2026 International Nuclear Atlantic Conference – INAC 2026
Escola de Guerra Naval, Rio de Janeiro, RJ, August 24 - 28, 2026

Dosimetric Performance of $CaSO_4$:(Dy, Eu, Li, Yb, Tb, Tm),Mn Phosphors for Low-Dose Measurements in Digital Mammography

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1. Introduction

Mammography, through images obtained using X-rays, enables the early detection of nodules and other breast abnormalities, often before they can be identified by conventional methods such as self-examination. However, its performance requires strict technical standards, since failures in image quality may compromise diagnosis or delay the initiation of appropriate treatment [1]. With the advancement of digital mammography, particularly following the introduction of tomosynthesis, an increase in the radiation doses delivered during examinations has been observed [2–3]. Given the potential risks associated with cumulative radiation exposure, accurate monitoring of the absorbed dose by patients is essential. This control must balance safety and effectiveness, ensuring that radiation doses remain as low as reasonably achievable without compromising the image quality required to detect subtle variations in tissues with similar densities.

Like any examination involving ionizing radiation, mammography carries a small but non-negligible stochastic risk of cancer induction. Therefore, the assessment of absorbed dose, particularly the mean glandular dose (MGD), becomes essential to ensure patient safety. In this context, dosimetric techniques such as thermoluminescence (TL) and optically stimulated luminescence (OSL) have proven effective for determining the entrance surface dose (ESD) and MGD in digital mammography units [4]. These systems are practical, low-cost, and easily integrated into Quality Assurance Programs.

This work aims to evaluate the applicability of $CaSO_4$ phosphor composites doped with Mn and co-doped with dysprosium (Dy), europium (Eu), lithium (Li), ytterbium (Yb), terbium (Tb), and thulium (Tm) as dosimeters using thermoluminescence (TL) and optically stimulated luminescence (OSL) techniques in mammography beams. The response of these new materials will be compared with that of traditional $CaSO_4$ dosimeters, which are widely used in Brazil.

2. Methodology

Eight new groups of dosimeters were developed in collaboration between the Federal University of Sergipe (UFS) and the Nuclear and Energy Research Institute (IPEN). The samples were prepared in pellet form, using polycrystals produced via the slow evaporation route, according to the methodology presented by

Silva [5], and incorporated into Teflon at a 1:1 ratio to ensure good mechanical resistance during measurements.

The dosimeters were irradiated using a Pantak-Seifert X-ray system (Isovolt HS model, 160 kV) equipped with a tungsten target, molybdenum filter, and an additional 2 mm aluminum filter, maintaining a fixed distance of 1 m between the source and the samples. The applied doses ranged from 0.25 mGy to 5 mGy, using a 28 kV beam, under conditions representative of the low-energy range typically employed in digital mammography examinations.

For the characterization of the TL/OSL responses, a Risø TL/OSL reader system (Risø National Laboratory, Denmark), model TL/OSL-DA-20, available at CEMRI/IPEN, was used. The TL emission curves were obtained using specific optical filters: the Schott BG-39 filter, with a transmittance range in the visible region (330–600 nm), and the Hoya U-340 filter, with a transmittance range in the ultraviolet region (270–380 nm), allowing selective analysis of emissions in different spectral regions. The OSL analyses were carried out under continuous-wave stimulation using blue LEDs, with an integration time of 40 s to obtain the decay curves and luminescence intensity of the samples.

3. Results and Discussion

The uniformity, relative sensitivity, and influence of optical filters on the TL and OSL responses were analyzed. The calibration curves, obtained for doses ranging from 0.25 to 5 mGy, demonstrated good linearity. $CaSO_4$:Li and $CaSO_4$:Mn stood out due to their high sensitivity, reproducibility, and suitability for clinical mammography dosimetry applications. Figure 1(a–c) shows the TL responses obtained using the Hoya U-340 and Schott BG-39 filters, as well as the OSL response. The Hoya filter (a), which is sensitive to the UV region, revealed strong emission for the Tm,Mn and Li,Mn samples. The BG-39 filter (b) favored the performance of $CaSO_4$, while in the OSL response (c), Li,Mn and Tm,Mn exhibited the highest luminescence intensities, reinforcing their potential for optical readout systems.

