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Optically stimulated luminescence dosimeter based on CaS:Eu,Sm

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Abstract Alkaline earth sulfides (MgS, CaS and BaS) crystal doped with rare-earth ions is an optically stimulated luminescence dosimeter with very high sensitivity, short time constant of the optically stimulated luminescence (OSL) separated perfectly from the stimulation. In this paper, an OSL dosimeter is described. It has linear dose response from 0.01 to 1000 Gy. The equipment, relatively simple and small in size is promising for applications in space exploration and for high dose irradiation and dangerous irradiation conditions.

Key words Optically stimulated luminescence, Radiation measurement, Radiation dosimeter

CLC numbers TL72, TL75$^+$1, TL816$^+$.2

1 Introduction

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 radiation dose absorbed by the sample and thus can be used as the basis of a radiation dosimetry method[1,2]. The process begins with radiation-caused ionization of valence electrons to form electron/hole pairs, which would be localized, through non-radiative trapping transitions, by defects within the material. 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[3-5]. This is the OSL signal, the intensity of which is proportional to the dose absorbed in the irradiation.

OSL has become a dosimetry choice for many areas of applications, such as dosimeters for personal and environmental radiation protection, and retrospective dosimeters for geological dating or accident survey[6-8]. The OSL phenomenon is similar to thermoluminescence (TL), differing just in the stimulation medium: heating for TL, and optical reset for OSL. But before their reading, OSL dosimeters are heated too, to anneal charges in shallow traps. OSL radiation dosimeters have broad dynamic range of measurement and high sensitivity. They need a relatively short period of time, and are capable of measuring an instantaneous dose approximately[9-11].

In this paper, we report developments in optically stimulated luminescent (OSL) dosimeters, which are alkaline earth sulfides (MgS, CaS, and BaS) crystal doped with rare-earth ions as an OSL with high sensitivity, short time constant of the luminescence separated perfectly from the stimulation spectra. It enables many applications in real time and online dosimeter. The crystal doped with Ce(Eu), Sm ions have two important characteristics necessary for OSL dosimeter, i.e thermally stable deep traps and an optical stimulation spectrum in the infrared region.

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2 OSL material properties and dosimeter principle

2.1 Principle of the radiation dose measurement using OSL material

OSL is one of measurements known as the stimulated phenomena. Such phenomena may be stimulated thermally (thermally stimulated phenomena or TSP) or optically (optically stimulated phenomena or OSP). TSP include thermoluminescence (TL), thermally stimulated conductivity (TSC), thermally stimulated exo-electron emission (TSEE), thermally stimulated capacitance (TSCap), deep level transient spectroscopy (DLTS), thermogravimetry (TG), differential thermal analysis (DTA) and others. Likewise, OSP include OSL, photoconductivity (PC) and optically stimulated exo-electron emission (OSEE)[12-14]. The relationship between these different phenomena is illustrated in Fig.1 using a schematic energy band diagram[15].

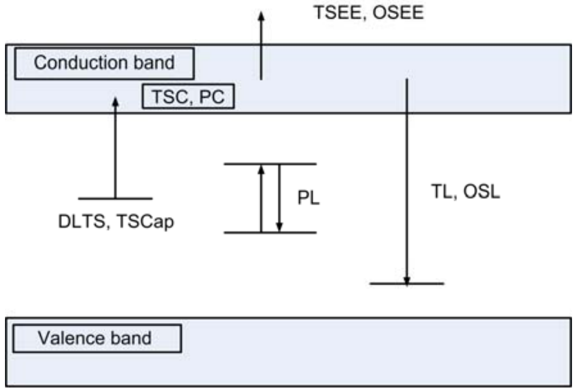

Fig.1 Schematic representation of seven popular thermally and optically stimulated phenomena. Capacitance techniques (DLTS and TSCap) measure signals proportional to the concentration of charge when they reside in the traps. Conductivity techniques (TSC and PC) monitor the charges after release from the traps as they transit through the conduction band. Luminescence techniques (TL and OSL) monitor the charges as they undergo radiative recombination with charge of opposite sign. Exo-electron processes (TSEE and OSEE) monitor the charges if they are emitted from the surface of the material. Although not the same type of stimulated phenomenon, PL is also indicated.

Rare-earth-doped alkaline sulfides have been known for a long time as efficient phosphors exhibiting both thermoluminescence and OSL[16-18]. The OSL results from a process beginning with the irradiation of insulator. The ionizing radiation creates in the oxide an amount of charges. Some stay trapped on localized defects after the irradiation. The time period of the trapping depends on the temperature, the activation energy of the traps, the type of the ionizing radiation. Stimulating the material thermally (TL) or optically (OSL) 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. The phenomenon is described on the Fig.2[19-22].

