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Medical Physics Laboratory I

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Contents

1 | Objective

- To study the characteristics of Optically stimulated luminescence material (Al_2O_3:C-Alumina)
- To calibrate the OSL research Reader in terms of absorbed dose and find out the unknown dose.

2 | Apparatus

- Alumina discs
- OSL Reader
- Radiation generating equipment (LINAC)
- Blue light Bleaching machine

3 | Theory

Luminescence dosimetry comprises two relative dosimetry techniques: thermoluminescence (TL) and optically stimulated luminescence (OSL). Of the two, TL dosimetry is older and better known, having been in commercial use since 1960s; OSL dosimetry, in commercial use since 1990s, is less known than TL dosimetry but has several features that give it an advantage over TL dosimetry. Both the TL and OSL phenomena became known soon after the discovery of ionizing radiation during 1890s, but remained limited to academic interest until 1950s when their potential for practical use in radiation dosimetry for measurement of absorbed dose and in archaeology for dating of archaeological artifacts was established. In many respects TL and OSL are similar: they both have the same theoretical background, they both can be described as a process of stimulated phosphorescence occurring in a previously irradiated crystalline mineral referred to as a phosphor, and in both the stimulation results in emission of visible light proportional to the dose absorbed in the phosphor. The major difference between the two techniques is in the agent triggering acceleration of phosphorescence: in the TL process the stimulating agent is heat while the OSL process is stimulated with visible light.

3.1 | Process of Optically Stimulated Luminescence

The free electrons and holes released by energetic charged particles migrate through the insulator in their respective energy bands and they either recombine or become trapped in an electron or hole trap, respectively, somewhere in the insulator. Two categories of trap are known:

- First category is called a **storage trap** and its purpose is to trap free charge carriers during irradiation and release them during subsequent stimulation either with heat (TL process) or with light (OSL process).
- Second category acts as a **recombination center** or luminescence center where a charge carrier released from a storage trap recombines with a trapped charge carrier of opposite sign. The recombination energy is at least partially emitted in the form of visible or ultraviolet light. The nature of the recombination process depends strongly on the relative magnitudes of the capture cross section of the unfilled storage traps and filled recombination centers

During irradiation of the insulator the secondary charged particles lift electrons into the conduction band either (i) from the valence band leaving a free hole in the valence band or (ii) from an empty hole trap thereby filling the hole trap. The system may approach thermal equilibrium in various ways:

1. Two free charge carriers meet and recombine (electron-hole recombination); recombination energy is converted into heat.
2. Free charge carrier recombines with a charge carrier of opposite sign trapped at a luminescence (recombination) center; recombination energy is emitted as optical fluorescence.
3. Free charge carrier becomes trapped at a storage trap, eventually resulting in natural phosphorescence or accelerated phosphorescence called TL when the accelerating agent is heat and OSL when the accelerating agent is visible or ultraviolet light.

