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Continuous wavelength and linear modulation optically stimulated luminescence characteristics of beta-irradiated ZrO_2

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Abstract

The Continuous Wavelength Optically Stimulated Luminescence (CW-OSL) and Linear Modulation Optically Stimulated Luminescence (LM-OSL) of ZrO_2 after irradiation with beta particles were studied. A typical OSL decay of light intensity showed a dependence on illumination time. The LM-OSL curve showed a maximum approximately at 41 s of illumination time. The LM-OSL curve of ZrO_2 showed an initial peak followed by a long tail one. The OSL signal showed more than one component. Plotted data as a function of absorbed dose showed linear behavior from 10 to 200 Gy from $^{90}Sr/^{90}Y$ beta source.

The present work summarizes the experimental results obtained for the OSL characteristics of ZrO_2 after beta irradiation in order to use it as a beta particles detector. A comparison between CW-OSL and LM–OSL characteristics are also presented.

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1. Introduction

Recent works on ZrO_2 have been devoted to the study of new materials as a TL dosimeter for UV radiation, mainly in the actinic region. It has been found that ZrO_2 has some desirable features for use as a TL dosimeter.

The integral of the luminescence emitted during the stimulation with light of the material is a measure of the total absorbed dose. This dosimetric method is termed Optically Stimulated Luminescence (OSL) [1–5]. During exposure to the stimulating light (visible or infra-red wavelengths) the OSL signal as a function of illumination time is observed to decay to a lower level, firstly with a rapid decay and then more slowly as the measurement proceeds. The normal procedure for recording OSL during dosimetry applications consists in recording the luminescence as a function of illumination time at room temperature.

These conventional measurement procedures using continuous wavelength optically stimulated luminescence (CW-OSL) was first used for dating archaeological samples [6]. In these conventional OSL measurements, an irradiated sample is

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exposed to a steady beam of stimulation light and the luminescence is continuously monitored as a function of the stimulation time. The OSL intensity is usually observed to decay monotonically with time at a decay constant which is governed by the stimulation light intensity, ϕ, and by the photo-ionization cross-section, $\sigma(E)$, of the trap.

An alternative measurement procedure to the CW-OSL method was proposed by Bulur (1996) [7]. Instead of maintaining a constant stimulation intensity ϕ, (as in CW-OSL), the intensity of the stimulating light is linearly increased according to the equation $\phi(t)=\phi_0+\gamma t$, where the stimulation light intensity $\phi(t)$ is varied at a rate $\gamma=\mathrm{d}\phi/\mathrm{d}t$ as a function of time and ϕ_0 is the intensity at $t=0$. The method is termed Linear Modulation OSL (LM-OSL) [8,9]. The measured OSL signal is then initially seen to increase linearly from $t=0$ until a time at which the traps become depleted. After that, the OSL intensity decays to zero at almost the same value of the non-irradiated sample. When the increase rate is constant the resulting curve is known as Lineal Modulation OSL. The time at which the LM-OSL signal reaches the maximum is determined by the ramp rate γ. In this case the OSL from traps with high photo-ionization cross-sections decays rapidly with stimulation time; meanwhile OSL from the traps with a small photo-ionization cross-section is characterized by long decay times. Thus, traps with the largest cross-section for the stimulation wavelength used in the measurement are quickly emptied giving rise to the fast decay component. Traps with a smaller cross-section yield the medium and slow components. Thus, the different traps contributing to the OSL signal are manifested by different peaks in the LM-OSL versus time curve [8].

The shape of the LM-OSL curve is directly related to the shape of the conventional OSL decay curve in which the stimulating light source is maintained at a constant intensity.

This paper describes the CW-OSL and LM-OSL curves from ZrO_2 for the purpose of analyzing the different LM–OSL curve shapes that one might expect and relating these to the corresponding CW-OSL curves.

