Design and Evaluation of an Additively Manufactured Plastic Scintillation Detector

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Abstract

In this project we design and build a plastic scintillation detector using additive manufacturing for use in detecting ionizing radiation with the intent being to create an unobtrusive wearable dosimeter. An off the shelf stereolithography printer was used with standard resin which was then doped with varying amounts of anthracene as the scintillating medium. The concentration of the dopant, method of mixing, and overall process was determined to produce a part which was mated with a standard photomultiplier tube producing an additively manufactured plastic scintillator. The overall detector was tested with medium to high energy gamma sources over short exposure periods clearly distinguishing the sources from background with a continuum response at low energies relative to the strength and energy of the source. Future work includes customization of geometry, coupling to other sensors, expansion to other printing methods, and evaluation of non-ionizing radiation sources to create a discreet wearable dosimeter.

Need statement

The purpose of this project is to create a solid plastic scintillating medium via additive manufacturing (AM) that will produce light output from an incident ionizing radiation source. When coupled with a light to converted or stored energy mechanism such as a photo multiplier tube, photo diode, or other light sensing source, the device becomes an AM plastic scintillation detector. This project has direct need in radiation detection applications particularly those that require inconspicuous operation, have unusual form factors, or integrate with other components. This project also represents an advancement in multifunctional AM where the part has innate properties due to its material construction in addition to the benefits already offered by AM.

Background

There are a variety of scintillation detectors commonly used for radiation detection and monitoring. These include organic, inorganic, and gaseous scintillators. Material density plays a large role in scintillation detectors and while plastic scintillators are intrinsically less efficient than inorganic scintillators, they are comparatively less expensive, have less total mass for the same size, and offer greater flexibility in manufacturing than inorganic crystal or other common scintillators. Plastic scintillators are traditionally either found naturally occurring or more commonly synthetically made through a polymerization process. Once formed these scintillators are made into stock shapes via extrusion other standard plastic manufacturing processes such as molding. Traditional plastic scintillators use a fluorescent material which acts as the primary scintillating medium suspended in a polymer matrix. This mixture of fluorescent medium and base is then often poured into a mold for final forming or extruded through a die similar to traditional plastic manufacturing.

These traditional plastic forming processes require complex molding and forming methods which add significantly to total cost, often require post processing, and limit manufacturing capability. This project adds a fluorescent medium to a standard AM consumable producing a net shape that is formed using a modified AM process. The produced net shape can be made such that it requires little to no post processing, can be adopted to a variety of light measuring or storing systems, and does not require any additional mold, casting, or other forming process.

Technical overview

The fundamental objective of this project is to convert ionizing radiation from a radiation source to a measurable signal such that the source can be discriminated from background radiation. This is achieved by placing the detector in proximity to the radiation source; creating a scintillating medium which converts the incident ionizing radiation flux to visible light; converting the light to a useful signal; and analyzing the resultant signal to discriminate the source from background. A cartoon diagram of this process is depicted in Figure 1.

The final part, an AM plastic scintillation detector, is made by first adding a fluorescing medium to a standard additive manufacturing consumable. In the specific case proven to date, anthracene, a solid aromatic hydrocarbon in powder form, is added to a commercially available ultraviolet light curable resin. Varying concentrations of anthracene have been evaluated and solubility of scintillator and additive manufacturing consumable have been considered. Additional fluorescent mediums have been evaluated. Photographs of the mixing process and resin are shown in Figure 2. The approach of this project can also be directly applied to any plastic filament process.

The resulting mixture of fluorescent medium and AM consumable is then used as a consumable in a modified AM process. In the specific process tested, the scintillator doped resin was used in a commercially available stereolithography process with modification producing a final part that is in its entirety an AM plastic scintillator. By itself the AM plastic scintillator will produce light from an ionizing radiation source, but when coupled with a light to current device such as a photo multiplier tube or other energy storage system, the composite device becomes an AM plastic scintillation detector. In the specific process tested, a standard stock shape was combined with a commercially available photo multiplier tube. Photographs of the printed scintillating part, photo multiplier tube used, and composite detector are shown in Figure 3.

The scintillation detector was then tested on two different ionizing radiation sources in a laboratory environment, specifically Co-60 a high energy gamma source and Cs-137 a lower energy gamma source. Background radiation measurements were also recorded, and the detector clearly discriminated both sources from background. The detector was also compared directly to a plastic scintillation detector made via a standard production process, and the detector performed comparable to or better than the standard detector in all testing. Experimental results from the ionizing radiation tests as well as a photograph of the experimental setup are shown in Figure 4.

Reflections

The final product, an AM plastic scintillation detector, has distinct advantages over traditionally manufactured plastic scintillation detectors. Specifically, the AM scintillation detector can be made such that is requires little to no post processing, the scintillating medium can easily be adopted to any geometry for light to signal processing, and the detector requires no mold, casting, or other manufacturing process. The AM detector also has intrinsic advantages associated with AM which include the ability to print complex geometries or designs not possible with traditional manufacturing, a potentially expedited manufacturing process since custom molds or castings are not required, and overall a more rapid design to product manufacturing capability.