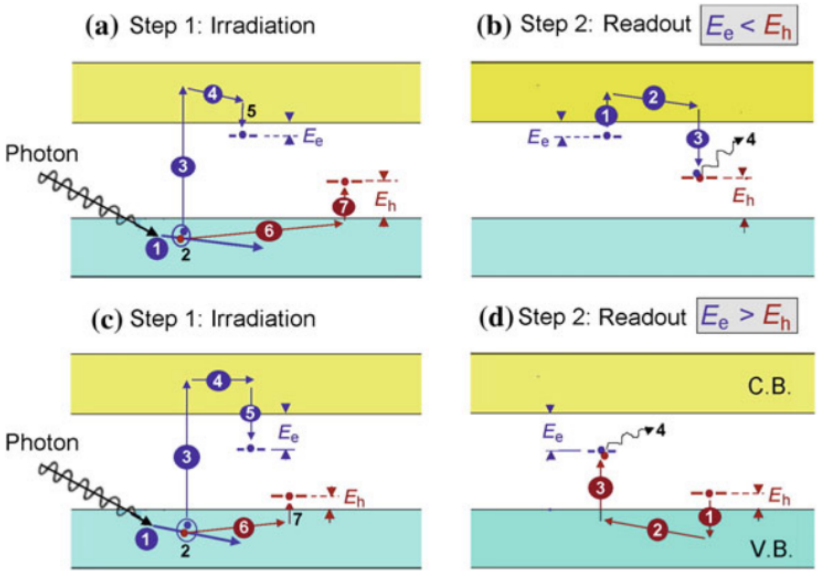


Figure 3.1: Two-step processes of optically stimulated luminescence (OSL). Parts (a) and (c) illustrate step 1, parts (b) and (d) illustrate step 2. [2]

Figure 3.1 illustrates the two major stages of the OSL dosimetry processes. Parts (a) and (c) show "Step 1: Irradiation" that consists of the following components:

1. Interaction (PE, CE, TP, and NPP) of photon with an atom of insulator (phosphor) and release of energetic charged particle (photoelectron, Compton electron, PP electron and positron).
2. ropagation of the energetic charged particle through insulator and creation of electron-hole (e-h) pairs through ionization of atoms or ions of the insulator. (Note: only one e-h creation is shown; however, each energetic charged particle creates thousands of electron-hole pairs).
3. If the electron of the e-h pair was supplied with kinetic energy E_K exceeding the energy gap E_g, the electron is lifted from the valence band into the conduction band (Note: if $E_K < E_g$, then both the electron and hole remain in the valence band, but they are bound together into a neutral entity called exciton, and migrate through the valence band).
4. Migration of free electron through conduction band of the insulator.
5. Trapping of electron into an empty electron trap.
6. Migration of hole of the e-h pair through valence band of the insulator.
7. Trapping of hole into an empty hole trap.

Parts (b) and (d) of Fig. 3.1 show "Step 2: Readout" of the OSL processes. Part (b) is for $E_e < E_h$, indicating that the electron trap is a storage trap and the hole trap is a luminescence center; part (d) is for $E_e > E_h$, indicating that in this situation the electron trap acts as a luminescence center and the hole trap acts as a storage trap. Part (b) has the following components:

1. Ejection of trapped electron from the electron storage trap into the conduction band as a result of exposure to light (OSL) of the previously irradiated insulator (phosphor).
2. Migration of free electron through the conduction band of the insulator.
3. Recombination of free electron with a trapped hole at a luminescence center.
4. Emission of visible or ultraviolet light (OSL).

Part (d) of Fig. 3.1 has the following components:

1. Ejection of trapped hole from the hole storage trap into the valence band as a result of exposure to light (OSL) of the previously irradiated insulator.

2. Migration of free hole through the valence band of the insulator.

3. Recombination of free hole with a trapped electron at a luminescence center.

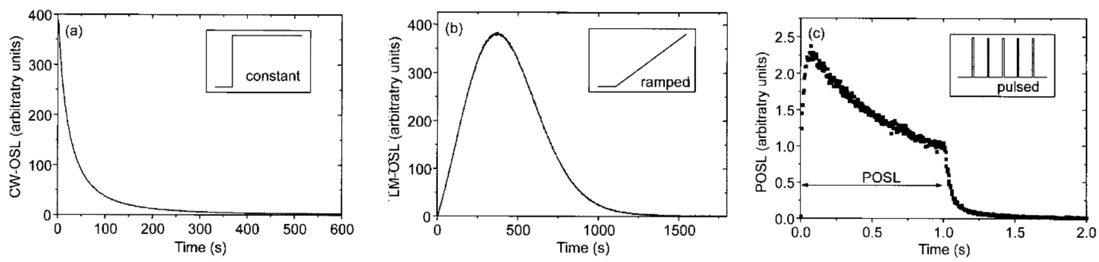
4. Emission of visible or ultraviolet light (OSL).

