Characterisation of LSO:Tb scintillator films for high resolution X-ray imaging applications

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Abstract

Within the framework of an FP6 project (SCIN^{TAX})[1] we developed a new thin film single crystal scintillator for high resolution X-ray imaging based on a layer of modified LSO (Lu_2SiO_5) grown by LPE (Liquid Phase Epitaxy) on a dedicated substrate. In this work we present the characterisation of the scintillating LSO films in terms of optical and scintillation properties as well as spatial resolution performances. The obtained results are discussed and compared to the performances of the thin scintillating films commonly used in synchrotron-based micro-imaging applications.

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1. Introduction

Third generation synchrotron light sources offer new possibilities for different X-ray imaging techniques thanks to their high brilliance and partial spatial coherence. These techniques (e.g. microtomography with absorption or phase contrast and holotomography) demand highly efficient X-ray detectors with a spatial resolution in the micrometer and even submicrometer range [1]. In addition, microtomography calls for fast and on-line working detectors, due to the necessity to collect fast and efficient several hundred images for a single tomogram. X-ray energies are typically between 6-30 keV for absorption radiography and up to 60 keV in phase contrast mode [2]. A successful approach to achieve x-ray imaging with submicrometer resolution is given by the combination of a transparent luminescent screen (single crystal scintillator) with diffraction limited microscope optics to magnify the

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luminescence image onto a CCD (Charge Coupled Detector) camera. In this context, a significant improvement to the detector DQE (Detective Quantum Efficiency) and speed performance could be provided by increasing the absorption efficiency and the luminescent efficiency of the scintillator. Within the framework of an EC project (SCIN^{TAX} - 6th framework program) we have developed a new kind of thin single crystal scintillator for high resolution X-ray imaging based on a layer of modified LSO grown by LPE (Liquid Phase Epitaxy) on a dedicated substrate [3]. In this work we have investigated a set of LSO scintillating films having thickness between 5.6 up to 24 μm. The samples were characterised in terms of optical and scintillation properties as well as spatial resolution performances. The results were compared to the performances of a 10 μm LAG:Eu (Eu^{3+} doped $La_3Ga_5O_{12}$) and a 17.8 μm GGG:Eu (Eu^{3+} doped $Gd_3Ga_5O_{12}$) scintillating films commonly used in synchrotron-based micro-imaging applications.

2. Experimental set-up

The synchrotron light source ANKA (Angstroemquelle Karlsruhe) is located at the Research Centre Karlsruhe (Forschungszentrum Karlsruhe / K.I.T.) and is operated with a ring electron energy of 2.5 GeV and beam currents of 180-80 mA. The dipole bending magnets work with 1.5 T magnetic field and the resulting critical energy is E_c=6.2 keV. The spatial resolution measurements were performed at the ANKA/TopoTomo beamline, which can work either in white or in monocromatic beam-mode. The available white beam energy spectrum ranges between 1.5 up to 40 keV (flux at sample position ~10^{16} ph/s, 5 mm x 10mm). The monocromatic energy spectrum is provided by a DMM (WSi/Si, PaB_4C/Si) and it ranges between 6 up to 40 keV with an energy resolution $\Delta E/E=10^{-2}$ [4]. To calculated the MTF (Modulation Transfer Function) we have measured the ESF (Edge Spread Function) by positioninig a GaAs edge in direct contact with the scintillator. Next, the MTF was calculated by using the ImageJ plugin "*Slanted Edge MTF*". The used detector is composed of a CCD detector (PCO4000) and an *OptiquePeter* visible microscope equipped with a 10x objective (NA=0.4) and a 2.5x eyepiece (total magnification of 25x). The light yield measurements were performed in the laboratory of the Special Detector group of European light source ESRF (Grenoble, France) by using an X-ray generator equipped with a Cu anode operated at 20 kV and 40 mA. The emitted radiation was filtered with a 25 thick Cu foil and the light intensity was recorded with a microscopic objective, 4x and a Sensicam CCD. The measurements were corrected for the absorption efficiency of the scintillator under analysis and the quantum efficiency of the CCD.

