

# EFFECTS OF MULTIPLE ORGANIC DYES FOR LUMINESCENT DOWN-SHIFTING LAYERS APPLICATION

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**ABSTRACT:** High energy photons in the UV region are not efficiently used in solar cells and limit the overall efficiency of the cell. Luminescent Down-Shifting (LDS) layers can be used to convert the high energy photons to a lower energy before it reaches the cell, which is more efficiently absorbed. In this study, an investigation of the optics of polymer thin-films LDS layer when comprising of mixed organic dyes, against single dye thin-films was investigated. The effect of creating a layer comprising of an equal ratio of BASF Lumogen Yellow 083, Lumogen Orange 240, and Lumogen Violet 570 in a polymethyl methacrylate (PMMA) polymer was investigated and compared to the experimental results from each single dye. This aided in determining whether using multiple organic dyes in a single film was beneficial for use as an LDS material. The interaction of the dyes with each other was investigated. It was determined that the combination of dyes created a larger absorbance range following the trend of each of the dyes it contained. The resulting emission of the mixed layer has an emission peak at the wavelength matching the longest emission peak wavelength of the comprising dyes. Further tests containing only two of the Lumogen dyes agreed with this finding.

Keywords: Luminescent Down-Shifting, Emission, Absorbance, Thickness, Organic Dyes, Lumogen

## 1. INTRODUCTION

With world population reaching 7 billion in 2011 and continuing to grow, there is a large strain on traditional fuel sources such as coal, oil and natural gas. These fuel sources also are placing the world's ecosystem in danger due to pollution. To combat this, the development of an energy source which is both sustainable and renewable is vital. Solar cells are photovoltaic (PV) devices which harness solar energy and convert it into electrical energy via the photovoltaic effect. The technology in PV devices has rapidly developed since the 1950s due to the strain a growing population has placed on the world. In Ireland in 1990, only 1.8% of the gross amount of energy used was renewable, which has increased to 8.3% in 2015 [1].

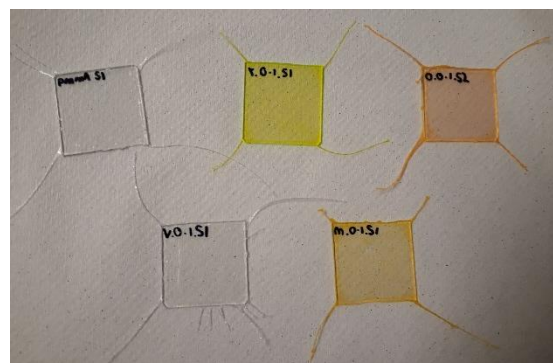
While PV cells are a renewable energy source, solar cells suffer large energy losses due to various factors. A portion of losses can be attributed to spectral losses in the conversion process, in which high energy photons are not efficiently absorbed by the solar cell [2,3]. This prevents the maximum efficiency from being reached. A process known as Luminescent-Down Shifting (LDS) is a method in which high energy photons are converted to a lower energy using a luminescent planar sheet on top of the existing solar cell [4,5]. It was first proposed in the 1970s by Hovel et al. as a method to increase the number of photons being absorbed. It is a desirable method as the planar sheets can be fitted to existing solar cells with ease and is an inexpensive process [6]. As the photons are shifted, they are absorbed in the photoconductive layer, creating more electron-hole pairs and increasing the external quantum efficiency. The incident photons, which have been converted, are more efficiently absorbed as they are at a lower energy, thus increasing the efficiency of the solar cell [7,8].

Different luminescent materials used have varying absorbance and emission peaks so they can be chosen more specifically depending on the material of the solar cell being used. For a LDS material to be beneficial or not the majority of photons down-shifted must not be reabsorbed by the LDS layer [9]. So far, the question of whether having multiple organic dyes in a single layer as a possible LDS material has not been fully addressed. This paper aimed to fill this gap in knowledge. In this paper, various organic dyes from Lumogen (BASF) will be used

to create thin-films both separately and combined to see what effect multiple dyes combined will have on each other.

## 2. METHOD

A host material consisting of PMMA and toluene in a ratio of 7:3 was magnetically stirred for 90 minutes at a low speed to prevent bubbles. This ratio was chosen as it would consistently produce thin-film layers of 50  $\mu\text{m}$  thickness on a substrate when fabricated using a spin coater (Specialty Coating Systems –G3P-12), as it has a thick viscosity without solidifying too quickly on contact with the air. The layers were coated at 1000 RPM for 240 seconds. Using the host material, 4 different solutions of 0.1 wt% concentration were mixed on the magnetic stirrer for 60 minutes. The 4 different sample solutions were Lumogen Yellow 083, Lumogen Orange 240, Lumogen Violet 570, and an equal amount of each dye in one solution, known as the mixed layer. Thin-films were then created using the four types solutions. The films were dried after spin coating, however were not yet easily removed from the substrate in a single film. To easily remove the thin-films, the samples were left in an oven at 40°C for 5 days, and in room temperature for a day further to allow for easy removal from the substrate. The resultant thin-films can be seen in figure 1 below.



