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A hybrid radiation detector based on a plasma display panel

Sungho Cho [a], Rena Lee [a], Min-Seok Yun [b], Gi-Won Jang [b], Jikoon Park [c], Jang-Yong Choi [d], Sanghee Nam [b,*]

[a] Radiation Oncology, Ewha Womans University Mokdong Hospital, Seoul 158-710, Korea
[b] Department of Biomedical Engineering, Inje University, Gimhae 621-749, Korea
[c] Department of Radiology Science, International University of Korea, Jinjoo 660-759, Korea
[d] Korea Food and Drug Administration, Seoul 122-704, Korea

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ABSTRACT

Recently, large-area image detectors have been investigated for X-ray imaging in medical diagnostic and other applications. In this paper, a new type of radiation detector is described, based on the integration of a photoconductor into a plasma display panel (PDP). This device, called a hybrid PDP detector, should be quite inexpensive, because it can directly leverage off the fabrication and materials technologies widely used in plasma display panels. Also, these new radiation detectors should operate under the most challenging environmental conditions, because they are inherently rugged and radiation-resistant and insensitive to magnetic fields. In this paper, we describe a hybrid digital radiation detector device, based on plasma display. The PDP panel is 7 in. in size with a 1000-μm pixel pitch, and filled with 700 Torr of Xe gas; the hybrid PDP panel is of the same structure, except for the photoconductor deposit. The glass absorption, dark current, X-ray sensitivity, and linearity as a function of electric field were measured to investigate its electrical properties. From the results, stabilized dark current density and significant X-ray sensitivity were obtained with both panels; however, the hybrid PDP detector showed better characteristics than the PDP detector. It also had good signal response and linearity. The hybrid digital radiation detector device based on a plasma display seems to be a promising technology for use in radiology and dynamic moving imaging.

1. Introduction

Digital radiation detectors have been studied as an alternative to digitizing analog X-ray films. They are preferable for several reasons, including their increased diagnostic utility, rapid diagnoses, and decreased cost and environmental pollution from the lack of developing chemicals required for traditional film [1–5]. Digital radiation detection technology based on thin-film-transistor (TFT) arrays has been used in medical devices. These flat-panel detectors are divided by the X-ray conversion method into direct and indirect methods.

The direct method of digital radiation detection involves a device for the acquisition of a digital image using a photoconductor that converts X-rays into electrical signals. They have some limitations, including difficult fabrication and breakdown due to their high operating voltage, although direct-method digital radiation detectors have high resolution [6,7].

As an alternative, digital radiation detectors have been made with phosphors that convert X-rays into light, and the light is then converted into electrical signal using PIN photodiodes in TFTs. However, products using this method have low image quality compared with the direct method due to a blurring effect of the phosphors [7]. Digital radiation detection technology is currently used as a major technology in only a few general hospitals because of the expense and the difficult and complex fabrication process.

Research into liquid crystals for applications in digital radiation detection has been conducted to address these problems [8,9]. This technique is an alternative radiation detector technology.

A plasma display panel (PDP) is an imaging device that can acquire numbers, letters, or graphics by exciting a patterned phosphor with ultraviolet radiation. The ultraviolet radiation is generated by operating a discharge voltage to two substrates, coated with several electrodes and filled with a Penning gas, such as Xe or Ne. PDP technology has developed rapidly. However, because of the strong flat-panel display market (TFT-LCD, PDP, OLED), new applications of display equipment will be sought because of the oversupplied display market.

As mentioned previously, PDP technology is a display technology using electrodes and gases. It can also be used as an X-ray detector by modifying its structure, materials, and gases, because it is generally similar to a radiation detector. In this study, the

* Corresponding author. Tel.: +82 55 320 3296; fax: +82 55 325 7931.
E-mail address: nsh@bme.inje.ac.kr (S. Nam).

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X-ray response characteristics of a pre-existing plasma display panel fabricated as a display were analyzed for applying PDP technology to digital radiation detection. A hybrid PDP with a photoconductor for use as a digital radiation detector was fabricated and its efficiency in detection and X-ray response was analyzed.

2. Experimental method

2.1. Sample fabrication

Fig. 1 shows cross-sections of a fabricated hybrid digital radiation detector, based on a PDP. Fig. 1(a) shows a typical PDP structure, with three electrodes, substrate, dielectric, MgO, phosphor, and 700 Torr Xe gas. Fig. 1(b) shows the structure of a PDP fabricated by a screen printing method with a photoconductor instead of the phosphor. The photoconductor was synthesized PbO, with much better X-ray properties than commercial PbO [10]. The glass as the top substrate was made as thin as possible for the X-ray window, but the panel was damaged in fabrication, because the glass was too thin. Accordingly, 1.2-mm-thick sodalime glass was used as the optimum substrate after considering X-ray absorption characteristics and the fabrication process. Fig. 2 shows a schematic diagram of the fabrication process, and the manufactured sample is shown in Fig. 3.

