



POSTER PRESENTATION

A comparative study of the luminescence properties of LYSO:Ce, LSO:Ce, GSO:Ce and BGO single crystal scintillators for use in medical X-ray imaging

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KEYWORDS

Inorganic scintillators;
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Abstract The present study is a comparative investigation of the luminescence properties of (Lu,Y)₂SiO₅:Ce (LYSO:Ce), Lu₂SiO₅:Ce (LSO:Ce), Gd₂SiO₅:Ce (GSO:Ce) and (Bi₄Ge₃O₁₂) BGO single crystal scintillators under medical X-ray excitation. All scintillating crystals have dimensions of 10 × 10 × 10 mm³ are non-hygroscopic exhibiting high radiation absorption efficiency in the energy range used in medical imaging applications. The comparative investigation was performed by determining the absolute luminescence efficiency (emitted light flux over incident X-ray exposure) in X-ray energies employed in general X-ray imaging (40–140 kV) and in mammographic X-ray imaging (22–49 kV). Additionally, light emission spectra of crystals at various X-ray energies were measured, in order to determine the spectral compatibility to optical photon detectors incorporated in medical imaging systems and the overall efficiency (effective efficiency) of a scintillator–optical detector combination. The light emission performance of LYSO:Ce and LSO:Ce scintillators studied was found very high for X-ray imaging.

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Introduction

Scintillation crystals of bismuth germanate, BGO (Bi₄Ge₃O₁₂), have been widely used in nuclear medicine diagnostic systems [1], because they combine good scintillation characteristics [2]. However, its decay time (~300 ns)

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limits its applications in fast imaging, i.e. Spiral Computed Tomography and Time of Flight (TOF) PET.

Cerium (Ce^{3+}) doped gadolinium oxyorthosilicate (Gd_2SiO_5 or GSO) and lutetium oxyorthosilicate, ($\text{Lu}_2\text{SiO}_5:\text{Ce}$ or LSO:Ce) are fast emitting scintillators employed mainly in PET detectors [1–6]. However, LSO is of high cost and GSO shows relatively lower light yield (≥ 8000 ph/MeV). Cerium doped lutetium yttrium oxyorthosilicate, ($\text{Lu,Y})_2\text{SiO}_5:\text{Ce}$ (LYSO:Ce), is a promising next generation scintillation crystal [5], with similar scintillation properties as LSO:Ce, it is cheaper to produce and may be a good alternative [6,7].

The present study is a comparative investigation of the light emission characteristics of BGO, GSO:Ce, LSO:Ce and LYSO:Ce single crystal scintillators under mammographic and general X-ray medical imaging conditions for potential use in integrated PET/CT detectors and other multimodal-detection systems [8].

Materials and methods

The emission efficiency (light yield) of a scintillator is often expressed by the absolute luminescence efficiency (AE) [9] (emitted light energy flux over incident and exposure rate) expressed in units of $[\mu\text{W m}^{-2}/\text{mR s}^{-1}$ or AE units]. An additional major consideration in medical imaging detectors is the light emission spectrum and its compatibility to the spectral sensitivity of various optical photon detectors. Spectral compatibility may be estimated by the spectral matching factor (SMF) and the effective efficiency (EE) ($\text{EE} = \text{AE} \times \text{SMF}$) [10].

For the present study GSO:Ce crystal was supplied by Hitachi Chemical Co. Ltd. LYSO:Ce crystal was supplied by Photonic Materials Ltd., Scotland, U.K. All crystals used in this study had dimensions of $10 \times 10 \times 10$ mm. Cerium activated crystals were doped with 0.5 mol% of cerium (Ce^{3+}). These crystals were irradiated by X-rays using a Philips Optimus X-ray unit and a General Electric Senographe DMR X-ray mammography unit. The whole range of available

Table 1 Spectral matching factors of BGO, GSO:Ce, LSO:Ce and LYSO:Ce with optical detectors