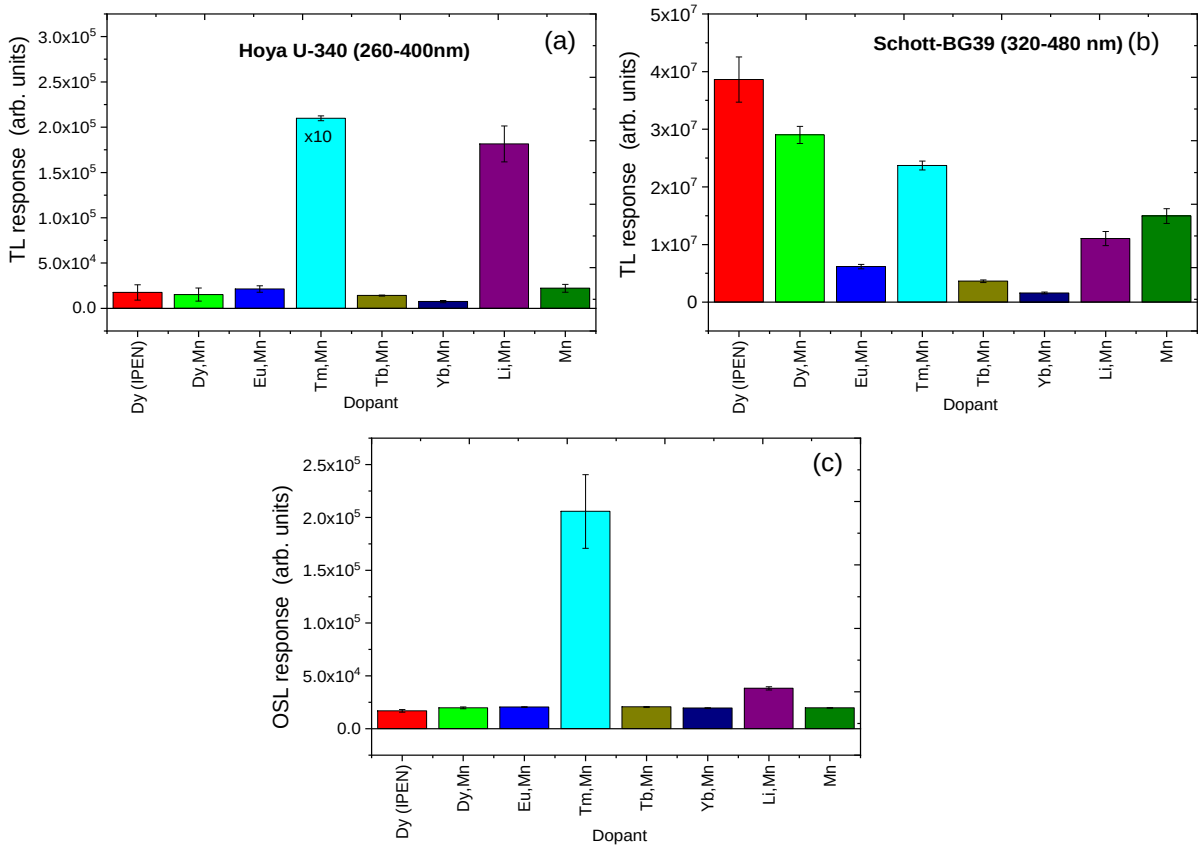

Figure 1: Relative TL response determined from the integrated glow-curve area obtained using the (a) Hoya

U-340 filter and (b) Schott BG-39 filter, and (c) relative OSL response calculated from the area under the entire decay curve of the $CaSO_4$-based phosphors irradiated with a dose of 5 mGy. Error bars represent the standard deviation of repeated measurements.

4. Conclusions

Among the tested compositions, the Tm,Mn and Li,Mn-doped materials stood out for presenting higher sensitivity in the ultraviolet (UV) region, particularly in OSL measurements, indicating additional advantages for applications in optical readout systems. For typical mammography dose ranges, the TL responses of these composites were also comparable to those of the standard $CaSO_4$ dosimeter in the visible region, demonstrating their potential as viable and low-cost alternatives for dosimetry in digital mammography. Furthermore, these materials exhibited good linearity within the analyzed dose range.

Acknowledgements

The authors gratefully acknowledge the support of the Brazilian agencies: Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP, Projects: 2023/04859-8 and 2018/05982–0); Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Projects: 305142/2021-6, 07493/2021-2, 405536/2023-2, and 406761/2022-1); National Institute of Radiation Technology in Health Science (INTERAS, 406761/2022-1-CNPq); and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) N. M. Trindade thanks to FAPESP (2024/03006-4) and CNPq (306929/2022-8, and 444110/2024-0).

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