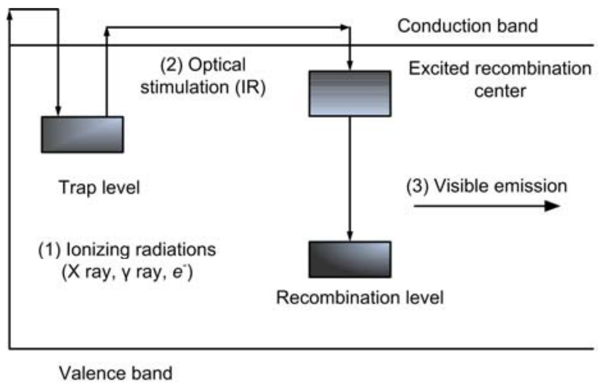

Fig.2 Mechanism of OSL.

2.2 Basic OSL properties of the CaS:Eu,Sm

The alkaline earth sulphide family (CaS, SrS and MgS) has been used in OSL dosimetry since OSL was suggested as a potential dosimetric method[23]. CaS:Eu,Sm as an OSL material allows a wide range of stimulation wavelengths (0.8 to 1.5 μm) for it to emit 0.50~0.75 μm luminescence. As spectra of the stimulation and emission are separated, it is possible to discriminate the luminescence from the stimulation using an adequate optical method. The stimulation can be effectively done using a Nd:YAG laser. The light emission can be detected by a photoelectric multiplier tube (PMT). Typical OSL and the stimulation spectra of CaS:Eu,Sm are given in Fig.3. The emission is right in high sensitivity range of the PMT and far away from the stimulating wavelength.

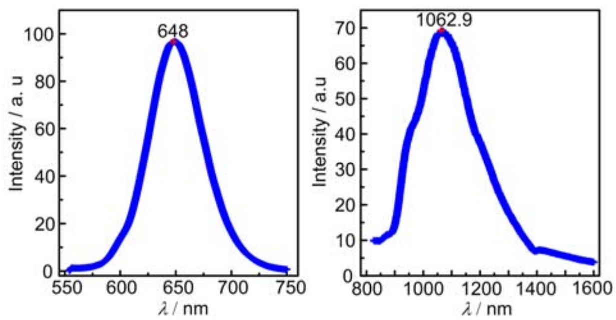

Fig.3 Optically stimulated luminescence and stimulated spectra of CaS:Eu,Sm.

3 Experimental

3.1 OSL dosimeter composition

An OSL system is composed of a sensitive OSL phosphor, a stimulation source and a photo-detector (Fig.4). The detector can be chosen according to purpose of the application, but silicon is not good at discriminating the stimulation from the luminescence.

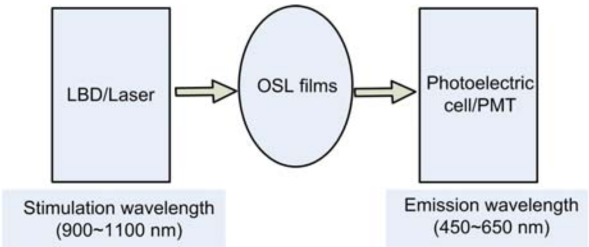

Fig.4 Generic structure of an OSL dosimeter.

In our system, the sample is stimulated with a solid state laser emitting 0.98 μm light and the OSL is collected with a PMT. The system block diagram is described in Fig.5.

The OSL material is enclosed in a polyethylene cap and positioned at the extremity of a multimode optical fiber. The fiber leads the infrared light from the solid state laser and conveys OSL signals toward the PMT. The luminescence light goes to the filter pack, and is measured by the PMT, which is connected to the counter (DAQ6210, National Instruments). Digital controls are used for modulation of the laser beam and power supply of the PMT.

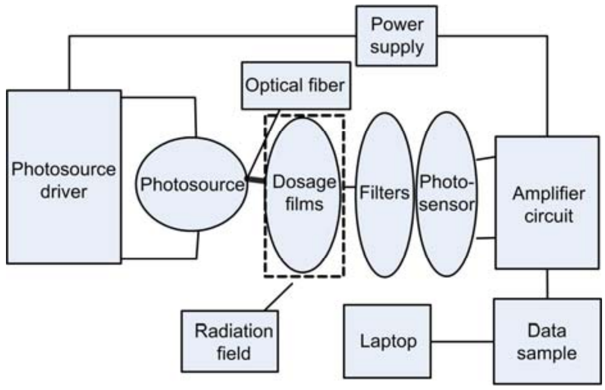

Fig.5 Block diagram of the OSL dosimeter.