3. Experimental results and discussion

One of the main requirements for the scintillators used in high resolution X-ray imaging applications is the absence of luminescence contribution from the substrate, which may blur the image. Currently, this is the limiting factor for the YAG:Ce and LAG:Ce (LAG:Eu) scintillating films: the undesired luminescence by the YAG substrate [5]. Another demand is the transparency of the substrate and of the scintillating film to the scintillation light in order to maximise the visible photon flux relied on the CCD detector. As we described in [6] the substrate used to deposit the LSO thin film is free from parasitic luminescence components. In Figure 1 we have reported the transmission curves of the substrate and of the LPE LSO:Tb/substrate together with the LSO:Tb radioluminescence spectrum. In the region of interest of the LSO:Tb scintillation spectrum between 470-630 nm both the substrate and the layer are transparent to the LSO:Tb light. Between 270-430 nm the LSO:Tb transmission is lower than the substrate one, due to the $^7F_6 \rightarrow {}^5D_3$ Tb^{3+} electronic transitions. A point to be stressed is that the greatest part of the scintillation light is emitted at about 540 nm where it can be efficiency detected by most of the detectors commonly used for X-ray imaging applications [7].

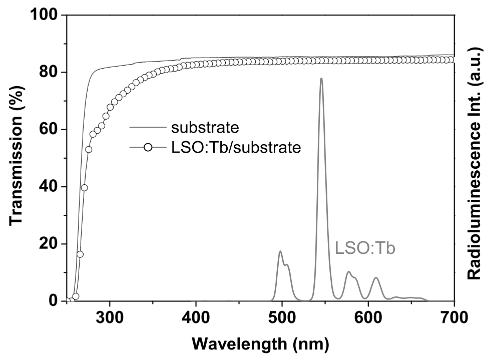

Figure 1: Transmission curves of the substrate and of the LSO:Tb scintillating film; LSO:Tb Radioluminescence spectrum.

As far as the light yield is concerned, the LSO light efficiency turned out to be 1.2 times the GGG light production and 2.8 times the efficiency of the 10 μm LAG crystal. To check the light yield uniformity on the LSO surface we have repeated the measurements in 3 different positions of the scintillator. The measured light yield values were equal to 129.1±4.1ADU, 123.8±3.9ADU and 132.4±4.2ADU indicating a good homogenity of the sample. In Figure 2 we have reported the MTF measured at 24 keV for a LSO:Tb and a LAG:Eu scintillating films having the same thickness equal to 10 μm. As it can be seen the MTF of the LSO:Tb scintillator is higher than the LAG:Eu one, indicating a superior performance from the spatial resolution point of view.

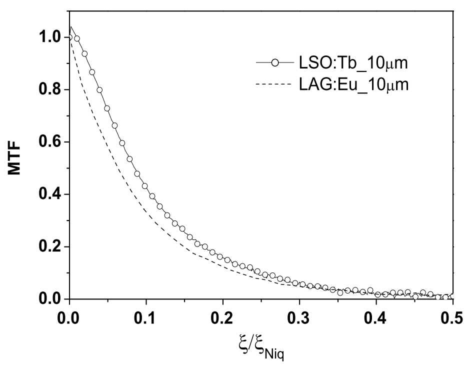

Figure 1: MTF comparision of a LSO:Tb and a LAG:Eu scintillating films with thickness equal to10 μm.

4. Conclusions

Summarysing our work, we have characterised a set of LSO:Tb scintillating films by investigating their optical, scintillation and spatial resolution properties. The LSO:Tb light yield is higher than the light efficiency of the GGG:Eu and of the LAG:Eu scintillators by a factor of 1.2 and 2.8 respectively. In addition, the spatial resolution performance of the LSO:Tb scintillator is better than the LAG:Eu one. Those result confirm the LSO:Tb being the right scintillator candidate for developing the next generation of indirect high resolution X-ray imaging detectors.

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