Optical detectors	BGO	GSO:Ce	LSO:Ce	LYSO:Ce
GaAs photocathode	0.91	0.93	0.93	0.93
Extended S-20 photocathode	0.89	0.90	0.94	0.94
APD Hamamatsu S5343	0.56	0.76	0.63	0.60
aSi:H/108H photodiode	0.74	0.70	0.58	0.57
PSPMT Hamamatsu 8500	0.80	0.71	0.85	0.86
CCD S100AB SITE [®]	0.87	0.88	0.88	0.88

X-ray tube voltages varied from 22 to 49 kV in the mammography unit, and from 40 to 140 kV in the general radiography unit. For measurements performed under X-ray mammographic conditions, the X-ray beam was filtered by a 30 mm thick block of Perspex to simulate beam hardening by human breast [11]. Similarly, a 20 mm thick Al was employed in the general radiography unit to simulate beam hardening by the human body [12].

The absolute luminescence efficiency was determined by performing X-ray exposure and light flux measurements, previously described by Valais et al. [10]. Six optical photon detectors currently used in digital radiography, computed tomography and nuclear medicine and their spectral matching factor with the scintillator crystals' X-ray excited light spectrum were examined (Table 1). The effective efficiency was determined using AE values multiplied by the values of the spectral matching factor reported in Table 1.

Results and discussion

The absolute luminescence and the effective efficiency of the examined scintillators were found to increase with the X-ray tube voltage (Figs. 1, 2 and 4). Fig. 1 shows the variation of the measured absolute luminescence efficiency of LSO:Ce, LYSO:Ce, GSO:Ce and BGO crystals with X-ray tube

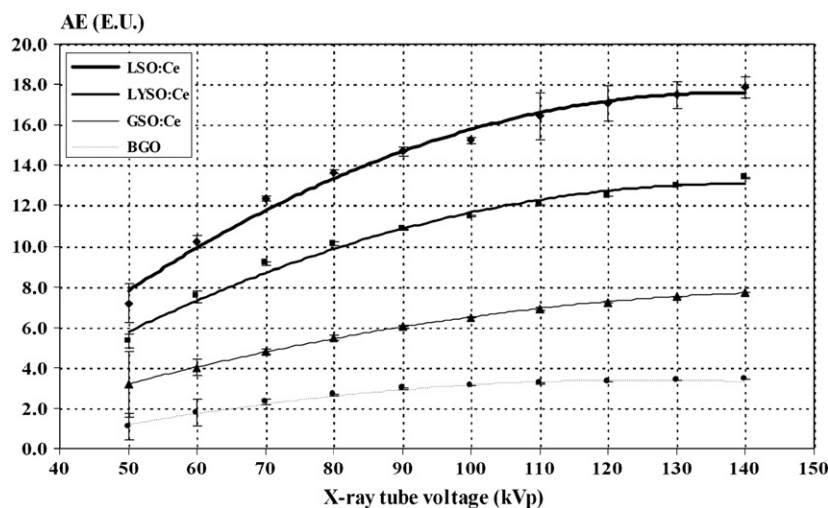


Figure 1 Variation of absolute luminescence efficiency (AE) of LSO:Ce, LYSO:Ce, GSO:Ce and BGO crystals for radiographic X-ray tube voltages, between 40 and 140 kV. AE units: $\mu\text{W s}/\text{mR m}^2$. Points: measured data, line: fitted curve.

