



Stony Brook University

Chemical deposition of wavelength shifter for the next generation VUV light trap photodetectors

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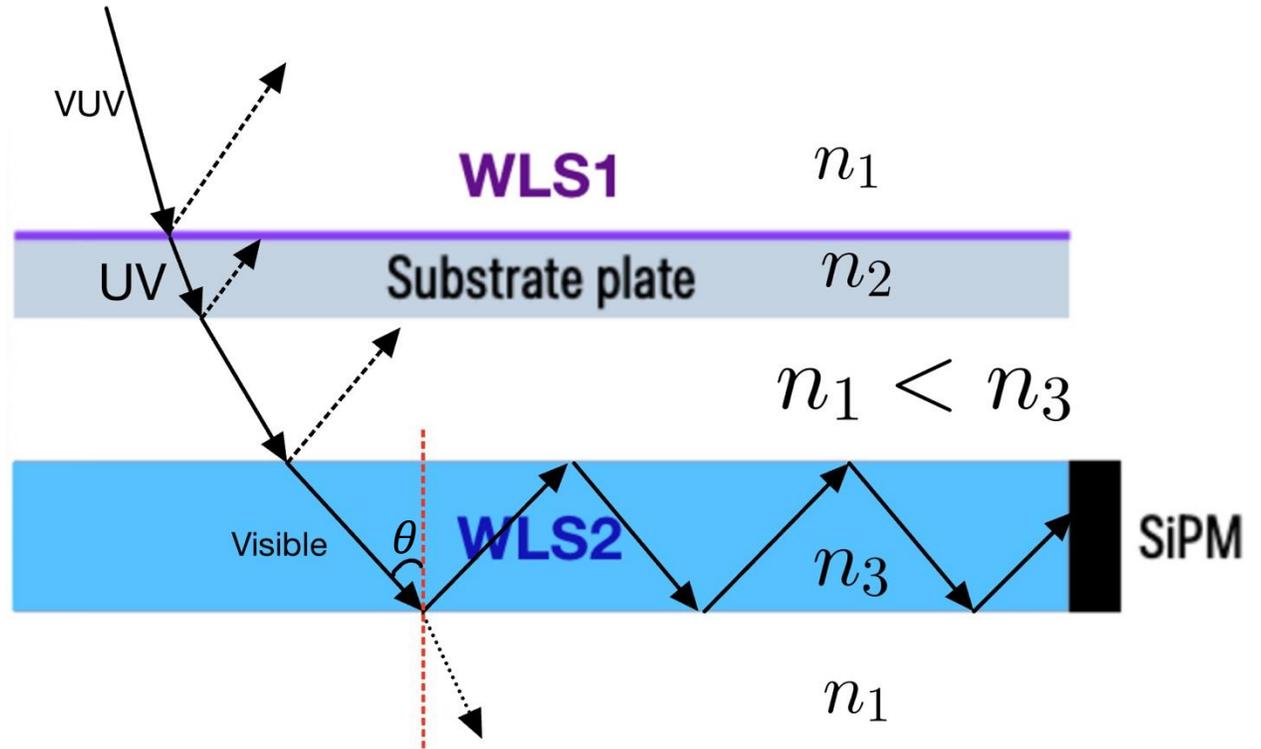
CPAD 2025 at Penn

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Background

- Investigation on a two-layer light trap to operate at cryogenic temperature.
- Critical angle for total internal reflection in WLS2 : given by θ_c
- Vacuum Ultraviolet (VUV) scintillation light of noble liquid.
- Need to wavelength shift the VUV to Visible and detect the light with Silicon Photomultiplier (SiPM).

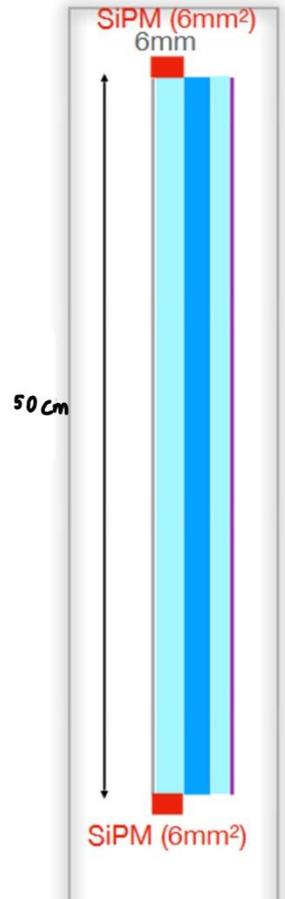


$$\theta_c = \arcsin\left(\frac{n_3}{n_1}\right)$$



Photodetector module

[Reflector - WLS2 - LAr - PMMA - WLS1]
VIKUITI foil - PMMA (doped) - LAr - PMMA - pTP film



Dimensions:

- Vary from 10cm x 10cm up to 50cm x 50cm depending on the physics requirements
- Prototype : 15cm x 15cm
- 1st layer: 3mm
- 2nd layer: 6mm

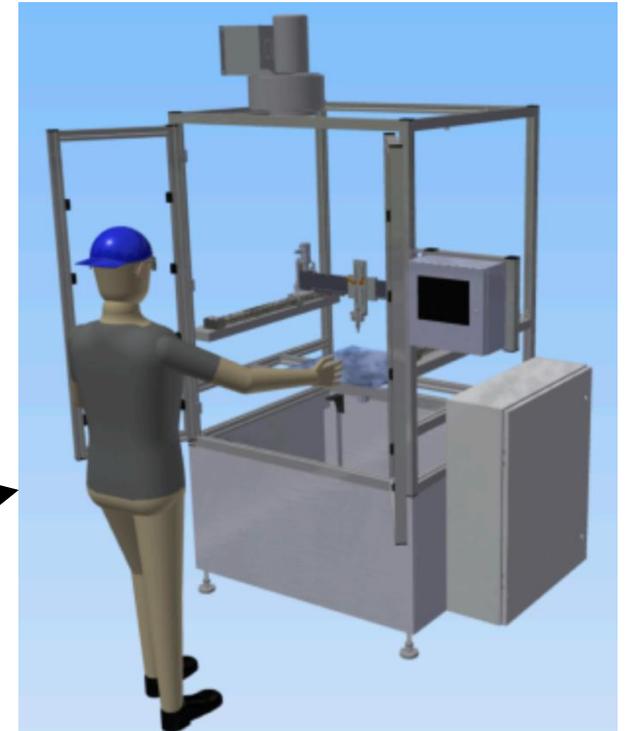
Components of the detector:

- 1st layer: UVT acrylic spray coated with WLS.
- 2nd layer: acrylic doped with Wavelength shifting material : ~350nm -> ~430nm.
- SiPMs mounted at two edges of the 2nd layer. Other edges without SiPMs will be covered with reflective foils.

The two layers are mechanically coupled.

