X-ray Sensitivity of Hybrid-type Sensor based on $CaWO_4$-Selenium for Digital X-ray Imager

Ji-Koon Park[a], Jang-Yong Choi, Sang-Sik Kang, and Dong-Gil Lee
Department of Biomedical Engineering, College of Biomedical Science and Engineering, Inje University, Kimhae 621-749, Korea

Jae-Hyung Kim and Sang-Hee Nam
Medical Imaging Research Center, Inje University, Kimhae, Kyungnam 621-749, Korea

[a]E-mail : pjk@drworks1.inje.ac.kr

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The development of digital x-ray detector has been extensively progressed for the application of various medical modalities. In this study, we introduce a new hybrid-type x-ray detector to improve problems of a conventional direct or indirect digital x-ray image technology, which composed of multi-layer structure using a $CaWO_4$ phosphor and amorphous selenium (a-Se) photoconductor. The leakage current of our detector was found to be ~180 pA/cm^2 at 10 V/m, which was significantly reduced than that of a single a-Se detector. The x-ray sensitivity was measured as the value of 4230 pC/cm^2/mR at 10 V/m. We found that the parylene thin film between a $CaWO_4$ phosphor and an a-Se layer acts as an insulator to prevent charge injection from indium thin oxide (ITO) electrode into an a-Se layer under applied bias.

Keywords : Amorphous selenium, Hybrid-type x-ray detector, Dark current, X-ray sensitivity

1. INTRODUCTION

The development of the digital x-ray detector has extensively progressed to applications for various medical modalities[1,2]. Currently, two types of detection methods have been realized in digital radiography. 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 silicon photodiode. The incident x-ray photons are converted into visible light in a scintillator layer. The visible light is converted to an electrical signal with a photodiode array. The indirect conversion method has a low spatial resolution due to the spreading of light in a scintillation layer[3-6].

In the direct conversion method, the absorbed x-ray photons are directly converted to electron-hole pairs in a photoconductor layer and collected as electric charges in storage capacitors. In general, superior spatial resolution is expected from the direct detection type, in which amorphous selenium (a-Se) is most commonly used as the conversion layer because of its simple conversion process[7-9]. However, the a-Se layer suffers from rather low x-ray sensitivity because it has an ineffectual x-ray stopping power and a high creation energy of about 50 eV for the generation of an electron-hole pair. Moreover, the direct conversion method has disadvantages, such as the breakdown of a-Se layer or the thin film transistors (TFTs) array due to the high electric field of 10 V/μm, namely, several kV for the a-Se based x-ray detector[10]. A method to increase the sensitivity of the detector is required. Some basic approaches to increasing the signal-to-noise ratio (SNR) are reducing the noise from the material and the external charge preamplifier; or increasing the conversion gain at the pixel level (e.g., improving the photoconductor or the phosphor conversion gain).

The former tries to decrease the noise and the dark current and to increase the SNR by using parylene as dielectric layers in various thicknesses. The latter tries to increase the efficiency of photogeneration in a-Se, a photoconductor that has already been highly developed in the field of x-ray imaging[11]. The hybrid x-ray detector generated a higher electric signal than did a conventional direct x-ray detector due to its simultaneous detection of electric signals induced by both direct x-ray absorption and light absorption in the phosphor layer.

In this study, we used a $CaWO_4$ intensifying screen on an a-Se layer. In this structure, the x-ray is converted to visible light in a $CaWO_4$ layer and visible light is converted to electric charges in the a-Se layer. Therefore, we tried to simultaneously signals with light as well as signals with an x-ray.

2. EXPERIMENTALS

2.1 Sample fabrication

The starting material used as a photosensor layer was Cl-doped a-Se:0.3 % As, also known as stabilized a-Se, films suitable for use as electroradiographic receptors, as described previously[5,6]. The a-Se films were onto an indium thin oxide (ITO) glass under 10^{-6} Torr with a. thermal evaporator. The evaporated a-Se film had a thickness of 50 μm and a surface area of 2×2 cm^2. An upper ITO electrode for measuring electrical signals was deposited using the sputtering method. A parylene passivation film was deposited using the commercially available parylene deposition system (PDS 2060, SCS, USA). Finally, a $CaWO_4$ phosphor of 200 μm thickness was directly coupled on the protection layer using optical adhesives (OA9352HT, Luventix Co., USA). Fig. 1. shows the cross-section of the fabricated hybrid-type detector.

