

# Optimization and Photostability Studies of Luminescent Organic Dyes for Solar Devices

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## Abstract

The overall efficiency of a solar cell is limited due to high energy photons within the UV region not being used efficiently. Luminescent Down-Shifting (LDS) layers are used to convert the high energy photons to a lower energy before it reaches the solar cell. The layers are placed on top of the cell and the resulting converted solar spectrum is more efficiently absorbed. In this study, the optimization of organic dyes for LDS thin films is discussed along with the results of photostability tests performed on the layers. The layers comprise combination of BASF Lumogen Yellow 083, Lumogen Orange 240, and Lumogen Violet 570 encapsulated in a polymethyl methacrylate (PMMA) polymer. It observed from the tests conducted over 3 months that the LDS thin-films experienced a degradation. A significant reduction in absorbance and emission spectra was observed. Reductions reached as high as 82% in the integrated spectra.

## Introduction

With a growing population, there is a large strain on traditional fuel sources. Therefore, the continued development of an energy source which is both sustainable and renewable is vital for the future. The shares of renewable energy have grown; in 1990, 1.8 % of Ireland's energy used was renewable; this has increased to 8.3% in 2015 [1]. Solar cells are photovoltaic (PV) devices which harness solar energy and convert it into electrical energy with the photovoltaic effect [2]. Technology in PV devices has been rapidly developed since the 1950s.

PV cells suffer from losses due to various factors. For instance, high energy photons are not efficiently absorbed by the PV cell in the conversion process [3], [4]. This paper focuses on this as it prevents maximum efficiency. Luminescent Down-Shifting (LDS) is a process proposed in the 1970s by Hovel et al., to increase the

number of photons being absorbed. High energy photons are converted to a lower energy using a luminescent planar sheet placed on top of the PV cell [5]–[7]. As LDS is fitted to pre-existing PV cells and it is an inexpensive process, it is a desirable method to enhance solar cell optical response [8]. The lower energy photons are absorbed in the PV cell and creates additional electron-hole pairs which increase the external quantum efficiency (EQE) [2].

## Method

A host material consisting of PMMA and toluene in a ratio of 7:3 was combined with 3 different Lumogen dye of varying concentrations. The 3 different samples contained Lumogen Yellow 083, Lumogen Orange 240, and Lumogen Violet 570. These dyes were chosen due to their high quantum yield of  $0.89 \pm 0.02$ ,  $0.98 \pm 0.02$  and  $0.84 \pm 0.02$  respectively [9] and varying stability from dye to dye [10]. Thin-films of 50  $\mu\text{m}$  thickness were fabricated on a glass substrate using a spin coating technique (Specialty Coating Systems – G3P-12). The thin-films of 50  $\mu\text{m}$  thickness were then annealed in a fume-cupboard over 24 hours. This allowed for easy removal from the substrate.

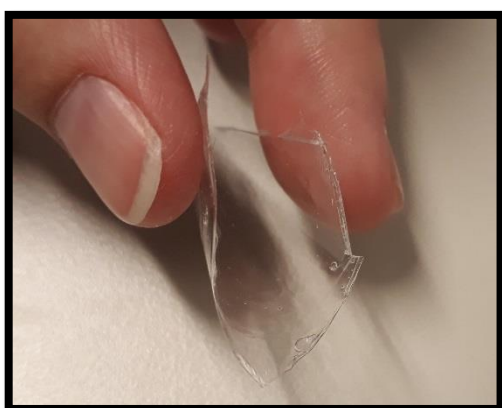
The absorbance measurements of the thin-films were taken using a StellarNet light source and spectrometer setup. The results are obtaining using the SpectraWiz software. The emission measurements were taken using a LabSphere Integrated Sphere and excitation light at 380 nm was used for Lumogen Violet, and 405 nm for Yellow and Orange samples. The total absorbance and emission was calculated by integrating their spectra, and subsequently compared. The samples concentration was varied and the optimum concentration was determined [11].

After the optimisation process, outdoor photostability tests were carried out. One of each sample at their optimised concentration was placed outdoors. Every two weeks the absorbance and emission

results were taken and their integral compared to see the degradation over time.

## Results

Uniform LDS layers were successfully fabricated with an average thickness of 50  $\mu\text{m}$ . The layers were easily removed after 24 hours from the substrate and were flexible, as shown in Fig. 1. Each dye was tested at a range of concentrations. The concentration of Yellow was varied between 0.10 wt% to 0.50 wt%, Orange was varied between 0.03 wt% to 0.30 wt%, and Violet was varied between 0.08 wt% to 0.25 wt%.