3.2 | Method of stimulation

- Continuous-Wave (CW) Stimulation: In this method, the OSL dosimeter is contin- uously illuminated with light of constant intensity. CW-OSL remains the most commonly used stimulation technique due to its simplicity, reliability, and ease of implementation.The emitted luminescence signal typically follows an exponentially decreasing trend with time. The output intensity depends on the initial trap population, the stimulation power, and the duration of exposure. For a fixed illumination time and constant stimulation power, the integrated luminescent output is directly proportional to the initial number of filled traps in the dosimetric material.

- Linearly Modulated (LM) Stimulation: In LM-OSL, the intensity of the stimulating light increases linearly with time, starting from zero and reaching a maximum value as the traps depopulate. The luminescence output exhibits distinct peaks corresponding to different trap depths. This feature is particularly useful when analyzing materials with multiple trapping levels, as it helps separate contributions from traps of different energies.

- Pulsed Stimulation: In pulsed OSL systems, short bursts of high-intensity light are used to stimulate the dosimeter, while luminescence is measured between successive pulses. Optical filters are employed to minimize contamination from scattered stimulation light; however, since the intensity of the stimulating beam is several orders of magnitude higher than that of the emitted luminescence, some leakage may still reach the detector. To overcome this, the pulsed-OSL system is designed so that the detection electronics are gated—i.e., the photomultiplier tube (PMT) output is recorded only during the dark intervals between light pulses. During each pulse, electrons are excited from traps to the conduction band. When the pulse ends, these electrons recombine at luminescent centers, producing measurable light emission. This method significantly improves the signal-to-noise ratio and reduces background interference, making it particularly effective for low-dose measurements.



(a) CW-OSL **(b)** LM-OSL **(c)** Pulsed-OSL

Figure 3.2: Different methods of light stimulation in OSL dosimetry.[1]

3.3 | Bleaching Procedure

After each readout, a certain fraction of trapped charge carriers may remain within the de- fect centers of the OSL phosphor. These residual trapped electrons contribute to background signals and can affect the accuracy of subsequent dose measurements if not properly removed. Therefore, a bleaching process is carried out to eliminate the effects of any previous exposure and to stabilize the electron traps for reuse of the phosphor.

Bleaching is performed using blue light illumination, which provides sufficient optical energy to release the remaining trapped electrons without causing thermal or structural damage to the phosphor material. In this procedure, all OSL discs are exposed to intense blue light for a sufficient duration to ensure complete optical bleaching. Typically, the phosphors are subjected to a blue light source of approximately 100 mW/cm2 for about 10 minutes, or alternatively, to continuous blue light exposure for a total period of at least 30 minutes.

This optical bleaching effectively empties most of the shallow and intermediate traps, thereby minimizing the residual signal and allowing the OSL phosphors to be reused for sub- sequent irradiations with reliable and reproducible results.

(a) Optical Bleaching Source

(b) OSL sample placed in Kanthal strip

Figure 3.3: Bleaching process of OSLD using blue light source.

3.4 | Types of OSLD

The Al2O3 : C phosphor exhibits strong sensitivity to low doses of ionizing radiation. Its main OSL emission peak occurs near 420 nm with a decay constant of approximately 35 ms, while a faster emission component appears around 335 nm with a decay constant of less than 7 ns. Both of these luminescence bands are produced when trapped charge carriers in the dosimeter are released by optical stimulation, typically using green light centered around 525 nm. Under continuous-wave (CW) OSL stimulation, maximum luminescence output is obtained when the stimulation wavelength is close to 500 nm.

