Luminescent emission spectrometer adapted to a TL/OSL reader for analysis of aluminum oxide detectors

Helena Cristina de Matos Garcia, Daniel de Castro Pacheco, Luiz Cláudio Meira-Belo
Centro de Desenvolvimento da Tecnologia Nuclear. Av. Presidente Antônio Carlos, 6627 Pampulha – Belo Horizonte.
helenacrisms@gmail.com

Abstract. Thermoluminescent readings are widely used in radiation dosimetry to measure absorbed doses. The signal emitted by thermoluminescent detectors is due to defects in the crystal structure and their emission usually occurs in some specific wavelength ranges. The difficulty in studying the emission spectrum is that, in general, photomultiplier tubes do not discriminate wavelengths and therefore only provide intensity information. The objective of this work was to adapt a RISØ TL/OSL reader to operate as a luminescence emission spectrometer, allowing to select the wavelength to be analyzed before the acquisition of luminescent readings. A monochromator driven by a stepper motor connected to an Arduino module responsible for controlling wavelength adjustments during readings was used. The equipment added spectral resolution to the conventional reader, allowing the determination of the response surface as a function of temperature, wavelength and light emission intensity for the studied detectors.

Keywords: Dosimetry; spectrometry; metrology.

1. Introduction
The area of radiation dosimetry has used the phenomenon of thermoluminescence since the 1950s to quantify absorbed doses and nowadays has been applied in several areas, such as personal and environmental monitoring, doses in patients for diagnosis and therapy, dating of geological samples and archaeological and others [1].

For the detection of ionizing radiation in routine activities, TLD type dosimetry (thermoluminescent dosimetry) is widely used. Such dosimeters contain one or more detectors sensitive to radiation fields and can store information about the absorbed dose of this radiation field for a certain time. Such information can be used to monitoring occupationally exposed individuals, patients or the environment. An important feature is that they are reusable several times after reading the TL signal [2]. After the use of the dosimeter during the determined period, the device is sent for analysis where the absorbed dose will be quantified in an appropriate TL reader. This reader consists of a heating system, a sample holder and a light detection unit, usually a photomultiplier tube. By heating the detector to the proper operating temperature, it will emit the luminescent signal that is picked up by the photomultiplier whose function is to amplify and convert the light signal into an electric signal. With the use of mathematical algorithms, a computer processes the information and provides the luminescent emission curve or only the value of the integral obtained in the reading of the detector. The thermoluminescent emissions in each material occur in different ranges of wavelength and are related to defects in the crystal lattice [3].
1.1. Thermoluminescence
Thermoluminescence is a feature present in some insulating or semiconducting materials and consists of the ability to store energy from radiation fields and when adequately thermally stimulated, the material releases excess energy in the form of light. The intensity of this light is proportional to the radiation accumulated over the years or in a given period [4].

Simplified models allow the understanding of the basic mechanisms of thermoluminescence having by band theory, including the presence of impurities and defects in the crystalline lattice. Considering the interaction of such a crystalline solid with a field of ionizing radiation of an electromagnetic nature, the electrons on valence band can be excited to one of the unoccupied energy levels on the conduction band, producing electron-hole pairs. Generally, after the characteristic time of the excited state, these electrons can return to the stable equilibrium state. However, in the vicinity of defects can occur the capture the charge carriers in metastable energy levels of defects, generally referred to as traps. The charge carriers can remain in this metastable configuration for long periods and in this model only return to the equilibrium state when they are appropriately stimulated [4].

1.2. Colors centers
Defects that generate local deficiency of negative charges, either by the absence of an anion or by the replacement of the stoichiometric ion with another of greater valence, introduce levels just below the conduction band that can capture electrons. Such a defect acts as a center of electrons.

Conversely, the substitution of a stoichiometric ion with a lower valency substitutional impurity is equivalent to the introduction of a level of energy just above the valence band. Since the release of an electron is equivalent to the formation of a hole, such a defect acts as a center of holes. In general, electron and hole centers can be classified respectively as electron or hole traps when the probability that the charge carriers are stimulated to the adjacent band is greater than the probability of recombining with their peers. When the probability of recombination is greater than the probability of stimulation, such a center is called the recombination center or luminescent center and this is responsible for the emission of a signal with a wavelength in the range of the optical spectrum that varies from the ultraviolet, passes through the visible spectrum to the infrared. Study the emissions and their different sources of data on the main information about the analyzed material, such as the presence of certain impurities and the specific types of luminescent centers [5] [6].

