Production of Scintillation Particle Detectors with Stereo Lithography-Based 3D Printing

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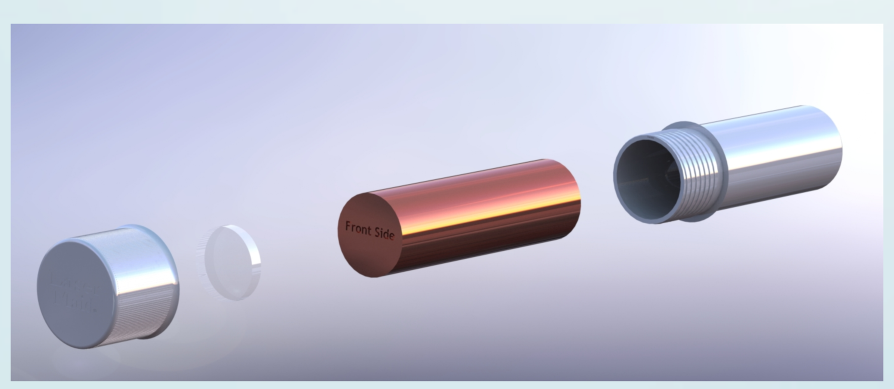
Abstract

One of the most important advances for modern experimental nuclear physics are scintillation-based detectors. Scintillators measure high-energy charged particles, which cause the material to fluoresce. These detectors must be optically clear so that the fluoresced light can be detected by a photomultiplier tube (PMT), which converts the signal into an electrical output that can be read out by a computer. My research is to design and directly 3D print scintillator detectors. I will test how well they can detect particles against standard machined detectors to improve detector efficiency.

3D Printed Dark Box

- The PMT is capable of detecting light coming from a scintillator attached to its lens on a single photon level.
- Therefore it's extremely sensitive to light, so it must operate in a completely lightproof environment, or in what's called a "dark box".
- To address that, an actual plywood box had to be built in the past to test the PMT.
- It was very large and not portable; the whole process of building it was a very labor intensive and time consuming process.
- Now I've designed and 3D printed a completely opaque cylindrical case for the PMT, shown below.
- Initially I printed the case using a Prusa plastic filament printer, but it was too small for the PMT to fit, so I reprinted it using Formlabs' Flexible resin, which is stretchy enough for the PMT to fit.
- This eliminated the need for an actual box; instead the PMT can now snuggly fit into it's own bespoke case, making it a lot more portable.

SolidWorks Exploded view of the PMT case design --→
Note that the cylinder in the middle represents the PMT in this assembly.