Material	Commercial Name	ρ	Z_{eff}	Glow Peak (°C)	Emission (nm)	Fading
Al_2O_3:C	nanoDot	3.95	11.28	∼200	∼410	4% in 3 months
BeO	Thermolox 995	2.85	7.21	∼210,330	∼335,390	5–10% in 3 months

3.5 | OSL Research Reader

PC controlled TL/OSL reader manufactured by Nucleonix systems is a compact integral unit, designed primarily to meet the requirements of TL/OSL research community in R&D labs and universities who are engaged in luminescence studies of TL/OSL material. Data acquisition is controlled by PC software. In OSL, optical stimulation by Blue and Green LED is also controlled by PC software and electronic circuits and embedded code in the microcontroller. System can be operated in TL or OSL modes required by the user.

The TL/OSL stimulation and detection chamber is a precisely fabricated, light-leakage-free mechanical assembly housing a photon counting module with a detection filter basket. The LED stimulation assemblies are positioned diagonally around the photon counting module within a cylindrical enclosure. A dedicated OSL sample holder, integrated with a Kanthal heater strip and a driver circuit, is also built into the chamber.

The optical stimulation system consists of blue and green LED clusters, each LED having a power rating of 3 W. Either the blue or green LED cluster (each containing two LEDs) can be operated during stimulation. The LEDs are positioned diagonally at 180◦ with suitable lens arrangements to provide uniform luminous intensity over the sample area.

The blue LED clusters, each with 3 W output and placed 180◦ opposite to each other, provide stimulation with a peak emission wavelength of 465 nm and an emission band of 460–470 nm. The green LED clusters have a similar configuration. Each LED assembly is equipped with a long-pass stimulation filter of 420 nm cutoff and 12.5 mm diameter, which prevents scattered light below 420 nm from entering

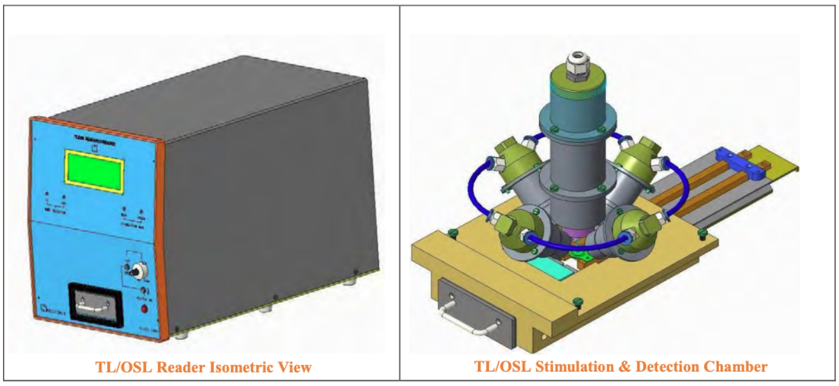


Figure 3.4: Schematic diagram of OSL Research Reader.

the photomultiplier tube (PMT) directly. A suitable focusing plano-concave lens is placed in front of each LED to focus the stimulation light onto the OSL sample positioned in the planchet.

3.6 | Filter Baskets and Their Configurations

For Optically Stimulated Luminescence (OSL) measurements, the detection system utilizes the U-340 filter basket. This basket is designed to selectively transmit the luminescence signal while effectively blocking the stimulating light, ensuring accurate photon counting from the dosimeter. The U-340 detection filter assembly provides an effective optical thickness of 7.5 mm, typi- cally achieved by stacking three individual U-340 filters. These filters are arranged with O-rings placed between each layer to ensure mechanical stability and prevent light leakage. The assem- bly is secured using a chuck nut, which must be tightened sufficiently to hold the filters firmly in position without applying excessive pressure that could damage the glass. The U-340 filter has a peak transmission around 340 nm and an effective blocking range for longer wavelengths, making it suitable for blue-light stimulation OSL measurements. This configuration enhances the signal-to-noise ratio by allowing only the emitted luminescence to reach the photomultiplier tube (PMT) while minimizing scattered stimulation light.

4 | Observation

After irradiation of the OSLD with known doses, the OSL reader gives the intensity counts for each disc. The following table shows the dose-dependent measurements of OSL.

