Available online at www.sciencedirect.com
ScienceDirect
Progress in Natural Science 18 (2008) 1203–1207
Progress in Natural Science
www.elsevier.com/locate/pnsc

Design of a novel optically stimulated luminescent dosimeter using alkaline earth sulfides doped with SrS:Eu,Sm materials

Yanping Liu[a,b], Zhaoyang Chen[a,*], Yanwei Fan[a], Weizhen Ba[a], Wu Lu[a], Qi Guo[a], Shilie Pan[a], Aimin Chang[a], Xinqiang Tang[a]

[a] *Xinjiang Technical Institute of Physics & Chemistry, Chinese Academy of Sciences, 40-1 South Beijing Road, Urumqi 830011, China*
[b] *Graduate School of Chinese Academy of Sciences, Beijing 100049, China*

Received 7 November 2007; received in revised form 10 April 2008; accepted 29 April 2008

Abstract

Optically stimulated luminescence (OSL) is the luminescence emitted from an irradiated insulator or semiconductor during exposure to light. The OSL intensity is a function of the dose of radiation absorbed by the sample and thus can be used as the basis of a radiation dosimetry method. Alkaline earth sulfides doped with rare-earth elements such as Ce, Sm and Eu are OSL dosimeters having very high sensitivity, and the OSL with a short time constant is separated from the stimulated light. In this paper, a novel OSL dosimeter designed with SrS:Eu,Sm materials is described. The dosimeter takes advantage of the characteristics of charge trapping materials SrS:Eu,Sm that exhibit OSL. The measuring range of the dosimeter is from 0.01 to 100Gy. The equipment, which is relatively simple and small in size, is promising for applications in space exploration and high dose radiation dosimetry.

Keywords: Optically stimulated luminescence; Radiation measurement; Dosimeter; Radiation protection

---

1. Introduction

Optically stimulated luminescence (OSL) technology is a dramatic breakthrough in radiation detection. The key to OSL technology is the detector material used. Alkaline earth sulfides doped with Ce (Eu), Sm ions have two important characteristics necessary for OSL dosimetry: the thermally stable deep traps and an optical stimulation spectrum in the infrared region [1,2]. The most predominant application in the market is the use of OSL as a dosimeter for measuring personnel radiation exposure [3–5]. For over 50 years Landauer has maintained its leadership in dosimeter manufacturing and dosimetry analysis services that now incorporate the OSL technology. OSL is the luminescence emitted from an irradiated insulator or semiconductor during exposure to light. The OSL intensity is a function of the dose of radiation absorbed by the sample and thus can be used as the basis of a radiation dosimeter method. The process begins with the radiation-caused ionization of valence electrons to form electron/hole pairs, which would be localized through non-radiative trapping transitions. Subsequent illumination of the irradiated sample leads to energy absorption of the trapped electrons for their transitions from the localized trap into the delocalized conduction band. Recombination of the freed electrons with the localized holes results in radiative emission and luminescence, which is the OSL signal, the intensity of which is proportional to the dose of absorbed radiation [6–11].

2. Properties of OSL materials and principles of dosimetry

2.1. OSL materials for the measurement of radiation dose

Rare-earth-doped alkaline sulfides have been known for a long time as efficient phosphors exhibiting both thermolumi-

---

[*] Corresponding author. Tel.: +86 991 3850821; fax: +86 991 3838957.
E-mail address: czy@ms.xjb.ac.cn (Z. Chen).

1002-0071/$ - see front matter © 2008 National Natural Science Foundation of China and Chinese Academy of Sciences. Published by Elsevier Limited and Science in China Press. All rights reserved.
doi:10.1016/j.pnsc.2008.04.002

nescence and OSL. During the emission of irradiation from an insulator, the ionizing radiation creates a large number of charges in the oxide, some of which remain trapped on localized defects after the irradiation [12–14]. The time period of the trapping depends on the temperature, activation energy of the traps, and the type of ionizing radiation. Stimulating the material thermally or optically provides the energy necessary to release the trapped charges and a radiative recombination may be observed. The number of emitted photons is proportional to the deposited dose [15–18]. The basic mechanism of the OSL is illustrated in Fig. 1, which shows that OSL results from a process starting from a wide band gap semiconductor or insulator. Ionizing radiation creates in the material a large number of trapped carriers. Some charges remain trapped on localized defects after irradiation for a time period depending on the temperature and the activation energy of the traps. Stimulating the material optically will provide the energy necessary to release the trapped charge. Then a subsequent radiative recombination may be observed. Quantifying the amount of emitted light makes it possible to evaluate the energy absorbed by the dosimeter. It is interesting to note that from an external point of view OSL can be considered as an anti-Stokes phenomenon because the stimulation wavelength is higher than the wavelength of the luminescence [19–23].

