OPEN ACCESS

PRZEGLĄD ELEKTROTECHNICZNY

Karol BOLEK[1], Krzysztof FORNALSKI[2], Maciej PRZYCHODZKI[3], Krzysztof WYRWAS[4],Katarzyna RUTKOWSKA[5], Piotr SOBOTKA[6]

ORCID: [1]0000-0002-0995-7760; [2]0000-0001-7452-0189; [3]0009-0002-3689-0677; [4]0009-0009-2168-568X; [5]0000-0001-6545-3244; [6]0000-0001-6762-6647

DOI: 10.15199/48.2025.08.15

Optimization of Optical Filters Configuration for Signals Separation in OSL Dosimetry

Optymalizacja konfiguracji filtrów optycznych do separacji sygnałów w systemach dozymetrii OSL

[1] mgr inż Karol Bolek, Faculty of Electronics and Information Technology, Institute of Microelectronics and Optoelectronics, Warsaw University of Technology, 00-662 Warsaw, Poland; E-mail: karol.bolek@pw.edu.pl
[2] dr hab. inż. Krzysztof Fornalski, Faculty of Physics, Warsaw University of Technology, 00-662 Warsaw, Poland E-mail: krzysztof.fornalski@pw.edu.pl
[3] mgr inż. Maciej Przychodzki, Faculty of Physics, Warsaw University of Technology, 00-662 Warsaw, Poland E-mail: maciej.przychodzki.dokt@pw.edu.pl
[4] inż. Krzysztof Wyrwas, Faculty of Physics, Warsaw University of Technology, 00-662 Warsaw, Poland E-mail: krzysztof.wyrwas.stud@pw.edu.pl
[5] dr hab. inż. Katarzyna Rutkowska, prof. uczelni, Faculty of Physics, Warsaw University of Technology, 00-662 Warsaw, Poland E-mail: katarzyna.rutkowska@pw.edu.pl
[6] dr inż. Piotr Sobotka, Faculty of Physics, Warsaw University of Technology, 00-662 Warsaw, Poland E-mail: piotr.sobotka@pw.edu.pl

Correspondence address: karol.bolek@pw.edu.pl

Abstract: The design of the spectral filtering system for optical signals emitted by optically stimulated dosimeters is a key element in developing and advancing passive dosimetry readout techniques. This paper presents the optimization method of filters configuration (i.e., filters set) that enhances the separation between the stimulating optical signal and the luminescence signal emitted by the dosimeter, which is critical for improving measurement efficiency. The proposed solution maximizes the ratio between the desired and stimulating signal, while minimizing the number of optical filters used.

Keywords: Optical Filters, Passive Dosimetry, Optically Stimulated Dosimeters, Luminescence

Streszczenie: Projektowanie układu filtracji spektralnej sygnałów optycznych pochodzących z optycznie stymulowanych dozymetrów stanowi kluczowy element w rozwoju i doskonaleniu technik odczytu dozymetrów pasywnych. W niniejszej pracy opisano metodę optymalizacji układu filtrów optycznych, która umożliwia skuteczne rozdzielenie sygnału stymulującego od sygnału luminescencji emitowanego przez dozymetr, co ma istotne znaczenie dla poprawy efektywności pomiaru. Zaproponowane rozwiązanie pozwala na osiągnięcie maksymalnego stosunku sygnału pożądanego do sygnału stymulującego, przy jednoczesnym ograniczeniu liczby zastosowanych filtrów optycznych.

Słowa kluczowe: Filtry Optyczne, Dozymetria Pasywna, Optycznie Stymulowane Dozymetry, Luminescencja

Introduction

Ionizing radiation, although naturally present in the human environment, is commonly perceived by the public as highly dangerous, even if decades of scientific research have clearly demonstrated that this perception is vastly exaggerated. At low dose levels, radiological risk is shaped more by conservative safety assumptions than by any empirical evidence [1]. Nevertheless, in response to current societal needs and growing geopolitical threats, it is essential to undertake a precise and rigorous assessment of radiological hazards. In this context, the expansion of nuclear power as a stabilizing element of the energy system, both in Poland and globally, along with the increased risk of radiological incidents due to the ongoing conflict in Ukraine, highlights the urgent need to improve and modernize methods for measuring ionizing radiation doses [2]. This growing demand is also reflected in the rapid expansion of the global radiation detection, monitoring, and safety market. In 2024, its value was estimated at 1.68 billion USD, projected to grow from 1.8 billion USD in 2025 to approximately 3.44 billion USD by 2034. This dynamic growth is driven by increasing industrialization, the expansion of nuclear power plants, and the growing use of radiation technologies in healthcare [3].