Dose	A	B	Net Intensity
Bg	444	444	0
0.5	15282472	13975510	14628547
1	24422620	23555965	23988848.5
1.5	29594792	29917852	29755878
2	34702132	35937210	35319227
3	45098778	41206552	43152221
UA	32726517	34434890	33580259.5
UB	42256628	39502916	40879328

Table 4.1: Dose-dependent measurements of OSL.

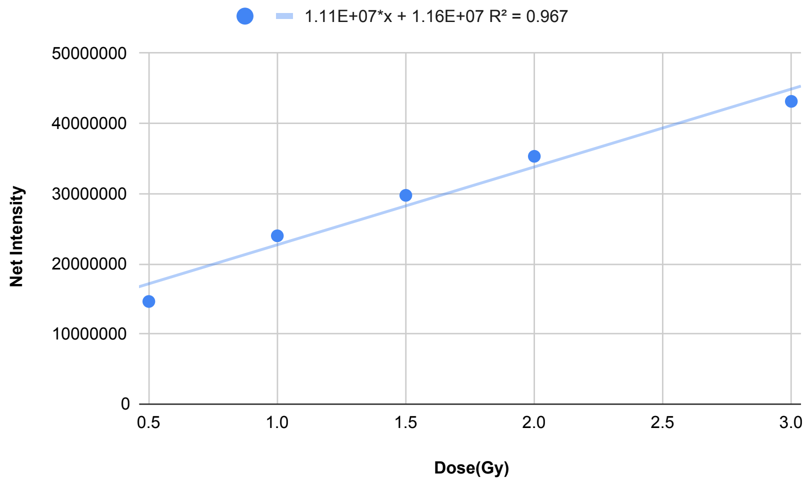


Figure 4.1: Dose vs Average Intensity graph for OSLD.

From the graph, we can see that the relationship between dose and intensity is linear. Using the linear fit equation, we can calculate the unknown doses. Using the linear fit equation:

$$\boxed{\text{Dose} = \frac{I - 1.16 \times 10^7}{1.11 \times 10^7}}$$

Where I = Intensity.

So for unknown A: the intensity is 33580259.5

$$\text{Dose} = \frac{33580259.5 - 1.16 \times 10^7}{1.11 \times 10^7} = \boxed{1.98}\ \text{Gy}$$

Similarly, for unknown B: the intensity is 40879328

$$\text{Dose} = \frac{40879328 - 1.16 \times 10^7}{1.11 \times 10^7} = \boxed{2.64}\ \text{Gy}$$

Error calculation:

Unknown	Calculated Dose (Gy)	Actual Dose (Gy)	Relative Error (%)
A	1.98	1.78	11.24
B	2.64	2.54	3.93

5 | Applications

- OSLDs are widely used in radiation therapy for patient dose monitoring and verification.
- They are employed in environmental radiation monitoring to assess exposure levels in various settings.
- OSLDs are utilized in personal dosimetry for occupational radiation workers to ensure safety and compliance with regulatory limits.
- They find applications in space missions for monitoring cosmic radiation exposure to astronauts.
- OSLDs are also used in archaeological dating and geological studies to determine the age of artifacts and sediments.

6 | Conclusion

From the experiment, we can conclude that the OSLD shows a linear relationship between dose and intensity. Using this linear relationship, we can calculate unknown doses with reasonable accuracy. The relative error for the calculated doses of unknown samples A and B are 11.24% and 3.93% respectively, indicating that the OSLD is a reliable dosimetry method for measuring absorbed doses in radiation therapy and other applications.

7 | References

[1] Lars Bøtter-Jensen, Stephen W. S. McKeever, and Ann G. Wintle. *Optically Stimulated Luminescence Dosimetry.* Elsevier, Amsterdam, 2003.

[2] Ervin B. Podgorsšak. *Radiation Physics for Medical Physicists.* Biological and Medical Physics, Biomedical Engineering. Springer, Berlin, Heidelberg, 2 edition, 2010.