2. Materials and methods
With the proposal to study and investigate luminescent centers of alumina detectors and other materials applicable to radiation dosimetry, an automated luminescent spectrometer has been designed and constructed that allows, from a commercial TL reader, to obtain scans with wavelength resolution. Each component of the automated luminescent spectrometer and its functions will be described in the next section.

2.1. Reader RISØ TL/OSL DA-20: base of the spectrometer
The Luminescent Dosimetry Laboratory is equipped with a Reader RISØ TL/OSL DA-20, which has a \(^{90}\text{Sr}^{90}\text{Y}\) radioactive source for samples irradiation, a heating system with a maximum temperature of 700 °C, which can vary the heating rate. In order to verify the operation of the equipment we use a detector with a known luminescent spectrum and perform a reading with routine parameters, Table 1:
Table 1. Parameters for routine readings

| Parameters | Sample | Irradiation (mGy) | Temperature Range |
|------------|--------|-------------------|-------------------|
|            | 01 Monocrystalline α-Al₂O₃:C | 125 | 0 to 350 °C |

2.2. Monochromator: separation of wavelengths

The monochromator is an optical instrument that allows selecting the wavelength to be transmitted from the incident light beam. The monochromator used in this work was produced by Optometrics, model DMC1-02. Externally the monochromator has two aperture slits (300 μm) and a wavelength range selector, with pitch adjustment of 0.1 nm, ranging from 200 nm to 800 nm. Internally, the device has a set of mirrors adjustable by a micrometric screw and a holographic grid, which is the dispersive element that allows separating the spectrum of incident light based on the frequency/length of the refractive index wave. In this way, each position of the mirrors corresponds to a specific wavelength.

For the use of the monochromator connected to the RISO reader, a coupling system was designed in SketchUp® software and produced in acrylic as shown in the Figure 1:

![Figure 1. 3D design of the coupling system (1) and coupling system made of acrylic opaque black (2)](image)

Considering that the readings are made from a light signal, it is especially important to minimize the entry of external light sources into the system. This boundary condition defined the choice of black and opaque (in range of 200 - 1100 nm) acrylic, the installed coupling is shown in the Figure 2:

![Figure 2. Monochromator coupled between the base of the reader and the photomultiplier.](image)
In addition to the external structure of the coupling system, an internal leveling plate was made which allows the installation and stabilization of a step motor, as can be seen in Figure 1. The plate also allows alignment between the monochromator inlet and outlet slits, the light signal and the photomultiplier tube.

Initially, the best positioning of the internal leveling plate was evaluated in order to obtain results in the best possible condition. For this, we use the same sample and the same parameters described in item 2.1. Once the best positioning is determined, we move on to the next step, always maintaining this alignment condition.

2.3. Programming, Arduino and automation of the spectrometer

The operation wavelength of the monochromator needs to be varied repeatedly, in an orderly and well-defined way so that the values can be read in the various wavelength. This task is repetitive and difficult to be performed accurately by a human operator. Therefore, an automation system for the spectrometer was developed so that the change could be made automatic and accurately.

In this system were used: an Arduino Uno board, light sensors (LDR and IR) and various electrical and electronic components. The main components of this system are presented in Figure 3, in a schematic drawing done in software Fritzing®.