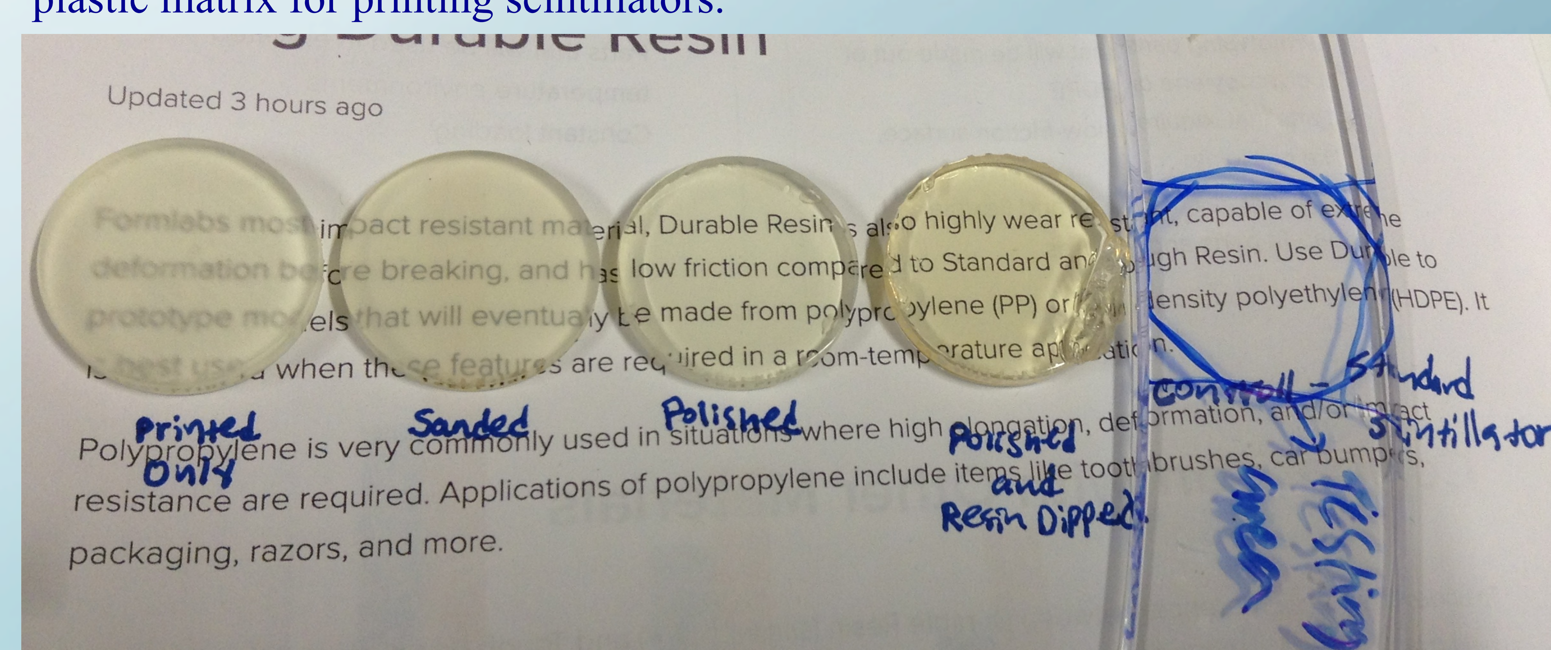
PMT case printed with Prusa – too small and Inflexible.

Formlabs Flexible resin PMT case and cap – same design but stretchy and elastic, so the PMT fits right in. Note that the scintillator test disk goes right into the cap, that way when the cap is screwed on, it's in contact with the the lens.

