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Electrical characteristics of hybrid detector based Gd_2O_2S:Tb-Selenium for digital radiation imaging

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Abstract

Fine Gd_2O_2S:Tb powders were synthesized by using a solution-combustion method for a high-resolution digital X-ray imaging detector. The PL spectrum showed that the phosphor was fully crystallized and that the Tb^{3+} ions substituted well for the Gd^{3+} sites. To investigate the X-ray response of the phosphor, a uniform Gd_2O_2S:Tb film was grown using a screen-printing method. The X-ray sensitivities of the 100 μm-Gd_2O_2S:Tb/30 μm -Se and 200 μm -Se detector were 470 and 420 $pC/cm^2/mR$, respectively, at an electric field of 10 V/μm. The results of the study suggest that the hybrid detector has a significant potential in the application of digital radiography and fluoroscopy systems.

Keywords: Digital X-ray detector; Gd_2O_2S:Tb; Amorphous selenium; X-ray sensitivity

1. Introduction

Digital X-ray imaging is a rapidly developing technology for radiography applications, including various inspection and medical diagnoses. Recently, flat-panel digital X-ray imaging has offered many advantages, such as high spatial resolution, good detective quantum efficiency (DQE), and real-time imaging acquisition without geometrical distortions [1–3].

Gd_2O_2S:Tb is widely used as a radiation phosphor. Further research on Gd_2O_2S:Tb is also expected to improve luminescent properties. Sub-micron Eu^{3+}-doped RE_2O_2S [RE = Y, Gd] phosphors have been studied in recent years because of their unique electrical, optical, and structural properties. In previous studies, the preparation of sub-micron phosphors using self-burning and sol–gel methods has been undertaken to examine the influence of particle size on luminescence properties [4–7].

In this report, fine composite oxalate particles were prepared under a simple solution-combustion

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system and then calcined to obtain a composite oxide. In the following sections, we report the results of our systematic investigation of the X-ray luminescent efficiency of Gd_2O_2S:Tb fine phosphor particles. In addition, the growth of thick layers of Gd_2O_2S:Tb phosphor particles using the simple technique of screen printing is reported. This technique is suitable for the preparation of thick films in large-area flat-panel X-ray imaging applications. Some experimental and theoretical aspects of the Gd_2O_2S:Tb-coupled amorphous selenium (a-Se) detector are described in this article.

2. Experiment

2.1. Phosphor synthesis and analysis

Gadolium ($(CH_3CO_2)_3Gd$, 99.9%, Aldrich), terbium ($(CH_3CO_2)_3Tb$, 99.999%, Aldrich), and sulfide ($C_{12}H_{10}O_4S$, 99.9%) were used as starting materials. Specified amounts of $(CH_3CO_2)_3Gd$, $(CH_3CO_2)_3Tb$, and $C_{12}H_{10}O_4S$ were separately dissolved in methanol to form three solutions, which were then mixed by stirring. This mixed solution containing Gd, Tb, and S was evaporated using the chemical evaporation method. After drying in air at 120 °C, the transparent powder was put into a 50-ml covered alumina crucible. This crucible was annealed at 450 °C in a furnace for 1 h and naturally cooled down to room temperature in the chamber. Emission and excitation spectra were recorded on a luminescence spectrometer (model FS900CDT), equipped with single-grating 0.3 mm monochromators and a 450-W Xenon lamp as an excitation source. The spectra recorded between 400 and 700 nm were free from any harmonic peak problem. The emission was detected using a cooled Hamamatsu R955 photomultiplier.

2.2. Fabrication of hybrid and a-Se Detector

For the fabrication of the a-Se alloy, which can be used in X-ray medical imaging, small amounts of As (0.3 wt%) and Cl (30 ppm) were added to enhance the conduction and thermal properties of a-Se (99.999%: Nippon Rare Metal Co.).

The photoconductive layer was prepared through the thermal evaporation of a-Se onto Indium Thin Oxide (ITO) glass. The thickness of the evaporated a-Se film measured 30 μm for the hybrid detector and 200 μm for the a-Se detector. After the formation of the a-Se layer, a transparent ITO layer with an area of $1.5 \times 1.5\,cm^2$ was evaporated as an upper electrode on the a-Se layer using a DC sputtering apparatus. Under the screen-printing method, a Gd_2O_2S:Tb-coupled selenium detector was used to grow Gd_2O_2S:Tb films uniformly on the upper ITO electrode of the 30-μm thick a-Se detector.

2.3. X-ray response measurements

In order to investigate the Tb concentration dependence of the normalized brightness on the screen-printed Gd_2O_2S:Tb films, the intensity of light emitted through the phosphors was measured. The light output of the Gd_2O_2S:Tb –irradiated by X-rays generated from a tungsten target was measured using a PIN-type silicon photodiode. The transmitted X-ray photons were measured with a 2060C Ion Chamber (Radical Corporation, USA) at different X-ray source voltages. The Gd_2O_2S:Tb films, with thicknesses of about 100 and 200 μm for synthesized fine and commercial bulk phosphors, respectively, were printed on a $2 \times 5\text{-}cm^2$ glass slides.

The leakage current flowing in the a-Se and hybrid detectors was measured without X-ray irradiation during the application of voltage. The experimental setup was composed of a high-voltage generator (EG&G 558 H, USA) for applying voltage and an electrometer (Keithley 6517A, USA). The X-ray generator used was a Shimadzu TR-500-125. A current integrator measured the collected charge by integrating the induced X-ray photocurrent.

3. Results and discussion

3.1. The luminescence properties of the Gd_2O_2S:Tb fine phosphor

The photoluminescence (PL) spectrum of the Gd_2O_2S:Tb phosphor is shown in Fig. 1. In order