Synthesis and physical characteristics of radiophotoluminescent glass dosimeters

Shih-Ming Hsu\textsuperscript{a}, David YC Huang\textsuperscript{b}, Hsi-Wen Yang\textsuperscript{c}, Tien-Chi Yeh\textsuperscript{a}, Wei-Lin Hsu\textsuperscript{c}, Chin-Hui Wu\textsuperscript{a}, Chin-Chang Lu\textsuperscript{c} and Wei-Li Chen\textsuperscript{a,*}

\textsuperscript{a}Faculty of Biomedical Imaging and Radiological Sciences, National Yang-Ming University, 155, Li-Nong Street Sec. 2, Pei-tou, Taipei, 112, Taiwan, Republic of China

\textsuperscript{b}Faculty of Memorial Sloan-Kettering Cancer Center at Mercy Medical Center, 1000 N, Village Avenue, Rockville Centre, New York, USA

\textsuperscript{c}Department of Material Science and Engineering, National United University, No. 1, Lien Da, Miao-Li, 360, Taiwan, Republic of China

*Corresponding author: Prof. Wei-Li Chen
National Yang-Ming University
Faculty of Biomedical Imaging and Radiological Sciences
155, Li-Nong St., Sec 2, Pei-tou, Taipei 112
Taiwan, Rep. of China
Email: d49220003@ym.edu.tw
Tel: 886-2-28267281
Fax: 886-2-28201095
ABSTRACT

The radiophotoluminescent glass dosimeter (RPLGD) was developed in the late 1950s while the reading technology was not sensitive enough to measure the low radiation dose and glass element sensitivity to radiation was also quite low. In recent years, the development of the pulsed UV laser excitation method which had high measurement accuracy was applied to the RPLGD. 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 and capability of repeatable readouts. It could be one of the most important radiation dose measurement instruments in the near future. Hence, some important physical characteristics of glass dosimeters including reproducibility of readout values, dose linearity, accumulative dose measurement, energy dependence and angular dependence were explored. In this study, four series of glass dosimeters were prepared from reagent powders of Na\textsubscript{3}PO\textsubscript{4}, Na\textsubscript{2}CO\textsubscript{3}, Al(OH)\textsubscript{3}, AgCl, and P\textsubscript{2}O\textsubscript{3}. It is necessary to develop the novel compound of RPLGD to measure radiation dose.

Keywords: radiophotoluminescent glass dosimeter; radiation dose; laser.
1. Introduction

The thermoluminescent dosimeters are widely used for monitoring the external dose of radiation workers and measuring the dose of patients in clinical radiotherapy and radiation diagnosis. A major problem with the thermoluminescent dosimeters is that the reading and analysis cannot be repeated once there are errors in the dose assessment. On the contrary, the radiophotoluminescent glass dosimeter (RPLGD) could be read infinitely because the pulsed ultraviolet laser beam reading did not eliminate the luminescent centers in RPLGDs.

During pulsed ultraviolet laser excitation in the reader, the color centers of RPLGD emit a radiation induced orange fluorescent light, which is called radiophotoluminescence phenomenon. Some researchers have investigated radiophotoluminescence phenomena for a long time (Cheka, 1964 and Schulman et al., 1951). The RPLGD was developed in the late 1950s (Piesch et al., 1986). A small element RPLGD system (Dose Ace system) was recently developed (ATG, 2004). The Dose Ace system used pulsed ultraviolet laser excitation method and gave readouts fully automatically. It has been used for dose verification in clinical radiotherapy and dose measurement of radiation diagnosis (Takayuki et al., 2005).

This work is targeted to study the physical characteristics of the Dose Ace system covering reproducibility of readout values, dose linearity, accumulative dose...
measurement, energy dependence and angular dependence and synthesis new radiophotoluminescent glass dosimeters. The first silver phosphor glass dosimeter was developed by Schulman (Schulman et al., 1951). In this study, homemade glass dosimeter were prepared from reagent powders of Na₃PO₄, Na₂CO₃, Al(OH)₃, AgCl, and P₂O₃.