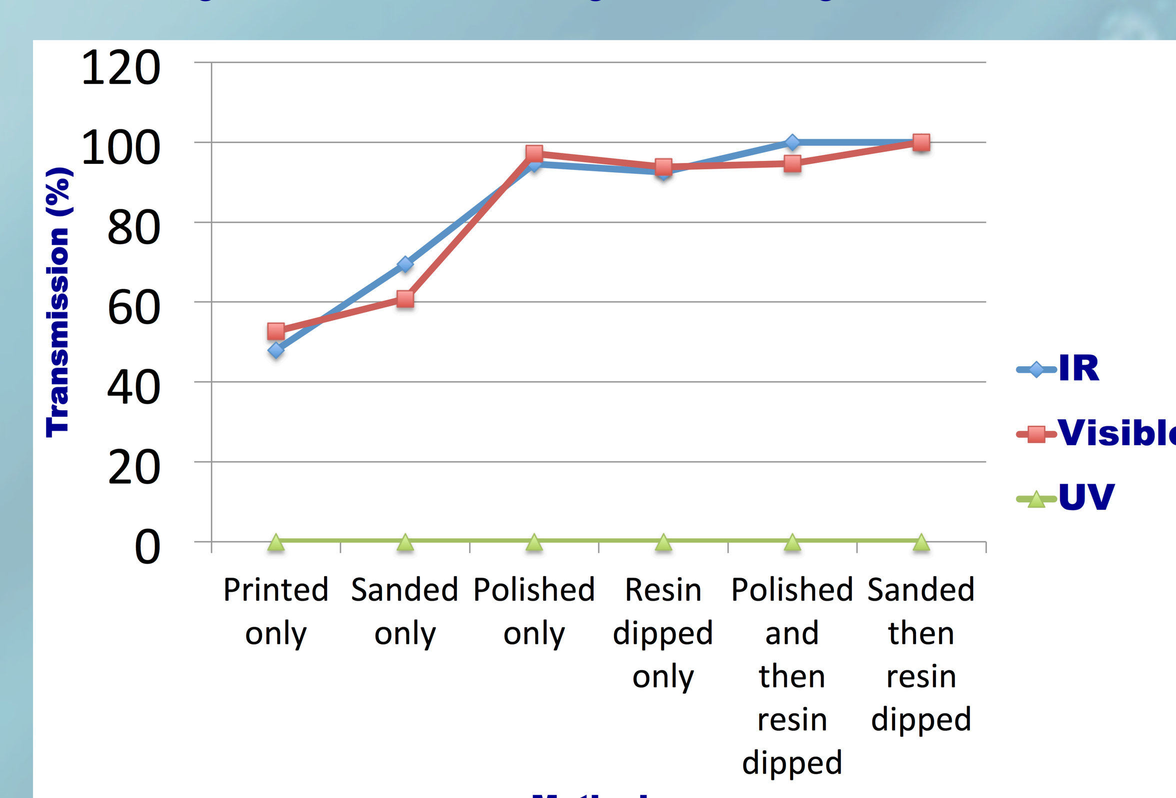
Optically Transparent 3D Prints

- Scintillators must be as transparent as possible, to be as efficient at transmitting photons to the PMT as possible.
- To figure out the best method of achieving optimal transparency, I first 3D printed a set of small disks using Formlabs' Form 2 liquid resin 3D printer and Clear resin cartridge.
- Different levels of optical transparency were then achieved on the disks though different combinations of sanding, cerium oxide polishing, and coating in resin.
- Next the disks were tested for transparency using a light meter, which measures the transmission and reflection percentages of various frequencies of light, as shown below.

- The method which produced the most optically transparent disk, will be used as the plastic matrix for printing scintillators.



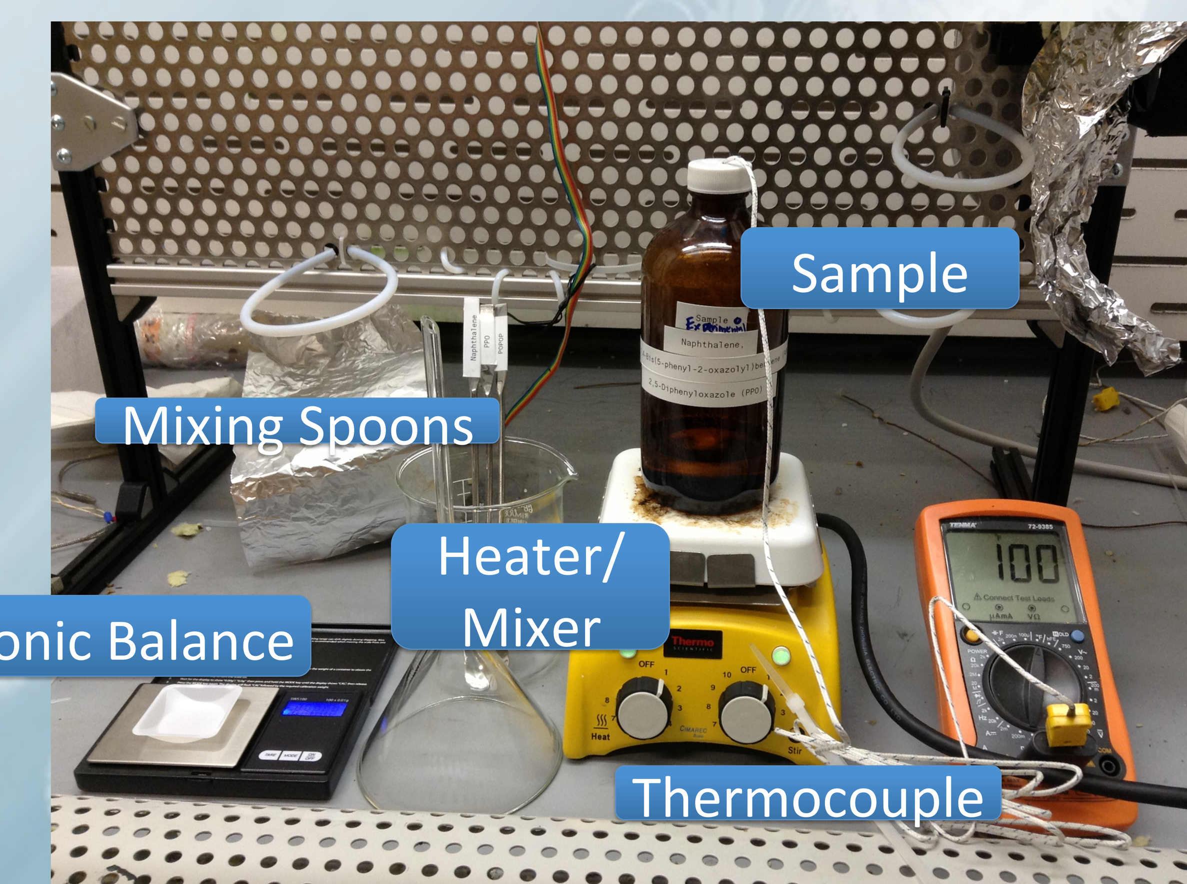
Example of results, with light transmission increasing from left to right.