In parallel with global trends, each European country, including Poland, maintains a national dosimetry system overseen by its nuclear regulatory authority (such as the National Atomic Energy Agency, i.e., Państwowa Agencja Atomistyki, PAA). These systems typically consist of a network of measurement stations distributed across the country, particularly along and near national borders, to continuously monitor both radioactive contamination (e.g., the airborne concentration of radionuclides) and ambient dose rates directly from the atmosphere [4]. The monitoring infrastructure combines active detectors (providing real-time data) with passive dosimeters (that require periodic readout). Additionally, aerosol and gas samples are collected using spectrometric probe assemblies. Beyond nationwide surveillance, individual monitoring is conducted around specific nuclear facilities–such as power reactors and radioactive waste repositories–within designated zones (e.g., Emergency Planning Zones and Restricted Use Areas), defined based on expected dosimetric readings [5].

The effectiveness of such monitoring systems relies heavily on the reliability and accuracy of the dosimetric methods employed. Although various physical phenomena are applied, using devices such as Geiger–Müller counters, ionization chambers, semiconductor detectors, and retrospective biological assays, only passive (integrating) dosimetry techniques are accredited by national or international bodies (in Poland, the Polish Centre for Accreditation, PCA) for official ionizing radiation dose measurements [6]. Passive dosimeters are devices containing radiation-sensitive materials that accumulate information about the absorbed dose over a defined time interval. Unlike active detectors, passive dosimeters require external readout using dedicated instruments. In Poland, three principal types of passive dosimeters are used, each defined by its readout mechanisms [4]: (i) Film dosimeters, the oldest and simplest ones (with the readout method limited by relatively high measurement uncertainty), rely on changes in photographic emulsion, with dose inferred through densitometric analysis of the developed film. For the improvement of the readout system sensitivity of radiochromic film dosimetry, it is necessary to select a well-balanced combination of band-pass filters and scanner light intensity [7]. (ii) Thermoluminescent dosimeters (TLDs) –the most widely used passive dosimeters worldwide–with the readout performed by heating the pellet (approximately 4–5 mm in diameter and less than 1 mm thick) in a nitrogen atmosphere, causing trapped charge carriers to recombine and emit light. The intensity of this light, typically measured by photomultiplier tube (PMT) or avalanche photodiode (started to be also employed more recently), is proportional to the absorbed dose (linearly related to the integral under the glow curve). (iii) Optically stimulated luminescence (OSL) dosimeters operate on a similar principle as TLDs but using monochromatic light instead of heat to release stored energy as luminescence [8].

OSL dosimeters (OSLDs) offer several advantages over film and TLD systems. First, OSL materials such as carbon-doped aluminum oxide (Al_2O_3: C) provide high sensitivity and low detection limits, enabling reliable measurements down to the micro Sievert range. Their dose response is highly linear across a broad span of exposures, with typical uncertainties of ± 3–7%, outperforming film dosimeters (with uncertainty of ± 15–20 %) and matching or exceeding most TLD systems. Unlike TLDs (whose heating-based readout permanently erases stored information), OSL dosimeters can be read multiple times without signal loss, allowing post-measurement verification and improved quality control. Additionally, OSL readout systems use low-power light sources and photodiodes instead of high-temperature furnaces or chemical processing, resulting in faster readout and lower operational costs. Finally, the compact and robust nature of thin OSL pellets also makes them resistant to environmental factors such as humidity and ambient light–especially when used with appropriate optical filters–making them well suited for both personal and environmental radiation monitoring [9].

A key challenge in OSL readout is achieving effective spectral separation between the intense stimulating beam and the much weaker luminescence signal. The stimulating light (with its intensity typically exceeding that of the emitted signal by several orders of magnitude) can pass through the thin pellet and directly reach the photodetector, introducing significant background noise. Increasing pellet thickness is not a viable solution, as it may adversely affect response to certain radiation types and degrade readout accuracy.

To achieve reliable and reproducible results when using OSL dosimetry [10], it is necessary to use suitable optical filters [11, 12, 13]. Such filters, playing a vital role in the functionality and accuracy of OSL readers and being the indispensable components in these systems, ensure that the detected signal is primarily from the luminescence of the sample rather than from the stimulation source. Moreover, the quality and accuracy of the OSL signal may be enhanced by the filters through selectively transmitting the desired wavelengths and blocking unwanted ones. Optical filters also contribute to the thermal stability of the OSL signal, ensuring that the dosimetric measurements remain constant under varying environmental conditions.

