Comparison of Typical Scintillators for PET

Niraj K. Doshi, Chuck W. Williams, Matthias Schmand, Mark Andreaco, Mehmet Aykac, Michael D. Loope, Lars A. Eriksson, Chuck L. Melcher, and Ron Nutt

***Abstract*--There has been a plethora of literature describing the various properties of scintillators that are commonly used in PET detectors. In this literature there usually is a comparison made with respect to light output and energy resolution. Unfortunately, many of these comparisons are misleading because the treatment of the different scintillators is not optimized to produce the best results that may be possible through proper surface treatment of the scintillator.**

In this research, there is a comparison made between the following scintillators: BGO, LSO, GSO, LYSO, and YSO. Again, the figures-of-merit for comparison were light output and energy resolution at 511 keV. Measurements were performed at two distinct stages:

1) After all of the crystals were cut without any surface improvements;

2) After improvement of the crystal surface.

All of the crystals were wrapped in Teflon tape and tested on the same calibrated test equipment to ensure no other conditions had changed except for the surface preparation.

Another experiment compared the effects of wrapping the crystal in Teflon tape versus collecting the scintillation light using a Teflon cap.

The results from the experiments show an average increase in light output after surface improvement of approximately 31.5% and an average improvement in energy resolution of about 13%. The largest improvement in light output was seen in the LSO crystals and the largest improvement in energy resolution was seen with the GSO crystals. The individual results of the experiments are presented in the manuscript.

Experimental results demonstrate an average improvement in light collection efficiency using the Teflon cap to be approximately 44% in the larger 4x4x20 mm crystals and approximately 24% in the 4x4x10 mm crystals.

I. INTRODUCTION

A key component in any PET system is the scintillator. There are a number of scintillators that have been used in PET applications including BGO, NaI(Tl), GSO, and LSO. Each one of these scintillators comes with some unique physical properties that may be further enhanced by controlling growing conditions, post-growth treatment such as mechanical or chemical polishing, and application-specific reflectors.

Numerous studies have been conducted to evaluate and compare various scintillators with respect to figures-of-merit such as light output and energy resolution [1]-[3]. Studies of different reflectors and processing methods have also been conducted [4], [5].

This study hopes to provide a *de facto* measurement of the light output and energy resolution characteristics of LSO as well as provide a rudimentary comparison of the various other scintillators with regard to those two aforementioned characteristics.

Experiments were conducted to compare raw saw cut crystals to chemically etched crystals. Other experiments allowed the comparison of light collection efficiency using Teflon tape wrapped crystals versus using a Teflon cap.

Although the experiments in this research were rudimentary, the results provide a fundamental comparative review of the various scintillators and their individual characteristics.

With proper scintillator growth, preparation and application, one is able to fully utilize the unique scintillator properties attributed to the various scintillators

II. MATERIAL AND METHODS

A. Scintillators

Five different types of scintillators were investigated during this research. These scintillators were LSO, BGO, LYSO, YSO, and GSO. All the scintillators listed above were provided by CTI, Inc. (Knoxville, TN.) except for GSO, which was provided by Hitachi Chemical Co. (Tokyo, Japan). The scintillators were cut at CTI into 4x4x10 mm and 4x4x20 mm crystals.

B. Hardware and software

All experiments were conducted using either a Hamamatsu R877 5" round photomultiplier tube (PMT) or a Photonis XP2020 2" round PMT. The PMT was connected to a Tennelec 145 preamplifier with a 500 pF capacitance setting. The preamplifier was further connected to a Tennelec 241 amplifier which was in turn connected to an Oxford Instruments PCA multichannel analyzer board plugged into a PC.

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N. K. Doshi is with the Detector R&D group, CPS Innovations, Inc., Rockford, TN. 37853, USA (telephone 865-218-2916, e-mail: niraj.doshi@cpspet.com).

C. W. Williams, M. Aykac, M. D. Loope, M. Schmand, and R. Nutt are with CPS Innovations, Inc., Knoxville, TN. 37853, USA.

M. E. Andreaco and C. L. Melcher are with the Advanced Crystal & Detector Technologies, CTI, Inc., Rockford, TN. 37853.

L. A. Eriksson is with the Karolinska Institute, SE-17177 Stockholm, Sweden.

A 30 µCi Na-22 point source was attached to a transparent plastic cap and was used as the radiation source.

Teflon (PTFE) tape was used as the reflector in those experiments that called for it.

C. Experiment I: Compare raw saw cut finish to a chemically etched finish

Several crystals of size 4x4x10 mm and 4x4x20 mm were cut from the various scintillator materials mentioned above. A set of crystals was wrapped in at least 4 layers of Teflon tape. Each crystal was then placed on the R877 5" round PMT inside a dark box and an energy spectrum was acquired for 30 seconds or until the peak of the photopeak had at least 500 counts. A diagram of the experimental setup is shown in Fig. 1. Energy spectra were then analyzed for photopeak location and the energy resolution was calculated based on the FWHM of the photopeak. No background subtraction was performed.

