Imaging performance characterization of the pixelated scintillation screens for neutron imaging

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1. Introduction

The application of neutron imaging is expanding to the fields of power sources such as fuel cells and lithium ion batteries and many scientific applications. Digital neutron imaging systems with high spatial resolution have become popular for the last decades. A cooled CCD camera in combination with a scintillation screen is widely used as digital detector for neutron imaging. Amorphous silicon flat panel detectors and CMOS detectors have been used as efficient measurement options to avoid lens optics [1-2]. Spatial resolution is mainly determined by the combination of scintillation screen and CCD detection system. The thickness of the conventional scintillation screen is related to spatial resolution because it trades off the light spread function and the light output of the screens. A lot of efforts have been made in x-ray imaging to improve spatial resolution using an array-structured scintillation screen [3-5]. The main idea is to reduce the diffusion of scintillation light by using the walls of array structures in scintillation screens [6, 8-9]. In this study, pixelated scintillation screens with various pitch size were fabricated and evaluated for neutron imaging.

2. Methods and Results

2.1 Neutron scintillation material for neutron imaging

$Gd_2O_2S(Tb)$ and $^6LiFZnS(Ag)$ have been widely used as thermal neutron scintillation material for neutron imaging. Gd and ^6Li have high thermal neutron absorption cross-section when compared with other elements. The reaction products of nuclear reaction with Gd and ^6Li generate the actual scintillation. The nuclear reactions of Gd and ^6Li are summarized as

$$n + {}^{157}Gd(16\%) \rightarrow {}^{158}Gd + \gamma - rays + conversion\ electon + X - rays$$
$$\sigma(cross - section) = 70,000 \quad (1)$$
$$n + {}^{155}Gd(15\%) \rightarrow {}^{156}Gd + \gamma - rays + conversion\ electon + X - rays$$
$$\sigma(cross - section) = 17,000 \quad (2)$$
$$n + {}^{6}Li(7.5\%) \rightarrow {}^{3}H(2.75MeV) + {}^{4}He(2.05MeV)$$
$$\sigma(cross - section) = 520b \quad (3)$$

2.2 Fabrication of the scintillation screens

The pixelated scintillation screens were fabricated by filling the silicon pixel structures with $Gd_2O_2S(Tb)$ paste or powder. $Gd_2O_2S(Tb)$ powder and binder were prepared to make $Gd_2O_2S(Tb)$ paste. The diameters of $Gd_2O_2S(Tb)$ powders ranges between 3um and 8um. The binder was composed of texanol and acrylic resin in the ratio of 8:1 weight percent. The binder with fixed ratio was stirred using a magnetic stirrer. The ratio of the $Gd_2O_2S(Tb)$ powder and binder were 4:1 weight percent. The conditioning mixer, ARE-250, was used for mixing and defoaming. $Gd_2O_2S(Tb)$ powder and binder were mixed in 1200rpm for 10minutes, and $Gd_2O_2S(Tb)$ paste was defoamed in 1000rpm for 10minutes by ARE-250. The $Gd_2O_2S(Tb)$ paste was poured into the silicon pixel structures. Texanol was evaporated using an oven at 150℃ for 10minutes, and the $Gd_2O_2S(Tb)$ paste was solidified. The fabricated $Gd_2O_2S(Tb)$ scintillation screen and the specification are shown in Figure 1 and Table I.

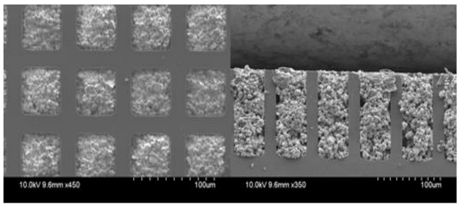

Fig. 1. SEM images of the fabricated $Gd_2O_2S(Tb)$ scintillation screen

Table I: The specification

	Depth (um)	Pixel pitch (um)	Wall thickness (um)	Fill factor (%)
(a)	150	130	30	59.2
(b)	150	120	20	69.5
(c)	150	110	10	82.6
(d)	150	70	20	51.0
(e)	150	60	10	69.5
(f)	150	50	10	64