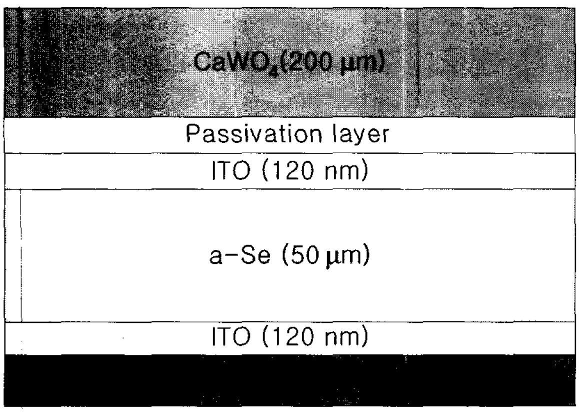

Fig. 1. The cross-section of the fabricated hybrid-type detector.

2.2 Resistivity and optical measurements

Resistivity is a direct measure of the leakage current through a material. When measuring resistivity, a sample is placed between two electrodes and a potential difference is applied between them. The resulting current is distributed through the volume of the sample and is measured using a picoammeter (Keithley Model 6517, USA). Fig. 1 shows the block diagram of resistivity measurement.

The photoemission spectrum of $CaWO_4$ was measured in the wavelength range of 200-800 nm using a double monochrometer (SPEX 1403, USA) equipped with an R943-02 photomultiplier tube. The excitation source was a 325 nm line of an 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 5 E, USA).

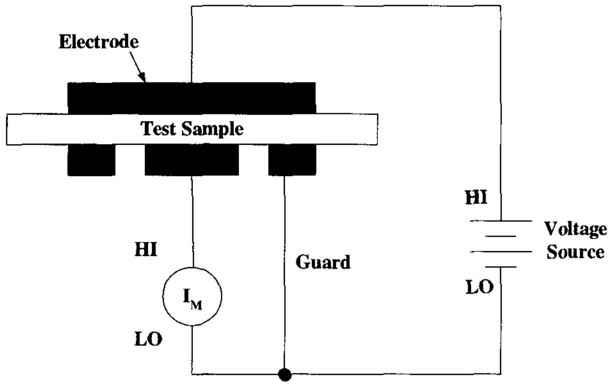

Fig. 2. The block diagram of resistivity measurement.

2.3 The leakage current and X-ray sensitivity

The method of reducing the leakage current is therefore an important consideration in the design of semiconductor detectors. The application of an electric field to the x-ray conversion material at a dark state (without x-ray exposure) influences the charge flow of electron-hole pairs inside the a-Se layer. It is very important to reduce the dark current since the generation of dark currents by the electric field constitutes unnecessary electrical noise.

Leakage currents flowing in an As-doped a-Se film were measured at the dark state while an electric field of from 2 to 12 V/μm was applied. The experimental setup for measuring the dark current was composed of a current amplifier (Keithley Model 428, USA) for measuring small dark currents, and a power supply (EG&G 558 H, USA) for applying high electric fields. After applying the electric field to the a-Se based x-ray detector, the leakage current flowing in the a-Se layer was measured for 60 seconds. The measurement of x-ray sensitivity was similar to that of the leakage current, except for the x-ray exposure. The x-ray exposure conditions were 70 kVp, 100 mA, and 0.03 second, respectively. Al layers were also used as x-ray absorption layers to control the x-ray dose exposed on the a-Se based x-ray detector. The exposure dose on the surface of the x-ray detector was monitored with an Ion chamber 2060 (Radical Cooperation, USA) during the measurement.

A Pb collimator was also used to control the extent of x-ray exposure on the fabricated x-ray detector. The experimental setup was protected with an Al chamber to prevent the measuring unit from misoperating. After applying a high electric field of dc 100-600 V DC to the x-ray detecting device, the output terminal of the current amplifier was connected with the input of an oscilloscope (LeCroy 334 AM, USA) to collect the electrical signal.