2. Materials and equipment

The materials used in this study were constituted by ZrO_2 + PTFE pellets. The powder of ZrO_2 was prepared by the evaporation method from a solution of zirconium hexachloride dissolved in ethanol. The powder obtained was sieved to select grain sizes between 100 and 300 μm. In order to facilitate handling, samples were made in pellet form. Sintered ZrO_2 + PTFE pellets of 5 mm diameter and 0.8 mm thickness were obtained by pressing a mixture of ZrO_2 powder and PTFE at room temperature and then sintering at a temperature slightly lower than that of the PTFE fusion, using the technique described in previous works [10,11].

Before the exposure of the samples to beta particles, they were annealed at 300°C for 10 min to erase all previously existing information.

Optically stimulated luminescence (both CW-OSL and LM-OSL) measurements were made in the Laboratories of the Department of Physics, Oklahoma State University, USA using the Riso automated TL/OSL reader DA–15 which is computer controlled and programmable via RS 232. OSL (both CW-OSL and LM-OSL) was stimulated using a green laser diode LED array with a wavelength of 523 nm and 30 mW/cm^2 of power density. The ramp rate γ used in the LM-OSL measurements was 0.1 m W/cm^2 s^1, reaching the maximum value at $t_f=300$ s. LM-OSL intensity was integrated during 300 s. All the beta irradiations were made at RT and using a beta irradiator $^{90}Sr/^{90}Y$ with an absorbed dose rate in air of 93.6 mGy/s.

All measurements for both CW-OSL and LM-OSL were carried out in nitrogen atmosphere at room temperature.

3. Results and discussion

Several processes can be taken into account to describe the behavior of OSL curves. Shallow traps are considered to play an important role whenever the OSL process involves stimulation into the delocalized bands to CW-OSL traps. The detrapping of charge by the shallow traps, followed by the optical release of this charge back into the conduction band, yields a non-exponential tail in the OSL decay.

The OSL decay of light intensity showed an illumination time dependence. As illumination time increases, the intensity of light emitted from the detector becomes constant after 100 s of illumination. Fig. 1 illustrates the CW-OSL curves obtained from ZrO_2 disks as a function of illumination time. In this figure, the CW-OSL decreases over time of stimulation of irradiated samples which is a clear indication of optical eviction of charges from the traps. These data were obtained by irradiating at room temperature and stimulating the samples with green light at room temperature.

LM-OSL curves were obtained by irradiating the samples at room temperature and stimulating them with a linear increasing intensity. This typical curve is shown in Fig. 2. No preheating was used between irradiation and the OSL measurements. The LM-OSL raising side of the peak or the fast component of the CW-OSL curve corresponds to the more shallow traps. This result may be due to the short time phosphorescence component, followed by the appearance of one peak at approximately 41 s.

Both the typical Linear Modulation OSL and conventional OSL curves as a function of illumination time are shown in Fig. 3 for ZrO_2. This figure shows a comparison between the two methods. Also, in this figure the three decay components for both CW-OSL and LM-OSL methods can be seen.

The CW-OSL response as a function of beta irradiation time is depicted in Fig. 4. These results are closely related with the absorbed dose of beta radiation. The integral signal CW-OSL versus $^{90}Sr/^{90}Y$ beta dose was plotted. A plot of these data after beta irradiation is shown in Fig. 5. The CW-OSL response of ZrO_2 as a function of beta absorbed dose is almost linear in the range from 10 to 200 Gy. Experimental data were fitted with a

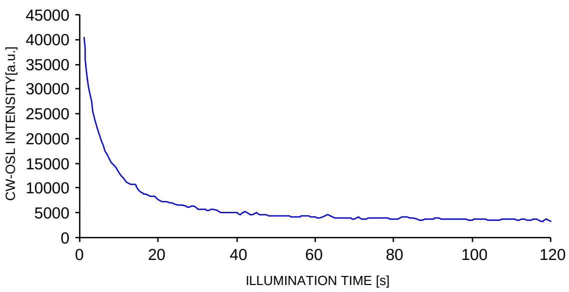

Fig. 1. Typical CW-OSL decay curve from ZrO_2 after irradiation to a $^{90}Sr/^{90}Y$ beta dose of 100 Gy and stimulation with wavelength band of 523 nm.