The AM detector also has a significant advantage in that the detector is made from a multifunctional material; specifically, the detector has the ability to serve as a radiation detection device while also serving as a structural component either on its own directly or as part of a composite unit. Two potential applications of this will be discussed to highlight this advantage. There is a well-established need for unmanned material reconnaissance to monitor for radiation sources. In most of these attempts, a radiation detector that is often heavy and obtrusive is mounted to an unmanned aerial vehicle (UAV). Using this project's approach, portions of the UAV could be made from the proposed process allowing both a customizable geometry, low total mass, and adequate structural integrity while also serving as the radiation detector. Similarly for personnel monitoring, the printed material could be incorporated into existing personnel protective equipment (PPE) such as helmets, vests, backpacks, or other worn device offering the same advantages mentioned for UAVs.

In addition to ionizing radiation detection which has already been demonstrated, formulations are in progress that use neutron or other radiation particle interaction processes so that other forms of radiation can be detected. More broadly one of the aims of this project is to demonstrate that custom AM consumables can be made and utilized that produce inherent functionality of the AM part itself. This combination approach of custom material formulation and custom manufacturing method has the potential to create multifunctional materials.

In this project, it has been demonstrated that: (1) a scintillating material can be added to an additive manufacturing consumable, (2) this scintillating material will survive the AM process producing a part that requires little to no post processing, and (3) the final part functions as intended which is specifically that the final part will scintillate in an ionizing radiation flux producing a measurable signal that can be used to discriminate a radiation source from background. These discoveries have considerable potential for use in a wide variety of traditional radiation detection applications including wearable dosimeters, radiation screen devices, portable detectors, and covert detection systems.

References

Baker, B., Joyce, P, Millett, M., Additively Manufactured Plastic Scintillation Detector - Non Provisional Patent Application No. 16/567,802

Figures

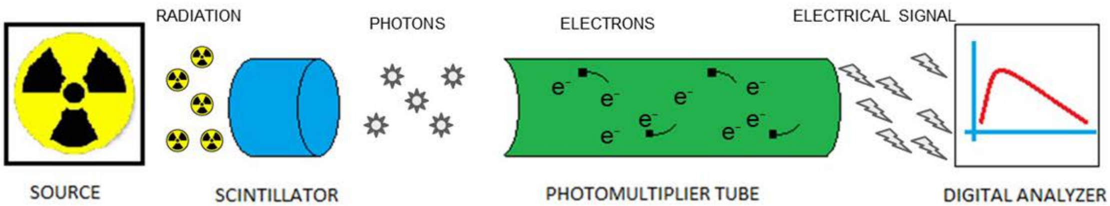
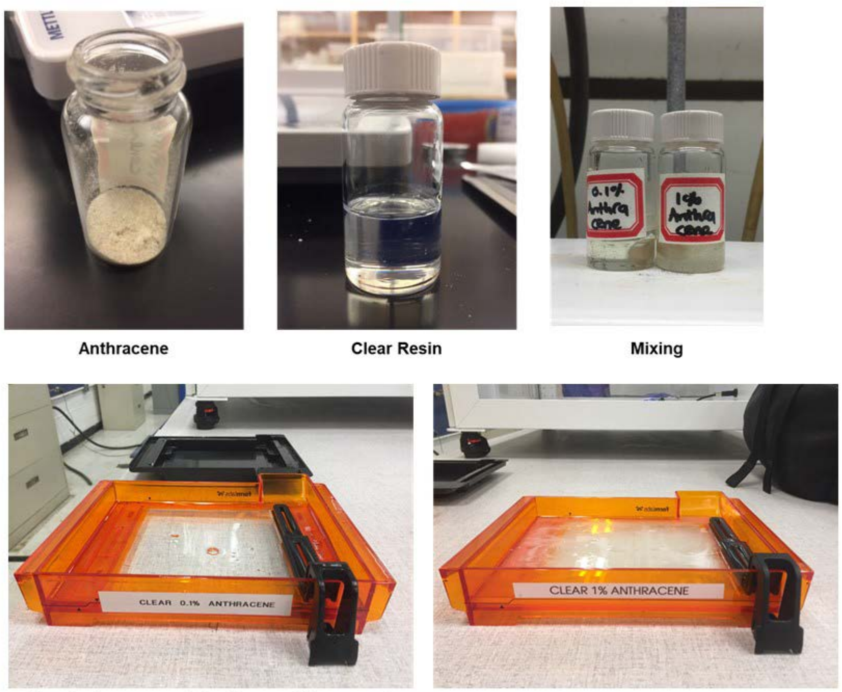