Motivation of the chemical deposition of WLS

- Vacuum deposition :
 - High vacuum
 - Low material efficiency
 - High cost
- This work investigates on the application of chemical deposition of an organic wavelength shifting material on an acrylic substrate:
 - Low cost
 - Can accelerate the coating process once automatized. 
- Applications: Noble liquid-based dark matter and neutrino experiments, nuclear and particle physics, etc. (see Wei Shi's talk)





Advantages of using an acrylic

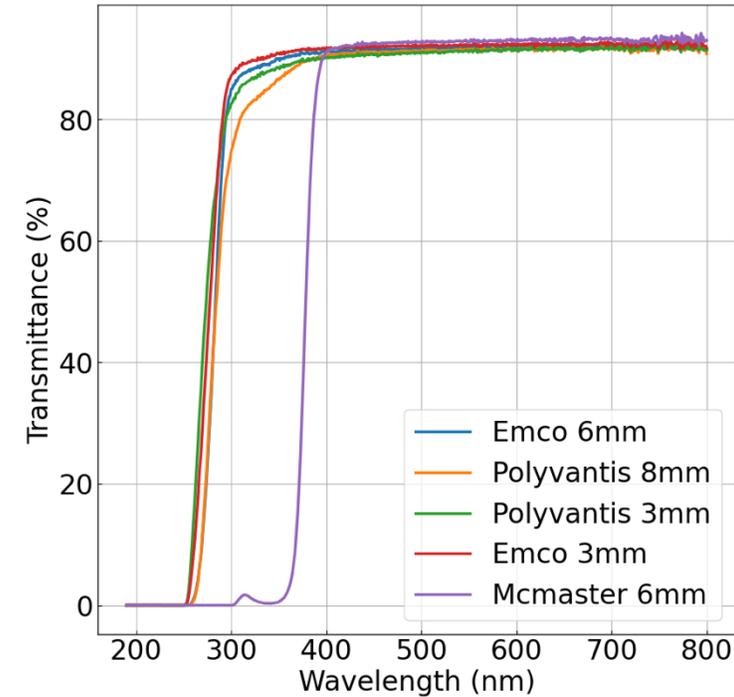
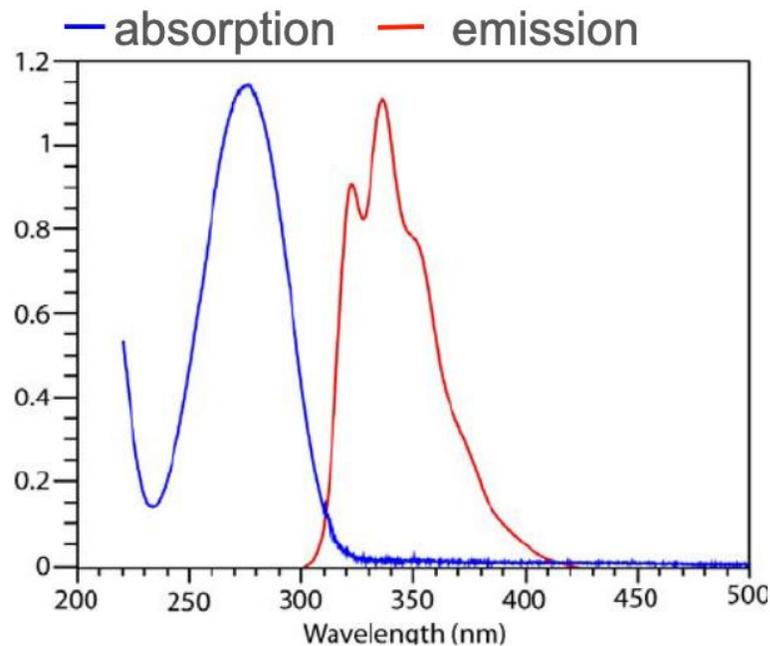
- Low weight (\leq half of SiO_2 -based substrate), but similar refractive index.
- Easy to manufacture, mechanically/cryogenically more reliable.
- More radio pure than typical glass substrate.
- Potentially easier to bond with the wavelength shifter.



Choice of the acrylic substrate

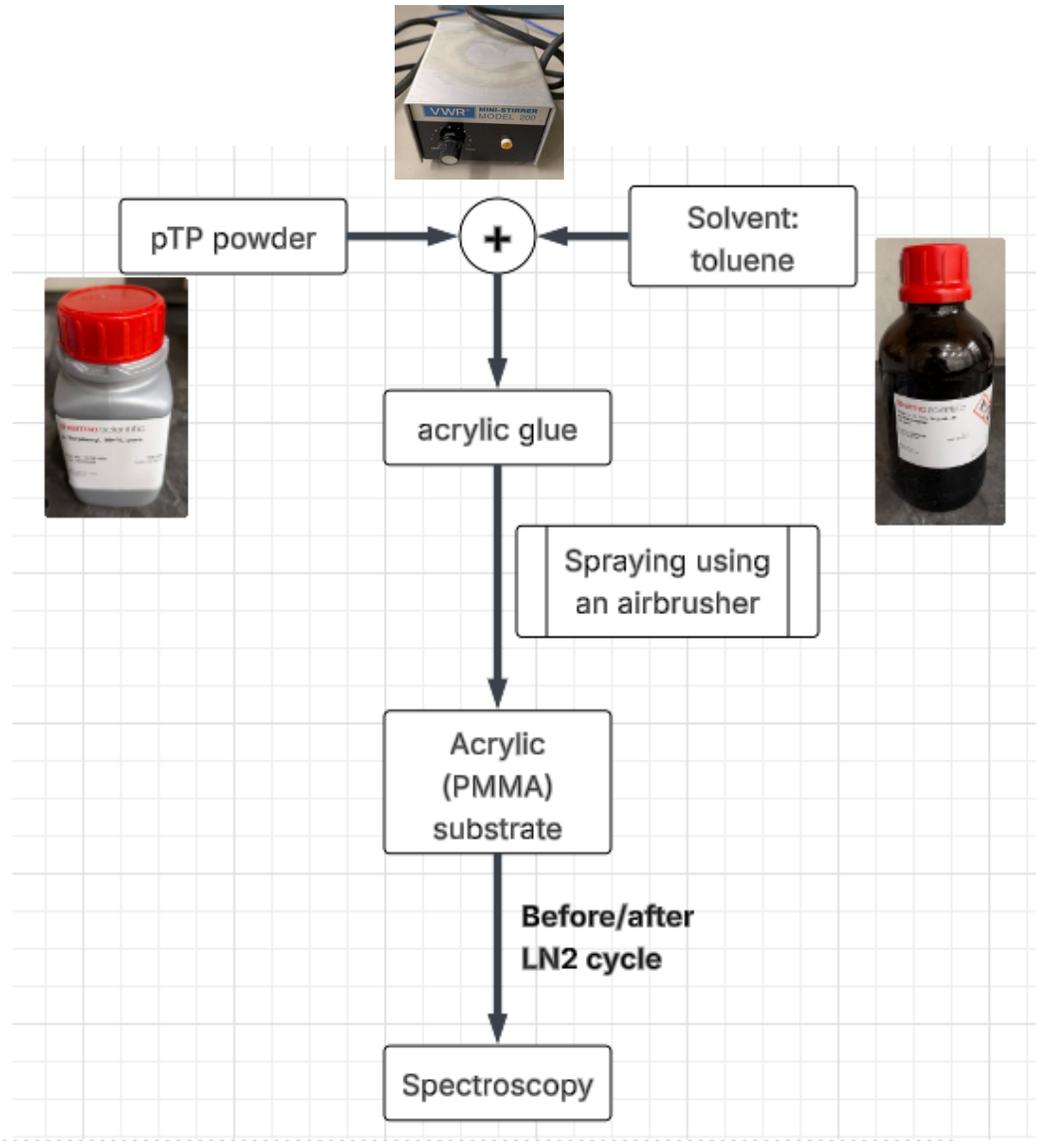
- p-terphenyl (pTP) emission light peaking at 350 nm
 - Needs a UV transparent acrylic: transmitting wavelengths > 300 nm
 - ⇒ Choice of a UVT acrylic with a cutoff at 260 nm