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 are the major criteria for selecting OSL materials. This efficiency is strongly dependent on the dopants and their concentration. Another important criterion can be deduced from Table 1, the separation of the stimulation and the emission spectra. An overlap in the spectra makes it difficult or 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
KCl:Eu	450–650	400–450
KBr:In	500–700	400–600
RbBr:Ti	600–800	300–450
RbI:In	600–800	350–450
$\text{A-Al}_2\text{O}_3$	300–450	350–500
CaS:Ce,Sm	850–1200	450–650

2.3. *Basic OSL properties of SrS:Eu,Sm*

The alkaline earth sulphide family of compounds (CaS, SrS, and MgS) has been used in OSL dosimetry since OSLs were firstly suggested as a potential dosimetric method. SrS:Eu,Sm as an OSL material allows a wide range of stimulation wavelengths (0.8–1.5 μm) to emit 0.45–0.70 μm luminescence. As the spectra of the stimulation and emission are separated, it is possible to discriminate the OSL from the stimulation using an adequate optical method. The stimulation can be effectively done using an Nd:YAG laser. The light emission can be detected by a photodiode.

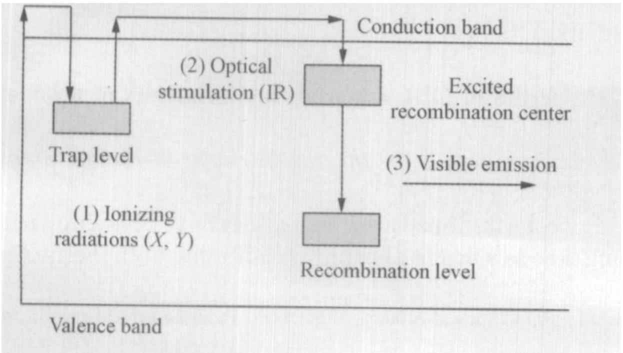

Fig. 1. Basic mechanism of the optically stimulated luminescence.

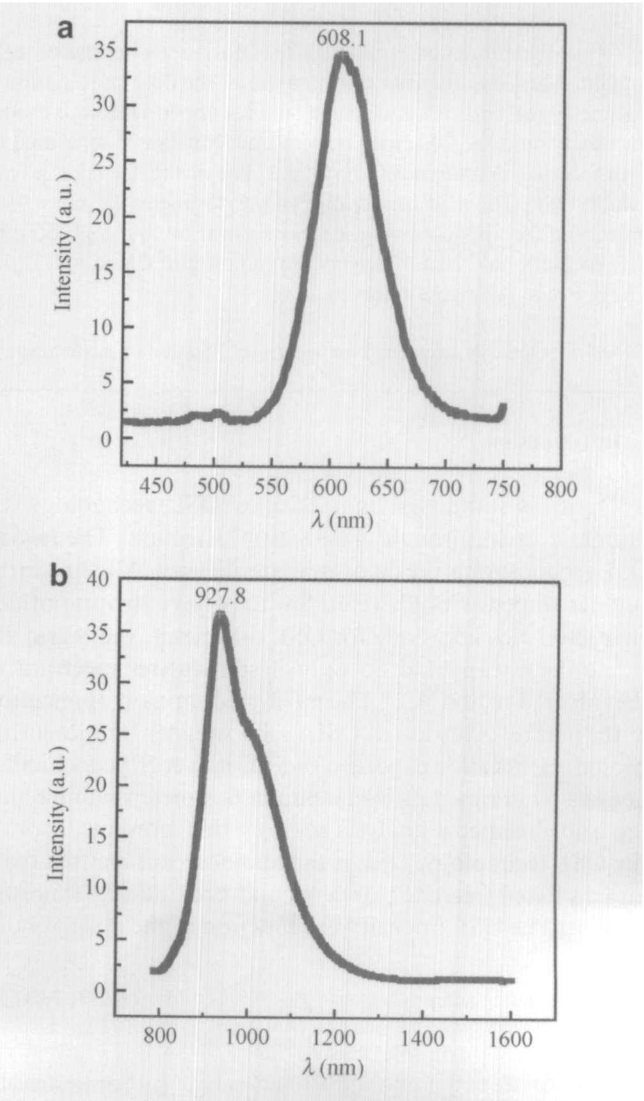

Fig. 2. Photostimulation luminescence spectrum (a) and photostimulation excitation spectrum (b) of SrS:Eu,Sm.