These crystals were then taken and chemically etched to produce crystals with a polished surface finish as shown in Fig. 2.

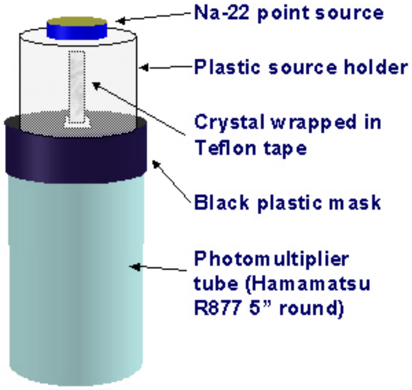

Fig. 1. Diagram of the setup for Experiment I which compared the crystals' surface finishes. Note that a black plastic mask with a 5x5 mm cutout was used to cover the PMT window so as to reduce the amount of scattered light collected.

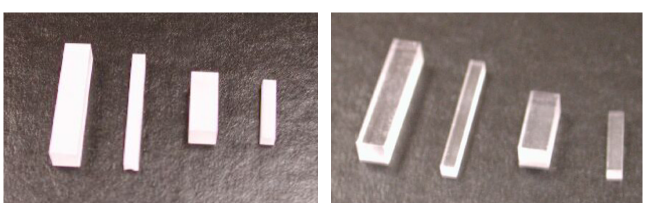

Fig. 2. The picture on the left is of the raw saw cut pixels. The picture on the right is of the chemically etched pixels.

D. Experiment II: Compare light collection efficiency when Teflon tape wrapped versus using a Teflon cap

Another set of crystals without any Teflon tape wrapping were placed on the XP 2020 2" round PMT face "end-on," as in the previous experimental setup.

The black plastic cover with the cutout on the face of the PMT was removed. A Teflon cap was placed on top of the crystal.

An energy spectrum was acquired for 30 seconds or until the peak of the photopeak had at least 500 counts. Energy spectra were then analyzed for photopeak location and the energy resolution was calculated based on the FWHM of the photopeak. No background subtraction was performed.

This method allowed almost all of the light to be captured coming from the crystal.

A diagram of this experimental setup is shown in Fig. 3.

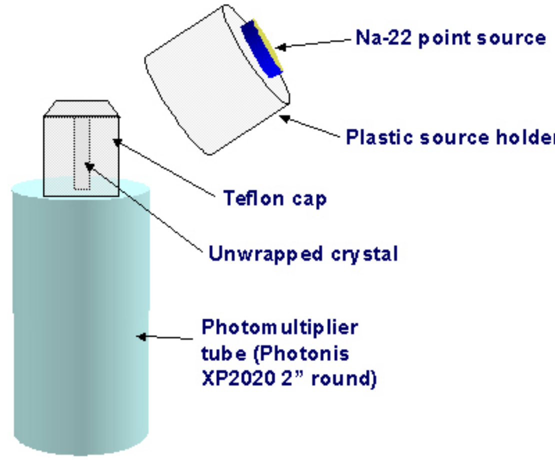

Fig. 3. Diagram of the setup used in Experiment II to compare the relative light collection efficiencies between Teflon tape wrapped crystals and using a Teflon cap.

E. Experiment III: LSO light output and energy resolution measurements

In this experiment, 26 LSO crystals that were 4x4x20 mm were individually wrapped in at least 4 layers of Teflon tape and placed on the XP2020 2" round PMT. Again, a black plastic mask with a 5x5 mm cutout was used.

An energy spectrum was acquired for 30 seconds or until the peak of the photopeak had at least 500 counts. Energy spectra were then analyzed for photopeak location and the energy resolution was calculated based on the FWHM of the photopeak. No background subtraction was performed.

III. Results

A. Experiment I

The various tables below detail the results obtained for this experiment.

TABLE I
DATA OBTAINED FROM CRYSTALS WITH A RAW SAW CUT FINISH

	4x4x20		4x4x10	
	PH	PHR	PH	PHR
BGO	123	12.74	142	10.62
LSO	520	11.60	505	11.40
YSO	481	8.48	500	8.28
LYSO	498	9.94	482	9.78
GSO	222	10.81	233	9.74

TABLE II
DATA OBTAINED FROM CHEMICALLY ETCHED CRYSTALS

	4x4x20		4x4x10	
	PH	PHR	PH	PHR
BGO	124	11.13	138	10.37
LSO	591	11.48	664	10.79
YSO	562	8.50	643	8.64
LYSO	612	9.30	609	9.94
GSO	205	9.63	266	8.46

