Neutron Imaging Performance at AIST: Insights into Current Status with Neutron Flat-Panel-Detector and IGZO-TFT

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ABSTRACT

Neutron imaging serves as a powerful tool for non-destructive observation of the internal structures of objects. It provides valuable information that is not attainable through X-ray imaging techniques. In this study, we present the imaging performance of a neutron flat-panel detector (nFPD) utilizing an In-Ga-Zn-O (IGZO) thin-film transistor (TFT)/photodiode array, which is directly coupled with a scintillator sheet composed of LiF/ZnS(Ag) and Gd2O2S(Tb). The utilization of IGZO TFTs exhibits remarkable tolerance against neutrons, enabling direct scintillator coupling to the sensor. This configuration facilitates high sensitivity and exceptional spatial resolution. Furthermore, unlike lens-coupled neutron cameras, the newly developed imaging detector offers a large field of view and possesses a thin and manageable form factor. During this conference, we present the neutron imaging results obtained using the IGZO nFPD, along with its comprehensive performance evaluation. Additionally, we demonstrate the application of three-dimensional computed tomography with neutrons using compact neutron sources.

1 Introduction

Neutron imaging has emerged as a powerful non-destructive tool for observing the internal structures of objects, offering valuable insights that surpass the capabilities of conventional X-ray imaging techniques. With the recent advancements in compact accelerator-driven neutron sources at AIST, neutron imaging has become more accessible [1]. Consequently, the demand for neutron imaging, particularly in industrial applications, has been steadily increasing. However, there remains significant room for improvement in neutron imaging detectors, specifically in terms of sensitivity, field of view, spatial resolution, radiation tolerance, and ease of handling. Addressing these areas of enhancement is crucial to further unlock the full potential of neutron imaging technology.

2 Principle of In-Ga-Zn-O thin-film-transistor-based neutron flat-panel detector

Figure 1 illustrates a cross-sectional view of the IGZO TFT-based neutron flat-panel detector (nFPD). The detector comprises a scintillator, a photodiode, an IGZO TFT, and circuits for signal readout. Neutron imaging demands various specifications, including field of view, spatial resolution, and sensitivity, which vary depending on the specific application. In this study, we have developed different types of nFPDs to meet these diverse requirements. For instance, we have designed a high-sensitivity detector utilizing a LiF/ZnS scintillator sheet. The LiF/ZnS sheet contains 6Li nuclei, which capture neutrons and emit α-particles and 3H-particles with a Q value of 4.7 MeV. These particles are subsequently absorbed in the ZnS phosphor, emitting scintillation photons at a peak wavelength of 450 nm. The scintillator sheet is directly coupled to a photodiode pixel array with an IGZO TFT readout, enabling the detection of visible light emitted by the scintillator. Notably, this IGZO TFT-based nFPD eliminates the need for fiber-optic plates or other coupling devices on the photodiode array surface, featuring 200 μm pitch pixels.

However, in the pursuit of higher spatial resolution, a scintillator thickness of 320 μm becomes problematic due to the spreading of scintillation photons, leading to cross-talk between adjacent photodiode pixels. To address this, we have developed a higher-resolution detector utilizing a thin Gd2O2S(Tb) scintillator sheet. Gd has a significantly high neutron cross-section, capturing neutrons and emitting internal conversion electrons, followed by scintillation photon emission from the Gd2O2S(Tb) material. These scintillation photons can be detected by the photodiode arrays and IGZO TFTs.

Signals from the photodiode array are digitized with a resolution of 16 bits using an analog front-end circuit and converted into 16-bit TIFF digital images. The acquired image data are then transferred to a computer via a USB cable. The external view of the nFPD is presented in Figure 2. To prevent direct irradiation of the digital processing part by the neutron beam, the sensor and digital processing components are physically separated. The high-sensitivity and high-resolution types of detectors have an effective area of 254 mm × 310 mm, 120 mm × 120 mm, and pixel sizes of 200 μm and 50 μm,

respectively. Both detectors are covered by a 1 mm thick aluminum window. Operating the detector is simple, requiring only a 15 V DC power supply connection and the USB cable connection to the computer."