When selecting filters to be applied in a specific practical arrangement of an OSLD reader, it is essential to analyze the distinctions between the two main types of optical filters, which are colored glass filters (CF) and interference filters (IF) [14]. These two types of filters not only operate differently but also exhibit diverse transmittance properties and responses to physical and environmental factors (e.g., light polarization, alignment with respect to the incident light beam, temperature). Specifically, optical filters, referred to as colored glass or volume filters, absorb some of the light energy, thereby allowing only the desired radiation to pass through the glass [15, 16]. The absorption characteristics depend on the glass thickness, resulting in filters that typically range from a tenth of a millimeter to several millimeters. The transmission of colored glass filters (CF) is an effect of the chemical elements they are made from, which results in a limited number of options available. Typically, they are characterized by a steep cut-off in transmission on the short wavelength side and a shallow cut-off on the long wavelength side. Although the transmission properties of these optical components are independent of the light incidence angle, they exhibit a reversible dependence on temperature. Conversely, interference filters (IF), also known as optical coatings or thin films, utilize interference effects to reflect undesired electromagnetic radiation while transmitting the desired wavelengths [17]. This interference is achieved by alternating very thin layers with varying refractive indices. Due to the surface-based reflection mechanism, such filters can be manufactured to be extremely thin. The fabrication methods allow interference filters to satisfy nearly any spectral requirements (including long-, short-, band-pass, and notch filter configurations) with minimal absorption across the wavelengths of interest. These filters typically exhibit steep cut-on and cut-off in transmission at both (i.e., the short and long wavelength) ends of the spectrum, which are much sharper compared to standard absorption filters. It is crucial to consider that their spectral characteristics undergo a slight shift with increasing ambient temperature, attributable to the thermal expansion of the layers and changes in their refractive indices. Unlike colored glass filters, the overall transmission spectra of interference filters shift towards shorter wavelengths as the angle of incidence increases. This effect becomes more pronounced at the oblique angles, resulting in a specific range of incidence angles within which these filters maintain their optical functionality.

In specific applications, including signal reading in OSL dosimetry, combining both filter types (i.e., color and interference ones) can provide the optical properties required for precise measurements. When creating the sequence of interference filters and colored glass filters some specific aspects have to be considered including: (i) determination of desired spectral characteristics, with interference filters being excellent for precise wavelength selection and broad wavelength blocking typically provided by the color filters; (ii) placing the filters in specific sequence with their order depending on the particular application – typically with the first filter selecting the precise spectral range, followed by the filter absorbing/reflecting any residual unwanted wavelengths; (iii) ensuring the correct alignment of the filters to maintain their optical functionality within the desired range of incidence angles; (iv) ensuring the combined filter setup being appropriate under the expected environmental (thermal) conditions; (v) applying suitable anti-reflective coatings to minimize any potential reflection between the filters, which can improve the overall transmission efficiency of the filters cascade.

Therefore, the studies presented in this paper focus on designing and optimizing an optical filtering system for spectral separation of the stimulating and signal beams, aiming to maximize measurement dynamic range and simplify the readout system. The analysis employs explicitly the various filter combinations that minimize the attenuation of the luminescence signal emitted by the pellet while effectively suppressing the stimulating beam.

Materials and Methods

The measurement system developed for the investigation was designed to closely replicate the optical paths of a typical OSLD reader (Fig. 1). In the standard OSL readout process, both the luminescence light emitted from the dosimeter and the excitation light (stimulating luminescence in the dosimeter but also partially passing through the dosimetric material) reach the photodetector (Fig. 1a). It is important to note that the intensity of the excitation light exceeds the luminescence signal by several orders of magnitude, which poses a significant challenge for spectral separation in the optical system. This issue was addressed in the designed measurement setup by carefully selecting the light sources and their intensities. Specifically, the green excitation light applied (with the wavelength of approximately 532 nm) falls within the optimal excitation wavelength range for Al_2O_3:C-based dosimeters [17, 18]. In addition, a 420 nm LED was used to mimic luminescence emission (i.e., no OSL material was present in the system during the tests), and its intensity was adjusted to match the op-

tical signal emitted by an Al_2O_3: C pellet exposed to a 5 mSv radiation dose. The 420 nm wavelength corresponds to the emission peak of this kind of dosimeter [20].

