Temperature-Dependent Photoluminescence of PEDOT:PSS for use as Transparent Electrodes in Time Projection Chambers

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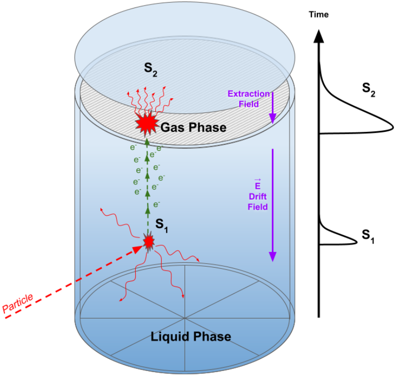
Dual Phase Detectors

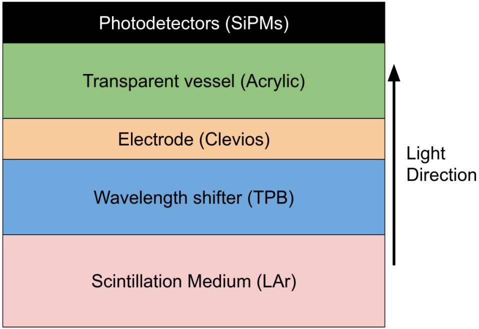
- Two-phase noble liquid detectors produce two signals per event [4]:
  1. **S1:** Initial particle interaction with liquid producing scintillation light.
  2. **S2:** Signal produced by drift electrons created by the initial interaction and accelerated by an electric field.
- Electrodes need to be transparent so that scintillation light can be detected.



TPC schematic diagram

Clevios

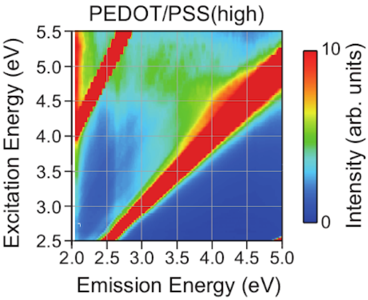
- Clevios is a conductive polymer that is optically transparent in thin films.
- Will be used to for the electrodes in DarkSide-20k.
- Testing the fluorescent properties of Clevios in our optical cryostat.



Order of coatings on the acrylic vessel for DarkSide-20k. Layers not to scale.

Experimental motivation

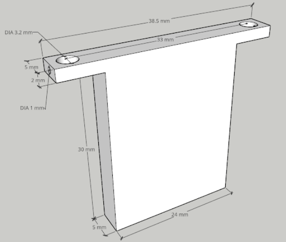
- Fluorescent properties of acrylic (PMMA) and 1,1,4,4-tetraphenyl-1,3-butadiene (TPB) have been studied in our lab [2, 3].
- Previous studies have indicated that Clevios may fluoresce, with maximum fluorescence occuring under UV excitations [5].

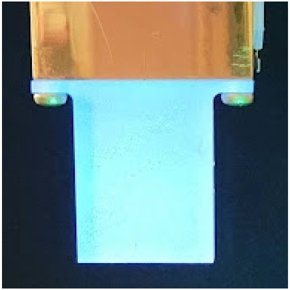


Fluorescent emission of Clevios under different excitation energies. Figure from Koyama et al [5].

Samples – Acrylic

- Acrylic samples are used to mimic the conditions within the detector.
- Samples are cut into shapes that will fit into our optical cryostat.
- Four samples are created:
  - Blank acrylic
  - 3 μm TPB
  - Thin Clevios ($\sim$ 40 nm)
  - Thick Clevios ($\sim$ 175 nm)

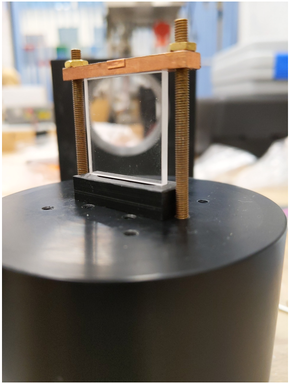




Top: Schematic of acrylic substrate. **Bot:** TPB coated acrylic sample fluorescing under UV excitation.

