Study on Electrical Properties of X-ray Sensor Based on CsI:Na-Selenium Film

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In this paper, we have introduced the x-ray detector built with a CsI:Na scintillation layer deposited on amorphous selenium. To determine the thickness of the CsI:Na layer, we have estimated the transmission spectra and the absorption of continuous x-rays in diagnostic range by using computer simulation (MCNP 4C). A x-ray detector with 65 ㎛-CsI:Na/30 ㎛-Se layer has been fabricated by a thermal evaporation technique. SEM and PL measurements have been performed. The dark current and x-ray sensitivity of the fabricated detector has been compared with that of the conventional a-Se detector with 100 ㎛ thickness. Experimental results show that both detectors exhibit a similar dark current, which was of a low value below 400 pA/cm^2 at 10 V/㎛. However, the CsI:Na-Se detector indicates high x-ray sensitivity, roughly 1.3 times that of a conventional a-Se detector. Furthermore, a CsI:Na-Se detector with an aluminium reflective layer shows a 1.8 times higher x-ray sensitivity than an a-Se detector. The hybrid type detector proposed in this work exhibits a low dark current and high x-ray sensitivity, and, in particular, excellent linearity to the x-ray exposure dose.

Keywords: Amorphous selenium, CsI:Na, Dark current, X-ray sensitivity, Digital radiography

1. INTRODUCTION

A new digital x-ray imager known to flat-panel x-ray detector has been studied for the application of a various medical modalities[1-5]. This new digital detector has many advantages over conventional radiography, such as a high dynamic range, fast imaging acquisition and display, digital archiving and retrieval systems, teleradiography, display of stored imaging with degradation, extended capabilities of data analysis and imaging processing. Currently, two types of detection methods have been realized in digital radiography[6]. One is an indirect conversion method and the other is a direct conversion method. The indirect conversion method is composed of a scintillation layer and a-Si photodiode. The incident x-ray photons are converted into visible light in a scintillator layer which is mainly composed of CsI (Cesium Iodide). The visible light is converted to an electrical signal by photodiode array with PIN structure. Although the indirect conversion method has a good detective quantum efficiency (DQE), it has a low fill factor when receiving an image signal. Moreover, the indirect conversion method has a low spatial resolution due to the spreading of light in a scintillation layer.

In the direct conversion method, absorbed x-ray photons are directly converted to electron-hole pairs in a photoconductor layer and collected as electric charges on storage capacitors. In general, superior spatial resolution is expected from the direct detection type, in which amorphous selenium (e.g. a-Se) is most commonly used as the conversion layer because of its simple conversion process[7-8]. However, a-Se layer suffers from rather low x-ray sensitivity because it has ineffectual x-ray stopping power and a high creation energy of about 50 eV for the generation of an electron-hole pair. Moreover, a-Se has disadvantages, such as the breakdown of the TFT array due to the high electric field of 10V/㎛, namely several kV, for the thickness(usually 500 ㎛) of a-Se based x-ray detector[9-10].

This study has investigated a new x-ray detector that combines a columnar CsI (Na) scintillation layer with a photosensitive amorphous selenium layer. In this structure, an x-ray is converted to visible light in a 50

㎛-CsI:Na scintillation layer and visible light is then converted to electric charges in a 30 ㎛-Se layer. The electron-hole pairs can be also generated from x-ray interaction in the a-Se photoconductor, which can improve the detection efficiency of electric charges. This research suggests that the new CsI:Na-Se x-ray detector with a hybrid type structure can resolve the following problems: the high voltage from the direct conversion method; the low conversion efficiency from the indirect conversion method.

Using MCNP 4C code, the transmission spectra and x-ray absorption according to the CsI:Na thickness was simulated. The performance of the fabricated hybrid detector was evaluated through SEM, PL, and electrical measurements.

2. EXPERIMENTAL

2.1 The fabrication of a CsI:Na coupled a-Se detector

As a bottom electrode for collecting electric charges, indium tin oxide (ITO) was evaporated on a slide glass (2× 2cm^2) by the DC sputtering technique. The selenium used in this study was prepared by alloying 0.3 wt% As and 30 ppm Cl to a-Se (99.999%, Nippon rare metal co., Japan), in which the electronic transport properties have been optimized [11]. Prior to CsI:Na deposition, an a-Se layer was coated on an ITO electrode by a thermal evaporator under 10^{-6} Torr. The a-Se layers have an area of 2×2 cm^2 and a thickness of 30 ㎛ and 100 ㎛, respectively. A transparent ITO layer(1.5×1.5 cm^2) was also evaporated on an a-Se layer as an upper electrode.

