A CaS:Ce,Sm-based dosimeter for online dosimetry measurement

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Abstract A film dosimeter based on optically stimulated luminescence (OSL) material of CaS:Ce,Sm was developed for online irradiation dosimetry measurement. The stimulation is provided by a laser with a wavelength of 980 nm, and the OSL luminescenceis collected by a photodiode. Using ^{60}Co *γ*-rays, we investigated the dosimetry characteristic of the dosimeter at different dose rates and total doses. The real-time detection results showed that the OSL signals versus total ionizing dose exhibited a good linearity in a dose range of 0.1–185 Gy.

Key words OSL, CaS:Ce, Sm, Online dosimeter, Radiation dosimetry

1 Introduction

With advances in laser and optical storage technology, optically stimulated luminescence (OSL) materials are extensively used on infrared detection and imaging, optical information processing, radiation dosimetry etc. A series of work on this material and its application have been conducted by researchers[1,2].

OSL technology, which is of quick reading, online resetting, and low power consumption, is an ideal way of radiation dosimetry. An OSL dosimeter based on SrS proposed by Ravotti F *et al.* [3] at CERN in 2004 was designed for the international space station. And studies on OSL dosimeters have been done at the University of Montpellier II[4–8]. In China, an Al_2O_3:C-based OSL dosimeter was developed by Tang Q *et al.*[9] in 2007, with a dose response range of 0.1–10 Gy. However, its bleaching time of 1000 s is too long for online measurement. In addition, the stimulated spectrum of Al_2O_3:C overlaps the emission spectrum, adding a difficulty in its OSL application.

In this work, OSL material of CaS:Ce,Sm was used as an on-line dosimeter for *γ*-ray irradiation. The spectral and off-line dosimetry characteristics of CaS:Ce,Sm have been investigated in our previous work[10,11], with stimulated spectrum of 750–1300 nm and emission spectrum of 450–650 nm.

The stimulation system is a laser, instead of LED used in Ref.[9]. This cuts down the bleaching time to just a few seconds, making it suitable for real-time detection. In this paper, we report the on-line dosimetry characteristics and the real-time detection results of the dosimeter.

2 OSL principle and experimental setup

2.1 OSL principle

As a wide band-gap semiconductor material, CaS has a band-gap of 2.4 eV, the doped lanthanide elements of Ce and Sm provide trap levels and recombination centers. As shown in Fig.1, the electronic transition can be divided into three phases[12]. Under a radiation environment, the ionizing radiations create a large amount of electron-hole pairs in the OSL material. Some of the free electrons recombine promptly, while the others are trapped for a long time. Stimulating the material with a proper optical wavelength provides the necessary activation energy, and the electrons are released from the traps. The electron recombination yields photon emission, and, the number of photons

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emitted is proportional to the dose deposited in the material, hence the way of evaluating the dose.

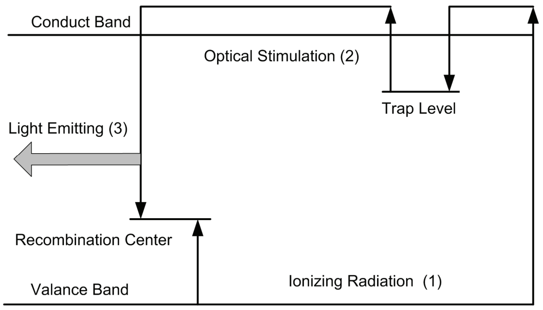

Fig.1 OSL schematic diagram of the electronic transition.

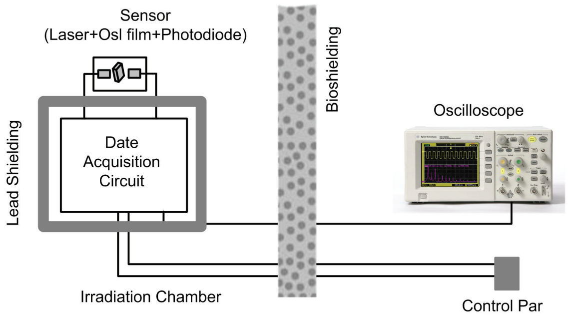

Fig.2 Schematics of the irradiation test experiment.

2.2 Experimental

The experiment was carried out in a ^{60}Co γ-ray source at dose rates of 0.66–216 rad(Si)/s and room temperature. Fig.2 is a schematic view of the irradiation test experiment, with the sensor and data acquisition circuit placed in the irradiation chamber. The circuit was shielded by Pb to protect it from radiation damage. The sensor was consisted of a laser with a wavelength of 980 nm to provide the stimulation, an OSL film made of CaS:Ce,Sm to measure the dose, and a photodiode to collect the luminescent of the OSL film.