pTP spectrum



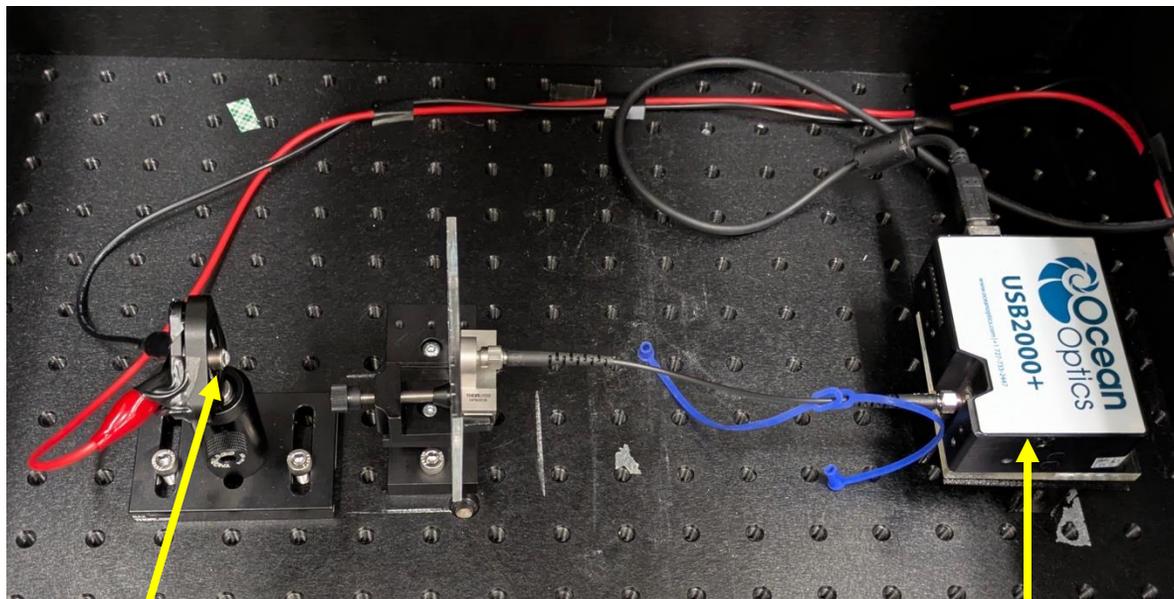
Coating method

- Acrylic glue:
 - binder of the pTP coating.
- PMMA substrate:
 - UV transparent acrylic with a cutoff at ~ 260 nm.
- Spectroscopy:
 - measurement of the pTP-shifted and transmitted light.



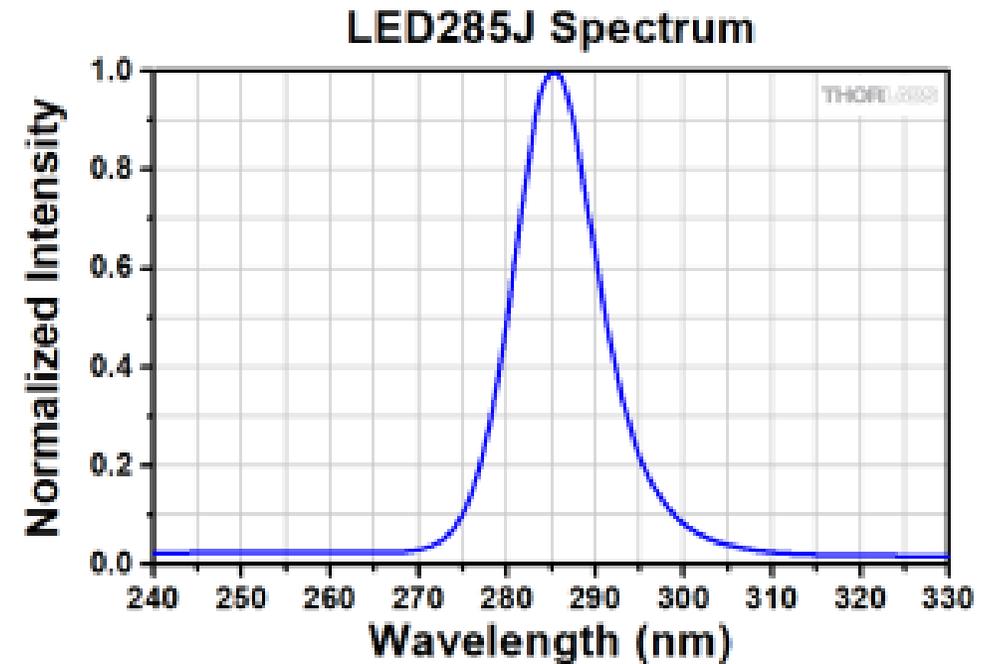
Setup of the spectroscopy

- Distance between the source, sample and the fiber optics connected to the spectrometer: fixed on the optical table.
- Measurements done in an optical black box.
- Spectrometer: OceanOptics USB2000+ with range of wavelengths 200 nm to 1000 nm.



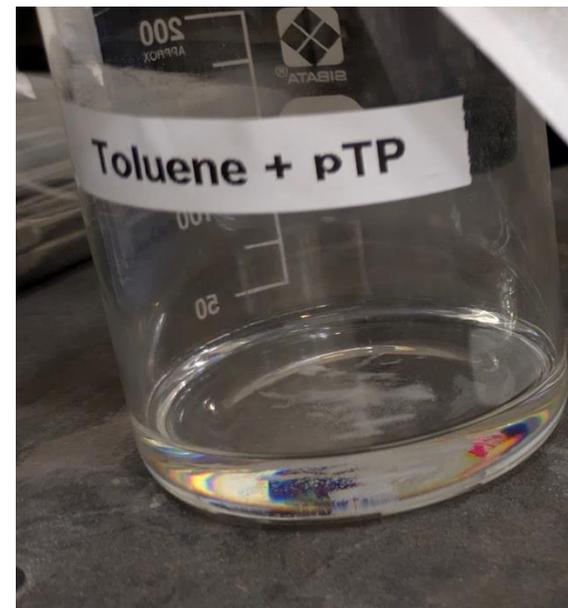
UV source

Spectrometer



Test of solvents for the WLS

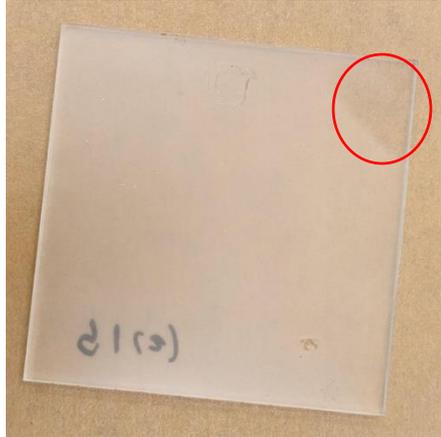
- Toluene : 9 mL of toluene can dissolve ~54mg of pTP.
- Acetone: 21 mL of acetone can dissolve ~54mg of pTP.
- THF : 9 mL of THF can dissolve ~86.4 mg of pTP
- Dichloromethane : doesn't dissolve the pTP -> The powder floats in the solution.