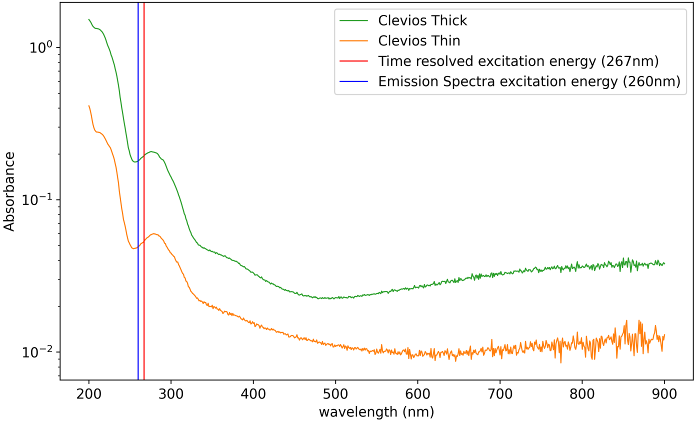
Samples – Fused Silica

- Fused silica samples are used to study the spectral properties of Clevios independent of acrylic.
- three samples are created:
  - Blank fused silica
  - Thin Clevios ($\sim$ 50 nm)
  - Thick Clevios ($\sim$ 185 nm)



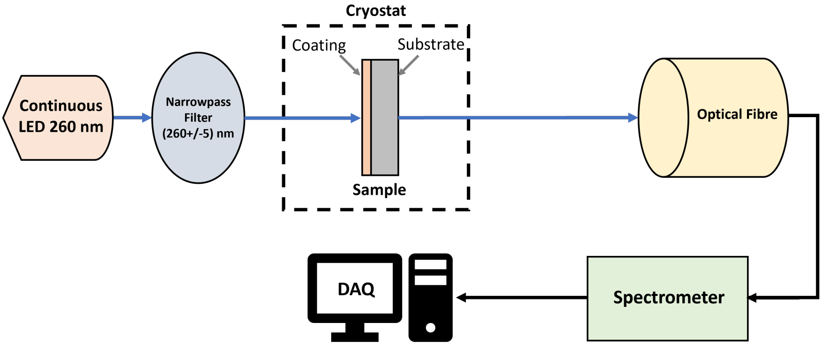
Uncoated fused silica sample.

Absorbance Spectra



Absorbance spectra of Clevios coated Fused silica samples. Vertical lines are the excitation energy used for time resolved (267nm) and emission spectra (260nm)

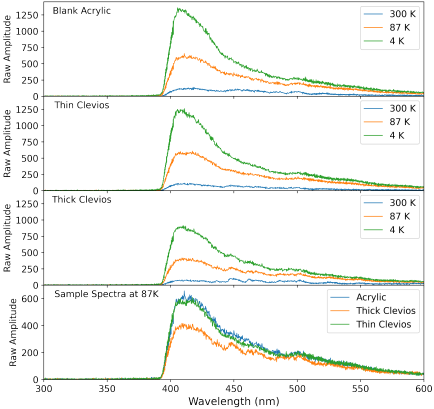
Emission Spectra Apparatus – Cryostat



Schematic diagram of the apparatus used for emission spectra.

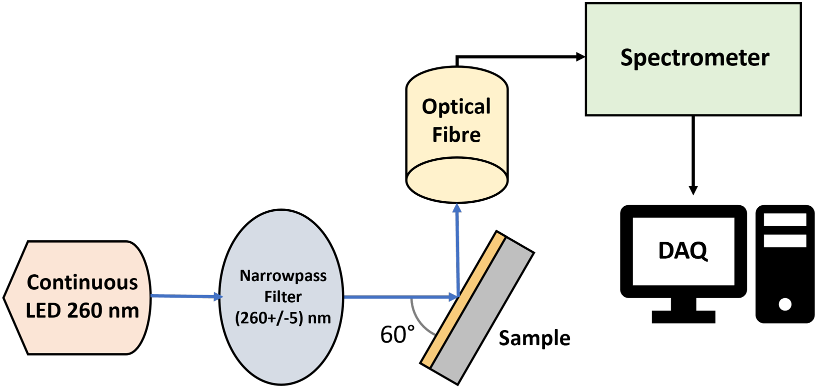
Emission Spectra Results – Cryostat

- All samples taken with the same excitation.
- No distinguishable peaks from Clevios.
- Temperature dependence follows trend seen previously in acrylic.



