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The study on optically stimulated luminescence dosimeter based on the SrS:Eu, Sm and CaS:Eu, Sm*

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With the increasing use of nuclear energy, there is a need for a wider range of efficient dosimeters for radiation detection and assessment. There has been a tremendous growth in the development of radiation detectors and devices in the past few decades. In recent years, the development of new materials for radiation dosimetry has progressed significantly. Alkaline earth sulfides (AES) have been known for a long time as excellent and versatile phosphor materials. In the present investigation, a number of phosphor samples such as mono-, binary and ternary sulfides of alkaline earths (II^a-VI^b) have been prepared and their TL properties have been studied with respect to exposure (x-ray) response and fading. In this paper, some results on SrS:Eu, Sm and CaS:Eu, Sm phosphors are presented. A type of novel OSL dosimeter is described. The dosimeter takes advantage of the characteristics of charge trapping materials SrS:Eu, Sm and CaS:Eu, Sm that exhibit optically stimulated luminescence (OSL). The measuring range of the dosimeter is from 0.01 to 1000 Gy. The OSL dosimeters provide capability for remote monitoring radiation locations which are difficult to access and hazardous. This equipment is relatively simple, small in size and has low power consumption. The device is suitable for space radiation dose exploration. In addition, it also can be used in IC and other radiation occasions and has good prospects.

Keywords: optically stimulated luminescence, radiation, dosimeter
PACC: 8760M, 8760P, 2880

1. Introduction

The most commonly used passive dosimeters are TLDs (thermo luminescent dosimeters) and radiological emulsions. They both provide the accurate value of the dose after posteriori processing. TLDs require a heavy and power consuming reader, the emulsions require chemical processing, they can not be used for space measurement. Now the more mature means for space radiation measuring is the PMOS (positive MOSFET) dosimeter.[1−4] The principle is that when the gate voltage is below a certain value the device turns off and above this value (threshold) the device is on. It is this threshold voltage which is used as the dosimeter parameter of the RADFET. The dosimeter can be used in real-time monitoring; it has small size and light weight.

But PMOS dosimeter also has certain limitations. According to the smallest readable threshold voltage drift (typically 1 mV/cGy), it can only have a measuring range covering 2–3 orders of magnitude for the accumulative dose.[5−8]

Optically stimulated luminescent (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. The process begins with irradiation causing ionization of valence electrons and the creation of electron/hole pairs. Pre-existing defects within the material then localize the free electrons and holes through non-radiative trapping transitions. Subsequent illumination of the irradiated sample with light leads to absorption of energy by the trapped electrons and their transition from the localized traps to the delocalized conduction band. Recombination of

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the freed electrons with the localized holes results in radiative emission and luminescence. This is the OSL signal, the intensity of which is proportional to the dose of absorbed radiation.[9,10]

2. OSL material properties and dosimeter principle

2.1. OSL material and measurement of radiation dose

Optically stimulated luminescence results from a process starting in a wide band gap semiconductor or insulator, as shown in (1) in Fig.1. 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. Stimulation of the material optically (2) will provide the energy necessary to release the trapped charge. A subsequent radiative recombination may be observed (3) 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 since the wavelength of stimulation is greater than the wavelength of the luminescence.[11−19]

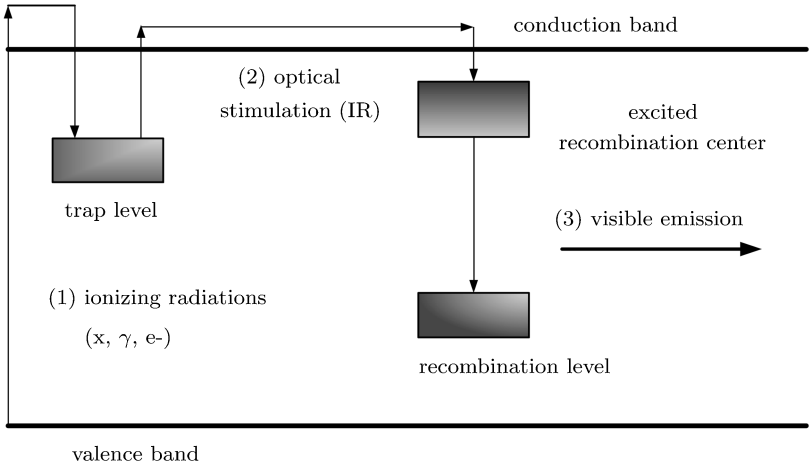


Fig.1. Basic mechanism of the optically stimulated luminescence.