The CsI:Na scintillation layer was obtained on the surface of an upper ITO electrode by a thermal evaporation method under 10^{-6} Torr. The starting materials for CsI:Na scintillation layer were prepared by mixing 99.99% CsI (Cerac co, Japan) and 99.9% Na (Cerac co, Japan). An evaporated CsI:Na scintillation layer has an area of 2×2 cm^2 and a thickness of 65 ㎛. To guide light toward a photosensitive a-Se layer, Al material was coated on the top surface of the CsI:Na scintillation layer as a reflective layer. Figure 1 shows the schematic cross-section of the (a) CsI:Na coupled a-Se detector (without Al layer), (b) CsI:Na coupled a-Se detector (with Al layer), and (c) a-Se detector.

Sodium doping was added to match the spectral emission of the CsI:Na scintillator with the absorption spectrum of the selenium. A conventional a-Se based x-ray detector was also prepared for the comparison purposes.

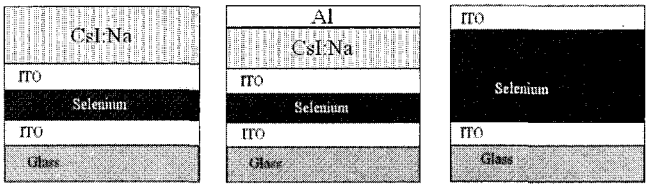

Fig. 1. The schematic cross-section of (a) CsI:Na-Se detector without reflector, (b) with reflector, and (c) a-Se detector.

2.2 Dark current and x-ray sensitivity

Scanning Electron Microscopy (JSM 820, Japan) was used to investigate the morphology and to inspect the surface of the vacuum deposited CsI:Na scintillator. The photo-luminescent spectrum of CsI:Na was measured in the wavelength range of 200-800 nm by using a double monochrometer (SPEX 1403, USA) equipped with an R943-02 photomultiplier tube. The excitation source was a 325n line of He-Cd Laser (Spirox Holding, USA). The absorption spectrum of the a-Se layer was measured in the wavelength range of 200-800 nm using a UV-VIS-NIR Spectrophotometer (Varian Cary 5E, USA).

2.3 Electrical measurement

Figure 2 shows the experimental schematic for measuring dark current and x-ray sensitivity. I-V characteristics of the a-Se layer were measured to investigate the electrical properties. Dark currents flowing in a-Se layer were measured at a dark state after applying an electric field at an interval of 2 V/㎛ from 2 to 10 V/㎛. The experimental setup for measuring the dark currents was composed of a high voltage generator (EG&G 558H, USA) and an electrometer (Keithley 6517A, USA). The measurement of x-ray sensitivity was

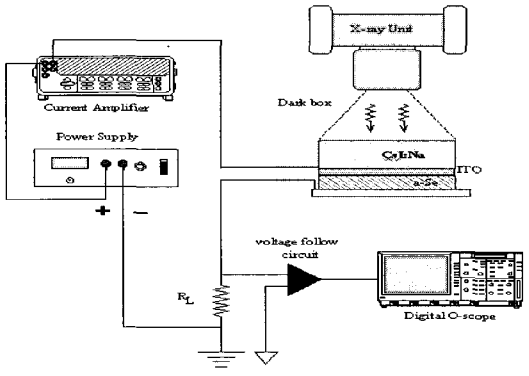

Fig. 2. Schematics for measuring dark current and x-ray sensitivity.

similar to that of dark current except for x-ray exposure. [12]. A Shimadzu TR-500-125 was used as a x-ray generator to measure x-ray sensitivity. The waveform of

the induced voltage generated by x-ray exposure was acquired by oscilloscope. The total charges were calculated from integrating an acquired waveform, by using AcqKnowledge 3.0. The radiation dose was monitored by an Ion Chamber 2060 (Radical Cooperation, USA) during measurement.