2. Materials and methods

2.1 Radiophotoluminescent glass dosimeter

The Dose Ace dosimetry system was composed of rod-shaped, sliver activated phosphate glass (FD-7 glass), plastic capsule and a fully automatic readout system. In 1971, Yokota and Muto developed a glass designated FD-7, which has low energy dependence, low pre-dose fluorescence level and higher sensitivity (Yokota and Muto, 1971). The weight compositions of the FD-7 glass are as follows: Ag (0.17 %), Al (6.12 %), Na (11.0 %), P (31.55 %) and O (51.16 %). The effective atomic number was 12.039 (Araki et al., 2004). A glass dosimeter GD-302M (Asahi Techno Glass Corporation, Shizuoka, Japan) and a fully automatic readout system FGD-1000 (Asahi Techno Glass Corporation, Shizuoka, Japan) were used in this work. The GD-302M consisted of a rod glass element FD-7 (12.0 mm in length and 1.5 mm in diameter) and a plastic capsule (13.0 mm in length and 2.8 mm in diameter). The
FGD-1000 was the readout system for GD series glass dosimeter using pulsed nitrogen gas ultraviolet laser excitation.

The heat treatment method is widely used for stability of color-centers in RPLGD. It can not change physical characteristics of RPLGD. Thus, the GD-302M must undergo heat treatment at 70°C for an hour to stabilize color-centers before reading radiophotoluminescence signals with the FGD-1000 reader. A Pantak X-ray HF 420 established at the Institute of Nuclear Energy Research (INER, Taiwan) was used to generate X-ray beam. The $^{60}\text{Co}$ (dose rate 23 cGy/m) and $^{137}\text{Cs}$ (dose rate 0.33 cGy/m) sources were established at the National Yang-Ming University (NYMU, Taiwan). A Pantak X-ray unit, $^{137}\text{Cs}$ and $^{60}\text{Co}$ sources were used to irradiate the RPLGD.

2.2 Synthesis of RPLGD

Four series of homemade glass dosimeters were prepared from reagent powders of Na$_3$PO$_4$, Na$_2$CO$_3$, Al(OH)$_3$, AgCl, and P$_2$O$_5$. The melting temperature was varied from 1100 to 1300 °C, depending on the synthesis glass composition. Thermal analyzers, scanning electron microscope/energy dispersive spectrometer, and laser excited system were used to analyze the homemade glass dosimeter. The diameter of the homemade glass is 1.5 mm and 12mm in length. Some researchers pointed out that the wavelengths of radiophotoluminescence did not depend on glass material
Dmitryuk et al., 1996). The spectral range of radiophotoluminescence of silver glass was 600 to 800 nm. Therefore, the homemade glass radiophotoluminescence intensity was measured by FGD-1000. The homemade glass was exposed to gamma-rays from the $^{60}$Co source.

3. Results and discussion

3.1 Dosimetric physical characteristics of RPLGD Dose Ace system

The reproducibility of RPLGD readout value is measured with 50 GD-302Ms. The GD-302M dosimeters were irradiated 5 Gy at the NYMU using a $^{60}$Co source. The same GD-302M dosimeter was exposed and read repeatedly for five times to calculate coefficient of variation and estimate the uniformity, as shown in Fig. 1. The coefficient of variation is defined as the standard deviation divided by the average of the five readout signals. The relative radiophotoluminescence response of each GD-302M is normalized to the average of those dosimeters which were measured five times. The uniformity of the radiophotoluminescence signals from 50 GD-302Ms is $\pm$ 1.50%. Each GD-302M’s coefficients of variation were from 0.13 to 3.51. The reproducibility of the 50 GD-302Ms readout value used in this work is within $\pm$ 1.89%.

The FGD-1000 reader can be read with two modes, including standard dose range
mode (10 μGy to 10 Gy, used in dosimetry of radiation diagnosis or environmental monitoring) and high dose range mode (1 to 500 Gy, used for dosimetry in radiotherapy). The dose linearity of GD-302M to absorbed dose in the range from 0.15 to 300 cGy and the range from 10 to 10000 cGy. Fig. 2 presents the dose linearity of GD-302M. Each dose point was measured by five GD-302Ms. After running the Microsoft Excel software, R-squared values between absorbed dose and readout value were close to 1 for both standard dose range and high dose range. It is found that the absorbed dose and readout value of GD-302M was a direct proportion function. RPLGD can be used for accumulative dose measurement. The accumulative dosage measurement is shown in Fig. 3. Expose the same dosage three times in succession before reading signals with the FGD-1000 reader. Each dose point was the accumulation irradiation three times and measured by five GD-302Ms. However, RPLGD is able to correctly record accumulative dosage.

