significant signal intensity. Consequently, the dose monitor based on the $Al_2O_3$ has difficulty in realizing a small and sensitive dose monitor. We, therefore, utilize a BaFBr:$Eu^{2+}$, which is more sensitive than the $Al_2O_3$:C but opaque, as the PSP and try to make the dose monitor small and sensitive enough to monitor in-vivo irradiation dose with little load for patients in the radiotherapy. In this paper, we discuss the usefulness of the proposed dose monitoring system in terms of downsizing the dose monitor probe with keeping the sensitivity required for the radiotherapy.

## 2. Dosimeter using photostimulable storage phosphor and optical fibers

### 2.1. Photostimulated luminescence (PSL)

When an ionizing radiation interacts with the PSP, electron–hole pair is produced and trapped by color center. Electron–hole pairs trapped at the color centers are stable and can be accumulated unless the release process is performed. In the release process, the PSP is irradiated by stimulus light and then the radiation energy accumulated in the form of electron–hole pairs is released as luminescence photons with the specific wavelength, which is shorter than that of stimulus light. This luminescence is referred to as the PSL, which is also called as optically stimulable luminescence (OSL). Because the number of the trapped electron–hole pairs is proportional to the irradiation dose, the PSL intensity can be a measure of the irradiation dose. The PSP, therefore, is the integrating-type detector elements, which can obtain larger signal than the noise based on Cherenkov radiation in the optical fiber, by accumulating the energy deposition in the detector element.

### 2.2. Basic configuration

An optical fiber probe mounting a scintillator at the end is well known as one of the small dosimeters (Yamane et al., 1999). The proposed micro-size dosimeter has similar configuration. The basic configuration of the proposed micro-size dosimeter is shown in Fig. 1. This system consists of the PSP, the optical fiber, a stimulus light source and a photo detector. We fabricated the prototype dosimeter to evaluate the basic performance. In this prototype, the imaging plate (IP, BAS-MS2025, Fujifilm), that is composed of BaFBr:$Eu^{2+}$, was used as the PSP detector element. This PSP has the peak wavelength of 630 nm and 400 nm in excitation and luminescence spectra, respectively. A laser diode (LPM-660-SMA), that has the output of 25 mW and the oscillating wavelength of 660 nm, was used as a stimulus light source. A photomultiplier tube (PMT, H6612, Hamamatsu Photonics) was used to detect the PSL. To transmit the stimulus laser light and the PSL, the multi-mode quartz optical fiber with the core diameter of 200 μm was used. Each light was divided by an optical fiber coupler. The IP was located and physically attached at the end surface of the optical fiber. The reflection light of the stimulus lights by the PSP was cut out by a band-pass filter, which transmits wavelength of $400 \pm 40$ nm and was mounted in front of the PMT. Because the most sensitive wavelength of PMT (420 nm) is close to that of the PSL, this PMT can efficiently detect it. The drive current of the laser diode was controlled by a PC-based pulse generator to generate periodic stimulus laser pulse. After irradiating radiation for a given period of time, the accumulated energy deposition was read out as the PSL by irradiating pulsed stimulus laser. This laser pulse also can erase the accumulated energy deposition in the PSP. The PSL signal was detected at the PMT. The detected PSL signals were recorded with a digitizer (WE-7311, Yokogawa Electric) and stored into the PC. The PSL intensity was derived by processing the digitized PSL data. This procedure was periodically repeated by the control PC. The repetition rate of the readout cycle is usually set to relatively short period, e.g. a few second, and constant repetition rate. We, therefore, can ignore and/or cancel out the cumbersome fading effect.

### 2.3. Detection of the PSL

Fig. 2 shows examples of the PSL signal and the reflected stimulus light passed through a band-pass filter. Under the condition where the PSP was irradiated by ionizing radiation, the peak of the PSL signal can clearly be observed during irradiating stimulus laser pulse. On the other hand, when the PSP was not irradiated by ionizing radiation, there was only a constant component with non-zero intensity, i.e. the reflection light of the stimulus laser by the PSP surface. We can determine this constant intensity of the reflection light from the end region of the signal, because the PSL signal quickly decays. The PSL intensity was derived from the peak area of the PSL signals by subtracting the constant reflection signal for five times the decay time of the PSL signal. The stimulus laser pulses were periodically irradiated under a certain operation condition, where, for example, the laser pulses were irradiated for 1 s and then halted for

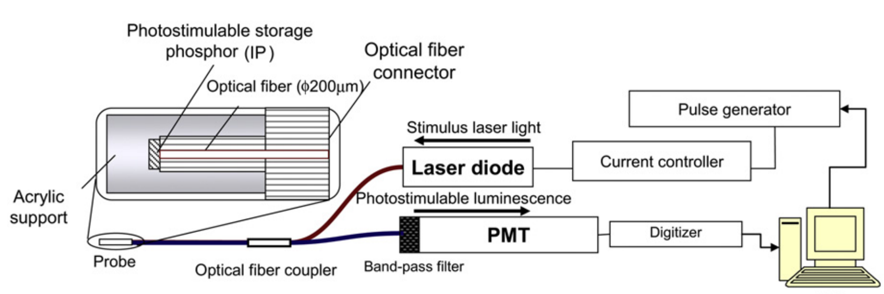


**Fig. 1.** Basic configuration of proposed micro-size dosimeter. This dosimeter consists of small probe. Stimulus laser light transition and photostimulable luminescence readout are conducted with an optical fiber.