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journal or publication title	Radiation Measurements
volume	46
number	12
page range	1571-1573
year	2011-12-01
URL	http://hdl.handle.net/2297/30104

doi: 10.1016/j.radmeas.2011.03.037

Properties of a novel radiophotoluminescent readout system using a cw modulated UV laser diode and phase-sensitive technique

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ABSTRACT

We have proposed and constructed a novel readout system for measuring a dose-dependent radiophotoluminescence (RPL) signal of a silver-activated phosphate glass dosimeter. The present reader consists of a modulated continuous-wave (cw) ultraviolet (UV) laser diode at 375 nm as an excitation and a phase-sensitive technique using a lock-in amplifier. Preliminary results using a home-made reader are compared with those of the conventional technique based on a combination of a pulsed UV N_2 laser excitation at 337 nm and a photon counting system.

PACS: 87.55. N-, 78.55 Hx, 78.70.Dm, 78.70.En

Keywords: Radiophotoluminescence (RPL), Glass dosimeter, Silver defects, Laser diode, Modulation

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1. Introduction

The silver-activated phosphate glass (designated PG:Ag) based on a RPL phenomenon has been widely used in personal and environmental monitoring of the dose (Chiyoda Technol Corporation, 2007; Ranogajec-Komor et al., 2008). When PG:Ag is exposed to ionising radiation, various colour centres such as Ag^0, Ag^{2+} and other silver-related species are produced and the existence of each these species has been confirmed by electron spin resonance (ESR) studies (Yokota and Imagawa, 1966). However, the spectral contribution of these small clusters to the overall spectrum of PG:Ag has not been elucidated until now.

Recently, we have ascribed (Kurobori et al., 2010a) these bands to X-ray-induced silver species and hole-trap centres on the basis of its strong analogy with silver-doped sodium chloride (NaCl:Ag). It was established from the peak fitting analysis, RPL decay curve analysis and heat treatments that the "A" band at 225 nm, the "B" band at 252 nm, the "C" band at 270 nm, the "D" band at 307 nm, the "E" band at 354 nm, and the "F" band at 424 nm were attributed to Ag^+, Ag_3^{2+} or Ag_3^+, Ag_2^+, Ag^{2+}, Ag^0 and hole-trap centres, respectively. Moreover, its origin and assignments of the Ag^0 centres was demonstrated to clarify the formation kinetics of silver nanoparticles in PG:Ag using a femtosecond (fs) laser pulse irradiation (Zheng and Kurobori, 2011a; Zheng et al., 2011b).

As the basic characteristics of these Ag_m^{X+} centres have been studied, a readout system has also been developed for the measurement of the RPL of the glass dosimeter (Piesch et al., 1986) based on a time-resolved technique using a pulsed UV N_2 laser excitation at 337 nm. However, in the case of a pulsed UV N_2 laser with a typical pulse width of 10 ns and repetition rate of 40 Hz, its peak power density amounts to (0.5~1) MW/cm^2. As a result, such a high peak power laser will cause the degradation of their radiation-induced colour centres after the first scanning readout-run, the instabilities of the excitation power and nonlinear effects in the sample. In contrast, in the case of a cw modulated laser diode with a repetition rate of 50 Hz, peak power density amounts to only 50 W/cm^2 in our system. As a result, much repeatable readout-runs can be done and output power is very stable for a long time without adjusting the laser system.

Recently, we proposed a new experimental technique (Kurobori et al., 2010b) to measure radiation-induced signal from a commercial RPL glass dosimeter. The purpose of this study is to construct a novel reader for the measurement of the RPL of the glass dosimeter using a modulated cw UV laser diode and phase-sensitive technique. In particular, preliminary results using a home-made reader based on the above conception are compared with those of the conventional technique based on a combination of a pulsed UV N_2 laser excitation and a photon counting system.

