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The readout characteristics of self-fabricated radiophotoluminescent glass dosimeter reading system

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HIGHLIGHTS

- The amount of fluorescence emitted from glass dosimeter was proportional to the radiation dose.
- The glass dosimeter luminescence signals were decayed in the remaining 10% of 10 μS.
- This study successfully completed the self-fabricated radiophotoluminescent glass dosimeter readout system.

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ABSTRACT

The major property of radiophotoluminescent glass dosimeter is its repeatable readout for the radiation measurements. Accordingly, the radiophotoluminescent glass dosimeter system will become one of the important dosimeters for dose measurement in the future. The aims of this study were to develop and characterize the self-fabricated radiophotoluminescent glass dosimeter reader system. The photomultiplier tube, charge-coupled device, nitrogen pulsed laser, band pass filter, 500 nm long pass filter and GD-302 glass dosimeter were used in this study. Based on our study, we found that the values of R-squared for both photomultiplier tube and charge-coupled device in reading system were 0.9968 and 0.9992, respectively, which shows that the relationship between luminescent signals or fluorescence images intensity of glass dosimeter and irradiation dose is direct proportion. These results suggest that the photomultiplier tube and charge-coupled device optical detector can be used in radiophotoluminescent glass dosimeter readout system.

1. Introduction

In radiation dose measurement fields, there are many different kinds of radiation dosimeters applied in the procedures to obtain the radiation dose of organs or tumors, and to verify the radiation output for quality assurance purposes. The film, thermoluminescence dosimeter, optically stimulated luminescence dosimeter, and radiophotoluminescence glass dosimeter are commonly used as passive radiation dosimeters [Albogamy et al., 2015; Granville et al., 2014; Sato et al., 2013; Yeh et al., 2015]. Wely, Schulman, Ginther, and Evans were self-fabricated the first radiophotoluminescent glass dosimeter system in 1949 [Yokota and Nakajima, 1965]. In comparison with the thermoluminescent dosimeter, the advantages of the radiophotoluminescent glass dosimeter are good reproducibility of readout values, long stability, low energy dependence, better dose linearity. The radiophotoluminescent glass dosimeter could be readout luminescence signals infinitely because the reader did not eliminate luminescent centers in glass. There advantages were verified from our previous study [Hsu et al., 2006].

The radiophotoluminescent glass dosimeter uses glass compound as the thermoluminescent material and applies laser excitation method along with heat readout technique. When irradiate

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the radiation dose, luminescent centers are formed in the glass and more luminescent centers formed with increasing radiation dosage. After irradiated by excitation light source (ultraviolet light or light-emitting diode), the electrons in the valence band are excited to the conduction band and emit 600 nm–700 nm visible orange light, then return to the original luminescent centers [Asahi Techno Glass Corporation, 2004]. Radiophotoluminescent glass dosimeter has become the popular dosimeter system in recent years [Kihong et al., 2013; Hsu et al., 2012]. The aim of the present study was to investigate the readout characteristics of self-fabricated radiophotoluminescent glass dosimeter system.

2. Materials and methods

2.1. Radiophotoluminescent glass dosimeter

The GD-302 (Asahi Techno Glass Corporation, Shizuoka, Japan) radiophotoluminescent glass dosimeters were used in this study. The GD-302 had the following weight composition: P (31.55%), O (51.16%), Al (6.12%), Na (11.00%), and Ag (0.17%). The effective atomic number and physical density of the GD-302 were 12.04 and 2.61 g/cm^3, respectively [Hsu et al., 2007]. The GD-302 dosimeter is composed of a rod glass element measuring 12.0 mm in length and 1.5 mm in diameter. GD-302 dosimeter must undergo preheat at 70 °C for 30 min before reading with the self-fabricated radiophotoluminescent glass dosimeter reader system.

2.2. Radiation source

The ^{60}Co gamma ray instrument (E-78, Atomic Energy of Canada Limited, Canada) were used to irradiate the GD-302 radiophotoluminescent glass dosimeters. The E-78 equipment (9169.0 Ci) was established at the National Yang-Ming University (NYMU, Taiwan).

2.3. Self-fabricated radiophotoluminescent glass dosimeter reader system

There are two sets of optical detector system, including the photomultiplier tube (PMT) and a charge-coupled device (CCD). Fig. 1 showed a flowchart of homemade radiophotoluminescent glass dosimeter reader system. Pulsed ultraviolet laser were penetrated the filter and through the condenser lens arrived at the dosimeter holder in the darkroom.

