A study on the real-time radiation dosimetry measurement system based on optically stimulated luminescence*

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Abstract The optically stimulated luminescent (OSL) radiation dosimeter technically surveys a wide dynamic measurement range and a high sensitivity. Optical fiber dosimeters provide capability for remote monitoring of the radiation in the locations which are difficult-to-access and hazardous. In addition, optical fiber dosimeters are immune to electrical and radio-frequency interference. In this paper, a novel remote optical fiber radiation dosimeter is described. The optical fiber dosimeter takes advantage of the charge trapping materials CaS:Ce, Sm that exhibit OSL. The measuring range of the dosimeter is from 0.1 to 100 Gy. The equipment is relatively simple and small in size, and has low power consumption. This device is suitable for measuring the space radiation dose and also can be used in high radiation dose condition and other dangerous radiation occasions.

Key words optically stimulated luminescence, online and realtime, dosimeter

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1 Introduction

In many radiation facilities that produce high dose such as nuclear power plant, radiation processing accelerators, nuclear medicine or medical radiotherapy, there are safety hazards of ionizing radiation injury. In medical radiation, physician must calculate the appropriate dosage to radiation tumor periphery. At present in vivo radiation therapy of new technologies, such measurement requires corresponding short time, high sensitivity (100 μGy)[1], online and real-time monitoring of the radiation dose to a certain region size. Meanwhile, the establishment of the real-time monitor integrated circuit to receive and accumulate the radiation dose of the survey technology will have a significance regarding the electronic device radiation hardness research. So more researches on the real-time and online monitoring of the radiation dose is needed.

2 The OSL materials

2.1 Basic mechanism

The optically stimulated luminescence (OSL) results from a process starting a wide band gap semiconductor or insulator, as shown in (1) on Fig. 1. Ionizing radiation creates a large amount of trapped carriers in the material. Some charges remain trapped on the localized defects after irradiation for a time period depending on the temperature and the activation energy of the traps. Stimulation of the material optically (2) will provide the energy to release the trapped charge. A subsequent radiative recombination may be observed (3) as shown in Fig. 1. Quantifying the amount of emitted light makes it possible to evaluate the energy absorbed by the material. It is interesting to note that, from an external point of view, OSL can be considered as an anti stokes phe-

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nonmenon since the wavelength stimulation is greater than the wavelength of the luminescence[2—11].

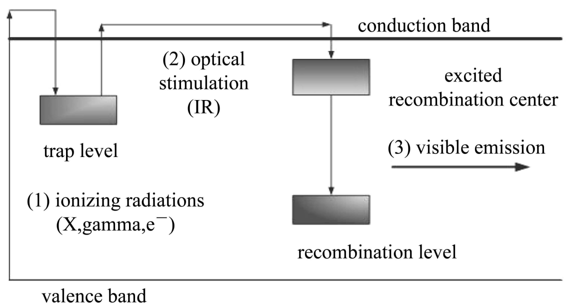

Fig. 1. Basic mechanism of the optically stimulated luminescence.

2.2 The main families of OSL materials

The major families, known for their high luminescence yields are listed in Table 1, along with their material, stimulation and emission wavelengths. The intrinsic ability to store charges for a long period of time and the efficiency of the luminescence is the major criterion for selecting OSL materials. This efficiency is strongly dependent on the doppants and their concentration. Another important criterion can be deduced from table, the separation of the stimulation and the emission spectra. An overlap in the spectra makes it difficult or is impossible to discriminate the emission from the stimulation.

Table 1. Summary of the major OSL materials and their characteristic wavelengths.

material	stimulation/nm	emission/nm
MgS:Ce,Sm	800—1500	500—700
SrS:Eu,Sm	900—1400	550—750
BaFX,X=Cl,Br,I	470—630	350—450
NaCl:Cu	400—500	325—375
KCI:Eu	450—650	400—450
KBr:In	500—700	400—600
RbBr:Ti	600—800	300—450
BbI:In	600—800	350—450
A-AI_2O_3	300—450	350—500
CaS:Ce,Sm	850—1200	450—650

2.3 Basic OSL properties of the CaS:Ce,Sm

CaS:Ce,Sm, as an OSL material allows a wide range of stimulation wavelengths from 0.8 to 1.5 microns and the emission is observed from 0.4 to 0.6 microns. Since the stimulation and the emission spectra are separated, it is possible to discriminate the OSL from the stimulation using an adequate optical method. The intensity of light emission can be detected by the PMT (photoelectric multiple tube) to measure the emission spectrum. Fig. 2 shows the X-ray diffraction pattern of CaS:Ce,Sm.

