Testing of the Spatial Resolution and Efficiency of Scintillating Fiber PET Modules[1]

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Abstract

Two experimental PET camera modules were constructed using (1) two 5 x 5 x 2.5 cm^3 detector stacks made of parallel 0.5 and 1.0 mm diameter scintillating fibers and (2) two 5 x 5 x 5 cm^3 detector stacks made of alternating x and y layers of 0.5 and 1.0 mm diameter scintillating fibers. Each stack was viewed by Hamamatsu R2486 position sensitive photomultipliers. The time resolution of the coincidence system was 10 nsec. The spatial resolution and efficiency of the PET modules was tested using an approximately 1 μci 0.5 mm diameter Na-22 source. The best results were achieved with the 1.0 mm parallel fiber stacks: 2.0 mm spatial resolution (FWHM) and 2.3 % efficiency. Possibilities to improve the characteristics of this arrangement and, particularly, the alternating x and y layer stacks are discussed.

I. INTRODUCTION

The recently developed plastic scintillating fiber with high photon yield show much promise for the development of a new generation of gamma ray detectors. In a previous paper [1] we discussed the Monte Carlo modeling of a PET detector constructed using two stacks of alternating layers of x and y scintillating fibers of 0.5 x 0.5 mm^2 cross section. The Monte Carlo simulation indicated that a detector of this sort would have a relatively good efficiency and a spatial resolution better than the positron smearing and angular deviation inherent to PET detectors. In another paper [2] we described the construction and operation of a similar PET system. In the present paper, we show the results of testing the spatial resolution and efficiency of scintillating fiber PET modules using different fiber diameters and stack configurations.

II. CONSTRUCTION AND TESTING

We have constructed two experimental PET camera modules using:

(1) two 5 x 5 x 2.5 cm^3 detector stacks made of parallel 0.5 and 1.0 mm diameter scintillating fibers (Fig. 1), each viewed by a Hamamatsu R2486 position sensitive photomultiplier. The two stacks were separated by 20 cm and connected in coincidence forming a PET module (Fig. 2),

(2) two 5 x 5 x 5 cm^3 detector stacks made of alternating layers of x and y fibers of 0.5 and 1.0 mm diameter (Fig. 3), each viewed by two Hamamatsu R2486 photomultipliers, one detecting pulses from the x layers and the other one detecting pulses from the y layers. The two stacks were separated by 20 cm forming another PET module.

The scintillating fibers are made of polystyrene scintillator (n=1.59) doped with Butyl-PBD and DPOPOP producing λ = 420 nm wave length photons, with a low refractive index (n=1.41) cladding of 30 μm thickness. The electronic readout system is the same as used in our

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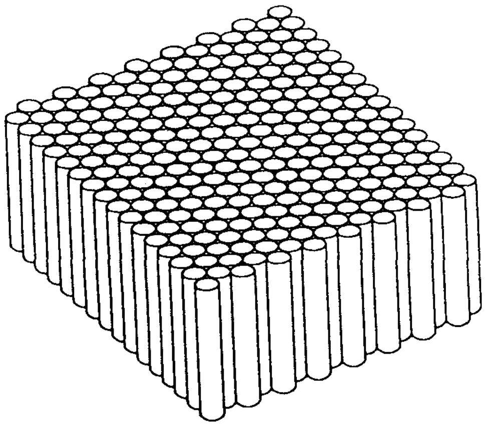

Fig. 1 Schematic view of the 5 x 5 x 2.5 cm^3 fiber stack made of parallel scintillating fibers

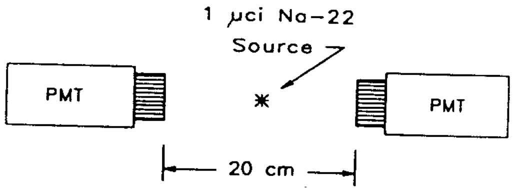

Fig. 2 Schematic view of the PET module made of two parallel scintillating fiber stacks

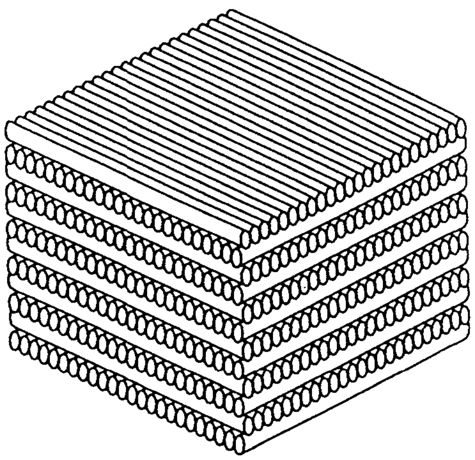

Fig. 3 Schematic view of the 5 x 5 x 5 cm^3 fiber stack with the x and y fiber planes rotated by 90° relative to each other

previous experiments [2]. The time resolution of the coincidence system is 10 nsec.

We started the testing with arrangement (1) using 1.0 mm fibers coated with a very thin light absorbing paint to avoid cross talk between the fibers, and positioning an approximately 1 μci Na-22 source of 0.5 mm diameter in the center of the two stacks (Fig. 2). This PET module permits the 2-dimensional reconstruction of the image. A 3-dimensional image reconstruction of a 5 cm deep section of an object can be achieved with a set of identical modules forming a circle. A deeper section of the object can be imaged either by moving it relatively to the circular PET detector, or by constructing several adjacent circles of PET modules leading to a larger depth of the PET system.

The 2-dimensional spatial resolution using the 1.0 mm fibers and the 0.5 mm source turned out to be about 2.0 mm (FWHM) (see Figs. 4 and 5), and the efficiency of the PET module was 2.3 %.

