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A High Efficiency Pixelated Detector for Small Animal PET

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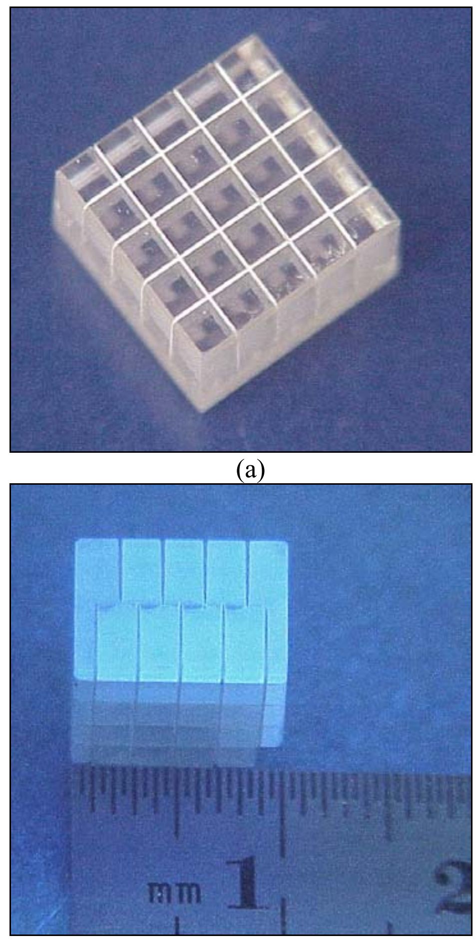
Abstract-- **We report on the development of a new high efficiency detector for small animal PET. The detector is based on a monolithic block of LSO pixelated using laser ablation technique. The laser processing allows pixelation with very narrow, 70 μm wide, inter-pixel gaps resulting in a substantially enhanced sensitivity when the detectors are operated in coincidence mode. This paper presents the first results of a detector module fabricated using this approach. Preliminary imaging data at 511 keV obtained by coupling the pixelated LSO to a position sensitive photomultiplier tube (PSPMT) and a position sensitive avalanche photodiode (PSAPD) are presented.**

I. Introduction

Positron Emission Tomography (PET) is a powerful an *in vivo* technique for imaging biological processes in small laboratory animals [1,2,3,4,5,6,7]. The fundamental advantage of PET is that quantitative functional information can be obtained non-invasively, allowing each animal to be studied repeatedly. With dedicated high-resolution PET imagers, researchers can measure the entire time course of radiotracers within a single animal, can perform repeated studies with the same subject over arbitrary time periods, and can monitor the effects of therapeutic interventions over time. Thus, each animal can serve as its own control in studies with a longitudinal design.

While the advantages of small animal imaging with PET are obvious, the challenges are also very significant. The main barriers to using PET in studies of laboratory animals have traditionally been poor spatial resolution, low sensitivity, high cost, and lack of accessibility. Thus, performance improvements while controlling cost is critical if small animal PET is to fulfill its potential as the powerful imaging modality it is.

At present high resolution scintillator arrays are usually constructed from individual elements [8,9,10,11,12]. For high spatial resolution, smaller scintillator elements are needed. A major difficulty here is that scintillator elements are very hard to cut and handle once they become 1 mm or less in cross-section. Furthermore, application of reflector and array formation becomes extremely challenging. Since the whole process has to be performed manually, it becomes time consuming and expensive. The best possible inter-pixel gaps, made with a diamond saw, are around 200 μm and the yield tends to drop quickly for smaller pixel sizes and as the number of elements per array increases. Other than providing finer spatial resolution and better sampling, narrow interpixel



(a)

(b)

Fig. 1. Photograph of a 1-cm^3 LSO scintillator pixelated using laser ablation. (a)Single side pixelation (b) offset pixelation.

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gaps and smaller elements provide advantage in terms of detection efficiency. The effective area for coincidence measurements is inversely proportional to the 4th power of the gap between pixels. As saw cuts are at best around 200 µm, for two 0.75 mm x 0.75 mm crystals in coincidence, the effective fractional surface area of a scintillator (LSO for example) is $(0.75/0.95)^2$ x $(0.75/0.95)^2 = 0.39$. For a gap of 100 µm, the fractional surface area would become 0.61, a roughly 60% improvement in efficiency for the same surface area crystals.