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 excitation, 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. The efficiency is strongly dependent on the dopants and their concentration. Another important criterion can be deduced from Table 1, namely 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
KCI:Eu	450–650	400–450
KBr:In	500–700	400–600
RbBr:Ti	600–800	300–450
RbI:In	600–800	350–450
A-AI_2O_3	300–450	350–500
CaS:Eu, Sm	850–1500	550–750

2.3. Basic OSL properties of the SrS:Eu, Sm and CaS:Eu, Sm

The alkaline earth sulfide family compounds (CaS, SrS, and MgS) have been suggested for use in OSL dosimetry since the first suggested use of OSL as a potential dosimetric method. SrS:Eu, Sm and CaS:Eu, Sm, as an OSL material allows for a wide range of stimulation wavelengths from 0.8 to 1.5 microns and the emission is observed from 0.55 to 0.75 microns. Since the stimulation and the emission spectra are separated, it is possible to discriminate the OSL from the stimulation using adequate optical methods. The stimulation spectra are such that these materials can be effectively stimulated using the fundamental wavelength from an Nd:YAG laser. The intensity of light emission is detected by the PMT (photoelectric multiple tube) for measuring the emission spectrum. A typical optically stimulated luminescence and Stimulation spectrum of SrS:Eu, Sm and CaS:Eu, Sm are given on Fig.2 and Fig.3, respectively. Such an emission is right in the PMT high sensitivity range and far away from the stimulating wavelength located at one micron and up.

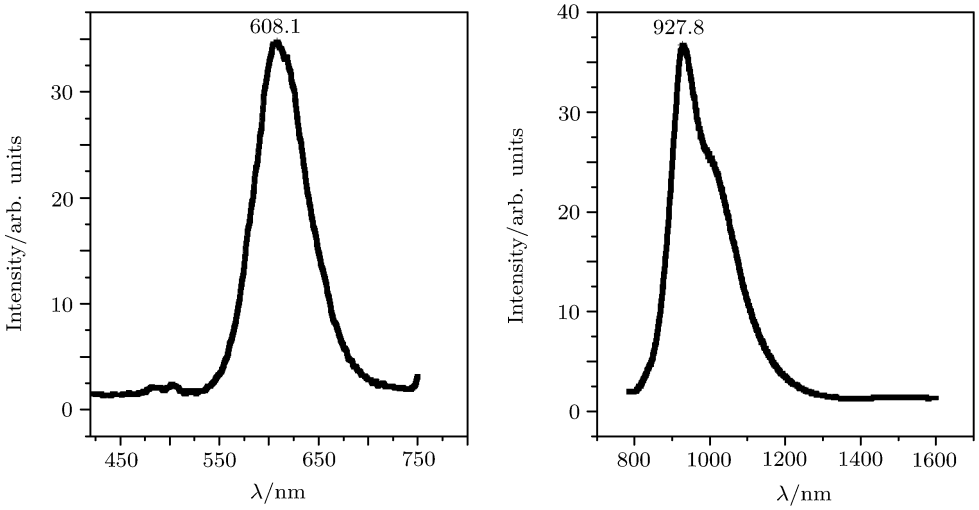


Fig.2. Optically stimulated luminescence and stimulation spectrum of SrS:Eu, Sm.

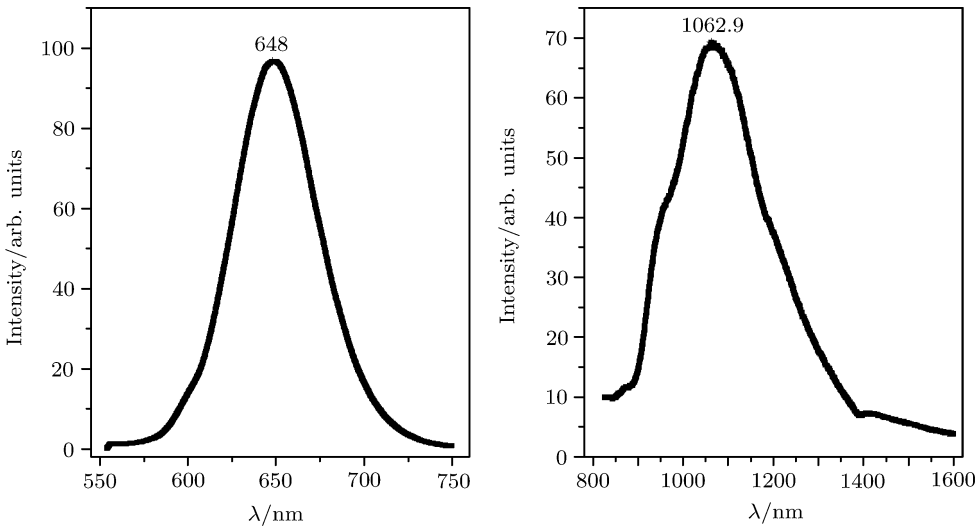


Fig.3. Optically stimulated luminescence and stimulation spectrum of CaS:Eu, Sm.