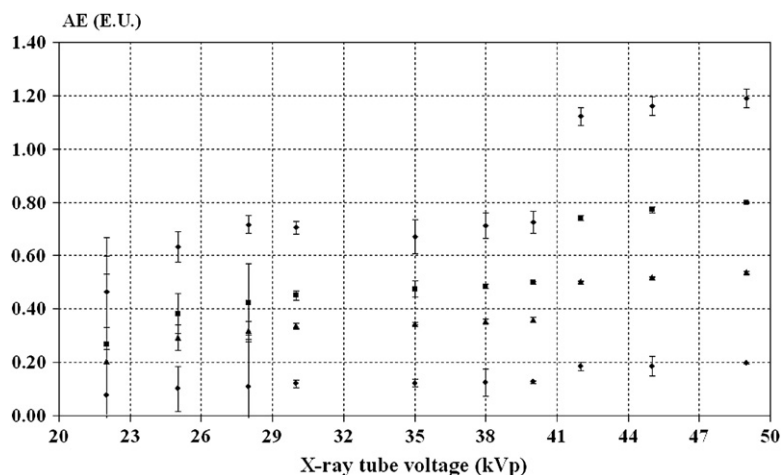


Figure 2 Variation of absolute luminescence efficiency (AE) of LSO:Ce, LYSO:Ce, GSO:Ce and BGO crystals for mammography X-ray tube voltages, between 22 and 49 kV. AE units: $\mu\text{W s}/\text{mR m}^2$. Points: measured data.

voltage using the general radiography unit. The range of tube voltages shown (50–140 kV) includes X-ray voltages used in X-ray computed tomography, digital radiography, fluoroscopy and other X-ray medical imaging applications. Fig. 2, shows the variation of absolute luminescence efficiency (AE) of LSO:Ce, LYSO:Ce, GSO:Ce and BGO crystals with X-ray tube voltages using the mammography unit.

As it may be seen in Figs. 1 and 2, AE increases, in a non-proportional way, with increasing X-ray tube voltage. LSO:Ce had higher AE in all X-ray tube voltages. The deviation between the AE curves is more prominent as the energy increases. Non-linear response has been also documented for LSO:Ce and GSO:Ce by Balcerzyk et al. [13].

The data points in Fig. 2 delineate a sharp increase of the absolute efficiency at 42 kV for all crystals examined in our study. This can be attributed to the X-ray spectrum alteration due to the change of the mammography tube filter from Rh to Al. On the contrary, no significant variation was observed when the filter changed from Mo to Rh at lower energies (38 kV). BGO crystal demonstrates a similar behaviour but in lower scale.

Fig. 3 shows the spectral response of BGO, LSO:Ce, LYSO:Ce and GSO:Ce crystals, respectively, under X-ray

excitation. Emission spectra peaks were found at 490 nm for BGO, at 425 nm for LSO:Ce and LYSO:Ce, and at 445 nm for GSO:Ce single crystals, respectively.

These spectra were found to be well matched with the spectral sensitivity curves of most optical detectors considered in this study (Table 1).

LSO:Ce was found with higher efficiency (17.8 AE units) than LYSO:Ce (13.4 AE units) in the X-ray tube voltages between 50 and 140 kVp. This was also observed in the mammography X-ray tube voltage range, between 22 and 49 kVp (LSO:Ce, 1.19 AE units, LYSO:Ce, 0.8 AE units). Although these two materials are reported to have almost similar light yield under (^{137}Cs) γ -ray excitation (Table 1), in the present investigation we observed a clear superiority in the LSO light output under medical X-ray excitation. Similarly, although GSO:Ce and BGO have been reported to exhibit similar light yields, our results (Figs. 1 and 2) demonstrate a well defined superiority of GSO:Ce, as far as the AE is concerned in both radiographic and mammographic X-ray tube voltages. The above considerations may be reasoned considering the differences in non-proportionality curves at low energies reported by Balcerzyk et al. [13] and Dorenbos et al. [14].