Emission spectra for blank acrylic, thick Clevios, and thin Clevios at 300K, 87K and 4K.

Emission Spectra Apparatus – Same Side



Schematic diagram of the apparatus used to take same side emission spectra.

Emission Spectra Results – Same Side

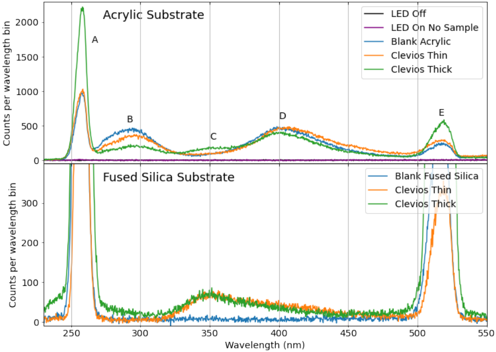
A: LED

B: Acrylic additive

C: Clevios Fluorescence

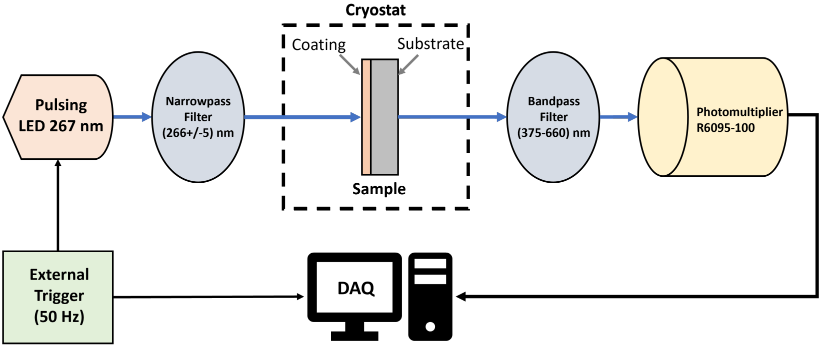
D: Acrylic fluorescence

E: LED harmonic



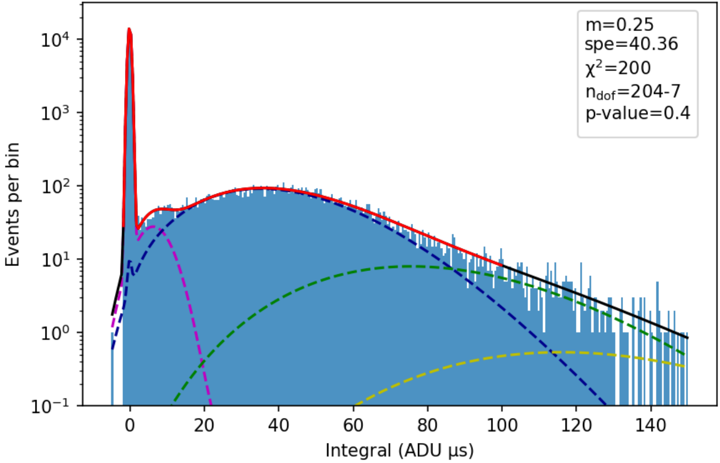
Emissions spectra for Clevios on acrylic substrates (top) and fused silica substrates (bottom)

Time-resolved – Apparatus



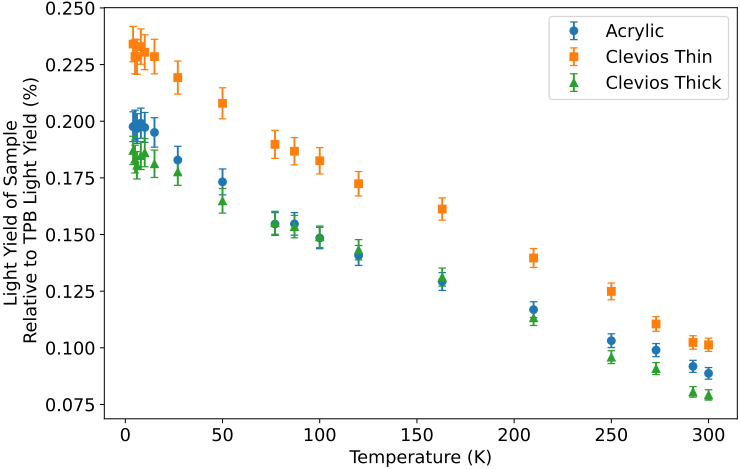
Schematic diagram of the apparatus used to take time-resolved measurements

