Delayed optically stimulated luminescence of Al$_2$O$_3$:Si,Ti phosphor

P S Page$^a$, B C Bhatt$^b$, N S Rawat$^b$, D R Mishra$^b$ & M S Kulkarni$^b$

$^a$Radiological Physics and Advisory, $^b$Radiation Safety Systems Division, Bhabha Atomic Research Centre, Mumbai 400 085, India

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In some Al$_2$O$_3$ samples, the OSL is seen to decay much more slowly than we would expect due to re-trapping of the released charge in shallow traps. The preliminary studies indicate that Al$_2$O$_3$:Si,Ti has some component of delayed optically stimulated luminescence (DOSL). Therefore, DOSL in this system has been investigated in detail and relative contribution of DOSL to the CW-OSL signal has been determined. Therefore, OSL readout has been performed at elevated temperatures (in the range 27-100ºC) in order to eliminate the contribution of DOSL in the CW-OSL signal. The dependence of DOSL signal on readout temperature can be explained in terms of Arrhenius equation of thermally released charges from shallow traps. The total contribution of the DOSL to the CW-OSL intensity is estimated to be about 1.4%. Although the contribution of DOSL to the CW-OSL integral signal is much less, it is advisable that OSL measurements be performed at 75ºC to avoid any contribution of DOSL signal to CW-OSL signal. The DOSL decay shows the second order exponential fit. The activation energy calculated for the trap responsible for DOSL is 0.5 ±0.04 eV.

Al$_2$O$_3$:Si,Ti was first developed by Mehta and Sengupta$^{1,2}$ as a sensitive thermoluminescent (TL) phosphor. This phosphor is reported to be five times more sensitive than the LiF (TLD-100) phosphor. The phosphor is prepared at high temperature under highly oxidizing conditions$^{1,3}$. The most sensitive material is obtained by doping with 300 ppm Si and 10 ppm Ti. The phosphor in the grain size range 88-175 $\mu$m has been found useful for use in radiation dosimetry. TL glow peaks at 50, 125, 250, 325, 475 and 625ºC with emission in blue region (420 nm) have been reported. Various dosimetric characteristics of this TL phosphor have been investigated and reported by Mehta and Sengupta$^{1,2,4}$. Recently, optically stimulated luminescence (OSL) has been reported in this phosphor$^{5,6}$.

Several research groups have tried to use optical stimulation as a dosimetric tool by using light to transfer trapped charge carriers from deep traps to shallow traps and then monitoring the phosphorescence at room temperature as the charge leaked away from the shallow traps. Several phosphors have been used in this mode but the method exhibits relatively low sensitivity. This “delayed” OSL emission has been given the acronym DOSL by Yoder and Salasky$^7$ but the method was suggested as a technique in dosimetry as early as 1969 by Miller and Colleagues$^{8,9}$ who studied the OSL emission from BeO. Later it was suggested for CaF$_2$:Mn$^{10}$, CaSO$_4$:Dy$^{11,12}$ and Al$_2$O$_3$:C$^{7,13}$, while Jaek et al.$^{14}$ used the method to study deep traps in feldspar and quartz. In each case one relies upon the fact that the traps to which the charge has been optically transferred during the stimulation are unstable at room temperatures so that the charge leaks slowly out of these traps and recombines at luminescence centers. In this sense, DOSL may also be called as optically stimulated phosphorescence. Markey et al.$^{15}$ for Al$_2$O$_3$:C has analysed the DOSL decay curve after 100 ms laser pulse and concluded that the OSL signal consists of two components: (i) a fast component that is temperature independent (for low temperatures) with a lifetime of about 35 ms (corresponding to the F-center lifetime), and (ii) a slower component that is temperature dependent and is due to phosphorescence from two shallow states with trap depths of 0.65 and 0.77 eV, respectively.

The aim of the present work is to investigate DOSL as well as its relative contribution to the CW-OSL signal in Al$_2$O$_3$:Si,Ti phosphor.