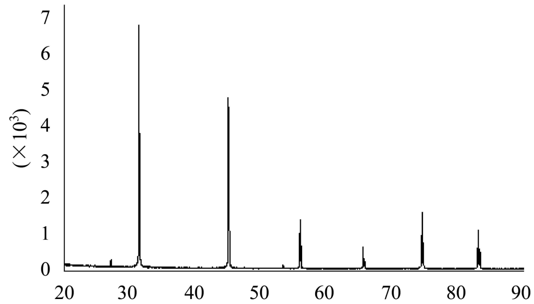

Fig. 2. The X-ray diffraction pattern of CaS:Ce,Sm.

Figure 3 shows the optically stimulated luminescence spectrum of CaS:Ce,Sm with a peak wavelength of 1104.9 nm. Fig. 4 shows the optically stimulated luminescence spectrum of CaS:Ce,Sm with a peak wavelength of 513.4 nm.

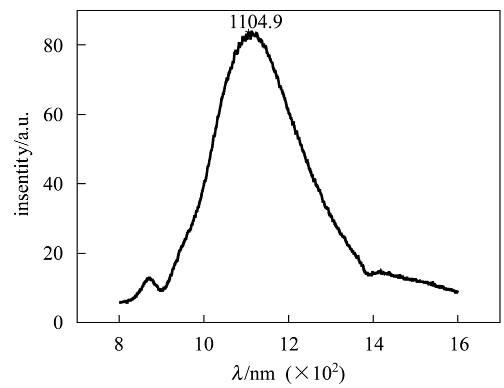

Fig. 3. Stimulation spectrum of OSL emission for CaS:Ce,Sm.

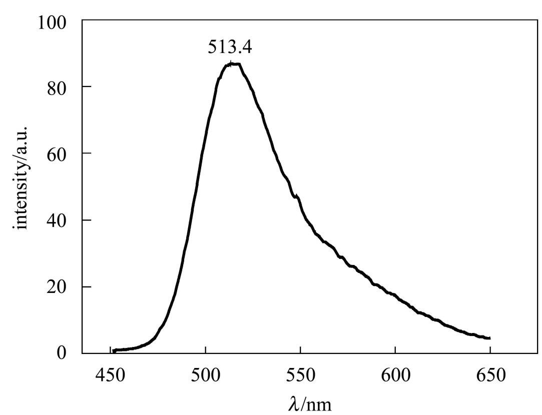

Fig. 4. The optically stimulated luminescence spectrum of CaS:Ce,Sm.

3 Experimental details

The schematic diagram of the portable fiber-optics reader based on OSL material CaS:Ce,Sm is presented in Fig. 5. All the electrical and optical components used are commercially available. The main optical components, the laser and the detector PMT are contained in a light-tight box. A fiber-optics cable is connected to the reader and dosimeter. Stimulation light from the laser is collimated on one end of the optical fiber.

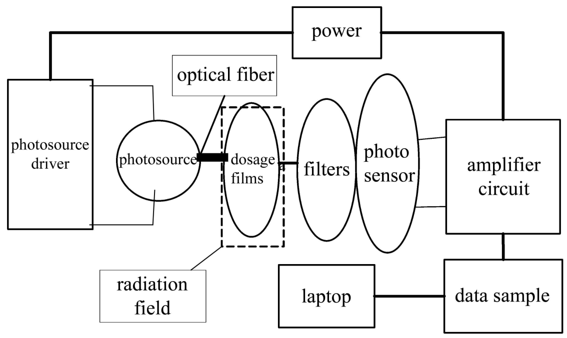

Fig. 5. The block diagram of the OSL online dosimeter.

The dosimeter is placed in a remote location, and is attached to the other end of the optical fiber. The luminescence light emitted by the CaS:Ce,Sm is transported back to the light-tight box through the same optical fiber. The blue luminescence is deflected through 90° by the beam splitter, separated from the laser by the filter pack, and measured by the PMT. The output of PMT is connected to the amplifier circuit and then to the National Instruments (NI) DAQ6210, which samples the PMT output, and a digital output port is used for the software-controlled modulation of the laser beam. Another digital port provides the power supply of the PMT. Additional components not presented in the diagram are the power supplies for the laser.

A segment of plastic tube, matched to the diameter of the optical fiber, is sealed at one end. After the dosimeter sample is placed into the resulting enclosure, the free end of the optical fiber is forced through the same opening of the plastic tube, until it contacts the OSL materials. The dosimeter and the adjacent fiber are covered with light-tight plastic box. The resulting structure is described in Fig. 6.

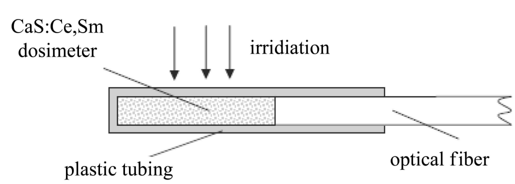

Fig. 6. The schematic of fiber-sample connection diagram.