To minimize inter-pixel gaps and to maximize the detector sensitivity, we have developed a laser ablation technique that allows monolithic blocks of crystals to be micro-machined. This technique permits fabrication and handling procedures to be simplified and automated, making it a time and cost efficient production process. Our experience using this technique shows that the loss of material due to breakage is significantly less than with the manual fabrication, and the overall manufacturing cost could be lower by as much as a factor of 4.

II. Scintillator Fabrication

We have successfully pixelated 1 cm^3 blocks of lutetium oxyorthosilicate (LSO) using an excimer laser. The laser output energy and the pulse repetition rate were experimentally optimized. To produce the required pixel pattern in LSO, a specially cut mask with a rectangular slot was mounted in front the beam port. The optics consisting of attenuators, mirrors, and a high quality lens was used to image the slot onto the target. For etching pixel patterns, the LSO block was mounted on a high precision X-Y scanning table whose motion was synchronized with the laser output to ensure that each spot along the scanned line receives identical number of pre-determined pulses.

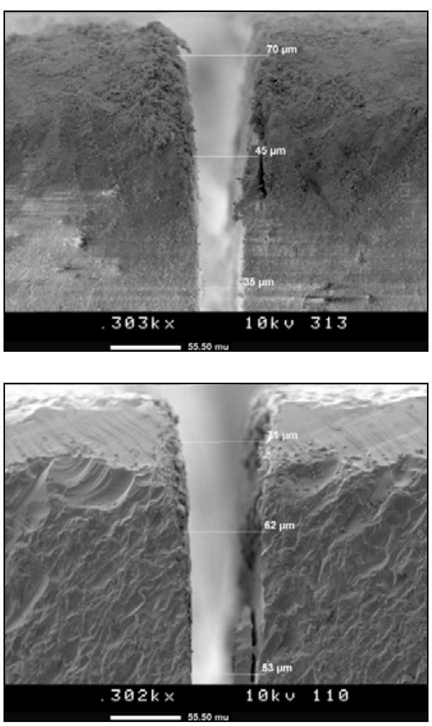

Fig. 2. SEM Profiles of a groove in LSO formed by laser ablation before (a) and after (b) chemical etching. Note the groove width of ~70 µm and the smoothness of the etched and cleaned groove walls, similar to that of the walls of the polished LSO crystal.

So far we have successfully processed 2 mm x 2 mm x 10 mm arrays with ~70 µm inter pixel gaps. **Fig. 1** shows pixel patterns in a 1 cm^3 micro-machined block of LSO. **Fig. 1(a)** shows an LSO block with the laser-etched grooves micro-machined from a single side up to a depth of ~ 9 mm, while **Fig. 1(b)** shows a double sided / offset configuration with the grooves going down to a depth of 5 mm from each side. The pixelated blocks were cleaned using chemical etching [13]. **Fig. 2(a)** is an SEM profile of the top of a laser cut groove showing the cut width of 71 µm. Fig. **2(b)** shows the same groove after the chemical etching and cleaning procedures. It is worth noting that the cuts in the block are sharp and clean, and the subsequent chemical etching makes the groove walls very smooth, conducible to either the application of a reflective layer or for filling up the interpixel grooves with reflective powder. To enhance light channeling within each pixel, a Polymist F5 brand PTFE diffuse reflector with >99% reflectance at 420 nm LSO emission was manually incorporated in the grooves.

III. Detector Characterization

A. Flood Histogram Measurements

To form a detector module, the offset pixel pattern array was coupled directly to a Hamamatsu R5900-M64 multichannel position sensitive photomultiplier tube (PSPMT). This tube has 64 channels arranged in an 8 × 8 grid, with each channel measuring roughly 2 × 2 mm on a 2.25 × 2.25 mm pitch. The detector was irradiated by a 0.2 mCi ^{22}Na source, which was located sufficiently far from the detector to provide a uniform flux onto the face of the detector. **Figure 3** is the flood histogram showing that

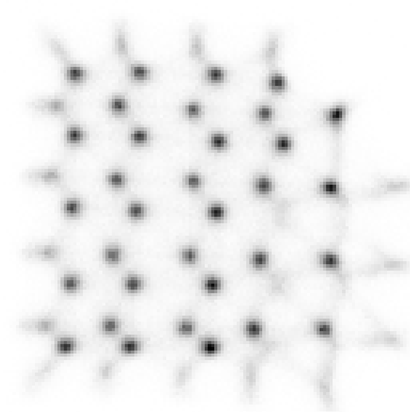

Fig. 3. Flood histogram obtained by coupling pixelated LSO block to the PSPMT. Note the improved spatial sampling and clear crystal identification obtained using offset cut pattern.

elements in both the top and bottom layers can be clearly resolved. As expected the offset pixel pattern improves spatial sampling and generates the possibility of obtaining 1 bit depth of interaction information.