When starting the operation, the system should be informed about the range of the spectrum to be scanned, namely: the initial value, the final value and the displacement step between each reading (in nm). The system uses an infrared (IR) sensor to read the input data from a conventional remote control. The data reported will be checked to see if they are within the operation range of the monochromator. After insertion of the parameters, the system starts the routine to check the state of the experiment, which is performed by a light sensor (LDR) that captures the change of the light signal (LED) of the RISØ reader that indicates the moment of irradiation. When new irradiation is identified, the Arduino sends the command to the drive relay of the step motor driver which is coupled to the monochromator. The motor receives the number of steps necessary to change the wavelength of the monochromator, according to the programmed interval. The system has also an LCD display that shows the information received during parameter programming and the current data in the execution of the spectrometer routine.
2.4. Test parameters
Two commercial monocrystalline aluminum oxide detectors from different manufacturers with similar characteristics were used for comparison of results. The two samples of monocrystalline detectors were submitted to the same parameters that are described in Table 2.

| Parameters | Temperature | Heating rate | Irradiation (mGy) | Wavelength scan (2nm step) |
|------------|-------------|--------------|-------------------|----------------------------|
|            | 20 to 350 °C | 5 °C/s       | 12.5              | 200 nm to 600 nm           |

The luminescent emission spectrometer built in this work was used to analyze monocrystalline aluminum oxide detectors (α-Al₂O₃: C), from different manufacturers, identified as Sample 1 and Sample 2. During the tests, each detector was irradiated and then read at predefined wavelengths on the monochromator to generate a TL response curve for each selected wavelength. In this process 200 temperature profiles were generated, which were organized as matrix and plotted as a response surface using Origin 2018b® software.

3. Results and discussion
The response surfaces of Samples 1 and 2 are shown in Figure 4. In both cases, the response surfaces obtained are similar, but the amplitude of the emission peak from Sample 1 is appreciably less than that of Sample 2.

![Figure 4. Comparison between response surface from monocrystalline detectors. Sample 1 (1) and Sample 2 (2).](image)

In Figure 5, the 2D projections corresponding to the surfaces shown above are presented. Note that this projection allows to represent the profiles that compose the peak. It is worthwhile noting that there is a coincidence in the wavelength peaks (410 nm), however, the temperature peaks are quite different, as well as the values of full width at half maximum (FWHM).

---

2 The temperature of 0 °C is a nominal value entered in the software. The actual starting temperature ranges from 19 to 23 °C (approximate laboratory ambient temperature).
4. Conclusion
This work was made an adaptation of a RISØ TL / OSL reader to operate as a luminescent emission spectrometer. The spectrometer thus constructed allows the determination of the luminescent response surfaces of different solid-state detectors in conditions very close to those of normal operation of the reader, since the main conceptual modification was the introduction of a monochromator between the sample and the photomultiplier. In addition, the range of radiation doses required for the use of this instrument is within the region of linearity of the detectors studied. In this study, two samples of aluminum oxide detectors considered commercially equivalent were used, however, the specificities of the materials of each manufacturer could be observed.

In this work a reader RISØ TL/OSL was adapted to operate as a luminescent emission spectrometer successfully. The spectrometer thus constructed allows the determination of the luminescent response surfaces of different solid-state detectors in conditions very close to those of normal operation of the reader, since the main conceptual modification was the introduction of a monochromator between the sample and the photomultiplier tube. In addition, the range of radiation doses required for the use of this instrument is within the region of linearity of the detectors studied. In this study, two samples of aluminum oxide detectors considered commercially equivalent were used, however, the specificities of the materials of each manufacturer could be observed.

References
[1] E. C. Silva, “Estudo das Propriedades Termoluminescentes de Cristais de K2YF5 e K2GdF5 Dopados com ions trivalentes opticamente ativos para dosimetria gama e de néutrons,” Universidade Federal de Minas Gerais, Belo Horizonte, 2008.
[2] L. Tauhata, I. Salati, R. D. Prinzio e A. R. D. Prinzio, Radioproteção e Dosimetria: Fundamentos, Rio de Janeiro: CNEN, 2013.
[3] F. Daniels, C. A. Boyd e D. F. Saunders, “Thermoluminescence as a Research Tool,” Science, vol. 117, nº 3040, pp. 343-349, 1953.
[4] A. J. Bos, “High sensitivity thermoluminescence dosimetry,” Nuclear Instruments and Methods in Physics Research, pp. 3-28, 30 Abril 2001.
[5] E. G. Yukiha, Desvendando a Cor e a Termoluminesceência do Topázio, São Paulo, 2001.
[6] E. G. Yukiha e S. W. McKeever, Optically Stimulated Luminescence: Fundamentals and Applications, 1 ed., Oklahoma: Wiley, 2010.