Time-resolved – Analysis



Integral histogram from the thick Clevios sample. Fit has been done to determine the Single Photo Electron (SPE) value.

Time-resolved – Light Yield



Light yield of each sample's fluorescence relative to TPB as a function of temperature.

Conclusion

- Clevios fluoresces around 350 nm.
- Fluorescence from Clevios is small when compared to the acrylic substrate, which itself is very small compared to TPB.
- Further work is needed to fully characterize the fluorescence from the Clevios independent of the acrylic.
- Manuscript currently under internal review.

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References I

[1] C. E. Aalseth, F. Acerbi, P. Agnes, et al. "DarkSide-20k: A 20 tonne two-phase LAr TPC for direct dark matter detection at LNGS". In: *European Physical Journal Plus* 133.3, 131 (Mar. 2018), p. 131. DOI: 10.1140/epjp/i2018-11973-4. arXiv: 1707.08145 [physics.ins-det].

[2] J.M. Corning et al. "Temperature-dependent fluorescence emission spectra of acrylic (PMMA) and tetraphenyl butadiene (TPB) excited with UV light". In: *Journal of Instrumentation* 15.03 (Mar. 2020), p. C03046. DOI: 10.1088/1748-0221/15/03/C03046. URL: https://dx.doi.org/10.1088/1748-0221/15/03/C03046.

References II

[3] E. Ellingwood et al. "Ultraviolet-induced fluorescence of poly(methyl methacrylate) compared to 1,1,4,4-tetraphenyl-1,3-butadiene down to 4 K". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 1039 (Sept. 2022), p. 167119. ISSN: 0168-9002. DOI: 10.1016/j.nima.2022.167119. URL: https://www.sciencedirect.com/science/article/pii/S0168900222005113 (visited on 09/21/2023).

[4] H J Hilke. "Time projection chambers". In: *Reports on Progress in Physics* 73.11 (Oct. 2010), p. 116201. DOI: 10.1088/0034-4885/73/11/116201. URL: https://dx.doi.org/10.1088/0034-4885/73/11/116201.

References III

[5] Takeshi Koyama et al. "Photoluminescence of poly(3,4-ethylenedioxythiophene)/poly(styrenesulfonate) in the visible region". In: *J. Mater. Chem. C* 3 (32 2015), pp. 8307–8310. DOI: 10.1039/C5TC01531F. URL: http://dx.doi.org/10.1039/C5TC01531F.

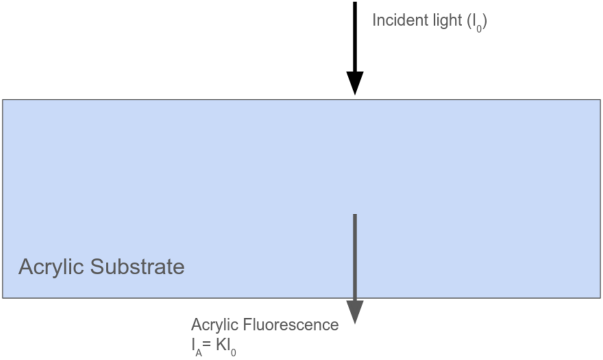
[6] S Tokar et al. "Single Photoelectron Spectra Analysis for the Metal Dynode Photomultiplier". In: (1999). URL: https://cds.cern.ch/record/683800.