2. Experimental details

A commercially available GD-450 dosimeter (AGC Techno Glass) was used as the radiophotoluminescent PG:Ag. The original dosimeter plate with a size of approximately 35 × 7 × 1 mm^3 was used. The weight composition of the GD-450 dosimeter was 31.55% P, 51.16% O, 6.12% Al, 11.00% Na and 0.17% Ag. All samples were coloured by irradiation from an X-ray unit (energy=8.05 keV, $\lambda_{CuK\alpha}$=0.154 nm) with a copper target operated at 30 kV and 20 mA. In this work, the samples were irradiated such that the absorbed doses ranged from 5 to 40 mGy. Absorption, excitation and emission measurements were performed at room temperature using a Hitachi U-3900H UV-vis and an F-2500 fluorescence spectrophotometer.

3. Results and discussion

Fig. 1 shows the absorption (dashed-and-dotted line), excitation (dotted line), and RPL spectra (solid line) of the X-ray irradiated PG:Ag. For the PG:Ag sample, the excitation is in the range of 250-400 nm and the RPL is in the form of a broad band extending from 400-700 nm). The absorption spectrum is obviously due to the superposition of a number of individual absorption bands corresponding to the different colour centres, as already reported (Kurobori

et al., 2010a). The excitation spectra consist of two different bands. One spectrum peaks at 310 nm for an emission at 560 nm (orange RPL), and the other peaks at 270 and 345 nm for an emission at 470 nm (blue RPL).

The new technique utilizes a modulated UV laser diode at 375 nm line instead of a traditionally used pulsed nitrogen laser at 337 nm line. Therefore, various RPL spectra excited by the commercially available laser lines at 266, 337, 355, 375 and 405 nm and at a 310 nm peak of the excitation spectra for a X-ray irradiated PG:Ag are also shown. It was found from Fig. 1 that the intensity of the orange RPL signal excited by 375 nm line (Laser Diode) was a little weaker than that of 337 nm line (N_2 laser). Note that the lifetime value (~5.6 ns) of the blue RPL at 470 nm is much shorter than that (~2170 ns) of the orange RPL at 560 nm and moreover, the 270 nm excitation band attributed to the Ag_2^+ centres (reaction: $Ag^0 + Ag^+ \rightarrow Ag_2^+$) is very unstable compared to the 345 nm band attributed to the Ag^0 centres (reaction: $Ag^+ + e^- \rightarrow Ag^0$) (Kurobori et al., 2010b).

The experimental setup for the RPL measurement is as follows: The excitation source is a 16-mW, cw laser diode (Coherent, CUBE 375-16C) at 375 nm that provides a linearly polarised output beam with $M^2 < 1.2$. The laser diode could be modulated by a rectangular waveform at frequencies up to 70 kHz (average power: P_{ave}=2.5 mW, peak power density: P_{peak}< 50 W/cm^2) and a portion of the driving voltage was fed as a reference signal of a lock-in amplifier (NF, LI-574A). The blue and orange RPLs were detected with a

photomultiplier (Hamamatsu, R1463) through appropriate filters and then amplified by a lock-in amplifier.

The relationship between the RPL intensity signal and the absorbed dose of the glass dosimeter ranging from 5 to 40 mGy for X-ray source was shown in Fig. 2. After running the Origin software, R-squared value between the absorbed dose and readout value was close to 1. It was found that the absorbed dose and readout value was a direct proportion function.

Figs. 3(a) and (b) show the typical RPL intensity signals measured using different readout systems. In general, the glass dosimeter GD-450 used in this work is set in a plastic badge with embedded plastic and metal filters used for the discrimination of radiation (Juto, 2002a). The PG:Ag sample with a plastic badge shielded by two kinds of plastic filters (P1 and P2) and three kinds of metal filters (Al, Cu and Sn) was irradiated by an X-ray source. Each signal was detected at the place of each filter position. Fig. 3(a) shows the RPL intensity (in count) ratio obtained from the traditional technique based on a combination of a pulsed UV N_2 laser excitation and a photon counting system. Each dose value in turn was 27.4, 26.4 and 6.42 mGy at the position of P1 (plastic filter, 0.2-mm-thickness), P2 (plastic filter, 0.5-mm-thickness) and Al (0.7-mm-thickness).