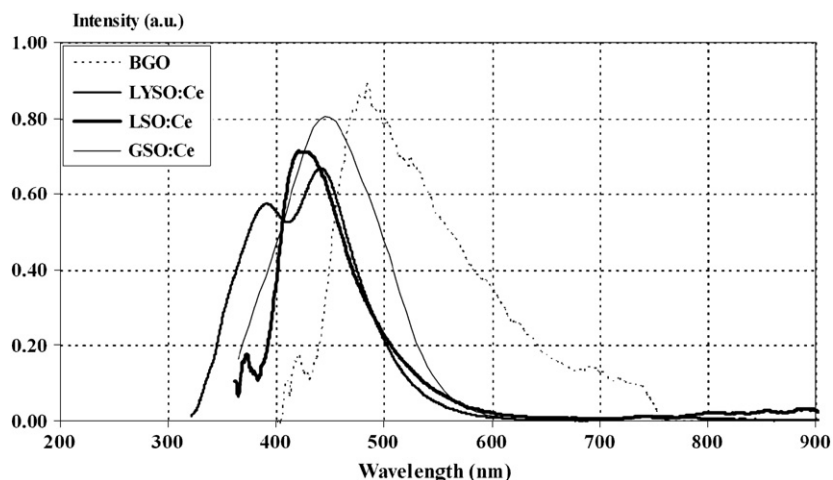


Figure 3 Normalized spectral response of BGO, LYSO:Ce, LSO:Ce and GSO:Ce single crystal scintillators.

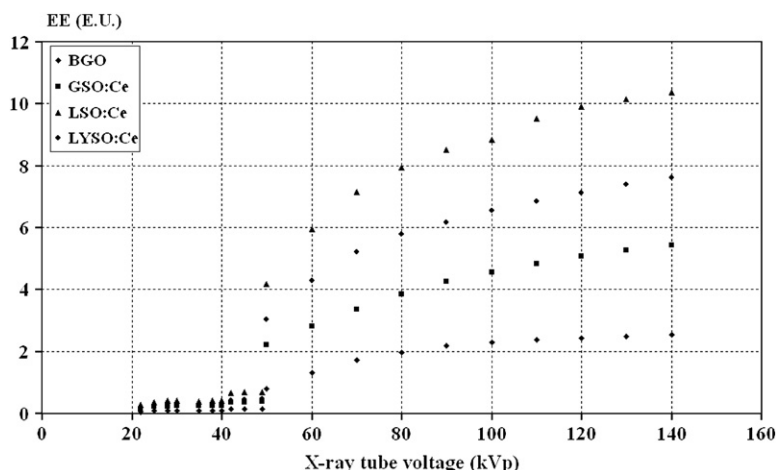


Figure 4 Effective efficiency of BGO, GSO:Ce, LSO:Ce and LYSO:Ce scintillators using the aSi:H/108H amorphous silicon photodiode.

All scintillators exhibited high spectral compatibility (matching factor >0.5) with most optical photon detectors used in medical imaging (Table 1). BGO exhibited the highest compatibility when combined with amorphous silicon photodiode, whereas the highest compatibility for all scintillators examined in our study was with GaAs photocathode. The effective luminescence efficiency (EE) of BGO, GSO:Ce, LSO:Ce and LYSO:Ce crystals is indicatively shown in Fig. 4 when combined with aSi-photodiode since it is widely used in medical X-ray imaging. The overall efficiency of scintillator–optical detector combination varies according to the matching factor (MF) value. Although in Table 1, BGO exhibits the highest compatibility with aSi among the other three scintillators, in Fig. 4 the overall efficiency (EE) of LSO:Ce remains the highest of all.

Conclusions

In conclusion, our measurements showed that the absolute efficiency of BGO, LSO:Ce, LYSO:Ce and GSO:Ce scintillator crystals increased with X-ray tube voltage under X-ray mammographic and general X-ray conditions. The light emission performance of LSO:Ce was found higher than LYSO:Ce, which in turn was found better than BGO and GSO. The emission spectra of all four scintillators examined in our study are well matched with the spectral sensitivities of the optical photon detectors often employed in radiation detectors. Taking into account the efficiency of LSO:Ce and LYSO:Ce scintillators, they can be considered as potential detectors in modern fast single detector multimodality imaging systems.

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