3. RESULTS AND DISCUSSION

3.1 Morphology and PL emission of CsI(Na), and absorption of a-Se layer

Figure 3 shows the SEM pictures of a fabricated CsI:Na-Se layer. The first SEM picture, as shown in Figure 3(a), shows a CsI:Na scintillation layer evaporated on an upper ITO electrode. It reveals that the thermally evaporated CsI:Na layer consists of a large number of small pillars or ellipsoids, roughly perpendicular to the substrate and running from the substrate to the top surface. Figure 3(b) shows the SEM picture of the top surface of CsI:Na polycrystalline film. The outer surface reveals a pyramid like structure that is somewhat formed. It can also be seen that the compaction factor of a CsI:Na polycrystalline structure is relatively high.

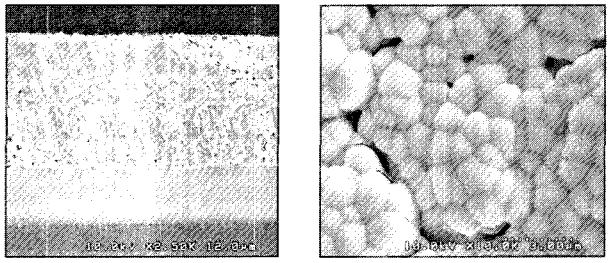

Fig. 3. SEM pictures of CsI:Na-Se detector: (a) cross-section view; (b) surface view.

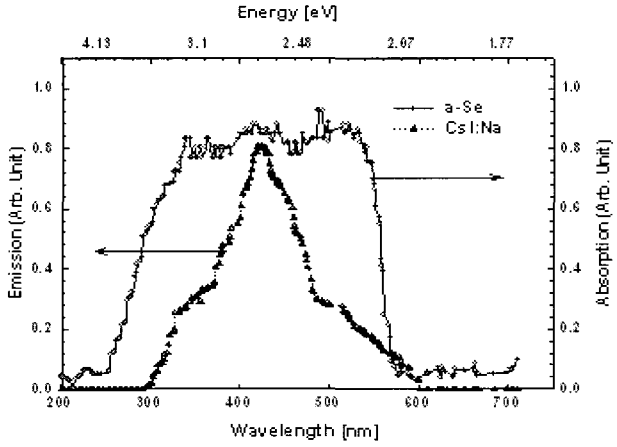

Fig. 4. PL emission of a CsI:Na scintillator and absorption of an a-Se layer.

Figure 4 shows the photoluminescence emission spectrum of a CsI:Na scintillation layer (65 ㎛) and the absorption spectrum of an a-Se layer (30 ㎛). The CsI:Na layers showed a single intensity centered at around 420 nm. This emission peak is in agreement with data reported in other studies. [13] While, the a-Se film showed a broad absorption spectra since the impurities of 0.3 wt% As and 30 ppm Cl were added to a-Se to improve the electrical properties.

3.2 Dark current and x-ray sensitivity

Figure 5 shows the dark currents of 65 ㎛-CsI:Na coupled 30 ㎛-Se detectors (without Al and with Al) and a 100 ㎛-Se detector as a function of electric fields. The measured dark currents of all x-ray detectors exhibited a similar increase for electric fields up to 10 V/㎛. For a field of 10V/㎛, low dark currents below 370 pA/cm2 were obtained, which can be used for the application of x-ray imaging detectors. A dark current is known to originate due to charge accumulations by charge carriers injected at the top ITO electrode/*a*-Se interface. A-Se film with a dielectric blocking layer showed a significant reduction in the charge due to accumulated negative charges at the interface between the top ITO electrode and the a-Se layer. Reduction of the internal electric field through repeated x-ray exposure was also an important factor contributing to the dark current of a-Se based detectors.

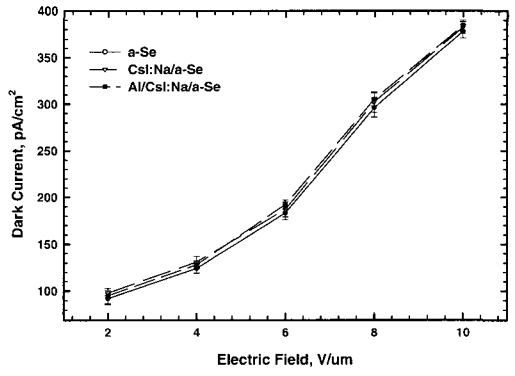

Fig. 5. Dark current according to electric field.

