Development of Si-PM Based Imaging Systems for Molecular Imaging

Seiichi Yamamoto
Nagoya University/Graduate School of Medicine, Nagoya, Japan
Email:s-yama@met.nagoya-u.ac.jp

***Abstract*— Silicon photomultiplier (Si-PM) is a promising photodetector for PET for the use in magnetic resonance imaging (MRI) systems because it is insensitive to static magnetic fields. Si-PM is also a promising for high resolution PET systems due to its small channels and high gain. We have developed several Si-PM based imaging systems for molecular imaging. First, we developed a high resolution Si-PM based PET system for small animals and tested its performance. The Si-PM PET system had 1.6mm FWHM resolution. Then we combined it into the MRI and simultaneous measurements were conducted. Although there were some interference between PET and MRI, images could be obtained with reasonable signal-to-noise ratio (S/N) on both modalities without any distortion. Finally we explored to improve the spatial resolution of the Si-PM PET system by reducing the scintillator size to be around 0.6mm pixels. We could resolve all pixels on the Si-PM based detectors. We conclude the Si-PM is a promising photodetector for the development of imaging systems for molecular imaging.**

***Index Terms*—Si-PM, High resolution, PET, PET/MRI, Molecular imaging**

I. Introduction

The simultaneous measurement of PET and MRI is a new field which can provide new insights on molecular imaging research. The advantage of PET is the ability to image the probes with high detection sensitivity. MRI has ability to provide high resolution anatomical images with large variety of tissue contrast. One advantage compared with PET/CT is that PET/MRI system can measure a subject fully simultaneously. It allows reducing the registration errors and imaging time for PET and MRI.

Photomultiplier tube (PMT) has been used for a long time for photodetectors for PET and SPECT systems because of its high gain, low noise, high speed response, excellent stability, and relatively low cost. Position sensitive PMT (PSPMT) is also used for most small animal PET systems. However PMT and PSPMT are sensitive to magnetic field, and are difficult to use inside MRI systems. Consequently PMT or PSPMT is basically not a good candidate for PET/MRI combined system. To solve these problems, using optical fibers between scintillatiors and PSPMTs were proposed for PET/MRI combined systems and several MR-combatable PET inserts and PET/MRI systems were developed [1]-[4]. In these systems, only the scintillators were positioned inside the MRI and the scintillation photons were transferred to outside the magnet where the magnetic field was low enough to use PSPMTs. In these systems, although no interference between PET and MRI was observed, the light loss due to the fibers was more than 70% and also the cost of fibers was high. For another approaches, avalanche photodiode (APD) and position sensitive APD based PET detectors have been used for PET inserts for PET/MRI combined system [5]-[6].

Silicon photomultiplier (Si-PM) is a promising photodetector for PET for the use in magnetic resonance imaging (MRI) systems because it is insensitive to static magnetic fields [7]. Si-PM is also promising for high resolution PET systems due to its small channels and high gains [8]. We have developed several Si-PM based imaging systems for molecular imaging. First, we developed a high resolution Si-PM based PET system for small animals and tested the performance. Then we combined it into the MRI and simultaneous imaging was conducted. We also explored to improve the spatial resolution of the Si-PM based PET system by reducing the scintillator size to realize an ultrahigh resolution PET system.

II. Material and Methods

A. *High Resoluiton Si-PM based PET System*

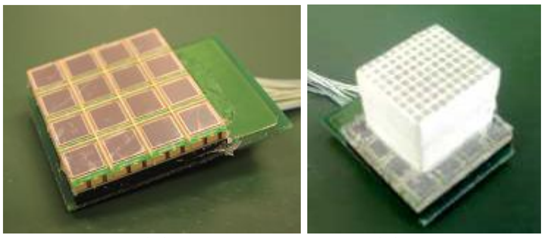
Fig. 1(A) shows a photograph of the Si-PM array used for the block detector for the PET system. Hamamatsu 4x4 Si-PM arrays (S11064-025P) were used because it has good uniformity and temporal response suitable for the pulse shape analysis. The Si-PM array has 4 x 4 channels of which size is 3mm x 3mm. The number of pixel per channel is 14400 [9].

To realize a depth-of-interaction (DOI) block detector, two types of Ce doped LGSO scintillators with different decay times were selected. LGSO has high light output and the decay time can be controlled by changing its Ce concentration [10]. Two types of LGSO scintillator of 0.75 mol% Ce (decay time: ~45ns: 1.1mm x 1.2mm x 5mm) and 0.025 mol% Ce (decay time:~31ns: 1.1mm x 1.2mm x 6mm) were selected. These LGSO scintillators were optically coupled in depth direction to form a DOI detector, arranged in 11 x 9 matrix and optically coupled to the Si-PM array with a 1mm thick light guide. The size

Manuscript received Dec 1, 2012; revised Feb 1, 2013.

doi: 10.12720/jomb.2.1.16-19

of the LGSO block is 13.2mm (transaxial direction) x 11.7mm (axial direction) x 11mm (depth). For the reflector between the LGSO scintillators, 0.1mm thick $BaSO_4$ was used. The fabricated Si-PM based DOI detector without the top reflector is shown in Fig. 1(B).