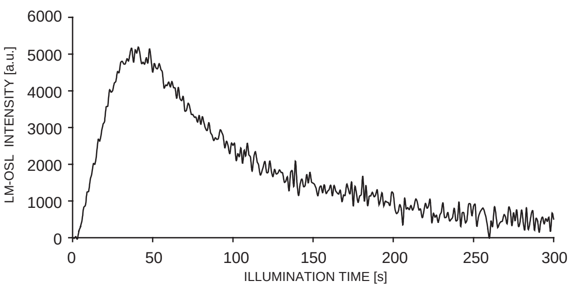

Fig. 2. Typical LM-OSL decay curve from ZrO_2 dosimeters exposed to 100 Gy $^{90}Sr/^{90}Y$ beta radiation at room temperature as a function of illumination time.

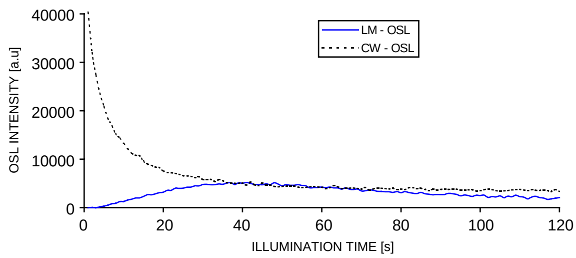

Fig. 3. Comparison of CW-OSL and LM-OSL decay curves as a function of illumination time.

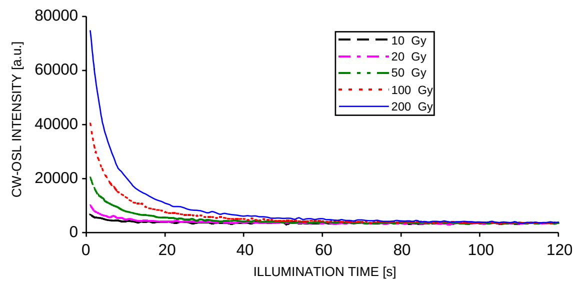

Fig. 4. 10–200 Gy beta dose response of ZrO_2 samples obtained after green light illumination of up to 120 s.

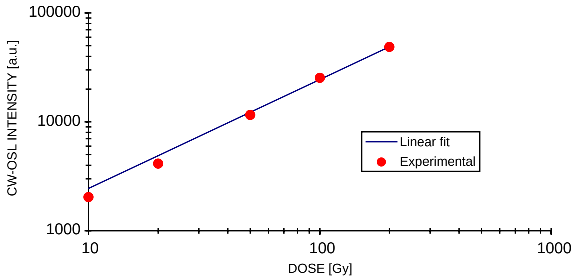

Fig. 5. Data plotted of CW-OSL response from ZrO_2 samples versus $^{90}Sr/^{90}Y$ beta absorbed dose irradiation time, using a green stimulation light over 120 s.

linear function. Statistics calculus provides a standard deviation of 0.23% between the experimental data and the linear function.

4. Conclusion

In this paper, Continued Wavelength Optically Stimulated Luminescence (CW-OSL) and Linear Modulation Optically Stimulated Luminescence (LM-OSL) methods have been applied to ZrO_2 irradiated by beta particles. Some hypotheses can be suggested from the comparison of CW-OSL and LM-OSL techniques. Fig. 2 shows the light intensity decay as a function of the illumination intensity in the LM technique. The presence of more than one trap in the crystal structure seems evident. Indeed, as the light stimulation increases up to 40 s, only shallow traps are involved; after that, deep traps are of interest. This kind of structure seems confirmed by the CW-OSL technique. Fig. 1 shows a very fast decay at the beginning of the CW stimulation. Fig. 3, showing the comparison between CW-OSL and LM-OSL techniques, seems to confirm the hypotheses given so far. The CW-OSL method shows that the OSL response of ZrO_2 as a function of absorbed dose is almost linear in the range from 10 to 200 Gy. The standard deviation, in percentage, between the measured data and fitting function, is very good (0.23%). Thus, the results given so far allow to conclude that ZrO_2 is a very attractive material for application as OSL dosimeter in ionizing radiation monitoring.

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