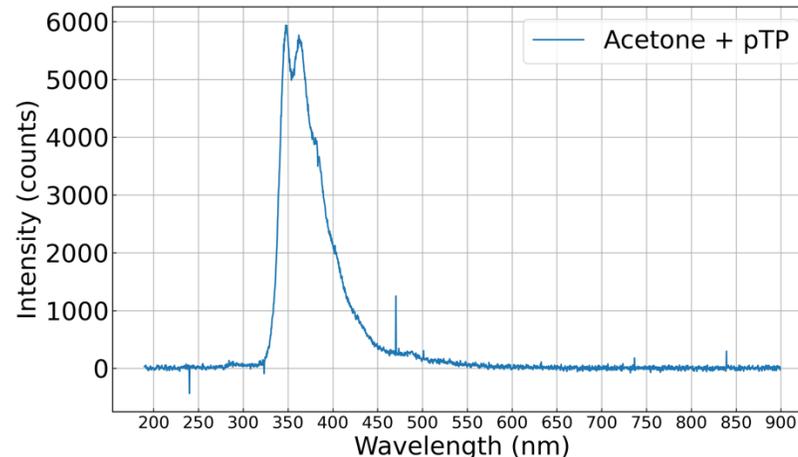
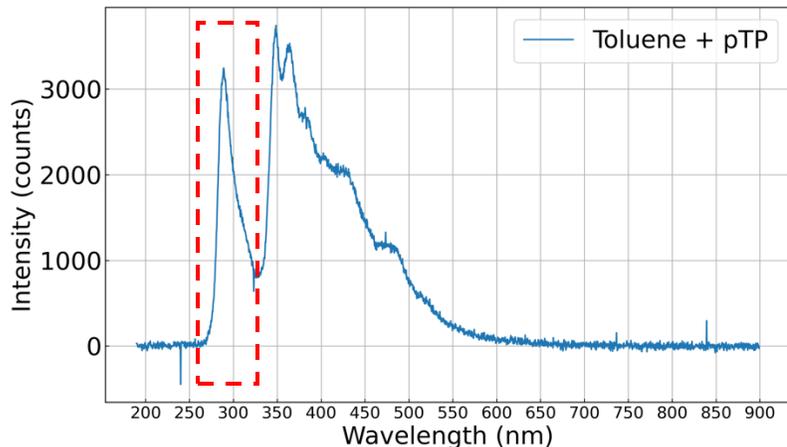
Sample prepared with toluene + pTP, and with acetone + pTP

UVT acrylic sprayed with toluene + pTP



Coating is fragile without any binding material

UVT acrylic sprayed with acetone + pTP

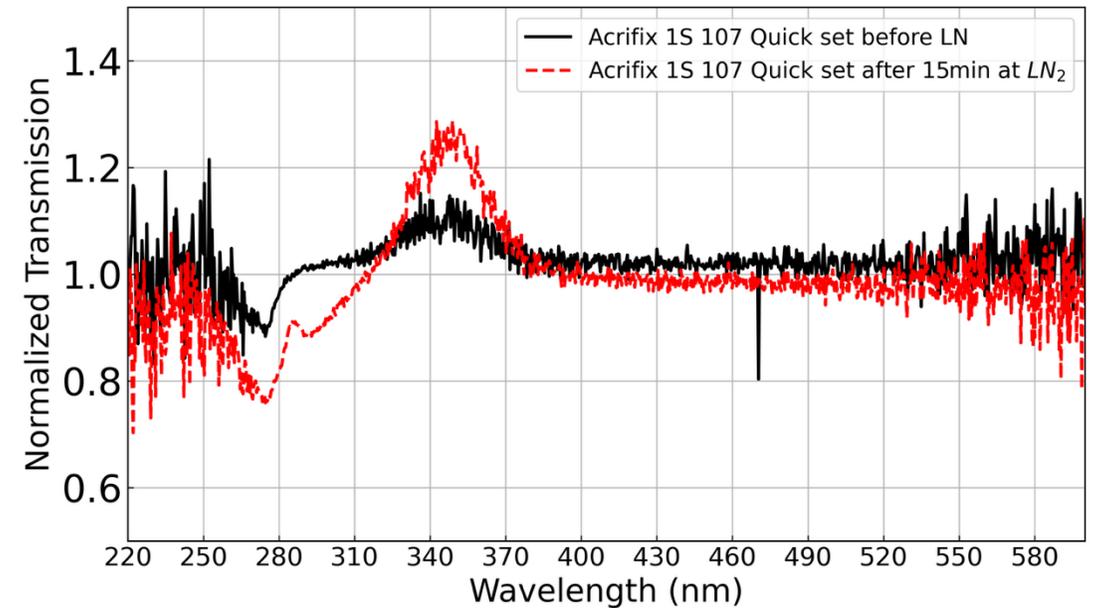
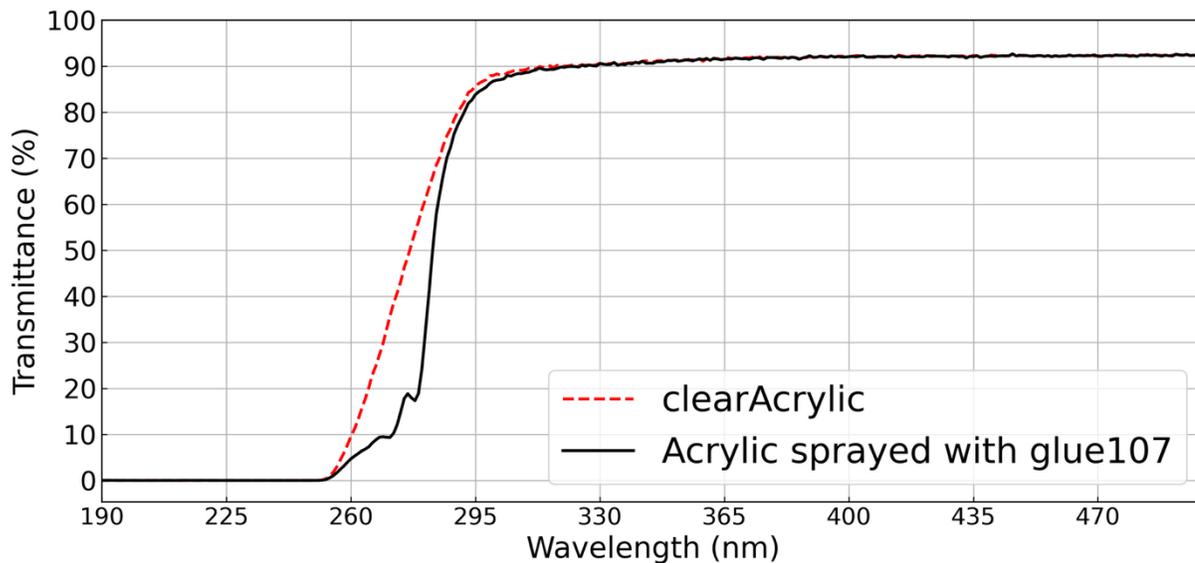


- pTP target densities of both samples : 1mg/cm²
- The source peaking at 285 nm is successfully shifted by the sample to ~350 nm.
- The two peaks of the spectrum is under investigation.
- Sample with toluene + pTP: part of the source is transmitted.
- The coatings are fragile.