Experimental Procedure

Al$_2$O$_3$:Si,Ti phosphor in the grain size of 88-175 $\mu$m was pre-irradiation annealed at 900ºC for 30 min and was allowed to cool to room temperature by withdrawing the sample from the furnace and placing on an alumina brick. TL and OSL...
measurements were carried out using the indigenously developed TL and OSL readers\textsuperscript{16}. The OSL measurements were carried out at room temperature for gamma irradiated samples using optical excitation unit, incorporated in the TL/OSL reader, consisting of high intensity blue light emitting diode (LED) cluster with $\lambda_p = 470$ nm, $\Delta\lambda = 20$ nm. The light intensity at the sample was measured to be $45$ mW/cm$^2$ for $350$ mA dc current through the LED cluster employed during measurements. The GG-435 and UG-1 optical filters were used to prevent the stimulation radiation from reaching the photomultiplier tube (PMT). The luminescence intensity was recorded using a photon counting module interfaced to the computer through RS-232 serial interface. For DOSL measurements, the irradiated sample was stimulated for $10$ s using blue ($470$ nm) LED stimulation source and DOSL signal was measured $10$ s after the termination of stimulation. All DOSL measurements are for the integration of light intensity signal for $90$ s.

Results and Discussion

The thermoluminescence (TL) glow curve of $\text{Al}_2\text{O}_3$:Si,Ti is shown in Fig. 1, for a readout cycle up to $400$°C. The glow curve shows four TL peaks at $158$, $191$, $276$ and $355$°C for the heating rate of $4$°C/s. Out of these, TL peak at $276$°C was observed to be most intense.

In CW-OSL method the stimulation light intensity is kept constant and the OSL signal is monitored continuously throughout the stimulation period, while the DOSL involves a sequential process of sample stimulation with light followed by luminescence measurement after the termination of the stimulation light.

Figure 2 shows the CW-OSL decay curve of $\text{Al}_2\text{O}_3$:Si,Ti phosphor. The phosphor was irradiated to $20$ Gy by gamma ray dose. The DOSL was measured for the same sample after cessation of stimulation light after $90$ s. The area under the dotted curve represents the DOSL which is shown in the inset of the Fig.2.

DOSL in this system has been investigated in detail and relative contribution of DOSL in the CW-OSL signal has been determined. Therefore, OSL readout has been performed at elevated temperatures (in the range $27$-100°C) in order to eliminate the contribution of DOSL in the CW-OSL signal. The sample was stimulated for $10$ s using blue LED stimulation source and DOSL was measured $10$ s after the cessation of stimulation. Figure 3 shows the DOSL as a function of readout temperature. This phosphor shows DOSL (having an integrated counts), which nearly disappears for OSL readouts performed at $75$°C. Beyond this temperature the background

![Fig. 1 — TL glow curve of $\text{Al}_2\text{O}_3$:Si,Ti of 0.5 Gy gamma irradiated phosphor](image1)

![Fig. 2 — CW-OSL decay curve for the $\text{Al}_2\text{O}_3$:Si,Ti phosphor irradiated for 20 Gy gamma dose. The area under the dotted rectangle shows the DOSL from the same sample which is shown in the inset](image2)

![Fig. 3 — DOSL of $\text{Al}_2\text{O}_3$:Si,Ti phosphor as a function of readout temperature](image3)
emission from the irradiated sample (not subjected to stimulation by blue light) increases with temperature while DOSL reduces drastically. The dependence of DOSL signal on readout temperature can be explained in terms of Arrhenius equation of thermally released charges from shallow traps. The total contribution of the DOSL in the CW-OSL decay curve was calculated as 1.4%. Although the contribution of DOSL to the CW-OSL integral signal is much less, it is advisable to perform OSL measurements at 75°C to avoid any contribution of DOSL to CW-OSL signal. The DOSL decay shows the second order exponential fit. The activation energy, calculated for the trap responsible for DOSL as 0.5 ±0.04 eV.

Conclusions

The following conclusion can be drawn from this study:

(i) Al$_2$O$_3$:Si,Ti exhibits DOSL during optical stimulation of the irradiated phosphor. The contribution of DOSL to the CW-OSL integral signal was estimated to be about 1.4%.

(ii) CW-OSL measurements performed at 75°C eliminate completely the contribution of DOSL in the OSL signal.

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References