Figure 1. Cartoon Diagram of Overall Objective



Resin trays used in Stereolithography process

Figure 2. Photographs of Mixing Process

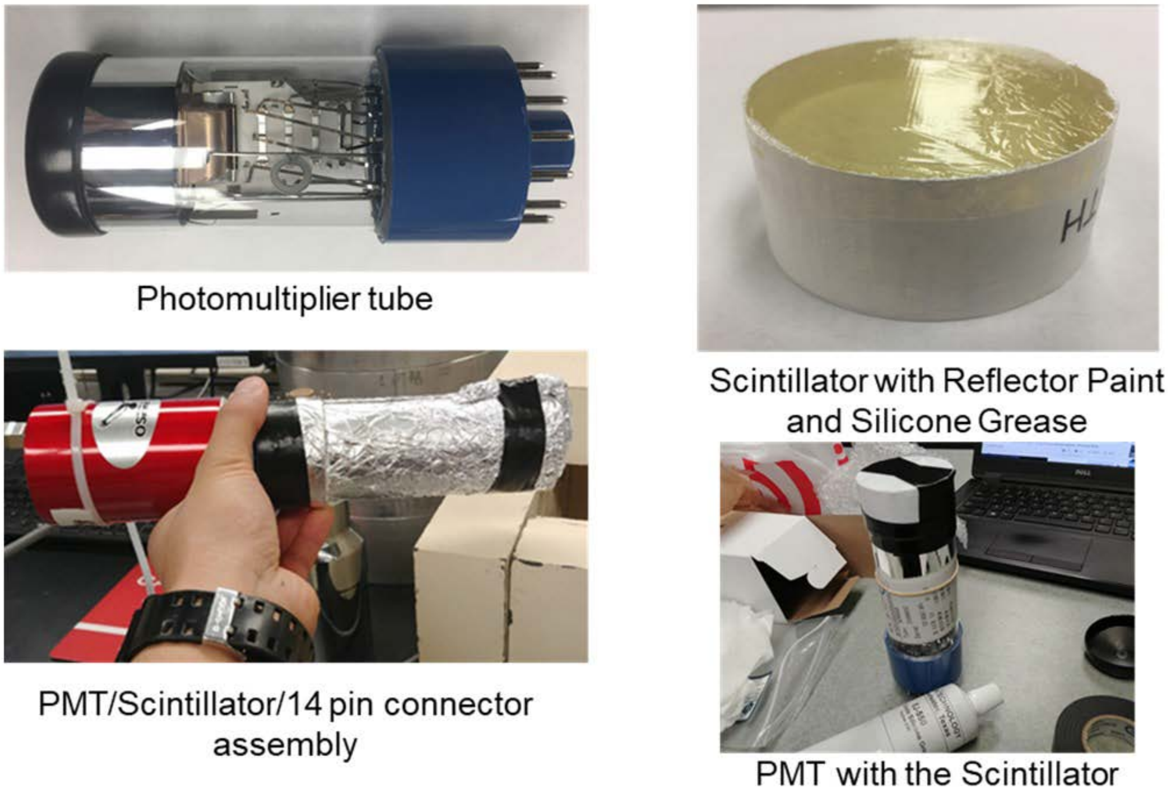


Figure 3. Photographs of Components of Detector

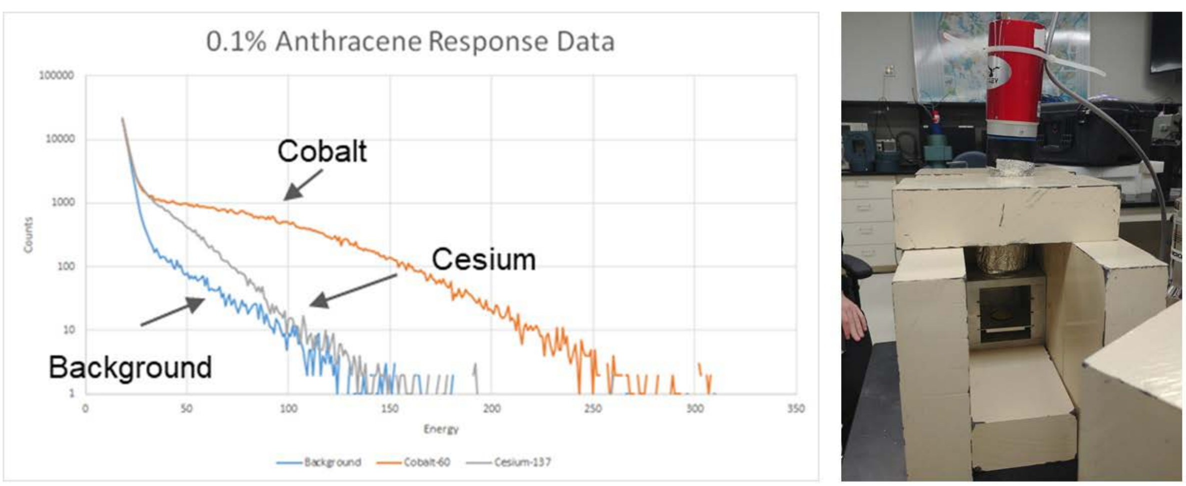


Figure 4. Example Experimental Results and Experimental Setup