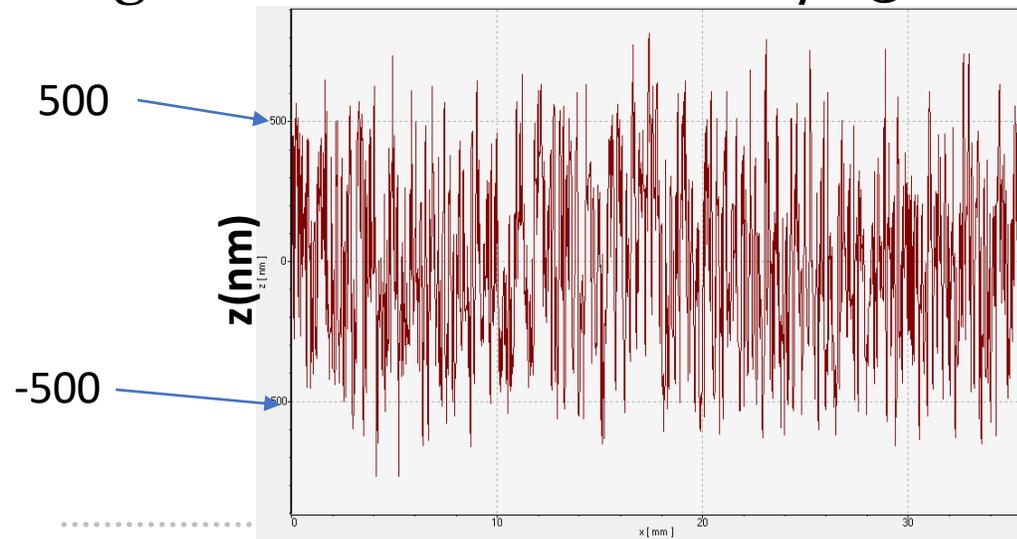
Test of acrylic glue as binder

- The acrylic blocks light $< \sim 260$ nm, and with the glue it blocks some fraction between ~ 260 nm and ~ 280 nm.
- $Normalized\ transmission = \frac{Transmission\ of\ the\ sample}{Transmission\ of\ the\ substrate\ only}$
- The acrylic glue (Acrifix 1S 107 Quick Set) blocks light around 280 nm and emits at ~ 350 nm.



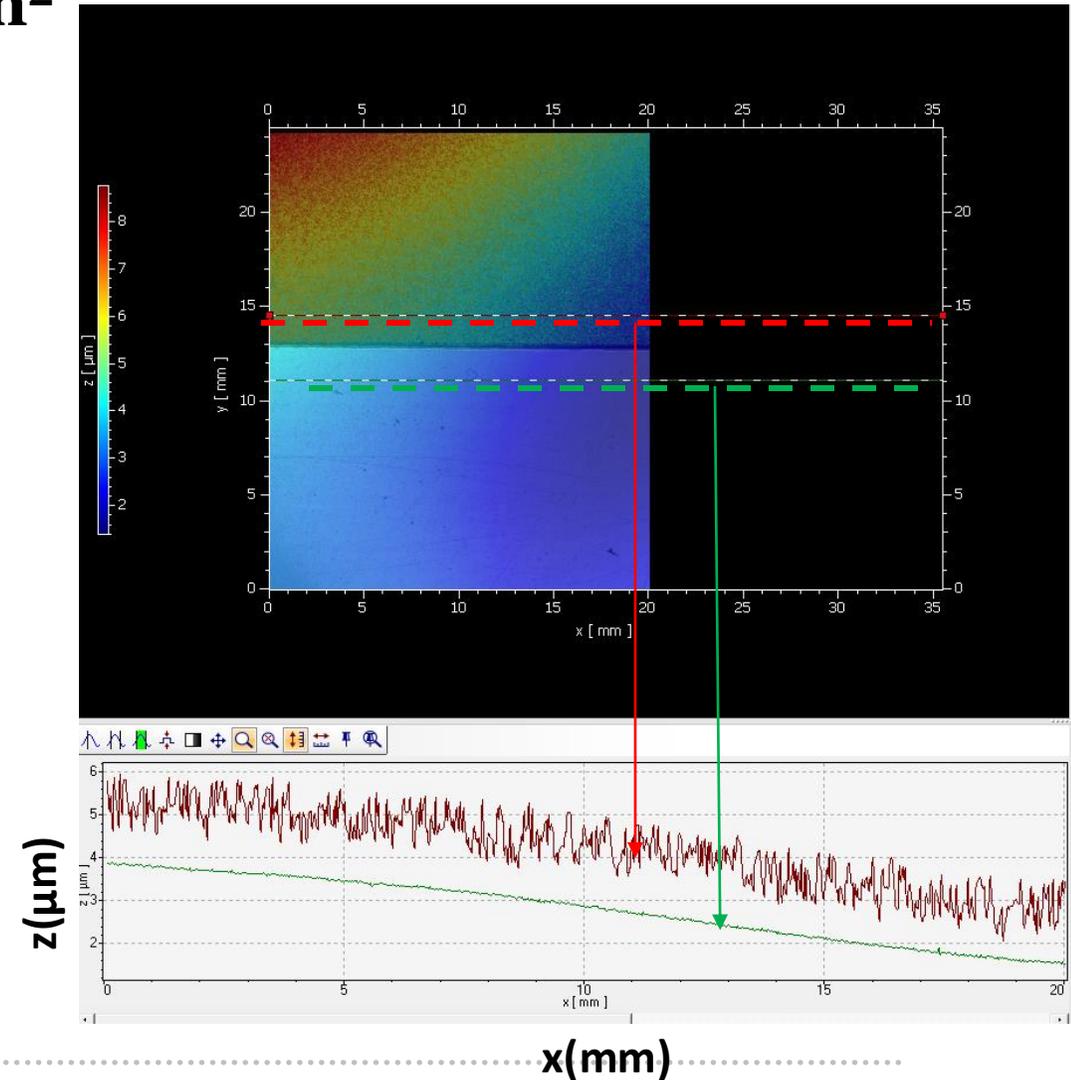
Thickness and roughness of the coated surface

- Target density of the pTP deposited: $1\text{mg}/\text{cm}^2$
- $1\mu\text{m} < \text{Thickness of the pTP layer} < 2\mu\text{m}$.
 - Expected thickness: $8\mu\text{m}$.
- Loss of pTP: $\sim 80\%$
- A glove box is prepared for the coating to reduce this loss.
- Roughness of the surface : $\pm 500\text{nm}$



