



Microarticle

Grains size and shape dependence of luminescence efficiency of Lu₂O₃:Eu thin screensI.E. Seferis^{a,b,*}, J. Zeler^b, C. Michail^c, S. David^c, I. Valais^c, G. Fountos^c, N. Kalyvas^c, A. Bakas^d, I. Kandarakis^c, E. Zych^b, G.S. Panayiotakis^a^a Department of Medical Physics, Medical School, University of Patras, 26500 Patras, Greece^b Faculty of Chemistry, University of Wrocław, 14. F. Joliot-Curie Street, 50-383 Wrocław, Poland^c Radiation Physics, Materials Technology and Biomedical Imaging Laboratory, Department of Biomedical Engineering, Technological Educational Institute of Athens, Egaleo, 12210 Athens, Greece^d Department of Medical Radiological Technology, Technological Educational Institute of Athens, 12210 Athens, Greece

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ABSTRACT

The aim of this work is to provide a comparative evaluation of luminescence efficiency of Lu₂O₃:Eu phosphors screens, in transmission mode, prepared with different grain shape and size, and manufactured by the sedimentation method. More specific, three screens were prepared with spherical grains of size 50 nm, 200 nm and 5 μm. Furthermore, two screens with rod-like shape grains and size of 500 nm and 1–8 μm. The behavior of Absolute Luminescence Efficiency (AE) at low energy X-rays (50 kVp) appeared to differ with the grains size and shape. Furthermore the rod-like grain screens appeared with reduced luminescence efficiency values.

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Introduction

Apart from the intrinsic properties of scintillating materials, the structural properties, such as grain size and shape seems to influence the luminescence efficiency of scintillating screens used in X-rays imaging applications due to different light propagation characteristics. The diffusion and propagation properties of light passing through nanoparticulated phosphors layers are still under investigation, with ongoing theoretical and experimental research, devoted to analysis of the physical and structural properties of those materials [1–5]. The aim of the current work is to provide a comparative investigation of luminescence efficiency of Lu₂O₃:Eu phosphors screens, prepared with different grain shape and size, and manufactured by the sedimentation method.

Method

Five thin screens were prepared with thicknesses (coating density) 33.1 mg/cm² (200 nm spherical grains), 33.3 mg/cm² (50 nm spherical grains), 35.2 mg/cm² (2–5 μm spherical grains), 31.7 mg/cm² (500 nm rod-like grains) and 33.2 mg/cm² (1–8 μm rod-like grains) on Borosilicate glass substrate 22 × 22 mm or

round quartz substrate with diameter 30 mm. In Fig. 1b, SEM images of the phosphors grains, synthesized at the University of Wrocław, are shown. Experiments were performed using a Philips Optimus X-ray unit. The Absolute Luminescence Efficiency (AE) measurements were acquired under X-ray irradiation in the range from 50 to 120 kVp and tube current product 63 mAs. The experimental setup incorporated a light integration sphere (Oriel 70451), coupled to a photomultiplier (EMI 9798 B) with an extended sensitivity S-20 photocathode. The photomultiplier current was amplified and fed to a Cary 401 electrometer [5]. An analog to digital converter was employed to digitize electrometer's output, which was then stored in a computer. AE was calculated from electrometer's output current and dosimeter data by: $AE = (i_{elec}/Sn_p a_s cg)/\dot{X}$. where i_{elec} is the electrometer's output current in pA, S is the area of the irradiated screen in cm² and n_p is the photocathode's peak photosensitivity expressed in mA/W. α_s is the spectral compatibility factor expressing the compatibility of the scintillator's emission spectrum to the spectral sensitivity of the photocathode. cg is the geometric light collection efficiency of the experimental setup, expressing the fraction of screen's emitted light [3]. The AE was expressed in units of μW m⁻²/mR s⁻¹, where μW m⁻² corresponds to the light energy flux and mR s⁻¹ to the exposure rate (\dot{X}) measured with a Piranha RTI dosimeter. The dosimeter reading was converting from Gy/s to R/s (One Roentgen of air kerma (kinetic energy released per unit mass) deposits 0.00877 Gy of absorbed dose in dry air) [6].