4 Experimental results and discussions

4.1 Dosage collection

Figure 7 represents the typical signal shape of an OSL. It is shown that when CaS:Ce,Sm material is stimulated by infrared light, the response time of luminescence intensity is very short. Meanwhile, the attenuation of stimulated luminescence signal is obvious. It means that the material is a short afterglow material. According to the spectrum of stimulation and stimulated luminescence of CaS:Ce,Sm material, we can apply it to measure radiation dose.

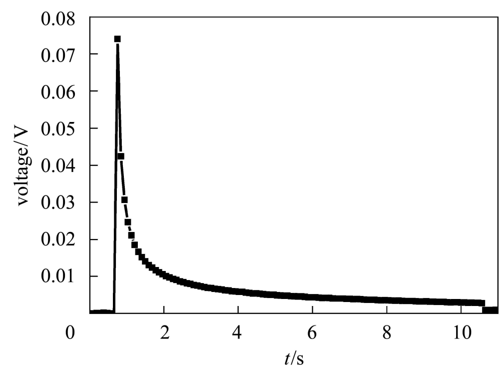

Fig. 7. The typical signal shape of an OSL.

The OSL films and optical fiber are coupled together as a dosimeter probe. According to the stimulation spectrum and optically stimulated luminescence spectrum of CaS:Ce,Sm material (Figs. 3 and 4), the 1064nm Nd.YAG laser is used as the infrared excitation source to stimulate OSL material. The probe is placed in ^{60}Co-γ radiation field, to measure different exposure dosage, a PMT is used to accept the OSL signal. A NI DAQ acquisition card is used to collect the signal. The radiation dose response curve of OSL film exposed in the ^{60}Co-γ radiation is shown in Fig. 8.

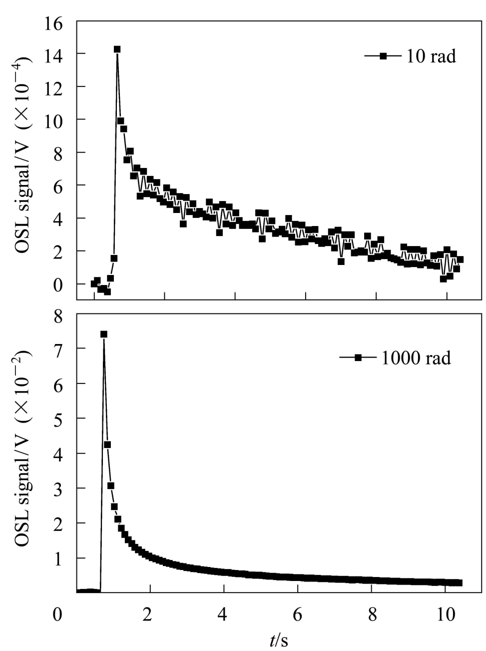

Fig. 8. Glow curves for CaS:Ce,Sm irradiated by different radiation doses.

4.2 Dosage calibration

A series of experiments have been performed using a ^{60}Co-γ source. The curve presented in Fig. 9 is recorded by increasing the dose step by step, varying both the distance source to sample and the exposure time to explore a 3 orders of magnitude range of doses. It demonstrates that there is a good linear relationship between stimulated luminescence signal values of CaS:Ce,Sm material and the dose. This is a very satisfactory result.

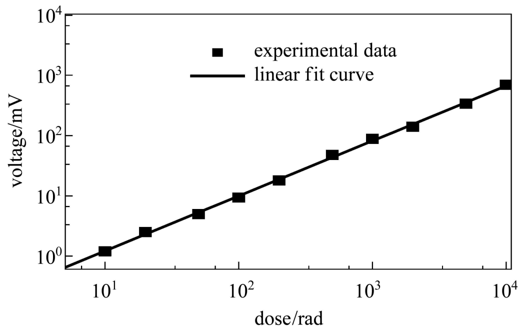

Fig. 9. The calibration curve of the OSL online dosimeter.

5 Conclusion

The OSL radiation dosimeter technically surveys a board dynamic measurement range and a high sensitivity. Optical fiber dosimeters provide an opportunity to perform remote radiation dosimetry measurements under a variety of environmental conditions that would preclude or limit the use of other dosimetry techniques. The equipment based on the CaS:Ce,Sm material is relatively simple and small in size, and has low power consumption. This device is suitable for measuring the space radiation dose; it also can be used in the high radiation dose condition and other dangerous radiation occasions. This device also has a good application. The future of the OSL relies on the fabrication of thin layer directly on active pixel sensors, or any other fast photo detector that could take advantage of the ns time constant, to push further the limits of the real time dosimetry. So there is still considerable room for improvement in optical fiber dosimetry technology including the development of materials with deeper, more stable traps as well as the development of analysis techniques that can account for the dynamic response of the materials to the radiation environment.

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