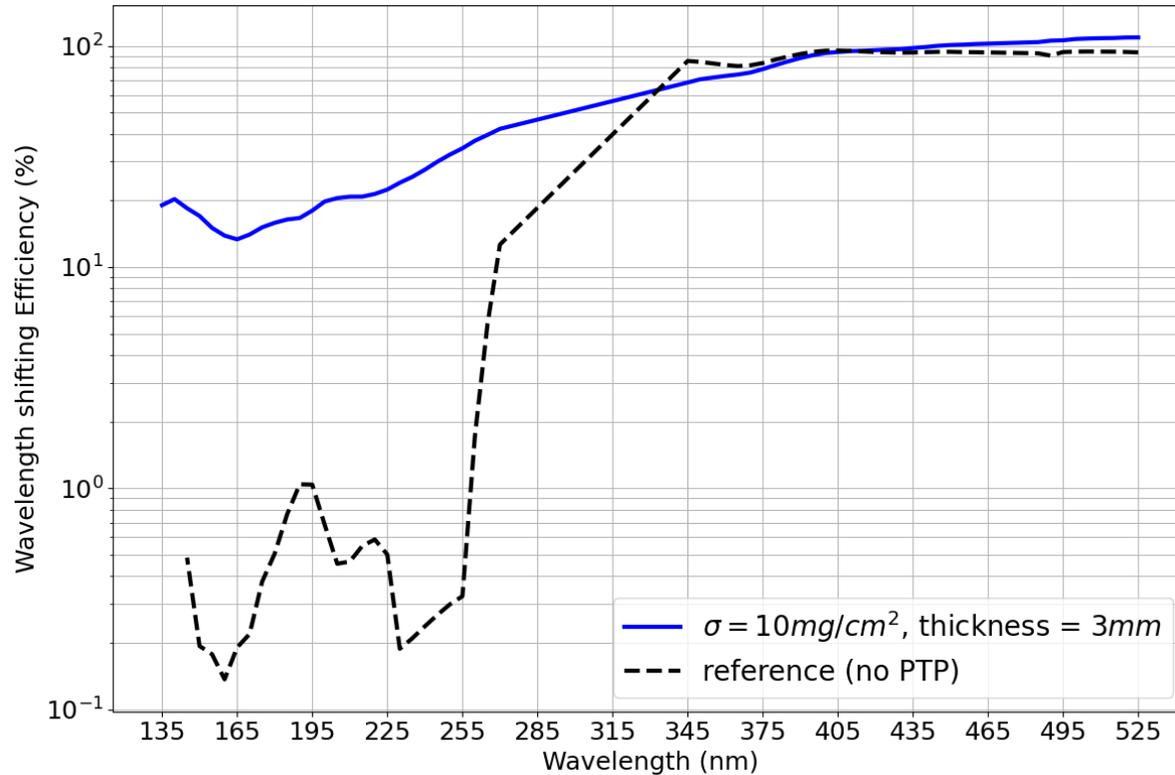
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$x(\text{mm})$





Wavelength shifting efficiency measurement

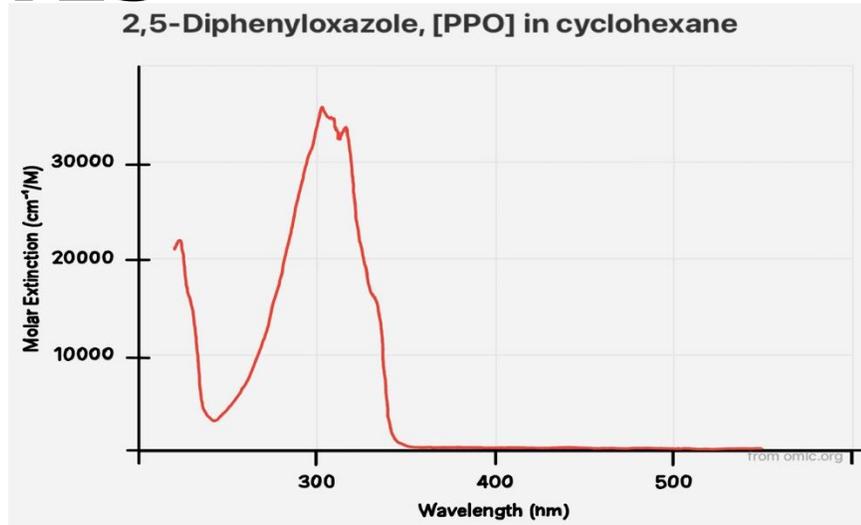


Alex Kish, Fermilab

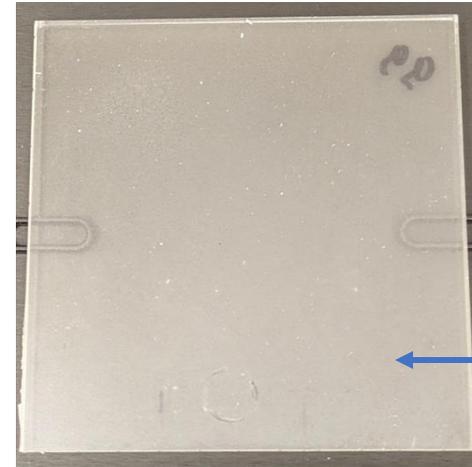
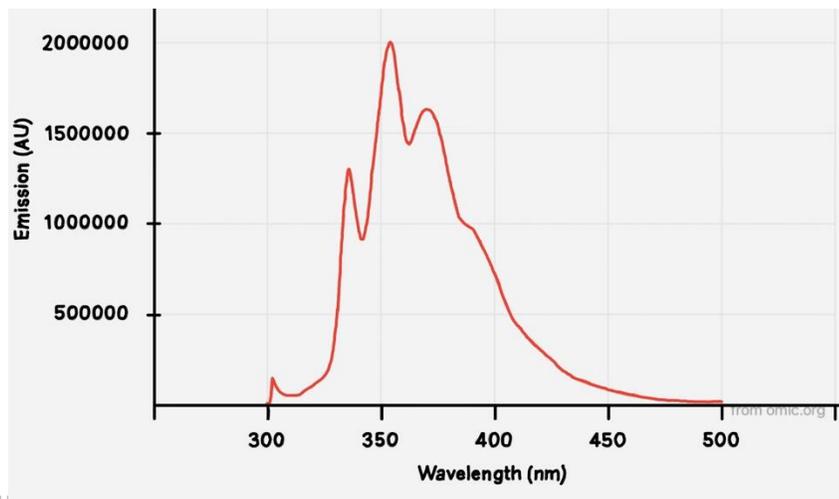
- Measurement done at the Noble Liquid Test Facility (NLTF) at Fermilab.
 - Using a monochromator : 135nm to 530nm
 - Measurement: light transmitted by the sample and collected at the back.
 - At wavelength < 260nm, only the pTP-shifted light is collected
- Black dashed line: clear UVT acrylic
 - The cutoff at ~260nm is observed
- Wavelength shifting efficiency at 135nm: ~20%

Trying the 2,5-Diphenyloxazole (known as PPO) as a WLS

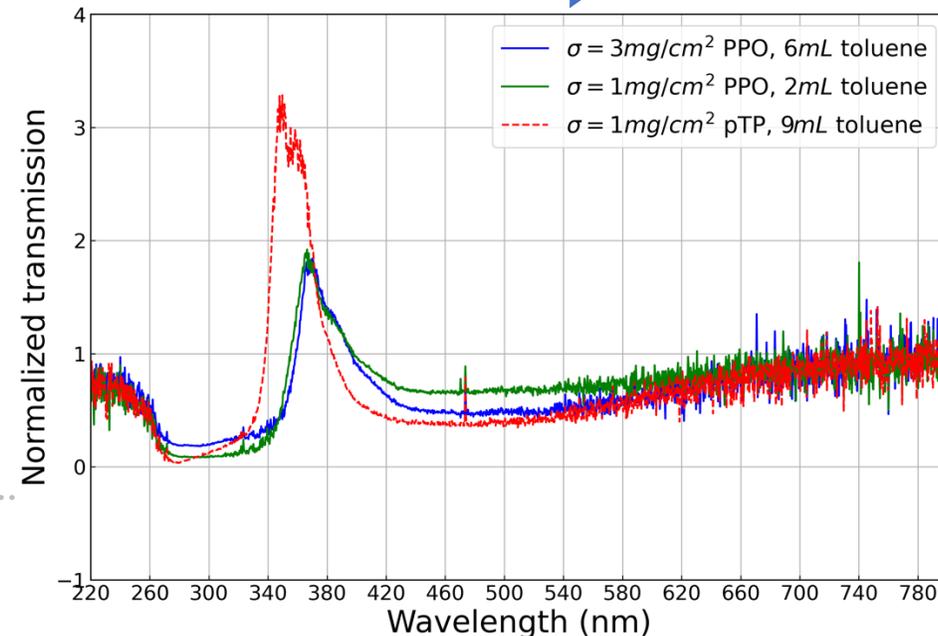
Absorption



Emission



- The emission spectrum of PPO peaks at ~ 370 nm.
- Toluene is an excellent solvent for PPO.
- The spray coating can also be used to deposit the PPO on the substrate.