The experimental system incorporates a Y-shaped optical fiber coupler that combines two optical signals with the input signal ratio set to 90% for green and 10% for blue light (Fig. 1b). The resulting mixed optical signal is directed to an optical filter assembly–which configuration is the focus of this study–and subsequently to a photomultiplier tube (PMT H10493–001, Hamamatsu Photonics, Japan). The described measurement system is used to evaluate two different types of optical filters (i.e., colored glass and interference filters) in various configurations to assess their effectiveness in separating the spectral components of the optical signal reaching the detector.

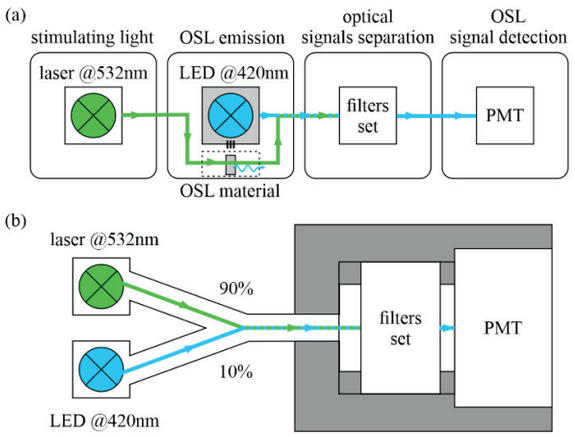

Fig. 1. (a) Diagram representing the idea of the OSLD readout system (where PMT – photomultiplier tube). Please note that in the equivalent system (marked in the light gray in the diagram) used in experimental tests, the OSL material was replaced by an LED operating at the same wavelength as the light emitted by OSLD. (b) Scheme of the actual measurement system used when performing filter set optimization. The light intensities that reach the PMT are the same as in the case of using the OSLD irradiated with a dose of 5 mSv. The dark gray shapes indicate the enclosures of the individual components within the system optical detection assembly.

Results

Figure 2 shows the measurement results for optical filters in various configurations. Specifically, Fig. 2a presents the ratio of blue light intensity I_B (imitating the luminescence signal from the OSLD) to green light intensity I_G (excitation signal) as a function of the number of filters used in different configurations. Two types of filters were used: an interference filter (IF) (FESH0450, Thorlabs Inc., USA) marked in black and a colored glass filter (CF) (FGB25S, Thorlabs Inc., USA) marked in blue. The points on the graph consist of rectangles, whose colors represent the filters used and the order in which they were placed in the optical measurement system. Specific color dashed lines and arrows indicate the direction and sequence in which the next filter is added to create a new configuration. In addition, the evolution of the paths was limited to the point where adding additional IF or CF filters does not significantly improve the signal-to-background ratio (I_B/I_G). Configurations from a single filter to four are considered to limit the number of possible options. The highest efficiency was obtained for three CF-IF--IF filters and four CF-IF-IF system filters. Moreover, three specific configurations with relatively high values of I_B/I_G ratio in configurations with defined numbers of filters (i.e., 2, 3, 4) are marked by geometric figures (square, triangle, and circle). Figure 2b represents the tested filter configurations from the perspective of the economy of the number of pieces used in the optical system. For this purpose, it was proposed to take the *n*-th root of the signal-to-background ratio (where *n* is the number of filters used in a specific filter set). In such a representation, the best configuration is the CF-IF package, which performs significantly better than the previously distinguished CF-IF--IF and CF-IF-IF-IF configurations, while maintaining a reasonably high I_B/I_G ratio (see Fig. 2a).