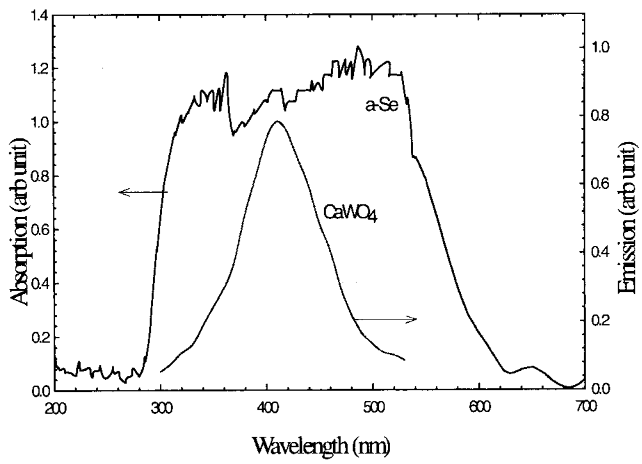

Fig. 4. Absorption spectrum of a-Se and emission spectrum of $CaWO_4$.

3. EXPERIMENTAL

3.1 Resistivity and optical characteristics

Figure 3 shows the resistivity of a parylene thin film as a function of the parylene dimmer. The resistivity of parylene was about 2~9×10[15] Ω-cm. This is similar to theoretical resistivity, not influenced by the parylene dimmer. The x-ray image sensors could be constructed by integrating an x-ray scintillation layer on top of the selenium layer. To obtain a higher x-ray sensitivity, we optimized the emission material via spectral matching of the scintillator emission wavelength and that of a-Se. As shown in Fig. 4, the emission wavelength of $CaWO_4$ was fits for the absorption wavelength of the photoconductor a-Se.

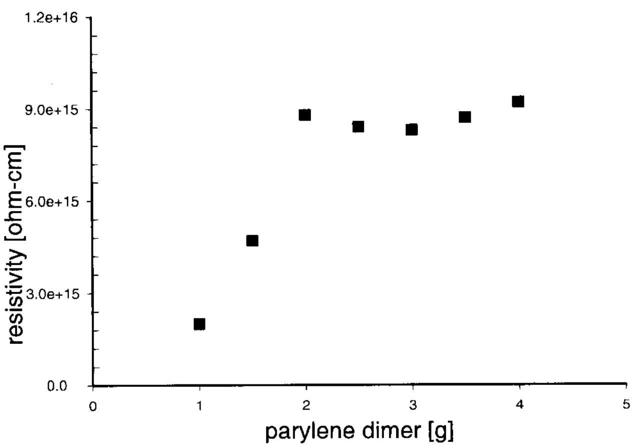

Fig. 3. Resistivity as amount of parylene dimmer.

3.2 The leakage current and X-ray sensitivity

Figure 5 shows the leakage current of an a-Se and hybrid detector as a function of bias. In the hybrid detector without a parylene layer, the leakage current increased with the applied voltage, and reached 315 pA / cm^2 at 10 V/μm.

On the other hand, the leakage current was efficiently suppressed to 180 pA/cm^2 at 10 V/μm. This results show that a passivation thin film between $CaWO_4$ phosphor and the a-Se layer acts as an insulator to prevent charge injection from an ITO electrode into the a-Se layer.

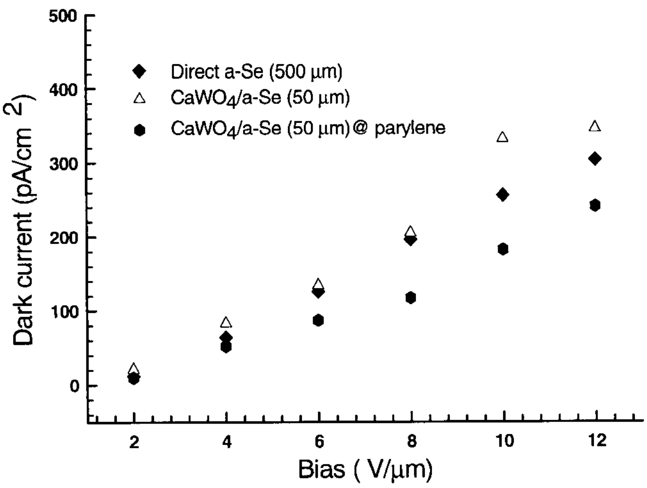

Fig. 5. The leakage current of an a-Se and hybrid detector as a function of bias.