(A) (B)

Figure 1. Si-PM array (A) and block detector (B) for the PET system

The Si-PM array was mounted on a printed board and the signal from each channel of the Si-PM was transferred to front-end electronics with 1.2m long small diameter coaxial cables. The signals from the Si-PM based block detectors are fed to front end electronics printed boards. The sixteen analog signals from the Si-PM array are individually amplified by operational amplifiers and summed for row and column using summing circuit. These signals are weighted summed with position dependent linear gain for each row and column signals to produce weighted sum signals. The weighted summed signals are transferred to data acquisition system through variable gain amplifiers.

We developed sixteen Si-PM based block detectors and they were arranged in a 68mm inner diameter. Fig. 2 shows photographs of the developed detector ring. The outside dimension of the detector ring is 11cm in diameter, 2cm thick.

(A) (B)

Figure 2. Si-PM based detector ring without light shield (A) and with shield with mockup of small animal (B)

Figure 3. Si-PM based PET during measurement of rat brain

Photograph of whole view of Si-PM based PET with a rat during measurement is shown in Fig. 3. Si-PM based PET detector ring is supported by a plastic ring which was connected to a flexible arm that can move freely when the stopper of the flexible arm is off. Also the animal bed which made of a 2mm thick plastic plate is supported by a flexible arm positioned on an X-Y-Z table. With these two flexible arms with the X-Y-Z table, we can position an animal with quite freely and precisely.

B. Simultanious imaging of PET and MRI

A 0.15T permanent MRI was used for the simultaneous measurement of PET and MRI. The Si-PM PET detector ring was installed on a plastic stand outside of the RF coil of the 0.15T MRI. The distance between the outer surface of the RF coil to the inner surface of the Si-PM-based PET was ~1.5 cm. Inside the RF coil (inner diameter, 30mm), small animal was set, and simultaneous measurements were made. The Si-PM PET with MRI is shown in Fig. 4.

Figure 4. Si-PM based PET during simultaneous measurement with 0.15T MRI

For the simultaneous measurements of the Si-PM PET and MRI of a small animal, F-18-FDG mouse brain imaging was carried out. MRI imaging was made with and without the Si-PM-based PET using a FLASH sequence.

C. Ultrahigh Resolution Si-PM based Block Detectors

For experiments of a high resolution Si-PM block detector, a LGSO block detector using 0.6 mm scintillators was made. A LGSO scintillator of 0.75 mol% Ce (decay time: ~45ns: 0.6 mm x 0.6 mm x 6 mm) was arranged in a 17 x 17 matrix. For the reflector between the LGSO scintillators, a 0.1mm thick $BaSO_4$ was used, and so the scintillator pixel pitch was 7 mm. The size of the LGSO block was 11.9 mm x 11.9 mm x7 mm.

The fabricated Si-PM based block detector without a top reflector is shown in Fig. 5. The Si-PM array was mounted on a printed board, and the signal from each channel of the Si-PM was transferred to front-end electronics (weighted summing board). Two block detectors were made and coincidence was measured between these two blocks.

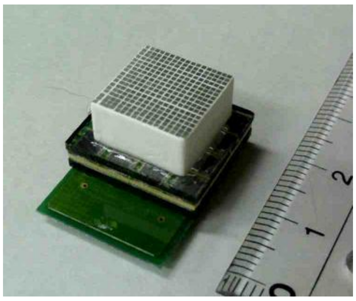
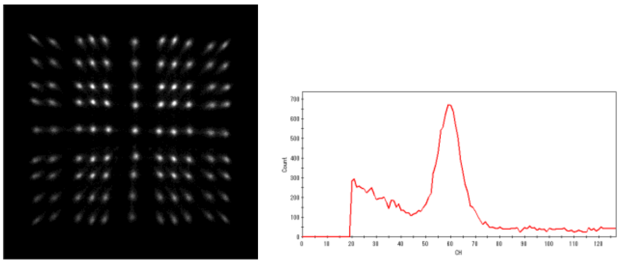


Figure 5 Si-PM based LGSO block detector with 0.6mm LGSO pixels

III. Results

A. High Resoluiton Si-PM based PET System

Two-dimensional distribution for Si-PM block detector is shown in Fig. 6(A). All 11 x 9 LGSO pixels are clearly resolved. Energy spectrum for one of the LGSO scintillator is shown in Fig. 6(B). Average energy resolution was 27%FWHM. Pulse shape spectrum showed two peaks with average peak-to-valley ratio of 1.4. Spatial resolution of the PET system was 1.6mm FWHM and sensitivity was 0.6% at the center of the field-of-view.