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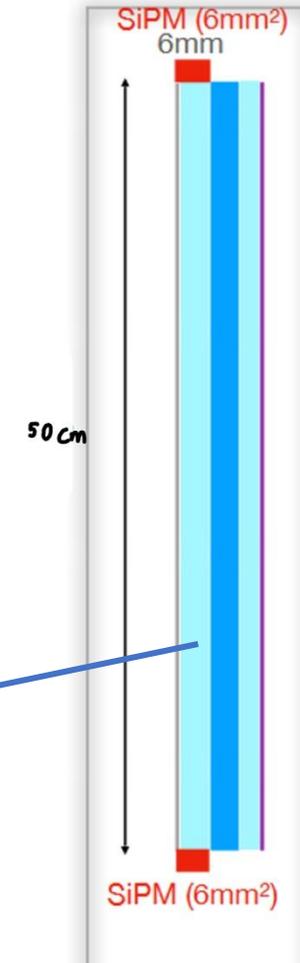
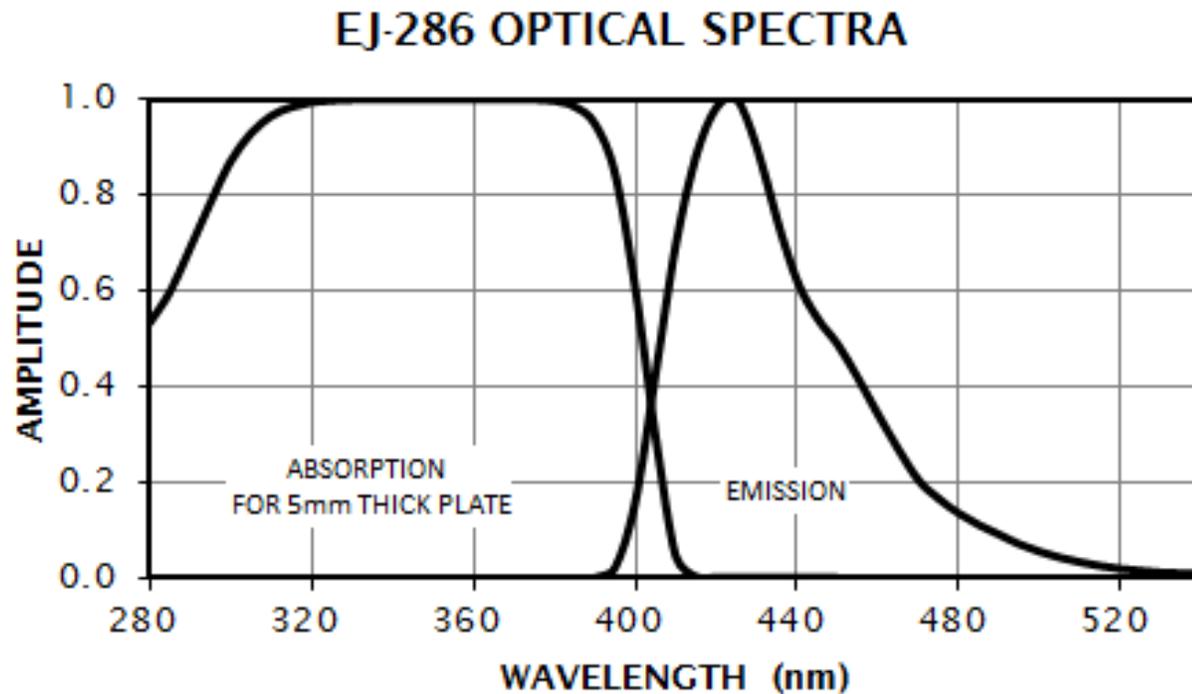
Source of PPO spectra:

<https://omlc.org/spectra/PhotochemCAD/html/020.html>

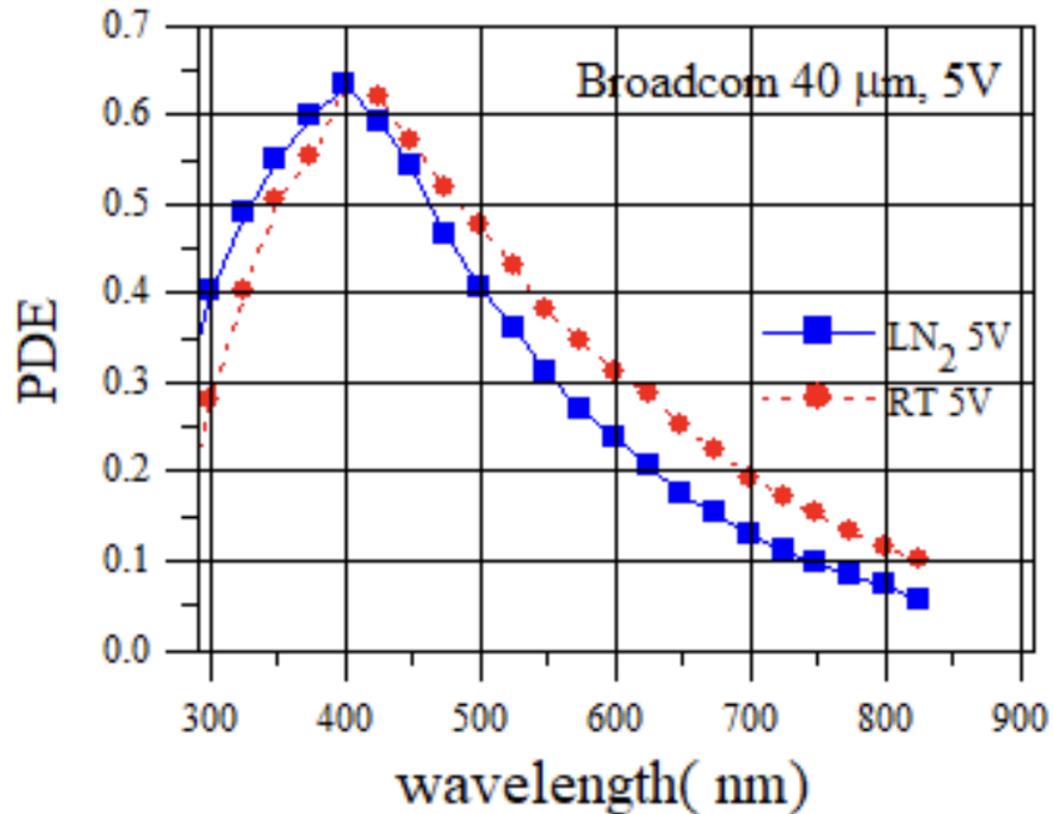
Absorption and emission spectra of ELJEN EJ286

- EJ286: second layer of the light trap
- Shift the ~ 350 nm emitted by the first wavelength shifter to ~ 430 nm.