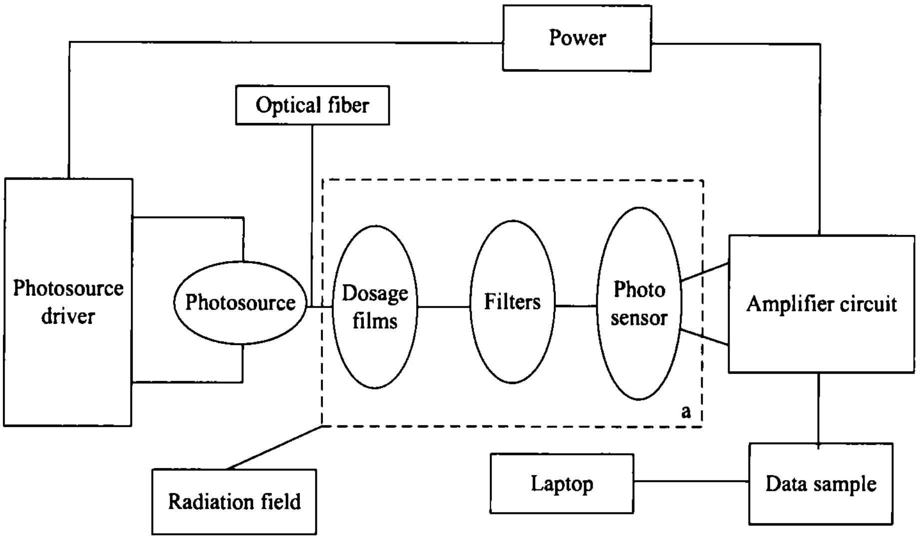

Fig. 3. Block diagram of the OSL dosimeter.

Typical OSL and stimulation spectra of SrS:Eu,Sm are given in Fig. 2, which shows that the emission is right in the high sensitivity range of the photodiode and far away from the stimulating wavelength.

3. Experiment

3.1. The OSL dosimeter composition

Any system based on OSLs requires, besides a sensitive OSL phosphor, two additional devices, a stimulation source and a photo-detector. The role of the stimulation source is to provide the energy necessary to de-trap the carriers. Various systems can be used to collect the luminescence depending on the application targeted, provided that they make it possible to discriminate the stimulation from the luminescence. From this point of view, silicon detectors are not suitable.

In our system, the sample is stimulated with a solid state laser emitting light at the wavelength of 0.98 μm and the OSL is collected with a photodiode .The system block diagram is given in Fig. 3.