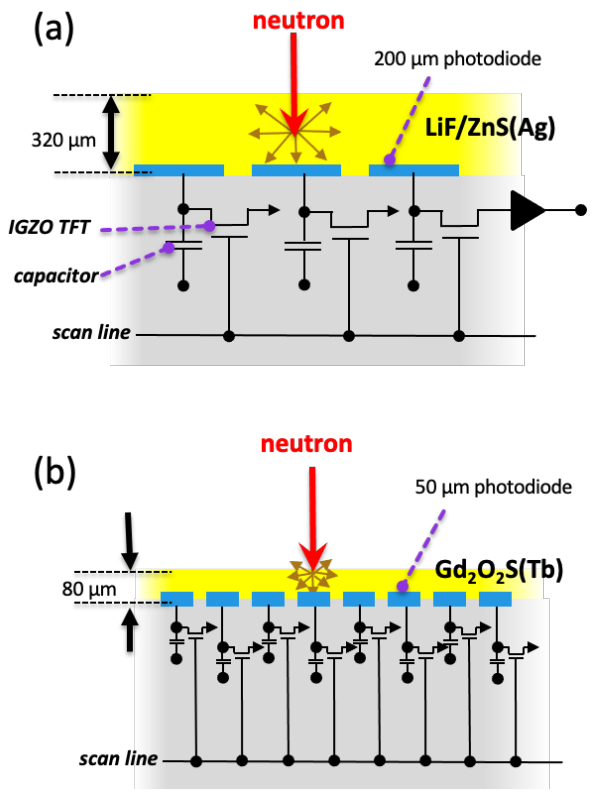

Fig. 1 Cross section view of the two types of IGZO TFT-based nFPD. (a) High sensitivity and large FOV type. 320 μm thick scintillator coupled with 200 μm × 200 μm pixel size sensor. (b) High resolution type. 80 μm thick scintillator coupled with 50 μm × 50 μm pixel size sensor.

3 Experimental Results

The neutron imaging performance of the two types of neutron flat-panel detectors (nFPDs) was evaluated using a Gd patterned chart [3]. Figure 2 illustrates the neutron transmission image of the star pattern of the chart obtained with each detector. The larger pixel nFPD demonstrated a high sensitivity, requiring only 20 seconds to capture a single image. In contrast, the smaller pixel nFPD has a size one-sixteenth that of the larger pixel nFPD, resulting in a neutron count that is also reduced by a factor of 1/16. Additionally, the Li-6 reaction emits more scintillation light compared to the Gd reaction. Consequently, the signal generated in the larger pixel nFPD is significantly larger, leading to higher sensitivity. On the other hand, the smaller pixel nFPD enables the acquisition of high-resolution images, albeit with longer integration times.

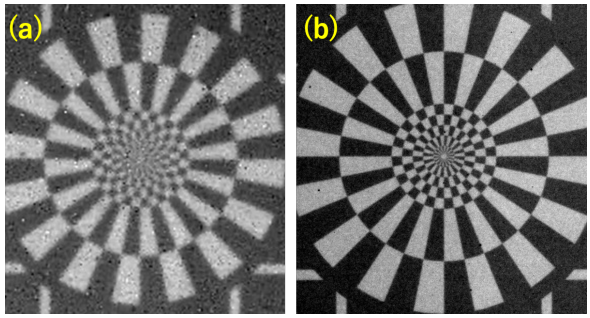

Fig. 2 Radiography of the Gd chart obtained with nFPD. (a) A radiograph obtained with high sensitive type nFPD (b) A radiograph obtained with high resolution type nFPD.

4 Conclusion

This work focuses on the development of two types of neutron imaging detectors to meet the diverse requirements of neutron imaging. One type of neutron imaging detector exhibits excellent sensitivity and a large field of view, making it well-suited for inspecting relatively large objects. This detector offers several advantages, including radiation tolerance, high neutron sensitivity, a spacious field of view, and ease of handling. Furthermore, the low charge leak of the IGZO TFT ensures prolonged exposure, enabling precise neutron imaging using a compact neutron source with a relatively small neutron flux. The simplicity and user-friendly nature of this neutron flat-panel detector (nFPD) are expected to lower the entry barrier for neutron imaging, thereby increasing the number of neutron users. Moreover, the nFPD's advantages, such as its high sensitivity, large field of view, and ease of handling, make it an excellent choice for high-intensity neutron sources, such as reactors and spallation neutron sources.

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