3. Experiment

3.1. The preparation of OSL films

The optically stimulated luminescence film preparation is an essential step for the dosimeter development. After repeated tests, we obtained the OSL films meeting our needs. The preparation process is as follows: Take the transparent organic material as the substrate material, disperse OSL material in the substrate material, then the OSL material is made into OSL films with thickness of 300 μm and area of 6 mm×6 mm. The OSL films have thickness uniformity, high transparency, formability and good consistency. Meantime, the OSL material is very well protected by the substrate material.

3.2. Structure of the OSL dosimeter

Any system based on OSL requires, besides the sensitive OSL phosphor, two additional devices, a stimulation source and a photo-detector, as shown on Fig.4. 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 aimed at, provided they make it possible to discriminate the stimulation from the luminescence. From this point of view, silicon detectors are not suitable. In this paper, stimulating the sample with a solid state laser emitting a 0.98 micron wavelength and collecting the OSL with a photomultiplier tube (PMT) made it possible to discriminate emission from stimulation. The intensity of light emission can be detected by the PMT for measuring the emission spectrum. The system bloc diagram is shown in Fig.5.

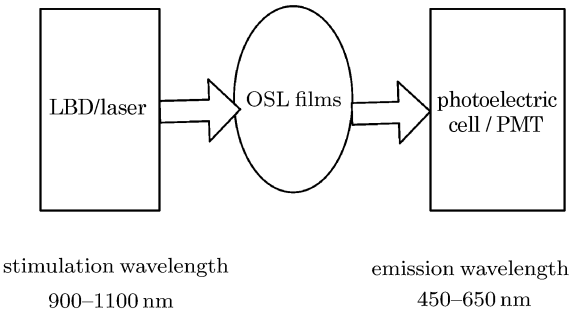


Fig.4. General scheme of an OSL dosimeter.

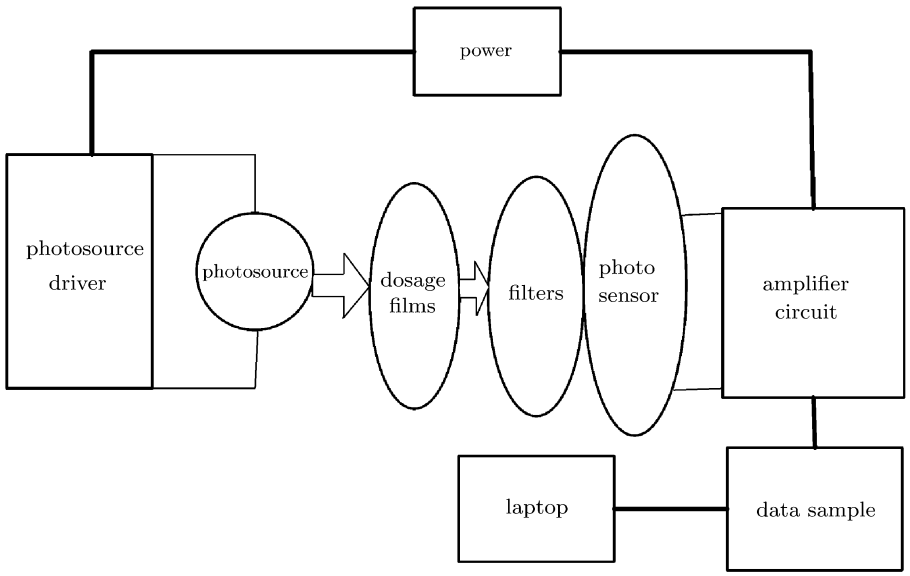


Fig.5. Block diagram of the OSL dosimeter.

The OSL sensitive material is enclosed in a polyethylene cap and positioned at the extremity of a multimode optical fibre. The role of the fibre is to lead the infrared stimulation provided by a laser and conveys the OSL signal toward a PMT. The luminescence light stimulated by a solid state laser is transferred back to 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. The sampler displays are shown in Fig.7. Additional components not presented in the diagram are the power supplies for the laser. All the electrical and optical components used are commercially available.