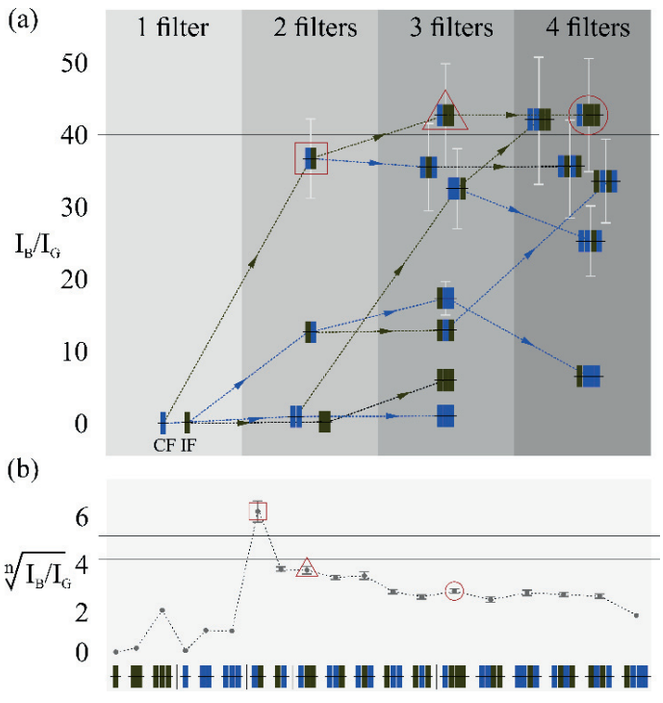

Fig. 2. Graphs representing the results obtained when experimentally optimizing the filter system composed of interference filters (IF, marked in black) and colored glass filters (CF, marked in blue). The most interesting results are additionally indicated with square, circle, and triangle red frames. Graph (a) shows the ratio of light intensities (I_B/I_G) measured by PMT when using different numbers and configurations of the filters. Graph (b) shows the value of the *n-th* root of the light intensities ratio measured by PMT, where n corresponds to the number of filters used in a given filters set configuration.

Discussion

The results obtained and presented in this paper allow for the formulation of several important conclusions.

Firstly, it is important to note that placing the interference filters (with a transmission window below 420 nm) in front of the photodetector means no need to be concerned about the type of excitation light source used in the OSLD readout system. It is particularly important when a green laser operating based on the second harmonic generation principle is employed. A contribution from the NIR first harmonic (also presented in the system) cannot be eliminated by the colored glass filters, and it may lead to distorted results by artificially increasing the measured signal. The application of interference filters effectively eliminates this issue and, consequently, in a broader context, it enables the use of a wider range of light sources for luminescence stimulation, not limited to LEDs, but also allowing the use of lasers, characterized by greater operational stability and higher power density compared to LEDs.

Secondly, the results clearly indicate that the best signal-to-background light ratio was achieved using a combination of colored glass and interference filters. More specifically, optimal results were obtained by placing the Schott filter first, followed by the interference filters. In this configuration, the colored glass filter suppresses scattered green light, while the interference filters eliminate the intense green light with the normal incidence to the filter plane.

Thirdly, when considering not only the ratio of intensities of transmitted blue to green signals but also the number of filters used within the set, the most favorable configuration consists of two filters: a colored glass filter followed by an interference filter. This is an important criterion, particularly in measurements involving low radiation doses, where the intensity of the blue light emitted from the dosimetric pellet is very low. Increasing the number of filters in such cases would further reduce the blue light intensity, which is undesirable. Additionally, the number of filters directly impacts the design and cost of the OSLD readout system–more filters mean higher overall system costs. Available information about existing OSL dosimeter readers indicates that systems typically employ only colored glass filters, without interference ones [20].

Conclusion

This study addressed a key challenge in OSL dosimetry: the need for effective spectral separation between the weak luminescence signal and the much stronger stimulation light. Through experimental analysis, it was shown that combining colored glass (CF) and interference filters (IF) significantly improves signal clarity.

The most effective configuration–a colored glass filter followed by one or two interference filters–maximized the signal-to-background ratio while maintaining system simplicity and cost efficiency. Notably, a two-filter setup (CF + IF, explicitly placed in this order) offers an optimal balance, making it suitable for low-dose measurements and scalable implementations.

These findings suggest that current OSL systems, which often rely solely on colored glass filters, could benefit from incorporating interference filters. Doing so would enhance measurement accuracy, allow the measurement of increasingly smaller doses, and expand the applicability of OSL dosimetry in both personal and environmental radiation monitoring by miniaturizing measuring devices.

Acknowledgement. This research was partially funded by the project entitled "The use of avalanche photodiodes for reading dosimeters with optically stimulated luminescence for the needs of nuclear energy in Poland" granted within the Excellence Initiative: Research University (IDUB) Programme at the Warsaw University of Technology.

