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Melt-Cast Organic Glass Scintillators for a Handheld Dual Particle Imager

Nathan P. Giha, William M. Steinberger, Lucas Q. Nguyen, Joseph S. Carlson, Patrick L. Feng, Shaun D. Clarke, and Sara A. Pozzi

***Abstract*—The light output, energy resolution, time resolution, pulse shape discrimination (PSD), interaction location reconstruction, and isotropic response of melt-cast small-molecule organic glass bar scintillators were characterized. The trans-stilbene organic scintillator detects fast neutrons and gamma rays with high efficiency and exhibits excellent PSD, but the manufacturing process is slow and expensive and its light output in response to neutrons is anisotropic. Small-molecule organic glass bars offer an easy-to-implement and cost-effective solution to these problems. These properties were characterized to evaluate the efficacy of constructing a compact, low-voltage neutron and gamma-ray imaging system using organic glass bars coupled to silicon photomultiplier (SiPM) arrays. A complete facility for melt-casting was setup at the University of Michigan and 6x6x50 mm^3 glass bars were produced and characterized. The results were compared to previous characterization of stilbene bars.**

I. Introduction

RESEARCHERS at Sandia National Laboratories recently discovered a small-molecule organic glass scintillating material with potential applications in radiation detection for nuclear nonproliferation and safeguards [1]. Previous work compared a Ø5.08×5.08 cm *trans*-stilbene and a Ø5.08×5.08 cm small-molecule organic glass scintillator and determined that organic glass exhibited higher light output than stilbene for a neutron energy range of 0.79 to 4.57 MeV [2]. Organic glass is also more favorable from a manufacturing standpoint. Its amorphous structure enables rapid fabrication via a bulk melt-casting procedure. By comparison, *trans*-stilbene is solution-grown which makes its production comparatively difficult, slow, and expensive.

The Handheld Dual Particle Imager (H2DPI) at the University of Michigan is a hand-portable neutron and gamma-ray imaging system based on stilbene bars coupled to silicon photomultipliers (SiPMs) on either side [3]. Organic glass may be a strong candidate for replacing the *trans*-stilbene bars in the H2DPI due to its higher light output and manufacturability. This work will directly compare several properties of organic glass and *trans*-stilbene bars that are relevant to neutron and gamma-ray imaging, including light output, time resolution, pulse-shape discrimination, interaction position reconstruction, and isotropic light output response.

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Nathan P. Giha, William M. Steinberger, Shaun D. Clarke, and Sara A. Pozzi are with the Department of Nuclear Engineering and Radiological Sciences, University of Michigan, Ann Arbor, MI 48109 USA (e-mail: giha@umich.edu).

Lucas Q. Nguyen, Joseph S. Carlson, and Patrick L. Feng are with Sandia National Laboratories, Livermore, CA 94550 USA.

II. Methods

Several $6 \times 6 \times 50$ mm^3 organic glass bars were melt-cast at the University of Michigan using the general casting procedure outlined in the supporting information of [1]. The bars were then wrapped in polytetrafluoroethylene (PTFE) tape. A designated ”sandbox” system analogous to the H2DPI was constructed, and is shown in Figure 1. It is composed of $6 \times 6 \times 50$ mm^3 bar-shaped scintillators coupled on either side to pixels of a SensL ArrayJ-60035-64P-PCB SiPM array via EJ-560 optical interfaces. The standard outputs of the SiPM arrays are read out by custom printed circuit boards then digitized and recorded using a CAEN V1730 14 bit, 500 MS/s digitizer. The sandbox system can quickly be disassembled and reassembled in alternative scintillator configurations. It is placed in a light-tight dark box during measurements.

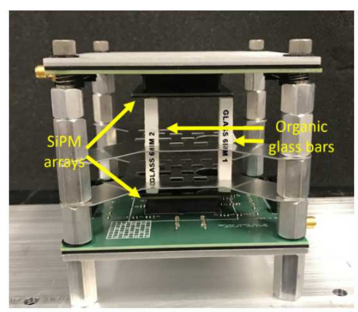

Fig. 1. H2DPI sandbox system with two melt-cast $6 \times 6 \times 50$ mm^3 organic glass bars coupled on either side to a SiPM array.