With a 25-m cable feedthrough the lead and concrete shieldings, the sensor was connected to an oscilloscope to record the OSL signal, and a control panel to control stimulation time of the laser. The irradiation time was calculated at different dose rates, and a stopwatch was used to record irradiation time.

3 Results and Discussion

3.1 OSL decay characteristic

The OSL decay curves in Fig.3 show that the number of trapped electrons depends on the irradiation dose of the material. The laser was turned on (at t=0) after irradiating the OSL film for a while (at t<0).

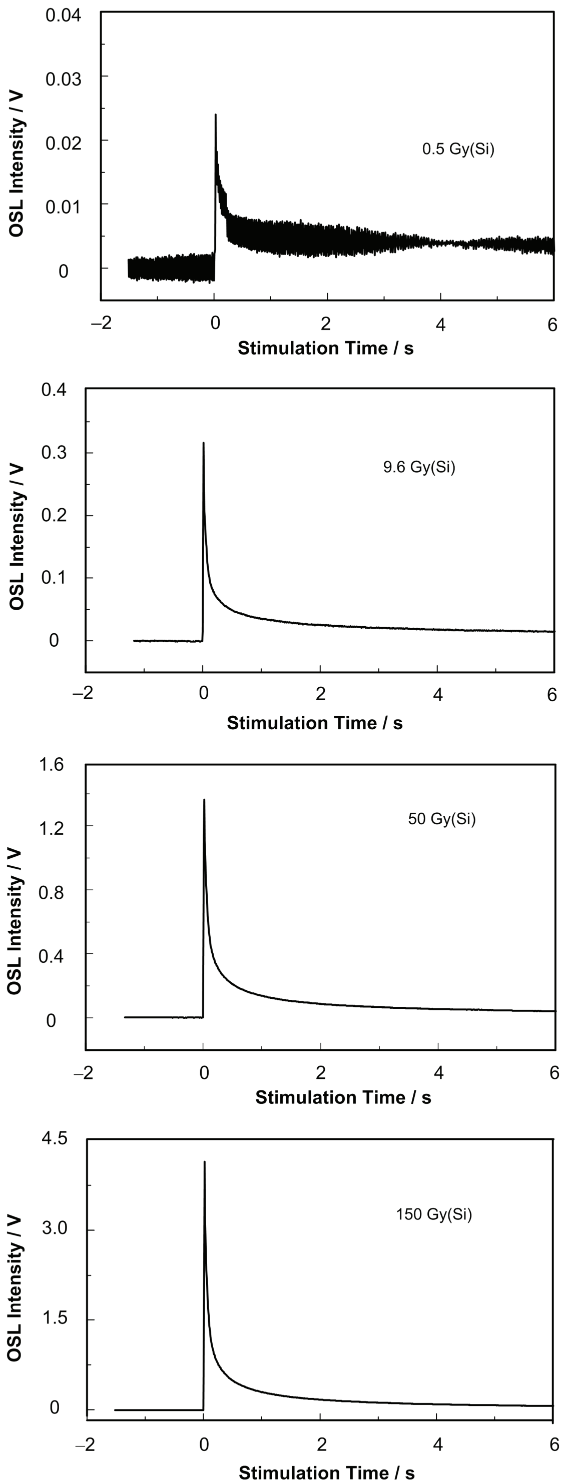

Fig.3 Different OSL decay curve at four total ionizing doses.

The OSL signal decays with the stimulation. The signal decay can be modeled with an exponential law[6]:

$$S_{\mathrm{OSL}}(t) = KN(D)F\ \exp(-\sigma Ft) \qquad (1)$$

where, K is a constant depending on both material and data acquisition circuit; D is the total irradiation dose of the material; N is the number of trapped electrons, which depends on D, F is a constant of stimulation flux, σ is cross section of the stimulated de-trapping process; and t is the stimulation time.

After a stimulation time of t, the ratio,

$$S_{OSL}(t)/S_{OSL}(0) = \exp(-\sigma Ft). \quad (2)$$

When σ is constant, at the same ratio, the bigger value of F is, the shorter the stimulation time of t is. The F of laser is much bigger than that of LED, so a much shorter bleaching time is obtained. It can be seen from Fig.3 that no matter what the total irradiation dose is, the OSL signal decays to 10% of the peak value after 2 seconds of stimulation, which is much shorter than the dosimeter Al_2O_3:C in Ref.[9]. A stimulation time of 10 seconds is enough for the dosimeter to reset according to the curves. In the on-line system, the stimulation time is just the reading or the bleaching time.