(A) (B)

Figure 6 Two-dimensional distribution (A) and energy spectrum of LGSO block detector for Si-PM-PET

Images of F-18-FDG study of rat brain measured by the developed Si-PM-PET are shown in Fig. 7 in which the structure of Hadrian gland can be observed. More details of this Si-PM PET are described in ref [11].

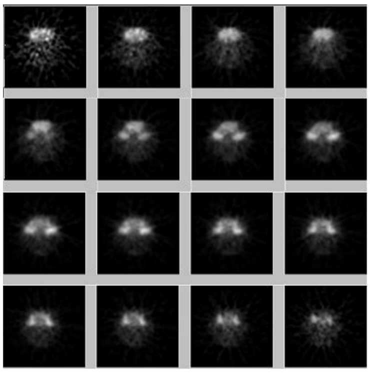


Figure 7. Images of F-18-FDG study of rat brain measured by the developed Si-PM-PET

B. Simultanious Imaging of PET and MRI

When the Si-PM-PT was inside the MRI and installed around the radio frequency (RF) coil of the MRI, noises from the RF sequence of the MRI were observed in the analog signals of the PET detectors. However we did not observe any artifacts in the PET images since the noise is smaller than lower energy threshold level. On the MRI side, there was significant degradation of the signal to noise ratio (S/N) in the MRI images compared with those without Si-PM PET. Simultaneous measurements of mouse brain using a Si-PM PET and an MRI were obtained with some degradation in the MRI images (Fig. 8). More details of the simulations measurement with Si-PM-PET and MRI are described in ref [12].

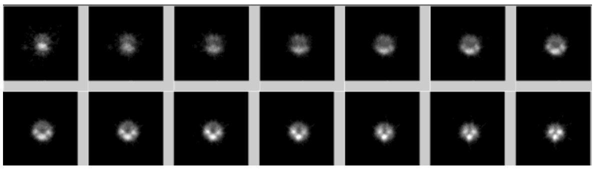
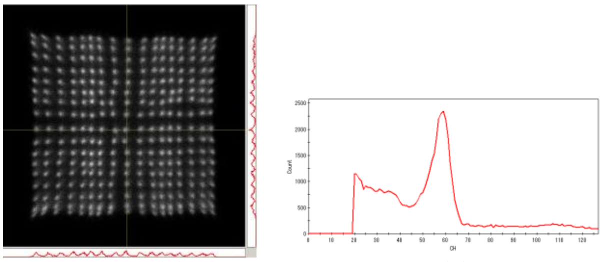


Figure 8. Si-PM PET images of mouse brain (F-18-FDG) simultaneously measured with 0.15T MRI

C. Ultrahigh Resolution Si-PM based Block Detectors

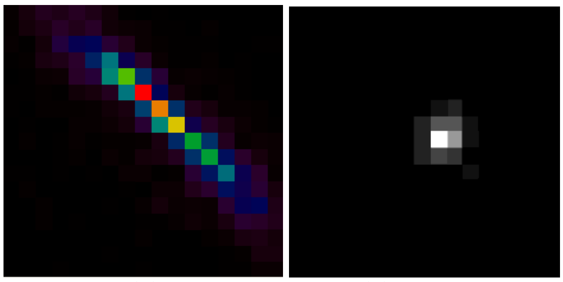
Two-dimensional distribution for the developed ultrahigh resolution Si-PM block detector is shown in Fig. 9(A). Most 17x 17 LGSO pixels are clearly resolved. Energy spectrum for one of the LGSO scintillator is shown in Fig. 9(B). The energy resolution of this spectrum was 17%FWHM.



(A) (B)

Figure 9. Two-dimensional distribution (A) and energy spectrum of LGSO block detector for Si-PM-PET

Sinogram for a Na-22 point source located between two ultrahigh resolution Si-PM block detectors is shown in Fig. 10(A). Counts are accumulated on almost one line. Reconstructed planner image of this point source is shown in Fig. 10(B). The counts are located almost in one pixel in the reconstructed image.



(A) (B)

Figure 10.sinogram (A) and point source image (B) of ultrahigh resolution LGSO block detectors based dual head imaging system

Two interesting application of this ultrahigh resolution dual head imaging system are shown in Fig. 11. One is the tweezers type coincidence imaging detector. The ultrahigh resolution block detectors are located on the tip of the tweezers, and the positron accumulation can be imaged between the block detectors (Fig. 11(A)). The other is the finger tip coincidence imaging system in which the block detectors are located on two fingers (Fig. 11(B)). Positron can be imaged by holding the subject between the detectors positioned on the fingers.