**Figure 1:** Top (L to R): Host Material, Yellow, and Orange. Bottom (L to R): Violet and Mixed thin-films

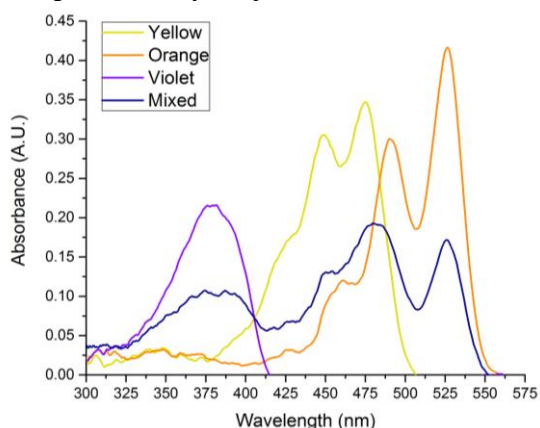
The absorbance and emission measurements of the thin-films were taken using a LabSphere Integrated Sphere

and the SpectraWiz software. For absorbance measurements, the setup consists of deuterium and halogen light sources to simulate the solar spectrum.

The emission measurements used the Follow Spot 1200 as a solar light source which was focused at different filters depending on the absorbance range of each Lumogen being tested. This was then collimated into an optic fibre which connected to an integrating sphere. Inside the integrating sphere is a holder which the thin-film is clamped to. The integrating sphere is then connected to a detector, and data accessed using SpectraWiz software. From these results, the absorbance and emission for each sample thin-film could be analysed.

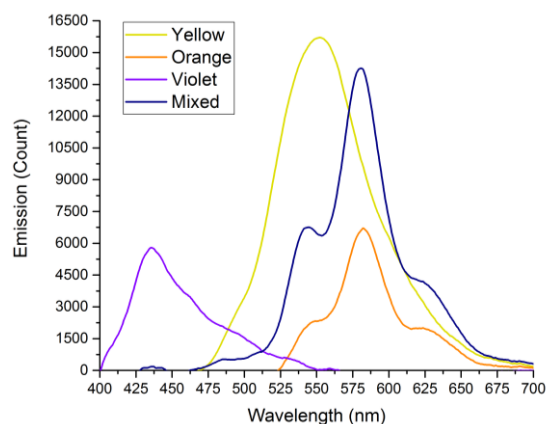
### 3. RESULTS

Uniform LDS layers were successfully fabricated at an average thickness of 50  $\mu\text{m}$ . The layers are flexible and easily removed from the substrate. As shown in figure 2 below, each Lumogen dye absorbs over a different region. As a result of mixing the dyes together in an equal ratio, the absorbance region of the mixed solution is over a much larger range. Yellow has a peak absorbance at 475 nm, Orange peaks at 526 nm, and Violet peaks at 381 nm, leaving the Mixed layer to peak at 480 nm.



**Figure 2:** Absorbance measurements of sample thin-films containing organic dyes

The emission measurements show the shift in peak wavelength, which can be seen in figure 3 below. Yellow emits at a peak of 552 nm (a shift of 77 nm), Orange emits at 582 nm (shift of 56 nm), Violet emits at 434 nm (shift of 54 nm), and finally Mixed emits at 581 nm (the largest shift of 101.5 nm).



**Figure 3:** Emission measurements of sample thin-films containing Lumogen Dyes

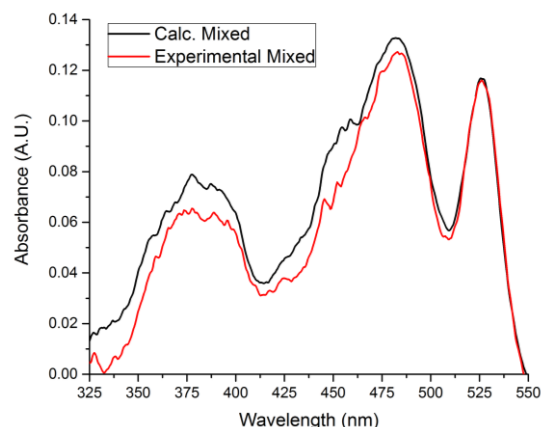
### 4. DISCUSSION

From the absorbance measurements of the samples, it is clear that the Mixed sample has a larger range, but as a consequence the height of the absorbance peaks are not as large as the organic dyes when not combined with each other.