Laser light sources used in this experiment was nitrogen pulsed laser. It provides a full half-wave pulse width of less than 3.5 ns of ultraviolet light and with a wavelength of 337.1 nm. Its maximum pulse frequency is 20 Hz. Energy of per pulse is 170 μJ, the maximum power is 45 kW. The beam size of ultraviolet light is 7 mm × 3 mm.

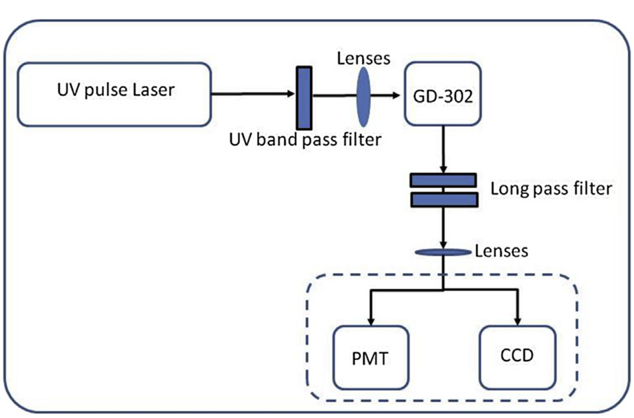

Fig. 1. The diagram of the self-fabricated radiophotoluminescent glass dosimeter readout system.

The UV band pass filter and 500 nm long pass filter were used in this study. The UV band pass filter was placed in the front of darkroom, therefore the other wavelengths of light cannot enter darkroom. The 500 nm long pass filter was placed after the darkroom to filter out the light below 500 nm. In other words, the wavelength of 500 nm or less light could not penetrate the optical lenses. The primary focusing lenses were to focus the laser light on the radiophotoluminescence glass dosimeter. The primary focusing lenses used in this experiment is fused silica which prevents UV penetration decreased. The secondary focusing lenses were to focus the luminescence beam to the optical detector system which to achieve good reception. Dosimeter holder is movable. When handling glass dosimeters, it could be extracted glass holder to replace the dosimeter.

The photomultiplier tube used in this study has a response frequency on 200 kHz. The maximum gain is 5 × 10^7 times. The H10492 photomultiplier tube (Hamamatsu Photonics, Japan) was used in this study. The spectral response was from visible light to near infrared. Input the different gain voltage in photomultiplier tube will have different magnifications. In this study the DFK41AU02 (The Imaging Source Europe GmbH, Deutschland) used as the charge-coupled device, chip size was 7.6 mm × 6.2 mm (type 1/2 ″). There are millions of photosensitive semiconductors in charge-coupled device. Based on the exposure time, the charge-coupled device could record the amount of fluorescence in the unit time. It could record the signal of two-dimensional images. Through the two-dimensional image that can be used in the observation of luminescence signal strength. The signal can be used to calculate the amount corresponding to the irradiation dose. The pixel size of the charge-coupled device is 4.65 μm × 4.65 μm. There are 1360 × 1024 pixels in charge-coupled device. The collected effective area of the optical signal was 3.7 mm × 2.8 mm.

3. Results and discussion

3.1. Glass luminescence signal from photomultiplier tube

The GD-302 dosimeters were irradiated with dose ranges of 0.05 Gy–70 Gy before reading signals with the self-fabricated radiophotoluminescent glass dosimeter reader system. The photomultiplier tube system can record the fluorescence signal intensity versus time for glass dosimeter. Therefore, the photomultiplier tube was used to record the glass dosimeter luminescence signal and analyze the fluorescence decay curve. The each luminescence signal value was normalized to that of 1 Gy value, and we found that the attenuation trend for each decay curve was the same (Fig. 2). In other words, these curves were related to the glass composition, but independent to radiation dose. The glass dosimeter luminescence signals were decayed in the remaining 10% of 10 μS and within 20 μs signals almost closed to zero.

The glass dosimeter luminescent signal intensity curve can be obtained the relationship between fluorescence signal intensity and irradiation dosage. The dose linearity of the GD-302 is shown in Fig. 3. The amount of fluorescence signals accumulation time was 8 μS. Three dosimeters were irradiated to each dose point (0.05–70 Gy) and the average readings were used. The results showed a good dose linearity response from this dose range. The value of R^2 for GD-302 was 0.9968 which shows that the relationship between luminescent signal of GD-302 and irradiation dose is direct proportion function.