The Dose Ace system has two kinds of capsules; without energy compensation filter (GD-302M) or with tin filter (GD-352M). Generally, GD-302M for therapy dose measurement whereas GD-352M for diagnosis dose measurement. The work set 7 points within the energy range of 20 to 662 keV. That includes photon energy 20 keV, 25 keV, 30 keV, 67 keV, 119 keV, 210 keV and 662 keV (137Cs). The GD-302M energy dependence response was between –3.1% to +331% from 30 keV to 662
keV and between −3.1% to +2.6% for GD-352M, as shown in Fig 4. The relative radiophotoluminescence signal was normalized to the GD-302M and GD-352M reading of 662 keV irradiation.

The angular dependence of the GD-302M is shown in Fig 5. The relative response was normalized to the GD-302M reading of the axis at 90°. Each angle point was measured by five GD-302Ms. The radiophotoluminescence signal readout center of GD-302M is 0.7 mm from its edge. At the vertical angle of -90°, the GD-302M response is almost 14% lower than that at 0°, which was due to the radiation attenuation.

3.2 Properties of homemade radiophotoluminescent glass dosimeter

All of homemade radiophotoluminescent glass dosimeters after 60Co gamma-rays irradiation have radiophotoluminescence signals. Table 1 presents the radiation sensitivity and reproducibility of value of homemade glass dosimeters. The homemade glasses have good reproducibility of readout values, but have different radiation sensitivity values. This was because the glasses have different synthesis components. The silver concentration affects the sensitivity. When the concentration of silver increased, the color center of glass dosimeter will enhance.
4. Conclusion

Recently, some researchers pointed out that the RPLGD system was quite viable for dosimetry applications in radiation diagnosis, radiation therapy, and high energy accelerators (Araki et al., 2004 and Takayuki et al., 2005). The RPLGD is characterized by many ideal properties for clinical dosimetry, such as small size (1.5mm in diameter and 12mm in length), contamination-free, high readout value reproducibility, wide range of measurement dose (10μGy to 500Gy), able to correctly record accumulative dosage and repeat readability until annealing. These advantages were verified in this work. Based on these results we make a conclusion that RPLGD could be one of the most important radiation dose measurement instruments in the near future.

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Figure and Table Caption

Fig 1. The reproducibility of readout values of the glass dosimeter GD-302M. The error bars represent the standard deviation of five measurements.

Fig 2. Linearity in response to the glass dosimeter GD-302M. The coefficients of variation of each GD-302M were less than 3.

Fig 3. The linearity of accumulative dose measurement. Each GD-302M was irradiated three times in succession before reading the values. Each accumulative dose point represents the readout average of 5 GD-302Ms and their coefficients of variation were less than 3.

Fig 4. Relative energy response of the glass dosimeter GD-302M and GD-352M. Each energy point was measured by three glass dosimeters. The coefficients of variation of each dosimeter were less than 3.

Fig 5. The angular dependence of the glass dosimeter GD-302M. The coefficients of variation of each dosimeter were less than 3.

Table 1. The radiation sensitivity and reproducibility of readout values of homemade glass dosimeters.
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Fig 5. The angular dependence of the glass dosimeter GD-302M. The coefficients of variation of each dosimeter were less than 3.
Table 1. The radiation sensitivity and reproducibility of readout values of homemade glass dosimeters.

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The glass dosimeters were irradiated 0.2 Gy by $^{60}$Co source. The unit of readout value was $\mu$Gy.

S1 and S2: FD-7 glass dosimeter.

N series glasses: The homemade glass dosimeter compound contains Na, P, O, Al, and Ag.

H series glasses: The homemade glass dosimeter compound contains Na, P, O, Al, Cl, and Ag.

K series glasses: The homemade glass dosimeter compound contains Na, P, O, Al, Cl, and Ag.

H and K series glasses have different quenching rate.