The 2.0 mm spatial resolution is close to the physical limit due to the positron smearing and angular deviation of the annihilation gammas combined with the spatial resolution of the position sensitive photomultipliers. This was demonstrated by replacing the 1.0 mm fibers by 0.5 mm diameter painted scintillating fibers. This PET module has the same spatial resolution of 2.0 mm, and an efficiency of 1.3%. The reduced efficiency can be explained by the smaller number of photons generated and collected in the thinner fiber. This can be proven by using unpainted 0.5 mm fiber resulting in a poorer spatial resolution of 2.6 mm caused by the smearing effect of the crosstalk between adjacent fibers, but in an improved efficiency of 1.9% due to the increased number of fibers collecting and transmitting more light to the photocathode (Table I).

Scintillating Fiber	1.0 mm (painted)	0.5 mm (painted)	0.5 mm (unpainted)
Resolution (mm) (FWHM)	2.0	2.0	2.6
Efficiency (%)	2.3	1.3	1.9

Table I
Spatial Resolution and Efficiency of PET Modules

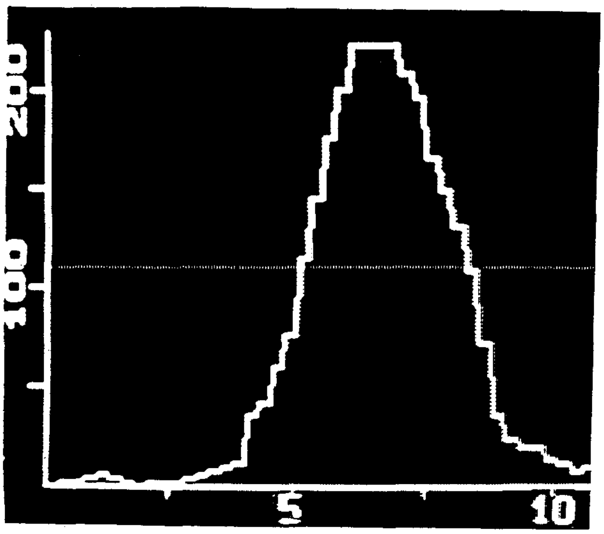

Fig. 4 Count rate vs. position (mm) along the center of the image of the 0.5 mm diameter 1 μci Na-22 source

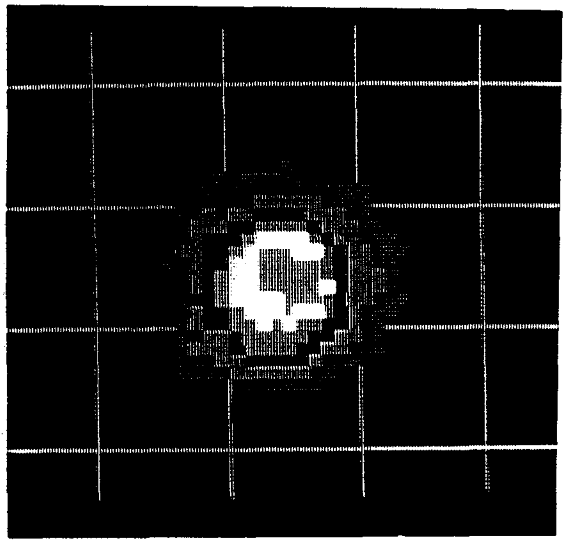

Fig. 5 Image of the 0.5 mm diameter 1 μci Na-22 source. Each square is 2.5 x 2.5 mm^2

The testing of arrangement (2) was carried out similarly positioning the 1 μci Na-22 source of 0.5 mm diameter in the center of the two stacks made of alternating layers of x and y fibers of 0.5 and 1.0 mm diameter. The efficiency of the 1.0 mm fiber PET module turned out to be impractically low because of the short range of the Compton electrons generated by the annihilation gammas, as expected from previous Monte Carlo simulations [1].

The spatial resolution of the PET module made of 0.5 mm diameter scintillating fibers turned out to be about 2.0 mm (FWHM), the same value as obtained for arrangement (1) using painted 1.0 mm and 0.5 mm fibers. This result further supports the assumption that this resolution is close to the limits which can be achieved with these experimental configurations. The efficiency of arrangement (2) turned out to be 0.3%, almost an order of magnitude smaller than the efficiency achieved with arrangement (1) using 1 mm fibers (see Table I). This decrease of efficiency can be explained by the requirement that the Compton electron has to cross two fibers instead of one, and generate enough light in both fibers to trigger the photomultipliers.

The 0.3% efficiency is less than expected from previous Monte Carlo simulations [1]. This could be explained partially by the fact that more photons must be produced to trigger the photomultipliers than assumed in the model. In addition the model was using square fibers instead of circular ones. We intend to improve the efficiency of arrangement (2) by applying reflecting coats at the end of the fibers opposite to the photomultipliers.

III CONCLUSION

A PET module consisting of two stacks made of 1.0 mm parallel scintillating fibers achieved spatial resolution of 2.0 mm (FWHM) and an efficiency of 2.3%. We plan to construct a circular PET system using a set of identical modules and test it for 3-dimensional resolution and efficiency.

After improving the efficiency of the other PET module consisting of stacks made of alternating x and y layers of 0.5 mm fibers, a similar circular PET system will be constructed and tested.

IV. REFERENCES

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[2] M. Atac, D.B. Cline, R.C. Chaney, E.J. Fenyves, G. Hademenos, P.P. Antich and M.D. Petroff, "High Resolution Scintillating Fiber Gamma Ray Detectors for Medical Imaging", IEEE 1990 Nuclear Science Symposium Conference Record, Arlington, Virginia, Oct. 22-27, 1990, pp. 1128-1130.