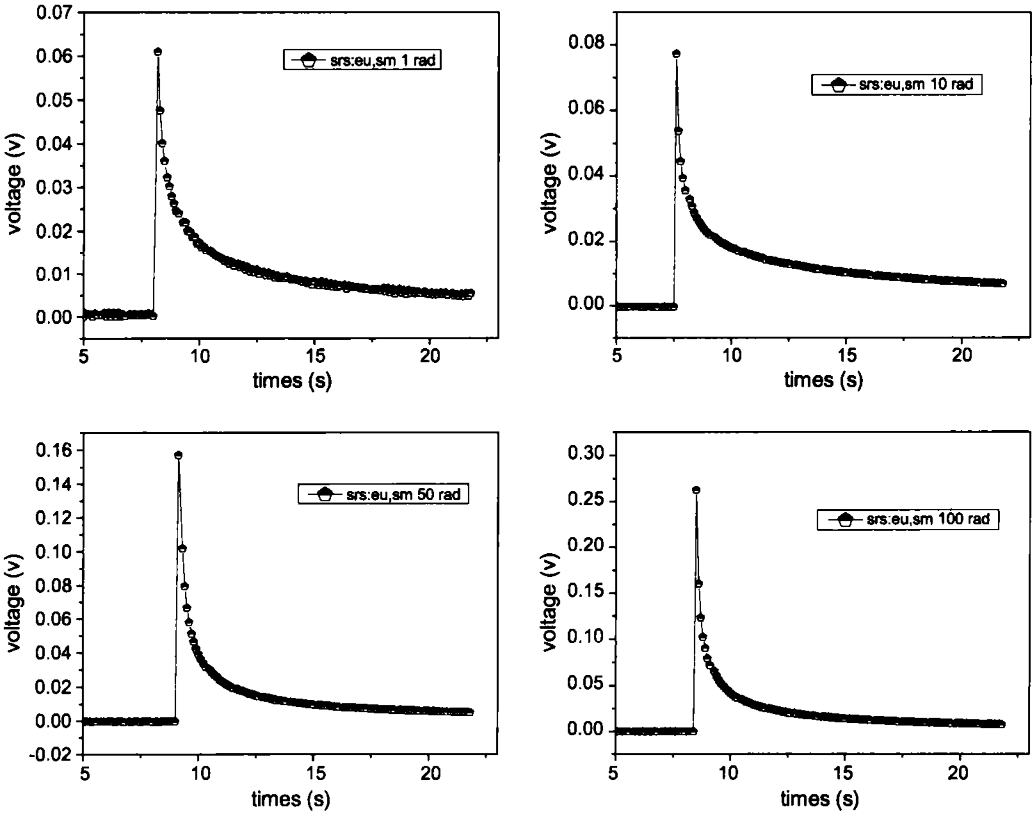

Fig. 4. Glow curves for SrS:Eu,Sm irradiated by different doses of ^{60}Co γ-rays.

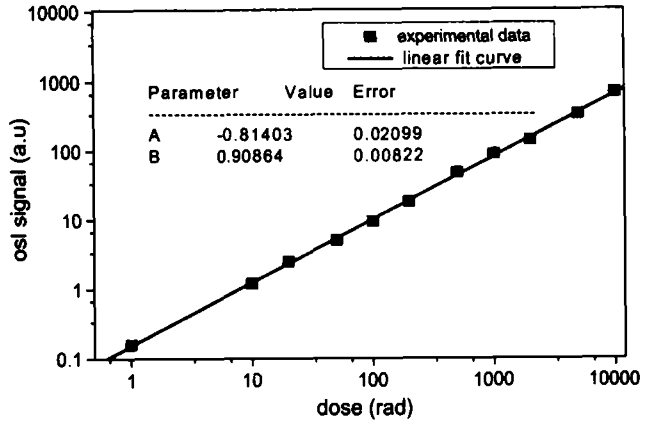

Fig. 5. Calibration curve of the OSL online dosimeter.

The OSL material was dispersed throughout polyethylene and positioned at the extremity of a multimode optical fiber. The role of the fiber is to lead to the infrared stimulation provided by a laser. The luminescence light entering the filter pack was measured by the photodiode, which was connected to the counter (DAQ6210, National Instruments). Digital controls were used for modulation of the laser beam and power supply of the photodiode. All the electrical and optical components used are commercially available.

3.2. Experimental results and discussion

3.2.1. Dosage collection

The SrS:Eu,Sm films were tested with ^{60}Co γ-rays. They were placed in an electronic balance cavity (6 mm × 6 mm × 0.3 mm) for exposure to a predetermined dose. It was found that the OSL material stimulated by infrared light had a very short response time of luminescence, which is the need for attenuation of the luminescence signals. According to the stimulation spectrum and OSL spectrum of SrS:Eu,Sm material (Fig. 2), a 980 nm Nd.YAG laser was used as the infrared excitation source. By measuring different exposure dosages, a dose response curve of OSL film exposed to the ^{60}Co γ-rays can be plotted (Fig. 4).

3.2.2. Dosage calibration

A series of experiments have been performed using ^{60}Co γ-rays. The minimum detectable dose was estimated to be 0.01Gy. The dynamic range, limited in this arrangement only by the saturation of the output amplifier, covers four orders of magnitude. The curve presenting the response of the OSL dosimeter as a function of the dose is presented in Fig. 5. The data in Fig. 5 were obtained with different doses across four orders of magnitude by varying the source-to-sample distance and the exposure time. This calibration curve shows a good linearity between the luminescence intensity and the dose. As usual, special attention was paid to the stability of the whole irradiated system with total dose.

4. Conclusions

The OSL dosimeter we have designed can work with high sensitivity in a broad dynamic measurement range. The equipment based on the SrS:Eu,Sm material is small and relatively simple to construct, and it is suitable for measuring radiation dose in space and in dangerous irradiation situations. The future of the disclosed OSL relies on the fabrication of thin layers directly on active pixel sensors [24], and any other fast photodetectors with the nano-second time constant, which are beyond the limits of a real time dosimeter. Therefore, more improvement in optical fiber dosimeter technology is required, including development of materials with deeper, more stable traps as well as the development of analysis techniques that can explain the dynamic response of the materials to the radiation environment. Further developments in, and investigations of, luminescence imaging systems for obtaining spatially resolved TL (thermal luminescence) and OSL signals from multi-mineral samples are also foreseen. These systems will give rapid and valuable information about the mineralogy of the sample and enable the individual analysis of luminescence signals obtained from signal grains in the sample. The OSL dosimeter has the potential to avoid the cumbersome mechanical and chemical separation processes presently required. Thus, it will be possible to map solid surfaces containing grains with different OSL sensitivities and different doses.