Backup Slides

Clevios Extended anaylsis

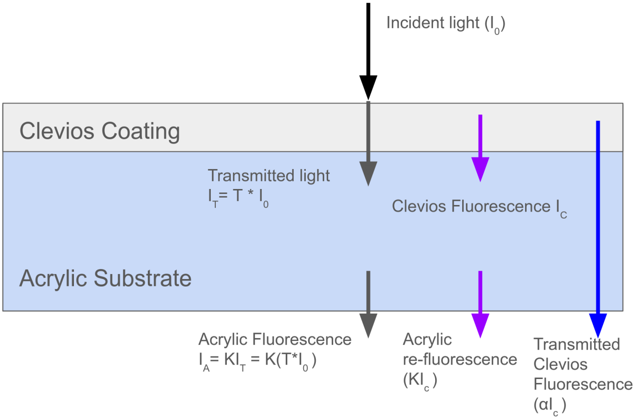
- Quantify the amount of fluorescence coming **only** from the Clevios.
  - Majority of fluorescence is coming from the acrylic.
  - Use optical properties of the Clevios to determine how much fluorescence there is from the acrylic.

Acrylic fluorescent model



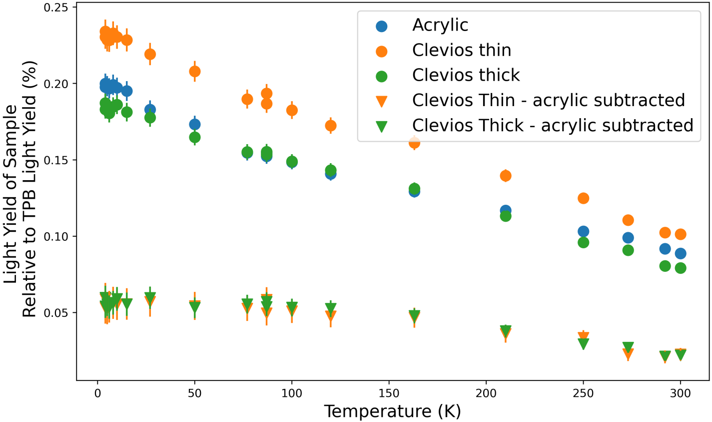
- Fluorescence quantified using intensity.
- Linear fluorescent model

Clevios Fluorescent model



- Each Clevios thickness has a quantified transmission.
- The blank acrylic sample can be used to model how much fluorescence comes from acrylic from a given excitation.

Light Yield Results – Acrylic Subtracted



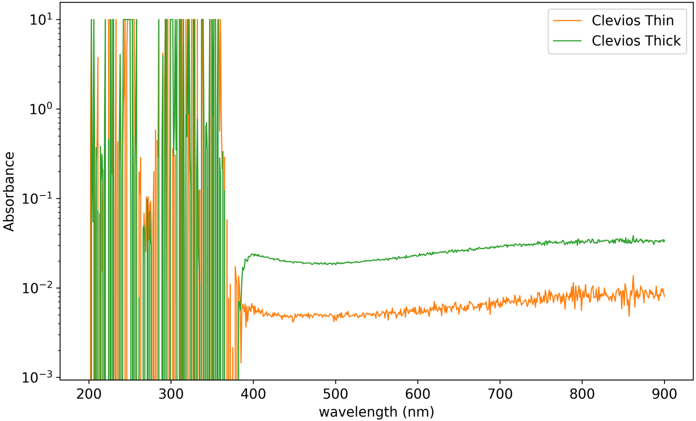
SPE Fitting Model

$$S_r(\varepsilon) = \sum_{n_1,n_2=0}^{\infty} \sum_{k_1=0}^{\infty} \frac{m^{n_1} e^{-m}}{n_1!} \frac{m_1^{n_2} e^{-m_1}}{n_2!} \frac{(n_1 * k)^{k_1} e^{(-n_1 * k)}}{k_1!}$$

$$* \frac{1}{\sqrt{2\pi(s_0^2 + (k_1 + n_2)s_1^2}} e^{-\frac{(\varepsilon - (x_0 + (k_1 + n_2)x_1))^2}{2(s_0^2 + (k_1 + n_2)s_1^2}}$$

- Model used to fit the SPE histogram [6].

Acrylic Absorbance



absorbance measurements from samples with acrylic substrates.