Fig. 3(b) shows the RPL intensity (in volt) obtained from the new technique at the place of each filter position using the same X-ray irradiated sample. The RPL intensity curve was recorded according to the following procedure: Firstly, before X-ray irradiation, the

background signal (dashed-and-dotted line) corresponding to the pre-dose fluorescence of the glass surface, stray light and dirt was obtained from the sample at the same sensitivity of the RPL signal. Secondly, the RPL signal was measured by repeatedly scanning irradiated areas of the samples with an appropriate time constant of a lock-in amplifier and with appropriate filters. As a result, the blue RPL signal with much shorter lifetime value will be automatically removed. Finally, the RPL intensity was obtained by subtracting the averaged background signal from the averaged RPL value.

As a result, each dose value was estimated to be 25.7, 24.3 and 6.20 mGy at each position of P1, P2 and Al filters, respectively, by the use of the linear relationship between the RPL intensity and absorbed dose as shown in Fig. 2. Moreover, the use of various filters gives additional information about incident radiation qualities such as gamma-, beta- and X-rays by measuring the RPL intensity ratio (Juto, 2002b). In this case, the RPL ratio for the X-ray irradiated sample was similar to that of beta-rays, which may be due to the low energy photons of 8.05 keV used in this work. However, more detailed information is needed for a satisfactory explanation.

4. Conclusions

The data obtained in this study allow for the following conclusions: Preliminary experimental results were demonstrated using a home-made reader based on a modulated UV laser diode and a phase-sensitive technique that we proposed and constructed. It was confirmed from the comparison between the conventional- and novel-readout techniques that the novel readout system with a modulated cw UV laser diode as an excitation and phase-sensitive technique has considerable potential for the measurement of the RPL of the glass dosimeters.

Acknowledgements

We would like to thank Prof. H. Nanto at Kanazawa Institute of Technology for his valuable discussion.

Figure captions

Fig.1 Absorption, excitation and RPL spectra of PG:Ag after X-ray irradiation. Excitation spectra were detected at 470 nm and 560 nm. RPL spectra were excited at corresponding available laser lines (i.e., 266, 337, 355, 375 and 405 nm) and at a 310 nm peak.

Fig. 2 Relationship between the RPL intensity and absorbed dose of the glass dosimeter.

Fig. 3 (a) RPL intensity ratio obtained from the traditional technique and (b) the RPL intensity obtained from the present technique at the place of each filter position (P1, P2, Al, Cu and Sn).