Acknowledgements

This work was supported by National Natural Science Foundation of China (Grant No. 10475112) and Western Light Foundation of 2005 years.

References

[1] Dusseau L, Plattard D, Vaille JR, et al. An integrated sensor using optically stimulated luminescence for in-flight dosimetry. IEEE Transactions on Nuclear Science 2000;47:2412–6.

[2] Fowler JF, Attix FH. Solid state integrating dosimeters. Radiation Dosimetry 1966;2:241–90.

[3] Lindmayer J. A new erasable optical memory. Solid State Technology 1988;31(8):135–8.

[4] Bogorad A, Bowman C, Dennis A, et al. Integrated environmental monitoring system for spacecraft. IEEE Transactions on Nuclear Science 1995;42:2051–7.

[5] MacKay GF, Thomson I, Sultan N, et al. Applications of MOSFET dosimeters on MIR and BION satellites. IEEE Transactions on Nuclear Science 1997;44:2048–51.

[6] Dusseau L, Polge G, Albert L, et al. Irradiated integrated circuits dose-attenuation mapping using optically stimulated phosphors for packaging dosimetry. IEEE Transactions on Nuclear Science 1998;45:2695–9.

[7] Wang SJ, Zhang H. Algebraic dynamics algorithm: Numerical comparison with Runge–Kutta algorithm and symplectic geometric algorithm. Science in China Series G: Physics Mechanics and Astronomy 2007;50:53–69.

[8] Buhler P, Desorgher L, Zehnder A, et al. Observations of the low earth orbit ration environment from MIR. Radiation Measurements 1996;26(60):917–21.

[9] Mackay GF, Thomson I, Sultan N, et al. Applications of MOSFET dosimeters on MIR and BION satellites. IEEE Transactions on Nuclear Science 1997;44(46):2048–51.

[10] Huntley DJ, Godfrey-Smith DI, Thewaltet M, et al. Nature 1985;313:105–7.

[11] Jutanulia S, Storti GM, Seideman W, et al. Use of electron-trapping materials in optical signal processing: I-Parallel Boolean Logic. Applied Optics 1990;29(32):4806–11.

[12] Bogorad A, Bowman C, Dennis A, et al. Integrated environmental monitoring system for spacecraft. IEEE Transactions on Nuclear Science 1995;42(6):2051–7.

[13] Dusseau L, Polge G, Mathias S, et al. High-energy particle irradiation of OSL films at CERN. IEEE Transactions on Nuclear Science 2001;48(6):2056–60.

[14] Idri K, Santoro L, Charpiot E, et al. Quality control of intensity modulated radiation therapy with OSL films. IEEE Transactions on Nuclear Science 2004;51(6):3638–41.

[15] Bøtter-Jensen L, McKeever SWS, Wintle AG, et al. Optically Stimulated Luminescence Dosimetry. 1st ed. Netherlands: Elsevier Science; 2003, 2-10.

[16] Hoshina T. 5d-4f radiative transition probabilities of Ce+3 and Eu2+ in crystals. Journal of the Physical Society of Japan 1980;48(4):1261–8.

[17] Yamashita N, Asano S. Photoluminescence of Sm3+ ions in MgS, CaS, SrS and BaS phosphors. Journal of Physical Society of Japan 1987;56(1):352–8.

[18] Barbier L, Cheret M. Energy pooling process in rubidium vapour. The Journal of Physiology 1983;B16:3213–8.

[19] Akselrod MS, Agersnap-Larsen N, McKeever SWS, et al. A procedure for the distinction between static and dynamic radiation exposures of personal radiation badges using pulsed optically stimulated luminescence. Radiation Measurements 2000;32:215 25.

[20] Akselrod MS, Akselrod AE, Agersnap-Larsen N, et al. Optically stimulated luminescence response of Al_2O_3 to beta radiation. Radiation Protection Dosimetry 1999;85:125–8.

[21] Akselrod MS, Lucas AC, Polf JC, et al. Optically stimulated luminescence of Al_2O_3. Radiation Measurements 1998;29:391–9.

[22] Akselrod MS, McKeever SWS. A radiation dosimetry method using pulsed optically stimulated luminescence. Radiation Protection Dosimetry 1999;81:167–76.

[23] Akselrod MS, Yoder RC, Akselrod GM, et al. Confocal fluorescent imaging of tracks from heavy charged particles utilizing new Al_2O_3: C,Mg crystals. Radiation Protection Dosimetry 2006;119(1):357–62.

[24] Akselrod MS, Yoder RC, Akselrod GM, et al. Development of a new electronic personal neutron dosimeter using a CMOS active pixel sensor. Radiation Protection Dosimetry 2006;119:357–62.