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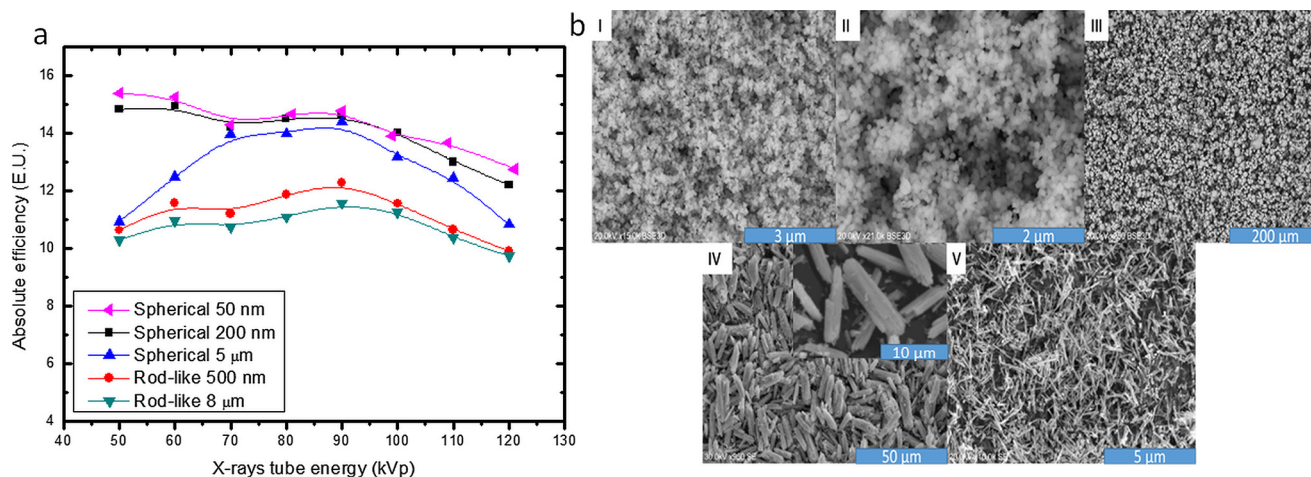


Fig. 1. (a) Absolute Luminescence efficiency of Lu₂O₃:Eu scintillating screens. (b) Scanning electron microscope images of Lu₂O₃:Eu powders used for screens preparation. I) 200 nm spherical grains, II) 50 nm spherical grains, III) 5 μm spherical grains, IV) 8 μm rod-like grains, the inset figure in IV, shows the agglomeration of grains, creating clusters of individuals, thicker, rod-like grains V) 500 nm rod-like grains.

Results and conclusions

Fig. 1 shows the variation of AE for all Lu₂O₃:Eu nanophosphor screens, prepared by sedimentation, with X-ray tube voltage, in the range from 50 to 120 kVp. Focusing on the spherical grains a different behavior of the AE curves at low X-ray energies from 50 to 70 kVp is observed. In particular, for the spherical grain screens prepared with 50 nm and 200 nm the AE decreases as the energy increases from 50 to 70 kVp, in contrast to the screen prepared with 5 μm grains. This behavior may indicate different visible light optical properties due to the dependence of light extinction on grain size and emitted light wavelength as was previously shown using Monte Carlo simulations [4]. Specifically, the light extinction coefficient, expressing the light attenuation passing through the phosphor layer, is higher for particles size approximately equal with the wavelength of emitted light, while for smaller grains this coefficient is considerable reduced. Thus, the light photons produced in the screen travel further within the phosphor layer before their first interaction with grains. Although the absorption probability is considered higher [4], the number of interactions with the grains is considered small because they are taking place closer to the exit of phosphor layer, thus near the detector. The rod-like grain screens follows also a different trend at low energies compared with 50 nm and 200 nm spherical grains screens. In this case the higher scattering and attenuation of light photons may be affected by the rod-like shape of those grains. The rod-like shape seems to be of high importance not only in light scattering but also in scintillating light emission distribution, since it is not clear if the light is emitted from all grain surface, or they act as fibers in which through multiple scattering leads the light to escape from their ends. In any case the number of produced photons, after the interaction with X-rays, are different for every side of each grain, if we consider the non-spherical and irregular shape. For this reason, is

difficult to make predictions or assumptions about the optical properties of rod-like grain screens. These properties could be also responsible for the low AE values compared with the spherical grain screens. However, in addition to the optical properties, the AE values are also a subject of synthesis procedure, affecting the defects population and distribution. The increasing part of all curves, from 70 to 90 kVp, is attributed to the K-absorption edge of the Lu₂O₃:Eu scintillator. The mass absorption coefficient is rapidly increased from 0.97 cm²/g at 63 keV to 1.52 cm²/g at 63.3 keV [7]. Afterwards, for X-ray tube voltage higher than 90 kVp the mass absorption coefficient is decreased as the X-ray tube energy increases. This affect the AE, since the absorption properties of X-rays, are generally reduced as a function of energy for the exposure conditions under consideration. Therefore the fraction of absorbed X-ray photons of the material, for equal screen thickness, decreased with increasing X-ray energy.

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