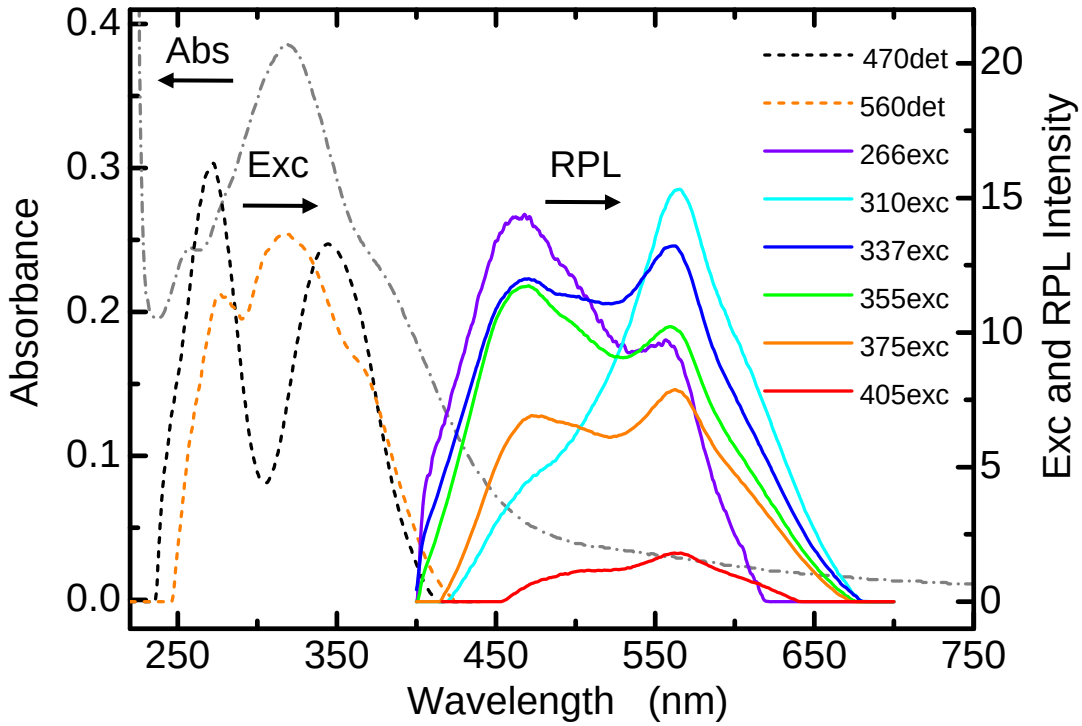

Fig. 1 C. Zhao et al.

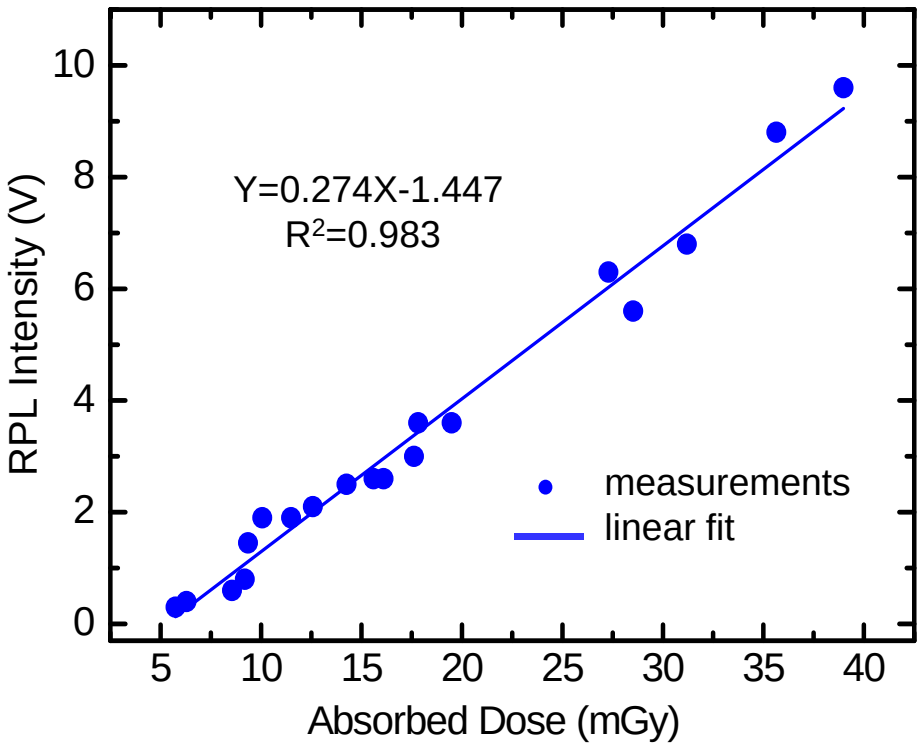

Fig.2 C. Zhao et al.