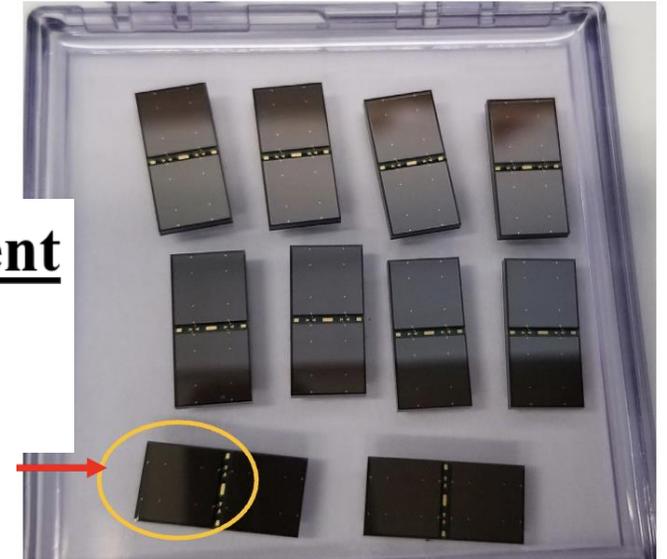
[Reflector - WLS2 - LAr - PMMA - WLS1]
VIKUITI foil - PMMA (doped) - LAr - PMMA - pTP film



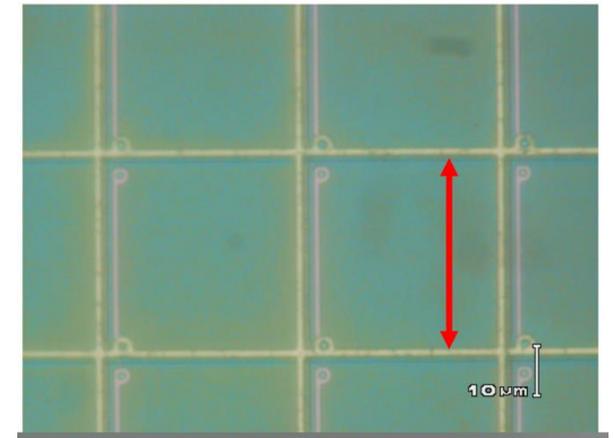
SiPM candidate for the light detection



one single element
6x6 mm²/each
Total: 0.36 cm²



Pixel size : 40 μm



The Broadcom SiPMs are being favored due to their high absolute PDE.



Summary

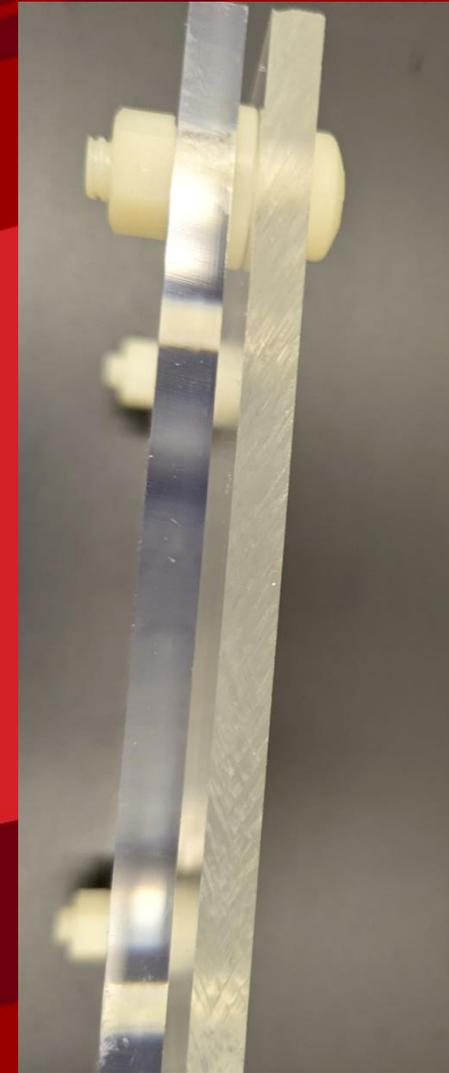
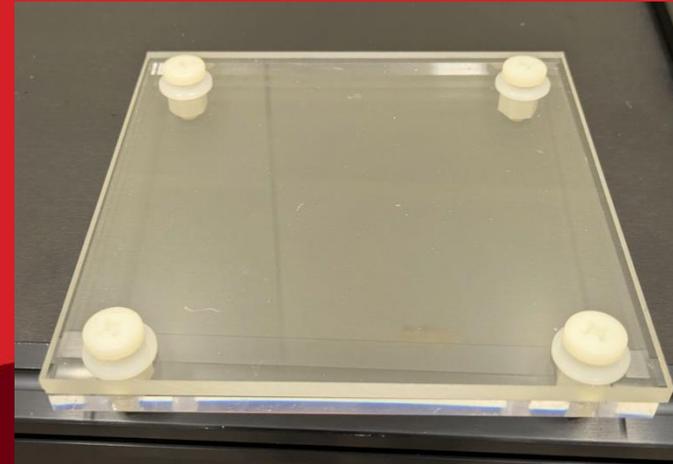
- The spray coating of wavelength shifting materials on an acrylic substrate is under development.
- UV transparent acrylics, good at cryogenic temperature, have been identified.
- The incident light of ~ 285 nm has been successfully shifted by WLS-coated sample.
- A wavelength shifting efficiency of $\sim 20\%$ is achieved at ~ 135 nm for the samples coated with pTP and acrylic glue.
- The samples coated with PPO are under investigation.



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Mechanical coupling of the two layers of the prototype



BACKUP

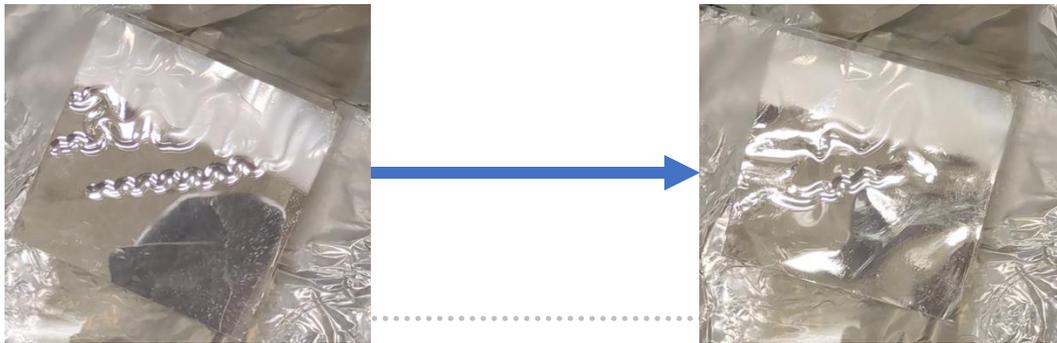
Backplane foil

2 parts epoxy: good at cryogenic temperature

- Tried degassing using a desiccator but not very effective



UV cured resin : cracks at cryogenic temperature



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Acrylic glue: The 3M foil peeled off in liquid nitrogen.