TABLE III
PERCENT CHANGE IN THE INDIVIDUAL CRYSTALS AFTER APPLYING A DIFFERENT SURFACE FINISH

	4x4x20		4x4x10	
	PH	PHR	PH	PHR
BGO	0.81%	-12.64%	-2.82%	-2.35%
LSO	13.65%	-1.03%	31.49%	-5.35%
YSO	16.84%	0.24%	28.60%	4.35%
LYSO	22.89%	-6.44%	26.35%	1.64%
GSO	-7.66%	-10.92%	14.16%	-13.14%

The average light output increase (increase in PH) was 14.4%. The average improvement in energy resolution (PHR) was 4.6%. Although, not all of the scintillators followed the same trend, it is apparent that surface finish plays an important role with respect to light output and energy resolution.

B. Experiment II

Again, the various tables below detail the results for this experiment.

TABLE IV
DATA OBTAINED WITH TEFLON WRAPPED CRYSTALS

	4x4x20		4x4x10	
	PH	PHR	PH	PHR
BGO	69.30	15.31	85.34	12.96
LSO	487.56	11.98	762.56	10.12
YSO	446.09	9.49	549.33	9.25
LYSO	356.72	11.51	434.63	10.85
GSO	164.17	11.24	205.51	9.92

TABLE V
DATA OBTAINED WITH A TEFLON CAP WHILE THE CRYSTALS WERE UNWRAPPED

	4x4x20		4x4x10	
	PH	PHR	PH	PHR
BGO	100.36	12.53	103.60	12.55
LSO	739.42	9.19	910.38	10.04
YSO	616.67	8.69	704.29	7.29
LYSO	526.82	9.24	552.39	8.08
GSO	224.54	9.96	255.34	9.14

TABLE VI
PERCENT CHANGE IN THE PH AND PHR BETWEEN THE TEFLON TAPE AND TEFLON CAPPED CRYSTAL SETUPS

	4x4x20		4x4x10	
	PH	PHR	PH	PHR
BGO	44.82	-18.13	21.40	-3.18
LSO	51.66	-23.31	19.38	-0.82
YSO	38.24	-8.45	28.21	-21.16
LYSO	47.68	-19.69	27.09	-25.49
GSO	36.77	-11.44	24.25	-7.87

The average change in light output (PH) for the 4x4x20 mm crystals was approximately 44%. The average improvement in energy resolution when using the Teflon cap with the 4x4x20 mm crystals was approximately 16%. The average increase in light output and improvement in energy resolution for the 4x4x10 mm crystals was measured to be approximately 24% and 12%, respectively.

C. Experiment III

The average measured light output of the LSO was approximately 5 times the light output of the BGO crystal used in the above experiments. The average energy resolution for the 26 LSO crystals was approximately 10.4%. The best and worst energy resolutions obtained from this batch of crystals were 9.1% and 12%, respectively.

IV. DISCUSSION AND CONCLUSIONS

The previous data demonstrate the various light output and energy resolution that may be achieved with the various scintillators. It is also apparent that there is a dramatic improvement in the light output and energy resolution after improving the surface finish of the scintillators through chemical etching.

The greatest improvement in the figures-of-merit across the scintillators after improving the surface properties beyond the raw saw cut finish was noted with the LSO and the GSO crystals. The LSO scintillator's light output increased approximately 31.5%. The GSO scintillator's energy resolution improved approximately 13%.

These marked improvements are directly attributed to the surface finish of the scintillators.

The results from the experiment comparing the light collection efficiency from a Teflon wrapped crystal to using a Teflon cap demonstrated a definite difference in the light collection efficiency between the two setups.

Apparently, not all of the light is collected even if the scintillator has been wrapped in at least 4 layers of Teflon tape. An average improvement in light output of approximately 44% was seen in the 4x4x20 mm crystals and an approximate increase of 24% was seen in the 4x4x10 mm crystals.

Using the Teflon cap, an average improvement in energy resolution of approximately 16% in the 4x4x20 mm crystals and approximately 12% in the 4x4x10 mm crystals was seen.

It is clear that the smaller crystals were not as susceptible to the method by which the light was collected and passed onto the PMT.

The overall results from these measurements tend to correlate well with previous measurements performed by other groups except for the LSO results. Unfortunately, the preparation of the LSO crystals by other groups may have led to erroneous and misleading results.

In these experiments, chemical etching of the crystals provided a better surface than a simple raw cut finish. Although, this is an added step to the detector fabrication process, it has been previously demonstrated by several groups that chemical etching improves overall light output and energy resolution [6], [7]. This research further supports those previous claims.

From the various measurements, one can see that there has been a degree of improvement in the overall scintillator quality from previous years. This improvement may only be exploited if careful preparation of the scintillators is performed and an optimization of the surface and reflectors is attained.

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VI. References

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