Unlike an off-line system, all our experiments were carried out in the irradiation stage, so during the bleaching time, the OSL film received an additional amount of irradiation dose. However, Fig.3 shows that the extra dose did not have much impact on the curve, because the stimulation provided by the laser would release promptly the trapped electrons caused by the extra dose. But a longer bleaching time would cause more loss of the dose measured, so in the continuous measurement of on-line system, a shorter bleaching time makes it suitable for real-time detection.

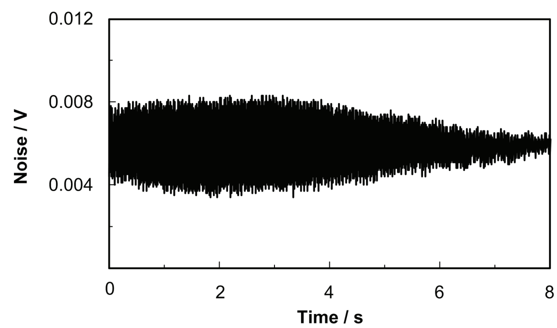

Fig.4 Noise without stimulation of the on-line system.

As shown in Fig.4, depending on the dosimeter and irradiation dose, the signal was inevitably affected by a noise of about 8 mV. This can be seen clearer at low doses. In addition, the 25-m cable of the online system introduced a big noise. Fig.3 shows that there is an obvious noise at 0.5 Gy. With increasing doses, the SNR (signal-to-noise ratio) of the system became bigger, and the impact of the noise on the signal became smaller. However, the existence of noise reduces sensitivity of the dosimeter. To obtain a better sensitivity, the dosimeter system needs to be optimized in our future work.

3.2 Total dose response

As shown in Fig.3, on switching on the laser, the OSL signal get the peak value immediately, the rising time of the luminescence can be considered as negligible, i.e the peak value of the signal is obtained at t=0. From Eq.(1), the peak value is given by,

$$S_{peak} = S_{OSL}(0) = KN(D)F \quad (3)$$

As the K and F are constant, the peak value of OSL signal is a function of the dose, i.e the relationship between the OSL signal and the dose provides a way for the dosimetry measurement.

The OSL film was irradiated to 0.1–150 Gy, and the peak values of OSL signal were recorded. The relationship between the OSL signal and dose is shown in Fig.5. A linear fitting of the dose response indicates that the R-square is 0.99961, which means that the OSL signal versus the total dose has a good linearity in the dose range of 0.1–150 Gy.

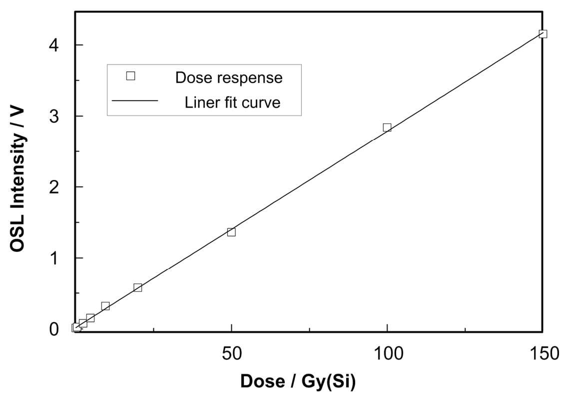

Fig.5 Dose response with dose range of 0.1–150 Gy.

The dosimeter was also tested at the dose rate of 50 rad/s. As shown in Fig.6, when the dose exceeded 185 Gy, the peak value kept at 4.85 V, so the dosimetry upper limit of the dosimeter is 185 Gy.

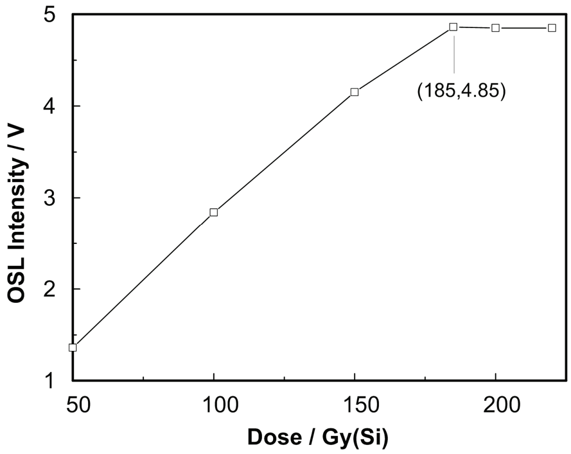

Fig.6 Dosimetry upper limit of the dosimeter obtained at the dose rate of 50 rad/s.