3.3. Experimental results and discussion

3.3.1. Dosage collection

OSL films are placed into electronic balance cavity (6 mm×6 mm, 0.3 mm thick) to accept from the ^{60}Co-gamma source a predetermined acceptable dose of radiation. By measuring the OSL of materials to be used in infrared photo-stimulated dosimetry, we obtain the luminescence intensity as a function of time, as shown in Fig.6. It is shown that when OSL material is stimulated by infrared light, the response time of luminescence intensity is very short. Meanwhile, the decay of stimulated luminescence signal is fast. It shows that the material is a short afterglow material. According to the spectrum of stimulation and stimulated luminescence of SrS:Eu, Sm and CaS:Eu, Sm material, we can apply it to measure radiation dose.

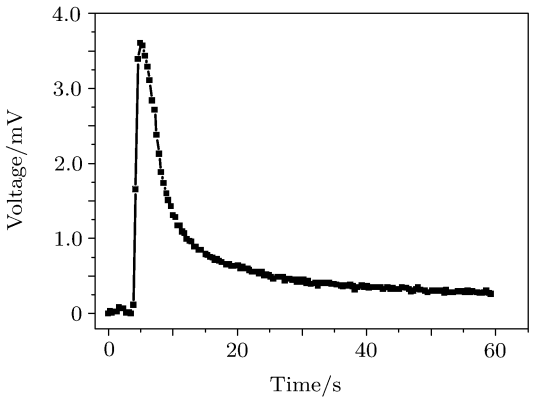


Fig.6. The curve of OSL signal as a function of time.

The radiation dose curve of OSL films accepting different exposure dosage of the ^{60}Co-γ source radiation is shown in Figs.7 and 8.

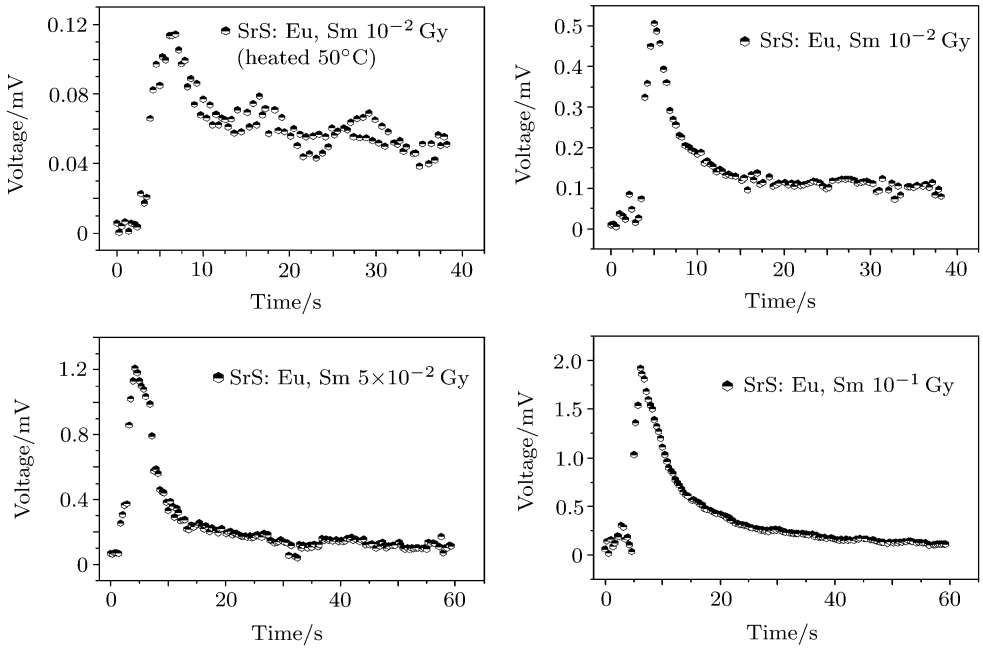


Fig.7. Glow curves for SrS:Eu, Sm irradiated by different dosages of ^{60}Co γ rays.