Figure 6 shows the x-ray sensitivity of CsI:Na coupled a-Se detectors (without Al and with Al) and a 100 ㎛-Se detector as a function of electric fields. The x-ray exposure condition was 60 kVp and 8 mAs. Data for all three curves was obtained by dividing the output charges produced by x-ray exposure with the dark charges.
Experimental results showed that CsI:Na coupled a-Se detectors exhibited higher x-ray sensitivity than the 100 ㎛-Se detector. The x-ray sensitivity of CsI:Na coupled a-Se detector with an Al layer was 1.8 times grater than

that of the 100 ㎛-Se detector. These increase of x-ray sensitivity in CsI:Na coupled a-Se detectors is probably due to the introduction of CsI:Na scintillator, since the x-ray absorption of CsI:Na is higher than that of a-Se.

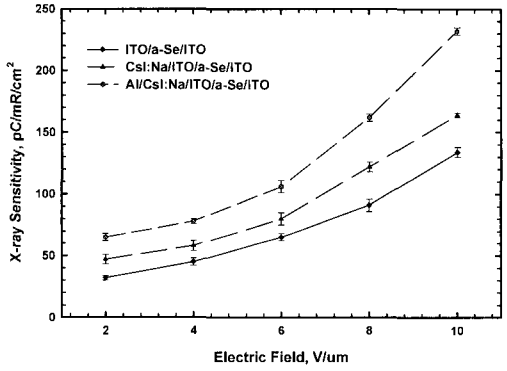

Fig. 6. X-ray sensitivity according to electric field.

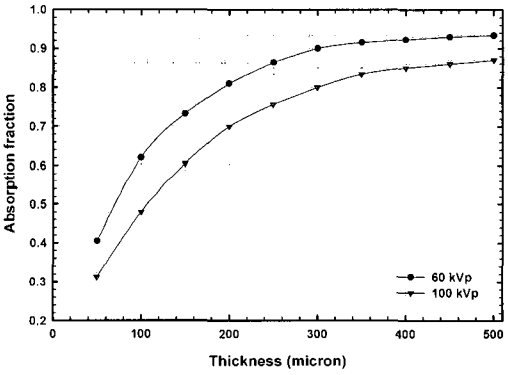

Fig. 7. Absorption fraction according to CsI:Na thickness obtained by MCNP.

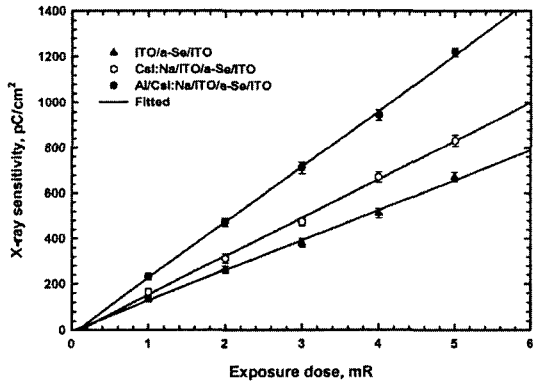

Fig. 8. Linearity of a-Se and hybrid detector.

Figure 7 shows the x-ray absorption fraction according to the thickness of CsI:Na obtained by MCNP 4C. This study used a 65 ㎛ thick CsI:Na scintillation layer. Therefore, one expects a high detection efficiency by increasing the thickness of CsI:Na layer and fabricating the CsI:Na layer with a columnar structure.

Figure 8 shows the x-ray sensitivities of developed x-ray detectors as a function of x-ray exposure. All x-ray detectors exhibited an excellent linearity with x-ray doses.

4. CONCLUSION

To solve the problems of a conventional x-ray detector, we made a new x-ray detector and evaluated its performance such as the morphology, dark current, x-ray sensitivity, and linearity. This detector consisted of a CsI:Na scintillation layer with an a-Se photoconductor layer. A MCNP 4C input code and estimated x-ray absorption fraction according to various CsI:Na thickness were developed. From SEM and spectrum measurements, the morphology of CsI:Na with pillar structure, the emission spectrum of CsI:Na and the absorption spectrum of a-Se were revealed and examined. 65 ㎛-CsI:Na coupled 30 ㎛-Se detector proposed in this work exhibited a low dark current and high x-ray sensitivity, and in particular, excellent linearity to x-ray exposure dose. The research presented, herein, reveals that a high detection efficiency is achieved by increasing the thickness of CsI:Na layer and fabricating the CsI:Na layer of columnar structure.

ACKNOWLEDGEMENT

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