The 4.85-V saturation can be due to the OSL material. The measured OSL signal is proportional to the trapped electrons induced by the irradiation. However, the number of traps introduced by the Ce- and Sm-doping in the CaS is finite, when all the traps are full, the electrons induced by further irradiation would not be tapped, hence the saturation.

Also, the saturation can be due to the data acquisition circuit. The operational amplifier has a driving voltage of ±5 V. Theoretically, the data acquisition circuit measures signals from −5 V to +5 V, but actually the minimum and maximum amplitude of measured signals may be a little less than −5 V and +5 V. Then, the saturation value of 4.85 V is possibly caused by the circuit.

3.3 Dose rate dependence

Total dose and dose rate are important parameters in radiation dosimetry. The proposed methodology is based on the assumption that the OSL signal depends on the total ionizing dose rather than dose rate, and the measured dose is not affected by the dose rate. To ensure measurement accuracy of the dosimeter in actual application, its dose rate dependence was studied.

To investigate a possible dose rate dependence of the dosimeter, the OSL films were irradiated at dose rates of 4, 8 and 12 rad/s to total doses of 2.4–24 Gy. The experiments were done at room temperature.

As shown in Fig.7, for all the three dose rates, the OSL response exhibits linearity. Little variations were observed among the signals at the same total dose. These could be caused by the noise of the circuit and the environment. The manual control of the irradiation time could contribute to the errors, too. However, the overlapped OSL response curves of different dose rates indicate that the OSL signal does not depend on dose rate. This is consistent with the result of Pierre Garcia *et.al* [13].

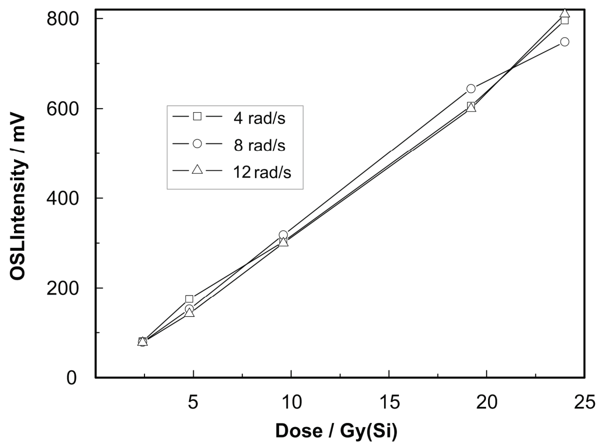

Fig.7 Dose response at three different dose rates.

4 Conclusions

The OSL dosimeter based on CaS:Ce,Sm developed at our laboratory was primarily devoted to on-line measurement in space. The stimulation time of 10 s makes it easy to reset the dosimeter. The OSL signal versus total dose exhibits a good linearity in a dose range of 0.1–185 Gy. These make the OSL dosimeter a suitable candidate for real-time dosimetry applications. Sensitivity of the dosimeter system will be optimized in our future work.

References

1 Kravets V G. Opt Mater, 2001, **16:** 369–375.

2 He Z Y, Wang Y S, Sun Li, *et al.* J Optoelectron Lasers, 2003, **14:** 729–732.

3 Ravotti F, Glaser M, Moll M, *et al.* IEEE Trans Nucl Sci, 2004, **51:** 3642–3648.

4 Benoit D, Ravotti F, Garcia P, *et al.* Phys Stat Sol, 2008, **205:** 1196–1202.

5 Ravotti F, Glaser M, Idri K, *et al.* Nucl Sci, 2005, **52:** 1568–1573.

6 Vaillé J R, Ducret S, Idri K, *et al.* Nucl Sci, 2003, **50:** 2358–2362.

7 Ravotti F, Benoit D, Lefebvre P, *et al.* J Appl Phys, 2007, **102:** 123102.

8 Vaillé J R, Ravotti F, Garcia P, *et al.* IEEE Trans Nucl Sci, 2005, **52:** 2412–2416.

9 Tang Q, Ma W J, Liu X W, *et al.* Nucl Technol, 2007, **30:** 917–919.

10 Liu Q J, Chen Z Y, Fan Y W, *et al.* Nucl Electron Detect Technol. 2007, **27:** 350–353.

11 Liu Q J, Chen Z Y, Fan Y W, *et al.* Atomic Energy Sci Technol, 2007, **41:** 390–393.

12 Chen R, Pagonis V, Lawless J L. Radiati Meas, 2010, **45:** 277–280.

13 Garcia P, Vaillé J R, Benoit D, *et al.* IEEE Trans Nucl Sci, 2007, **54:** 2272–2275.