Received: 13.08.2025, **Accepted:** 19.08.2025,
Published: 29.08.2025

REFERENCES

[1] Wade A., Radiation and Reason: The Impact of Science on a Culture of Fear. Aylesbury, United Kingdom: *Wade Allison Publishing*, (2009)

[2] Ulański P., Długosz-Lisiecka M., and Nowosielska E., Bezpieczeństwo radiacyjne – promieniowanie jonizujące i niejonizujące. null: null, (2023)

[3] Accessed: Jun. 10 2025. [Online]. Available: https://www.precedenceresearch.com/radiation-detection-monitoring-and-safety-market

[4] Raport Roczny Prezesa PAA – Państwowa Agencja Atomistyki – Portal Gov.pl, Państwowa Agencja Atomistyki. Accessed: Jul. 01 2025. [Online]. Available: https://www.gov.pl/web/paa/raport-roczny-prezesa-paa

[5] Grabowski D., Kurowski W., Muszynski W., Rubel B., Smagala G., Swietochowska J., Radiation monitoring network in Poland, *Nukleonika*, 46, (2001), no. 4, 147–149

[6] Duch M. A., Dombrowski H., i Hranitzky C., Overview of passive area dosimetry systems used in European coun-

tries, 2021), *European Radiation Dosimetry Group e.V. (EURADOS)*
[7] Kamomae T., Simulation for improvement of system sensitivity of radiochromic film dosimetry with different band-pass filters and scanner light intensities, *Radiol Phys Technol*, 4, (2011), no. 2, 140–147
[8] Akselrod M. S., Bøtter-Jensen L., and McKeever S. W. S., Optically stimulated luminescence and its use in medical dosimetry, *Radiation Measurements*, 41, (2006), 78–99
[9] Akselrod M. S., Larsen N. A., and McKeever S. W. S., A procedure for the distinction between static and dynamic radiation exposures of personal radiation badges using pulsed optically stimulated luminescence, *Radiation Measurements*, 32, (2000), no. 3, 215–225
[10] Bøtter-Jensen L., McKeever S. W. S., and Wintle A. G., OSL measurement technology, in Optically Stimulated Luminescence Dosimetry, *Elsevier*, (2003), 311–350
[11] Park C.-Y., Chung K.-S., Lee J.-D., Chang I.-S., Lee J., and Kim J.-L., Development of Thermoluminescence and Optical Stimulated Luminescence Measurements System, *Journal of Radiation Protection and Research*, 40, (2015), no. 1, 46–54,
[12] Park C.-Y., Chung K.-S., Lee J.-D., Chang I.-S., Lee J.-I., and Kim J.-L., Development of OSL Dosimetry Reader, *Journal of Radiation Protection and Research*, 37, (2012), no. 1, 10–15
[13] Park C.-Y., Park Y.-K., Chung K.-S., Lee J.-D., Lee J., and Kim J.-L., An Integrated System for Radioluminescence, Thermoluminescence and Optically Stimulated Luminescence Measurements, *J Radiat Prot Res*, 43, (2018), no. 4, 160–169
[14] Hecht E., Optics, 5 ed/fifth edition, Global edition. Boston Columbus Indianapolis New York San Francisco Amsterdam Cape Town Dubai London Madrid Milan Munich: *Pearson*, (2017)
[15] Keller C. U., Navarro R., and Brandl B. R., Colored Glass Filters, in Field Guide to Astronomical Instrumentation, *SPIE*, (2015). 22 2025. [Online].: https://spiedigitallibrary.org/eBooks/FG/Field-Guide-to--Astronomical-Instrumentation/Colored-Glass-Filters/Colored-Glass-Filters/10.1117/3.2064991.ch14
[16] Weber M. J., Handbook of optical materials. The CRC Press laser and optical science and technology series. *Boca Raton: CRC Press*, (2003)
[17] Macleod H. A., Thin-film optical filters, Fifth edition. Series in optics and optoelectronics. B*oca Raton London New York: CRC Press, Taylor & Francis Group*, (2020)
[18] Umisedo N. K., Yoshimura E. M., Gasparian P. B. R., and Yukihara E. G., Comparison between blue and green stimulated luminescence of Al2O3:C, *Radiation Measurements*, 45, (2010), no. 2, 151–156
[19] Yang Z., Vrielinck H., Jacobsohn L. G., Smet P. F., and Poelman D., Passive Dosimeters for Radiation Dosimetry: Materials, Mechanisms, and Applications, *Adv Funct Materials*, 34, (2024), no. 41, 2406186
[20] Yukihara E. G. and McKeever S. W. S., Spectroscopy and optically stimulated luminescence of Al2O3:C using time--resolved measurements, *Journal of Applied Physics*, 100, (2006), no. 8, 083512
[21] Bøtter-Jensen L., Thomsen K. J., and Jain M., Review of optically stimulated luminescence (OSL) instrumental developments for retrospective dosimetry, *Radiation Measurements*, 45, (2010), no. 3–6, 253–257