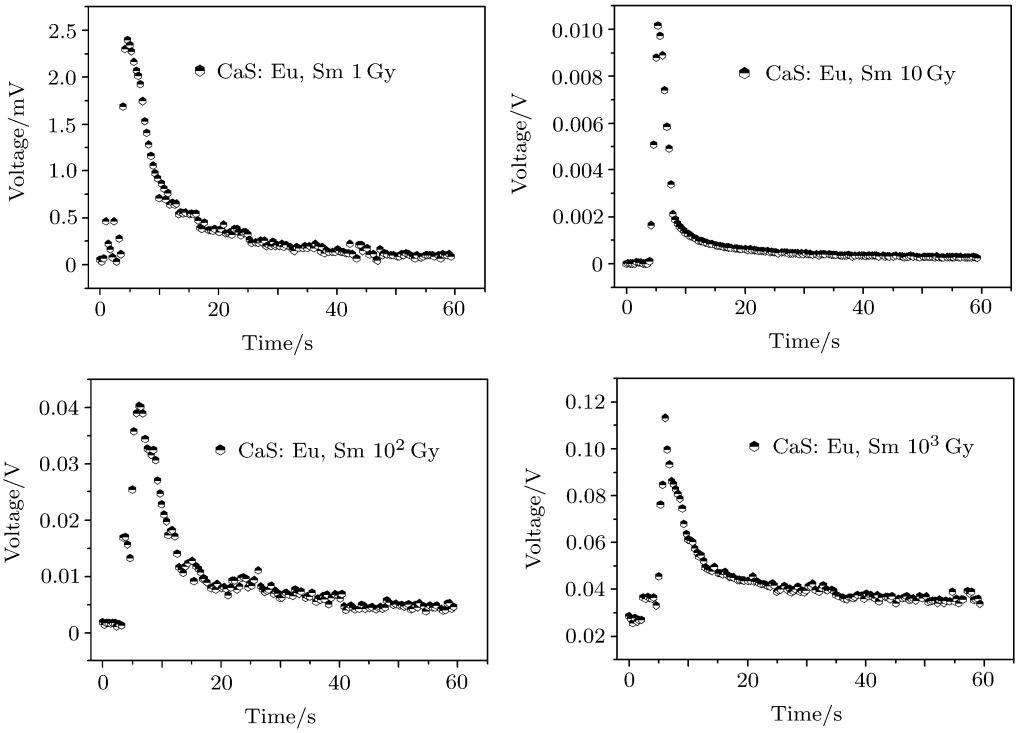


Fig.8. Glow curves for CaS:Eu, Sm irradiated by different dose ^{60}Co γ rays.

3.3.2. Dosage calibration

A series of experiments have been performed using a ^{60}Co-γ source for sensitivity calibration of the prototype dosimeter. The minimum detectable dose

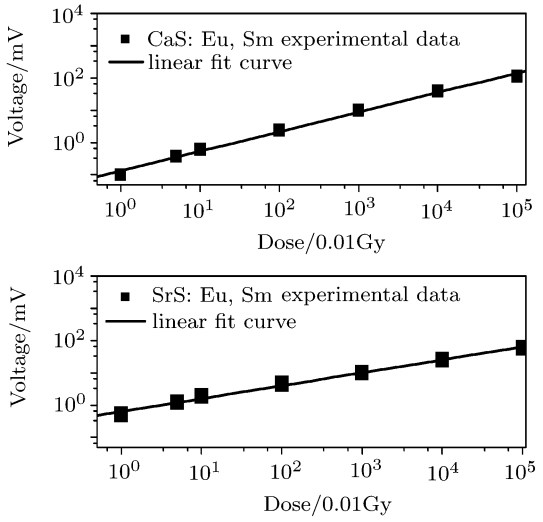


Fig.9. Calibration curve of the OSL online dosimeter.

was estimated to be 0.01 Gy, the dynamic range, limited in this arrangement only by the saturation of the output amplifier, covers 5 orders of magnitude. The curve presenting the response of the OSL dosimeter as a function of the dose is presented on Fig.9. This is a very satisfactory result. Meanwhile, special attention has been paid to the stability of the whole irradiated system with total dose.

4. Conclusion

The optically stimulated luminescent (OSL) radiation dosimeter covers a broad dynamic measurement range and has high sensitivity. The OSL dosimeters provide capability for remote monitoring of radiation locations which are difficult to access and hazardous. We have developed an integrated sensor to measure the dose in our experiment. The equipment is relatively simple and small in size, and has low power consumption. This device is suitable for the space radiation dose exploration. In addition, it also can be used in IC and other radiation occasions. This device has good prospects. The future of the OSL relies on the fabrication of thin layer directly on active pixel sensors, or any other fast photo-detectors that could take advantage of the ns time constant, to push further the limits of what is called the real time dosimeter. So there is still considerable room for improvement in optical fibre dosimeter technology, including the development of materials with deeper, more sta-

ble traps as well as the development of analysis techniques that can account for the dynamic response of the materials to the radiation environment. Further developments in, and investigations of, luminescence imaging systems for obtaining spatially resolved TL and OSL signals from multi-mineral samples are also anticipated.

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