**Fig 1:** Showing the flexibility of a PMMA thin-film

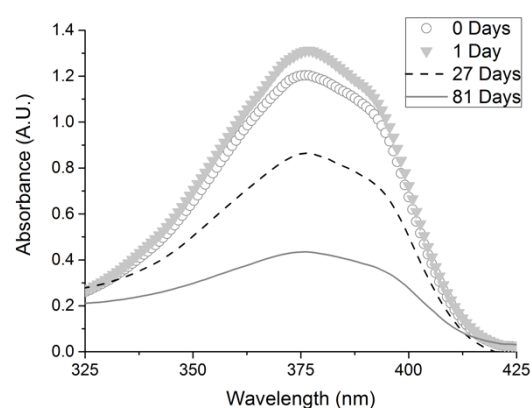
The integrated values of the absorbance and emission spectra are then compared for each sample. As the concentration is varied, a clear point at which the absorbance and emission is at a maximum is observed. At concentrations higher than this point, the integrated emission drops due to re-absorption. It was found that in 50  $\mu\text{m}$  thin-films, the optimum concentration for the Lumogen samples was 0.08 wt%, 0.44 wt%, and 0.18 wt% for Orange, Yellow, and Violet, respectively.



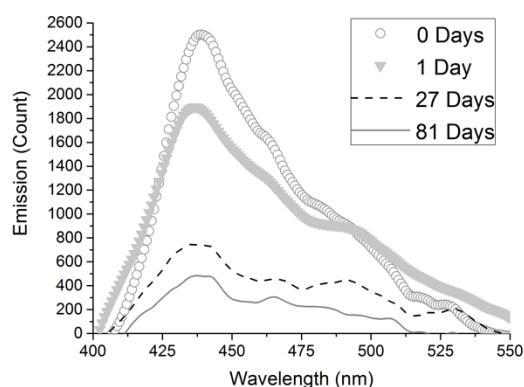
**Fig 2:** Samples placed outdoors in holder with window on top. L-R: PMMA, Yellow, Orange, and Violet

With each optimised dye layer, they were then placed outdoors for a duration of 81 days. These photostability tests carried out between 6<sup>th</sup> of December to the 12<sup>th</sup> of March. Hence, the hours of sunlight exposure were less compared to summer. The average irradiance in this time was 164  $\text{W}/\text{m}^2$  with maximums reaching 846  $\text{W}/\text{m}^2$ . Weather conditions varied from clear days to snow in the duration of these tests.

Violet experienced the largest reduction in absorbance and emission ranges with the peak absorbance reducing from 1.20 to 0.43 A.U. in 81 days, as seen in Fig.3. The integrated value for absorbance and emission for each dye before the test began (0 days) and at 81 days is shown below in table 1 calculated by percentage change.



**Fig 3:** Absorbance spectra of Lumogen Violet for outdoor tests



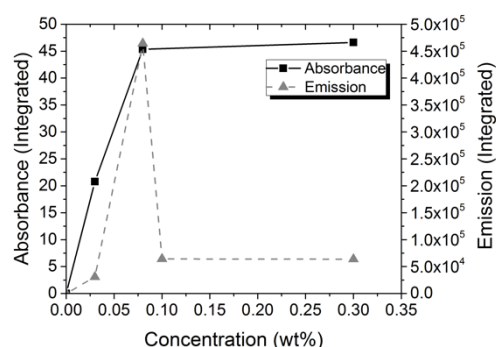
**Fig 4:** Emission spectra of Violet Lumogen in outdoor tests

Sample	Condition	% Change
Orange	Absorbance	- 0.2
	Emission	- 30.7
Yellow	Absorbance	- 74.7
	Emission	- 63.5
Violet	Absorbance	- 58.1
	Emission	- 82.1

**Table 1:** Reduction in absorbance and emission for optimised samples

## Discussion

When optimising the concentration of each Lumogen dye in a thin-film, the integrated values of the emission and absorbance allowed for the optimum concentration to be found. As the concentration is increased, at a certain point, the emission intensity begins to reduce, as shown in figure 5. The process occurs due to fluorescence quenching.



**Fig 5:** Integrated absorbance and emission of Lumogen Orange 240 at various concentrations

For Orange Lumogen, the optimum concentration was determined to be 0.08 wt%, for Yellow Lumogen, 0.44 wt% and for Violet Lumogen it was found to be 0.18 wt%.

The outdoor photostability tests were conducted with all samples under the same conditions. A clear photodegradation of the optimised samples was experienced over the time these tests were conducted, as shown in table 1. The greatest degradation of absorbance was observed in Yellow which decreased by 74.7 % within 81 days. As for emission, the largest reduction occurred in Violet with 82.1 %. This suggests the addition of UV blockers could be beneficial to elongating the lifetime at which these dyes could be used when placed on a solar panel.

## Conclusions

The optimum concentration for LDS thin-films of 50  $\mu\text{m}$  thickness was determined for organic Lumogen dyes. Orange 240 was optimised at a concentration of 0.08 wt%, Yellow 083 at a concentration of 0.44 wt%, and Violet 570 at 0.18 wt%. After long-term photostability tests of 81 days, all optimised thin-films experienced photodegradation. The highest absorbance reduction was in Yellow at 74.7 %, and emission reduction was highest in Violet at 82.1 %. Overall, all samples experienced degradation within 24 hours and could benefit from UV blockers to increase the lifetime when used on PV devices.

## Acknowledgements

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