The LSO array was also coupled to the sensitive surface of a position sensitive avalanche photodiode (PSAPD) developed by RMD[14]. The detector module was exposed to the uniform flood field from a 0.1 mCi ^{137}Cs gamma rays (662 keV). Signals from the four resistive contacts and the anode contact were processed using standard NIM electronics and the position information was derived using the specially developed electronics [14]. These data have clearly shown that the detector modules based on laser pixelated LSO can provide unambiguous identification of the pixel of interaction. The pixel separation of 1 mm in case of the offset pixel array was clearly resolved. The measured peak to valley ratio for 662 keV interactions was ~ 10.

B. Energy Resolution Measurements

Initial energy resolution measurements were made at RMD using a 200 nCi ^{22}Na source and a conventional PMT based spectroscopy setup. A monolithic (unpixelated) single crystal block of LSO and a laser pixelated block of LSO of identical dimensions were used for comparison. The two blocks were coupled to a Hamamatsu E974-13 PMT using a optical coupling grease with the refractive index of 1.45, and the PMT output was fed to a spectroscopy amplifier with a gain of 100 and a time constant of 0.25 μs. . The source was located approximately 2 cm away from the detector assembly and the energy spectra were measured using a standard PC based multichannel analyzer. The photo peak data were fitted to a Gaussian to extract the FWHM resolution.

As shown in **Figure 4**, both the LSO samples showed comparable energy resolution of approximately 15% at 511 keV with the crystalline LSO block showing a slightly better resolution. The slight difference in the measured energy resolution may be explained partly by the 15% lower light collection from the pixelated sample, well-known crystal to crystal signal variations in differing LSO blocks and non-uniformities in the reflector fabrication.

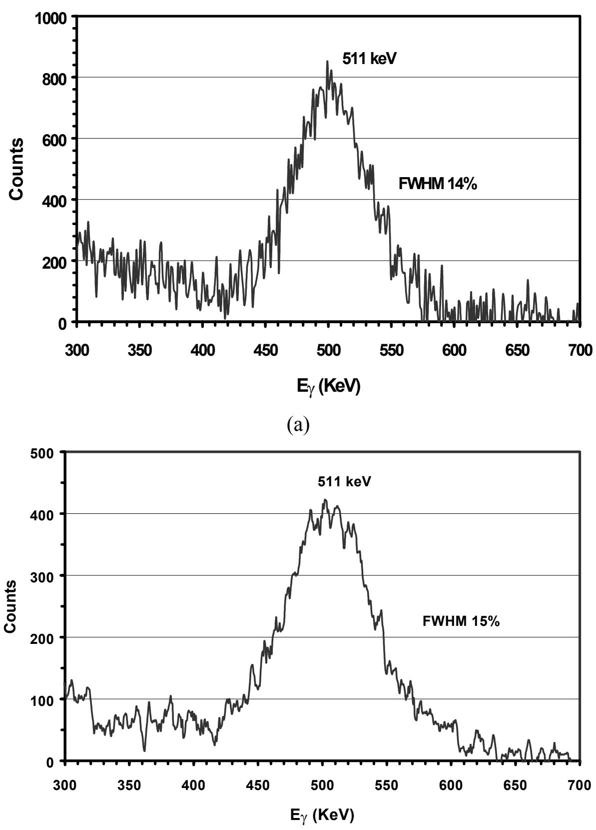

Fig. 4. Energy resolution of a 10 mm x 10 mm x 10 mm LSO block for 511 keV ^{22}Na gamma rays. (a) Un-pixelated crystalline LSO: 14% (b) Pixelated LSO: 15%.

IV. Conclusion

The results presented here demonstrate the possibility of producing high resolution, high sensitivity, low cost PET detector modules using laser ablation. The future work will include optimization of the detector components including crystal surface processing and reflector fabrication.

Laser ablation technique will allow the development of PET modules for small animal research at an affordable price. Development of such modules should result in significant advancements in the field of small animal research and other areas of nuclear medicine.

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