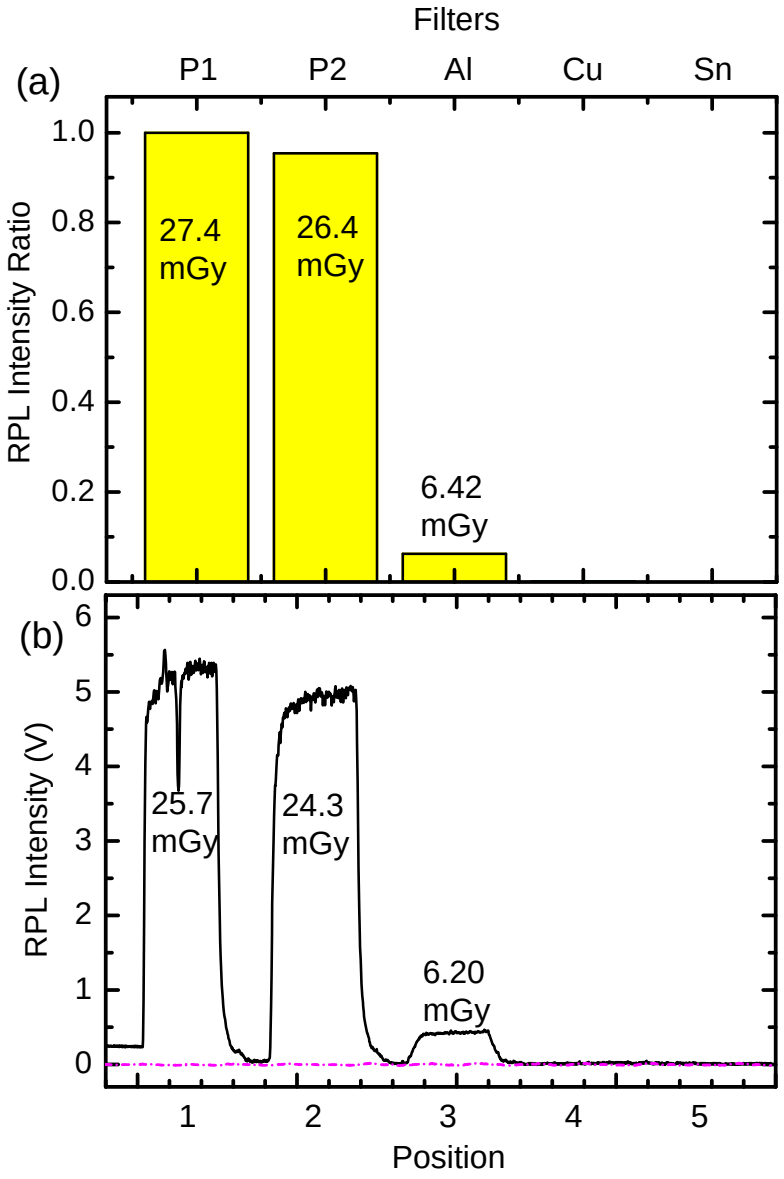

Fig.3 (a), (b) C. Zhao et al.

References

Chiyoda Technol Corporation, 2007. <http://www.c-technol.co.jp/technol_eng/>

Juto, N., 2002a, FB News, No. 308, 10-14 (in Japanese).

Juto, N., 2002b, FB News, No.309, 5-9 (in Japanese).

Kurobori, T., Zheng, W., Miyamoto, Y., Nanto, H., Yamamoto, T., 2010a. The role of silver in the radiophotoluminescent properties in silver-activated phosphate glass and sodium chloride crystal. Opt. Mater. 32 (9), 1231-1236.

Kurobori, T., Zheng, W., Zhao, C., 2010b. Silver-activated radiophotoluminescent glass: band assignments and a novel readout system using a modulated UV laser diode. IOP Conf. Series: Mater. Sci. Eng. 15(1), 012026-012033.

Piesch, E., Burgkhardt, B., Fischer, M., Röber, H. G., Ugi, S., 1986. Properties of radiophotoluminescent glass dosimeter systems using pulsed laser UV excitation. Radiat. Prot. Dosim. 17 (1-4), 293-297.

Ranogajec-Komor, M., Knezevic, Z., Miljanic, S., Vekic, B., 2008. Characterisation of radiophotoluminescent dosimeters for environmental monitoring. Radiat. Meas. 43 (2-6) 392-396.

Yokota, R., Imagawa, H., 1966. Radiophotoluminescent centers in silver-activated phosphate glass. J. Phys. Soc. Jpn. 23 (5), 1038-1048.

Zheng, W., Kurobori, T., 2011a. Assignments and optical properties of X-ray-induced colour centres in blue and orange radiophotoluminescent silver-activated glasses. J. Lumin. 131 (1) 36-40.

Zheng, W., Kurobori, T., Miyamoto, Y., Yamamoto, T., 2011b. Formation and assignment of silver defect centres in phosphate glass induced by femtosecond laser pulses, to be published to Radiat. Meas.