Each of the properties listed in the background section is characterized for the stilbene-based H2DPI. This work will characterize an organic glass bar-based system.

A. Light Output

The light output of organic glass for gamma-ray and neutron interactions was well-characterized in [2] for a Ø5.08×5.08 cm cylinder. The measured light output in this system is a strong function of the light collection efficiency, due in large part to the scintillator geometry. Light output will be calibrated on the 478 keV Compton edge measured from a Cs-137 source. A neutron time-of-flight experiment will be performed to calibrate light-output response for proton recoils.

Two (6mm)^3 organic glass cubes were melt-cast and calibrated with one (6mm)^3 stilbene cube on the 478 keV edge

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for 30 min. Figure 2 shows a glass cube coupled to a SiPM pixel.

Fig. 2. (6mm)^3 organic glass cube coupled to a SiPM array pixel.

B. Time Resolution

Time resolution is measured by placing a Na-22 source between two detectors and analyzing annihilation photon coincidences. This setup is shown in Figure 3.

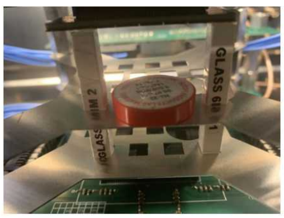

Fig. 3. Na-22 time resolution measurement with two organic glass bars.

The resulting distribution of the measured time difference between the two interactions is approximately Gaussian, and its full width at half maximum (FWHM) is considered the time resolution.

C. Pulse Shape Discrimination

Neutron light output is nonlinear in organic scintillators, and results in proportionally larger tails in pulses from neutron interactions. Pulse shape discrimination (PSD) will be quantified by measuring a Cf-252 source, as in [2].

D. Interaction Location Reconstruction

The fraction of light detected by the top and bottom of the bar depends on the interaction location. Calibration curves for reconstructing the interaction location will be developed through collimated measurements at defined heights [4].

E. Isotropic Response

Neutron light output in stilbene depends on the crystal direction through which the recoil proton travels. As organic glass is amorphous, its response should be uniform with respect to the recoil direction. A Cf-252 spontaneous fission source will be placed along the three Cartesian axes to demonstrate this.

III. Preliminary Results

The experiments outlined in sections A and B in Methods were conducted. Figure 4 shows Cs-137 spectra for a stilbene cube (blue) and two glass cubes (orange and green). The pulse integral corresponding to 80% of the maximum of the Compton edge for each cube is displayed in the legend.

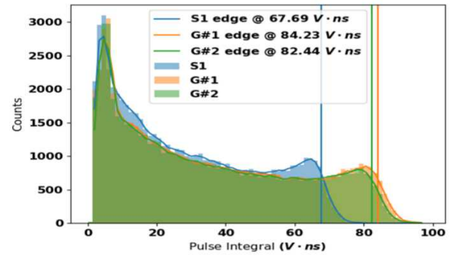

Fig. 4. Cs-137 spectra for stilbene and glass cubes.

Figure 5 shows the distribution obtained from the Na-22 time resolution measurement conducted in Figure 3. Its FWHM is 340 ps.

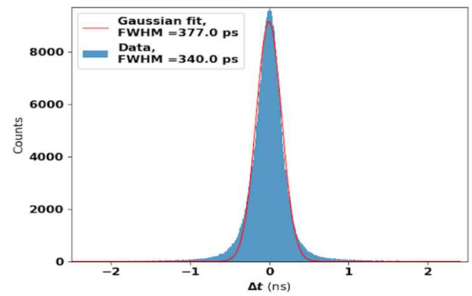

Fig. 5. Na-22 time difference histogram.

IV. Discussion

Preliminary results confirm that small-molecule organic glass exhibits greater light output than stilbene at 478 keVee. They also suggest that organic glass exhibits better time resolution than stilbene bars of the same dimension.

V. Conclusion

The results presented indicate organic glass may offer significant advantages over stilbene in a handheld dual particle imager. The remainder of the outlined characterization will be performed in the coming months.

References

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