3.2 Experimental results and discussions

3.2.1 Dosage collection

The CaS:Eu,Sm OSL films were tested with ^{60}Co γ-rays. They were placed in an electronic balance cavity (6 mm ×6 mm ×0.3 mm) for exposures of predetermined doses. It was found that the OSL material stimulated by infrared light had very short response time of luminescence, hence the need of attenuation of the luminescence signals. According to the stimulation and OSL spectra of CaS:Eu,Sm material (Fig.3), a 980 nm Nd:YAG laser was used as the infrared excitation source. By measuring different exposure doses, dose response curve of the OSL film exposed to the ^{60}Co γ-rays was obtained (Fig.6).

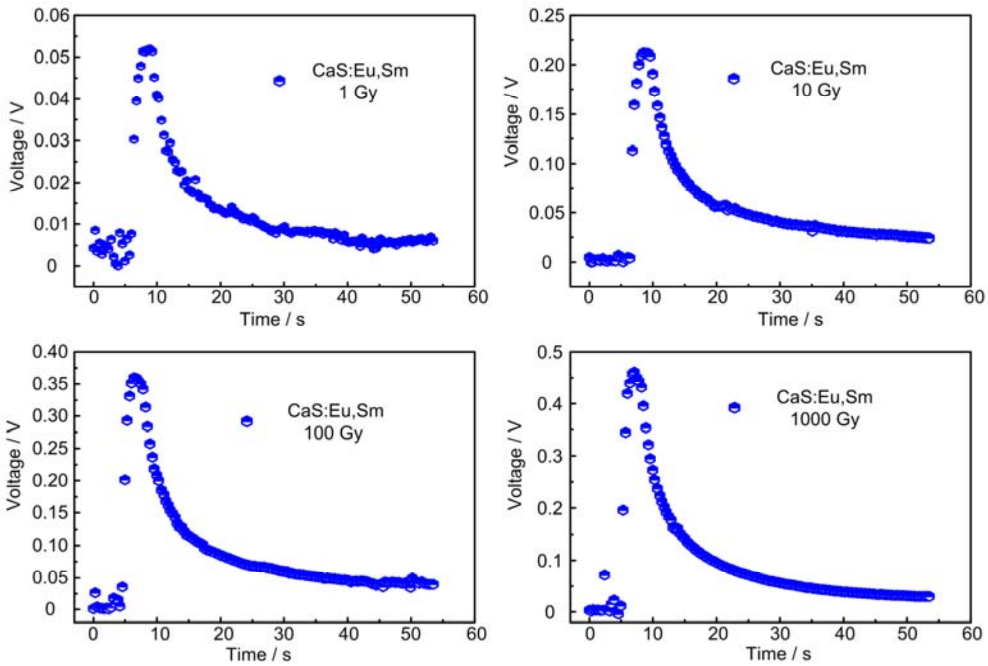

Fig.6 Glow curves for CaS:Eu,Sm irradiated to different doses.

3.2.2 Dose calibration

The data in Fig.7 were obtained with different doses across five orders of magnitude by varying the source-to-sample distance and the exposure time. It shows a good linearity between the luminescence intensity and the dose.

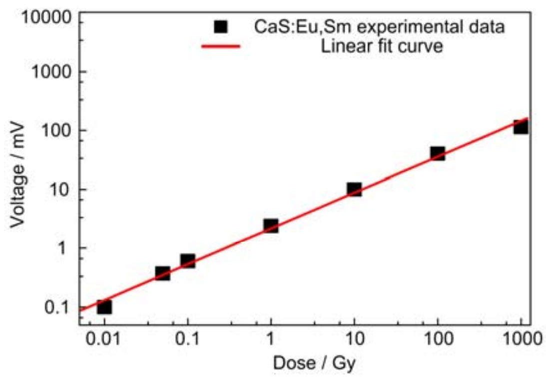

Fig.7 Calibration curve of the OSL online dosimeter.

4 Conclusion

The OSL dosimeter works with high sensitivity in a board dynamic measurement range. With the optical fiber, remote dosimetry measurements can be realized under a variety of environmental conditions that would preclude or limit the use of other dosimetry techniques. The equipment based on the CaS:Eu,Sm material is relatively simple and small in size. It is suitable for measuring radiation doses in the space, and in high dose and dangerous irradiation conditions. The future of OSL relies on its thin layer fabrication on active pixel sensors[24], and any other fast photo detector that is able to take advantage of the ns time constant. Efforts are needed in improving techniques in the optical fiber dosimetry. These include developing both the materials with deep stable traps and the analysis techniques that account for the material's dynamic response to radiations. Developments in luminescence imaging systems for obtaining spatially resolved TL and OSL signals from multi-mineral samples are also foreseen.

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