2.3 Fabricated scintillation screen evaluation

A cooled CCD detector was installed in HANARO NRF. The CCD camera had 1300 x 1340 pixels. 85mm f/1.4 and 135mm f/2.0 Nikon lens were used in the CCD based detection system. The relative light output was measured using each pixel value of the CCD camera in accordance with neutron exposure time. The pixel values in the obtained images from neutron imaging were averaged to measure the relative light output of fabricated scintillation screens. The relative light output measurement is shown in Figure 2. Relative light output in accordance with the neutron exposure time is plotted in Figure 3.

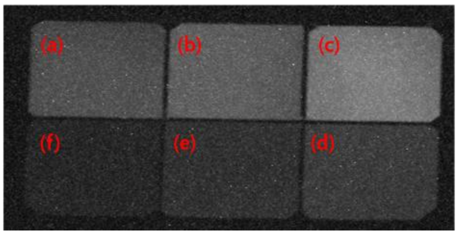

Fig. 2. The obtained image

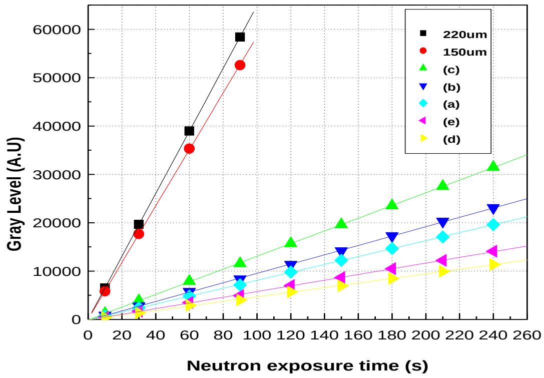

Fig. 3. Relative light output in accordance with the neutron exposure time of non-pixelated and pixelated $Gd_2O_2S(Tb)$ scintillation screens

Relative light output of the fabricated scintillation screens with 120um and 60um pitch was, respectively, 16.0% and 9.43% of the non-pixelated scintillation screen with 150um thickness. The reasons of the light output decrease are fill factor and wall effect of pixelated scintillation screens when compared to the non-pixelated scintillation screen with 150um thickness. The light output of (b) is much higher than that of (e) although the fill factors are the same. When assuming the scintillation light is totally absorbed at the wall, geometric efficiency of (b) and (e) was, respectively, 12.5% and 7.1% of the non-pixelated scintillation screen. When considered the both fill factor and wall effect, the calculated light output of (b) and (e) was 8.6% and 4.9% of the non-pixelated scintillation screen. Experimental data is about 2times higher than calculated data because of the reflected scintillation light at the wall. Relative light output in accordance with the fill factor is plotted in Figure 4.

3. Conclusions

Pixelated scintillation screens for digital neutron imaging were fabricated for spatial resolution improvement. Pixelated scintillation screens with a smaller pitch need to overcome low light output. Therefore, thin reflective layer coating on wall surfaces may be needed to conserve the light output while keeping the higher resolution.

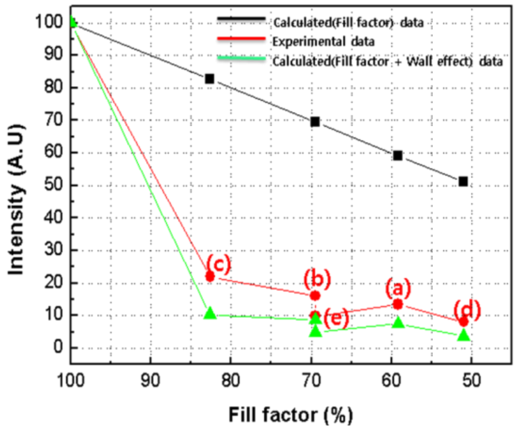

Fig. 4. Relative light output in accordance with the fill factor

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