Percentages of transmission of three different light frequencies verses different methods of polishing. Note that none of the methods used allowed UV transmission whatsoever.

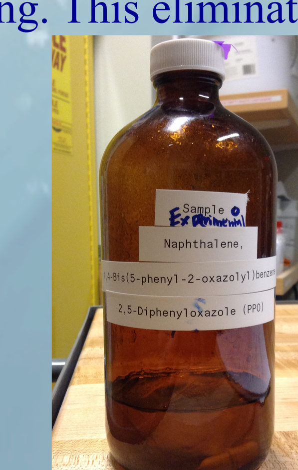
Mixing Scintillator Recipes

- I've also been working on determining the ideal conditions under which resins with different amounts of scintillating ingredients can be mixed and printed. The key is to find a good temperature at which:
  1) Scintillating chemicals stay fully dissolved
  2) Don't decompose from overheating

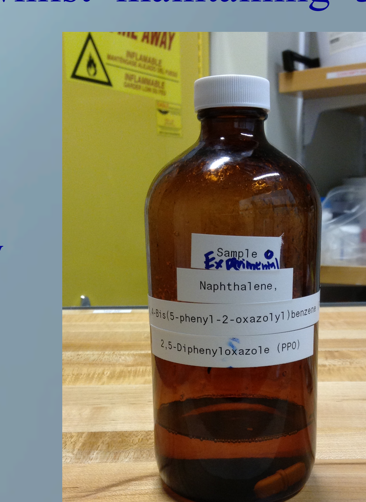


Experimental set-up

- The ingredients used in every sample are the same, namely naphthalene, POPOP, and PPO. In the set-up above I'm using 15% naphthalene, 1.5 % PPO, and .08 % POPOP, by weight.
- Dissolved scintillating ingredients will recrystallize below 38°C (≈ 100°F)
- To address that, mixing and printing must be done whilst maintaining 38°C and constant stirring. This eliminates the recrystallization:



Before and after heating – the crystallization goes away



- This experiment is all about optimizing the ratio of scintillating ingredients in the resin to produce the most efficient detector. Therefore, I've also made a table of different recipes, which will be mixed, printed, and tested for efficiency using the PMT. Here are a few sample recipes from that table:

Sample Number	Naphthalene Content (% by weight)	PPO Content (% by weight)	POPOP Content (% by weight)
1	15	1.5	.08
6	55	1.5	.1
13	55	2.25	.12

Conclusions and Future Research

- In conclusion, SLA 3D printing can be used to create custom dark boxes of arbitrary geometric complexity as well as optically transparent parts.
- Best methods of post-processing were polishing and coating in resin, producing visible light transparencies of 97.15% & 100% and infrared transparencies of 94.6% & 100%, respectively.
- Ideal temperature for direct 3D printing of naphthalene-based plastic scintillators were found to be at or slightly above 38°C
- The next step of my research is mixing the rest of the recipes and 3D printing them to be tested for scintillation efficiency. I plan to continue altering the recipes further to reach maximum detection efficiency possible.