(A) (B)

Figure 11. Two possible application of ultra high resolution block detectors, tweezers type coincidence imaging system (A) and finger tip coincidence imaging system (B).

IV. Conclution

We developed several Si-PM based imaging systems for molecular imaging. The high resolution Si-PM based PET system was useful for small animal imaging. And it could be used in the MRI and simultaneous imaging was also possible. More high spatial resolution block detector could be realized with Si-PM which will be potentials to be new instrumentations. It is concluded that Si-PM is a really promising photodetector for molecular imaging.

Acknowledgment

The author wishes to thank members of Department of Nuclear Medicine and Tracer Kinetics, Osaka University Graduate School of Medicine, especially for Professor Hatazawa, for collaboration of these researches. This work was supported in part by a grant from the Ministry of Education, Science, Sports and Culture, Japan and the National Institute of Biomedical Innovation, Osaka, Japan.

References

[1] Y. Shao, S. R. Cherry, K, Farahani, R. Slates, R. W. Silverman, and K. Meadors, et al. "Development of a PET detector system compatible with MRI/NMR system," *IEEE Trans Nucl Sci*, vol. 44, pp. 1167-1171, 1997.

[2] S. Yamamoto and H. Murayama. "A block detector for a multi-slice depth of interaction MR-compatible PET," *IEEE Trans Nucl Sci*, vol. 52, pp. 33-37, 2005.

[3] S. Yamamoto, J. Hatazawa, M. Imaizumi, M. Aoki, and E. Sugiyama, at al., "A Multi-slice Dual Layer MR-Compatible Animal PET System," *IEEE Trans. Nucl. Sci*, vol. 56, pp. 2706-2713, 2009.

[4] S. Yamamoto, M. Imaizumi, Y. Kanai, M. Tatsumi, M. Aoki, and E. Sugiyama, et al., "Design and performance from an integrated PET/MRI system for small animals," *Ann Nucl Med*, vol. 24, no. 2 pp. 89-98, 2010.

[5] B. J. Pichler, M. S. Judenhofer, C. Catana, J. H. Walton, M. Kneilling, and R. E. Nutt, et al., "Performance test of an LSO-APD detector in a 7-T MRI scanner for simultaneous PET/MRI," *J Nucl Med*, vol. 47, pp. 639-647, 2006.

[6] M. S. Judenhofer, H. F. Wehrl, D. F. Newport, C. Catana, S. B. Siegel, and M. Becker, et al., "Simultaneous PET-MRI: A new approach for functional and morphological imaging," *Nat Med*, vol. 14, pp. 459-465, 2008.

[7] S. J. Hong, I. C Song, M. Ito, S. I. Kwon, G. S. Lee, and K-S. Sim, et al., "An investigation into the use of Geiger-mode solid-state photomultipliers for simultaneous PET and MRI application". *IEEE Trans. Nucl. Sci*, vol. 55, no. 3, pp. 882-888, 2008.

[8] S. Yamamoto, H. Watabe, and J. Hatazawa, "Performance comparison of Si-PM-based block detectors with different pixel sizes for an ultrahigh-resolution small-animal PET system" *Phys. Med. Biol*, vol. 56, no. 20, pp. 4147-4159, 2011.

[9] Hamamatsu Photonix, MPPC Array, Data Sheet. [Online]. Available:http://www.hamamatsu.com/resources/pdf/ssd/s11064_series_kapd1025e04.pdf

[10] S. Shimizu, K. Kurashige, T. Usui, N. Shimura, K. Sumiya, and N. Senguttuvan, et al. "Scintillation properties of Lu Gd SiO: Ce (LGSO) Crystal," *IEEE Trans. Nucl. Sci*, vol. 53, no. 1, pp. 14-17, 2006.

[11] S. Yamamoto , M. Imaizumi, T. Watabe, H. Watabe, Y. Kanai, and E. Shimosegawa, et al., "Development of a Si-PM-based high-resolution PET system for small animals," *Phys Med Biol*, vol. 55, no. 19, pp. 5817-5831, 2010.

[12] S. Yamamoto, T. Watabe, H. Watabe, M. Aoki, E. Sugiyama, M. Imaizumi, Y. et al. "Simultaneous imaging using Si-PM-based PET and MRI for development of an integrated PET/MRI system". *Phys Med Biol*, vol. 57, no. 2, pp. 1-13, 2012.

Seiichi Yamamoto, Ph. D.
He is currently a professor of Nagoya University Graduate School of Medicine, Department of Radiological and Medical Laboratory Sciences. He graduated Nagoya University in 1980, worked in Shimadzu Corporation for 15 years, then moved to Kobe City College of Tech. From 2012, He moved to Nagoya University. His research interests are molecular imaging system development and application.