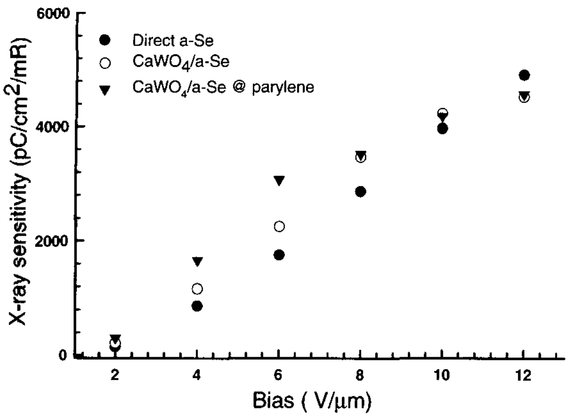

Fig. 6. The x-ray sensitivity of an a-Se and hybrid detector as a function of bias.

Figure 6 shows the x-ray sensitivity of direct a-Se and the hybrid detector as a function of the applied bias. The x-ray sensitivity of the hybrid detector exhibited the value of 4230 pC/cm^2/mR at the typically supplied voltage of the direct a-Se detector (10 V/μm). This value was lower than that of a direct a-Se detector of 500 μm thickness but exhibited excellently increased x-ray sensitivity than did the direct 50 μm a-Se (~600 pC/cm^2/mR) due to the 200 μm $CaWO_4$ screen. Fig. 7 shows, however, that the SNR of the hybrid detector with the parylene layer was higher than that of the hybrid detector (without parylene) and the direct a-Se detector due to the former's lower dark current. In addition, our hybrid detector had a maximum SNR at 6 V/μm due to its higher dark current according to its increasing a bias voltage. These results show that the feasibility of the new detector design for digital x-ray imaging.

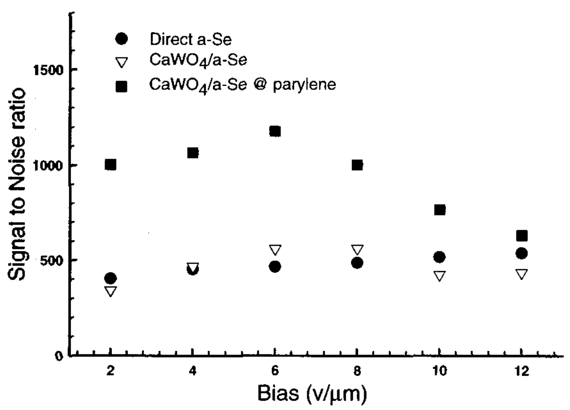

Fig. 7. The signal to noise ratio of an a-Se and hybrid detector as a function of bias.

4. CONCLUSION

We proposed a new hybrid-type x-ray detector, which composed of a multi-layer structure using $CaWO_4$ phosphor and an a-Se photoconductor. The measured dark current for our hybrid detector was found to be ~ 180 pA/cm^2 at 10 V/μm, which is significantly lower than that of the a-Se detector. The x-ray sensitivity was measured as 4230 pC/cm^2/mR at 10 V/μm. The ratio of the output signal charge to the leakage charge of the hybrid detector with the parylene layer was maximum at the bias of 6 V/μm. Our proposed hybrid detector improved the TFT array breakdown due to high voltage and low x-ray sensitivity, as well as low detection efficiency due to a low fill factor. Further work to investigate the optimization of the structure of the hybrid detector is in progress, as for example, to determine the optimal thickness of the $CaWO_4$ phosphor with the reflective layer and the a-Se layer, among others.

ACKNOWLEDGMENT

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