2.2. Glass absorption

Generally, PD200 glasses are used as top and bottom substrates in a PDP, but in this study, the top glass has to play the role of an X-ray window in the digital radiation detection device. Thus, a top substrate glass as thin as possible was desirable to minimize X-ray absorption. However, this increases the possibility of damage to the panel, because of physical weakness. The optimum glass thickness was selected by experiment and simulation. Experiments were performed with several thicknesses of glass to assess damage when packaging them, as well as to provide MCNP simulations and X-ray absorption measurements.

2.3. Electrical properties

The device in Fig. 4 was set up to assess the electrical characteristics of the fabricated sample, and the performance of the hybrid and general PDPs were compared through measurement protocols, such as dark current, sensitivity, linearity, and signal-to-noise-ratio (SNR) [11]. The experimental setup consisted of a power supply (EG&G 558H, USA) for voltage application and an electrometer (Keithley 6517A, USA). The X-ray generator unit was a Shimadzu TR-500-125 (Japan), and the radiation dose was monitored using an Ion Chamber 2060 (Radical Cooperation, USA). We performed an *I–V* measurement to evaluate the electrical properties of the manufactured detector. We also tested the linearity of the detector for dependence on X-ray dose.

3. Results and discussion

Fig. 5 shows the X-ray absorption of the glass. Both glasses had high absorption, over 70% in low-energy bands. Sodalime glass had better transmission properties than PD 200 glass, but both presented problems in absorption when using them in an X-ray detector. It was considered that this problem should be addressed by substituting the glass for a thin X-ray window material, like that in a GEM detector, or researching new kinds of glass.

Fig. 6 shows the dark current according to the applied voltage. The signal of the dark current caused in the converting material is an important factor in the imaging performance of a digital X-ray detector. A low dark current indicates noise reduction and lower exposure to X-ray doses for the patient. We evaluated the dark current as a function of the applied voltage against a-Se, general PDP, and hybrid PDP detectors. As shown in Fig. 6, for the a-Se, the dark current was 0.1025 and 0.231 nA/cm^2 at operating voltages of 200 and 400 V, respectively. For the general PDP detector, it was 0.0154 and 0.0502 nA/cm^2, and for the hybrid PDP, it was 0.0148 and 0.0455 nA/cm^2, respectively. From these results, the dark current with the PDP was lower than with the a-Se. In particular, for the hybrid PDP and general PDP detectors, compared at high operating voltages from 1000 to 5000 V with the a-Se, a 100-fold lower dark current was measured.

From these results, the improved SNR affected the quality of the image and the stability of the detector operation. Sensitivity depends on the quantum efficiency and the primary conversion efficiency, such as the electrical charge. It can also affect the spatial resolution and the dynamic range of an X-ray detector [8]. The sensitivity of the detectors was measured as functions of constant exposure dose and applied voltage (Fig. 7). The X-ray exposure conditions were 70 kVp, 100 mA, and 0.03 s. At operating voltages of 200 and 400 V, with the general PDP detector, sensitivities of 0.153 and 0.406 nC/(mRcm^2), respectively, were measured; they were 0.2035 and 0.5123 nC/(mRcm^2), respectively, with the hybrid PDP detector. In the case of the a-Se, the sensitivities were 0.27 and 0.69 nC/(mRcm^2) at operating voltages of 200 and 400 V. However, a commercial a-Se detector did not work at these operating voltages and showed over 3 nC/(mRcm^2) at 1000 V. The sensitivity is proportional to the probability of interaction with materials in the X-ray beam path, but due to the higher dark current from the higher operating voltage of the a-Se, the SNR of the PDP detector was higher than for a-Se (Fig. 8). Especially in the case of the hybrid PDP, a higher SNR was measured than with the PDP detector. When comparing charge generation mechanisms of the PDP and hybrid PDP detectors, in the case of the PDP detector, the X-ray incidence was attenuated by the window and drift current was generated by movement of electrons from ionized Xe. In the hybrid PDP detector, higher sensitivity was measured by adding the drift

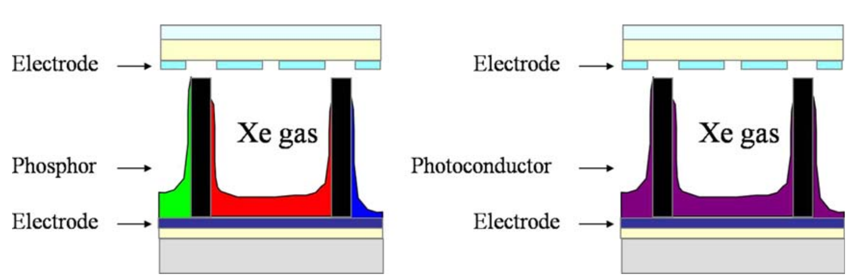

Fig. 1. Cross-sections of fabricated hybrid digital radiation detectors based on PDP (a) general PDP detector and (b) hybrid PDP detector.