**Table 1:** Table containing the absorbance and emission peak and range of wavelengths

	Absorbance		Emission	
	Peak (nm)	Range (nm)	Peak (nm)	Range (nm)
<b>Yellow</b>	475	300 - 506	552	470 - 700
<b>Orange</b>	526	400 - 560	582	525 - 700
<b>Violet</b>	378	315 - 416	434	400 - 600
<b>Mixed</b>	480	300 - 550	581	468 - 700

To determine if the absorbance curve attained for the Mixed layer is as expected, a curve was calculated using the results from the layers individually. To determine this curve, the absorbance results from each layer were added together and divided by 3 as they were combined in equal quantities. This produced the curve as shown below.



**Figure 4:** Mixed sample experimental results compared against calculated.

The emission peak of the Mixed layer is blue shifted 1 nm than the emission peak of Lumogen Orange. From this it can be gathered that when a sample consists of materials which have various emission peaks, the resultant peak will be formed at the wavelength which is longest. Further tests performed included fabricating thin-films consisting of only two dyes – a solution of Violet and Orange, and a solution of Violet and Yellow. When the characteristics were measured, they too had emission peaks matching the dye which has the longest wavelength.

#### 4. CONCLUSION

LDS polymer thin-films were fabricated with various organic Lumogen Dyes and investigated. The layers were uniform at a thickness of 50  $\mu\text{m}$  due to optimising the ratio of PMMA to toluene in the host material. This was further optimised by testing different recipes on the Spin Coater to consistently create this thickness. Through this investigation, it was determined that when different dyes, Lumogen Yellow 083, Lumogen Orange 240, and Lumogen Violet 570 in this case, with different absorbance and emission ranges or peaks are combined, the resulting emission of the layer will take on the peak of the dye which emits at the longest wavelength. The absorbance of the resulting thin-film is also over a much larger range, encompassing each of the dyes which are present in the thin-film.

#### 5. ACKNOWLEDGEMENTS

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#### 6. REFERENCES

- Holland, M., and Howley, M. (2016). Renewable Electricity in Ireland 2015. 32. Available at: [http://www.seai.ie/Publications/Statistics\\_Publications/Renewable\\_Energy\\_in\\_Ireland/Renewable-Electricity-in-Ireland-2015.pdf](http://www.seai.ie/Publications/Statistics_Publications/Renewable_Energy_in_Ireland/Renewable-Electricity-in-Ireland-2015.pdf).
- Klampaftis, E., Ross, D., McIntosh, K.R., and Richards, B.S. (2009). Enhancing the performance of solar cells via luminescent down-shifting of the incident spectrum: A review. *Sol. Energy Mater. Sol. Cells* 93, 1182–1194. Available at: <http://www.sciencedirect.com/science/article/pii/S0927024809000762>.
- Rothmund, R., Kreuzer, S., Umundum, T., Meinhardt, G., Fromherz, T., and Jantsch, W. (2011). External quantum efficiency analysis of Si solar cells with II-VI nanocrystal luminescent down-shifting layers. *Energy Procedia* 10, 83–87. Available at: <http://dx.doi.org/10.1016/j.egypro.2011.10.157>.
- Hovel, H.J., Hodgson, R.T., and Woodall, J.M. (1979). The effect of fluorescent wavelength shifting on solar cell spectral response. *Sol. Energy Mater.* 2, 19–29.
- Van Sark, W.G.J.H.M., Meijerink, a., Schropp, R.E.I., Van Roosmalen, J. a M., and Lysen, E.H. (2005). Enhancing solar cell efficiency by using spectral converters. *Sol. Energy Mater. Sol. Cells* 87, 395–409.
- Danos, L., Parel, T., Markvart, T., Barrioz, V., Brooks, W.S.M., and Irvine, S.J.C. (2012). Increased efficiencies on CdTe solar cells via luminescence down-shifting with excitation energy transfer between dyes. *Sol. Energy Mater. Sol. Cells* 98, 486–490. Available at: <http://dx.doi.org/10.1016/j.solmat.2011.11.009>.
- Ahmed, H., Sc, B., and Sc, M. (2014). Materials Characterization and Plasmonic Interaction in Enhanced Luminescent Down- Shifting Layers for Photovoltaic Devices.
- De JONG, M. (2015). Deposition of luminescent thin films for solar energy applications .
- Ross, D., Klampaftis, E., Fritsche, J., Bauer, M., and Richards, B.S. (2012). Increased short-circuit current density of production line CdTe mini-module through luminescent down-shifting. *Sol. Energy Mater. Sol. Cells* 103, 11–16. Available at: <http://dx.doi.org/10.1016/j.solmat.2012.04.009>.