

# Characterisation of Luminescent Downshifting Layer effects on Silicon Solar Cells

Cass, B. \*, Chandra, S., Sethi A., & McCormack, S. J.

Solar Energy Applications Group, Dept of Civil, Structural and Environmental Engineering, School of Engineering, Trinity College Dublin, College Green, Dublin 2, Ireland

Corresponding author: [mccorms1@tcd.ie](mailto:mccorms1@tcd.ie)

## 1. Abstract

This paper presents the effects of the characteristics of a polymer layer applied to a silicon based dual connection solar cell. The characteristics of the polymer solution of which is used as the base of a Luminescent Downshifting (LDS) layer before the addition of a dye. This layer aids in the shifting of the wavelength of light from a range that is not effectively used. The LDS has a large affect upon the solar cells improvement when applied correctly.

The characteristics of the LDS layer were tested in this investigation along with the affects of different dyes, the thickness of the layer that is applied to the cell and the consistent quality of the layer before, during and after application. . The ability to absorb light, fragility of the layer and the application of the layer are affected by these changes. From the implementation of the LDS layers, it can be shown that the variation in the characteristics can have an impact on the solar cell's performance.

## Keywords:

Photovoltaics, Luminescent Downshifting Layer, Polymer layer,

## 2. Introduction

While a base Si PV cell can be limited in its ability to absorb photons in the spectral wavelength region between 300 - 560nm[1][2][3]). The addition of a Luminescent Downshifting layer allows the higher energy photons found outside of the spectral range in which the Si PV not absorbs efficiently, to be converted to lower energy photons that can successfully interact with the cell underneath the LDS layer.

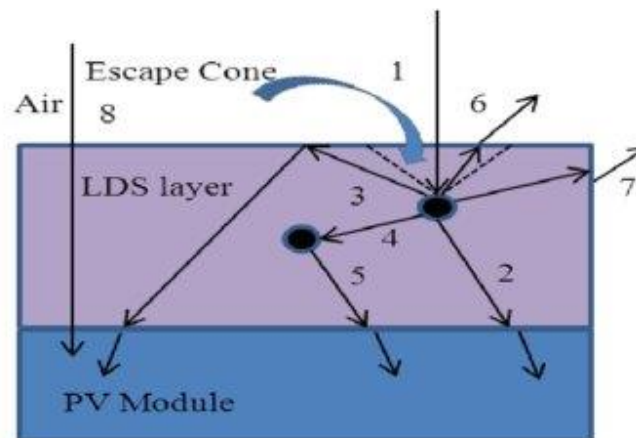


Fig.1 Diagram of PV modules with LDS layer on top [1]

The LDS is a thin polymer film doped with a luminescent dye that is applied to the pv cell. The film can increase the capacity for absorption of photons within certain wavelengths depending on the wavelength of the dye used. While an LDS film can affect the overall efficiency due to parasitic absorption from the host materials, emission at less than unity, additional interface will increase reflection losses. [4]The thickness of the film can be affected by many different attributes of the polymer solution making process and fabrication methodology. The areas that will be focused on are the dye used, the polymer solution preparation process, speed in which the polymer can mix, the ratio of solvent to polymer and volume of

polymer mixture used in the application. The dyes used were Lumogen F Violet570 (V570) produced by BSAF and Methyl Orange produced by Sigma Aldrich

### 3. Methodology

The LDS must be prepared using a base PMMA polymer stock solution, which is the solution used throughout the process to avoid any possible variation or undesired variable to occur, mixed with a polymer of choice, again with the same prefix. Chloroform was the solvent chosen to prepare PMMA stock solution to fabricate the LDS film, The solution was prepared by mixing, the Poly(methyl methacrylate) (PMMA) from Sigma Aldrich in the chloroform solvent. The ratio of the solution's concentration (PMMA: chloroform solution) mix is the first process to affect the thickness of the layer. A ratio of 3.83 g PMMA: 10ml of chloroform was first used. This was determined through smaller scale testing on 2 x 2 cm cells through spin coating. Batches of 11.49 g of PMMA and 30 ml of chloroform were made to allow multiple tests of the same polymer solution and produce a more consistent layer, if a single amount of polymer solution was made, the areas that affect the thickness are more exaggerated. These batches were mixed using a magnetic stirrer at 300 rpm for 45-60 mins. When the PMMA was fully dissolved, with no particles floating in solution, a clear and viscous fluid remained. The polymer solution was then mixed with a dye for downshifting depending on dye wavelength. For the dye to be added to the polymer mixture, it was made in a stock solution. This was comprised of chloroform of 15ml and 1 %wt of V570. 0.2 %wt of the dye was used in polymer mixture. The LDS layer with V570 dye is shown in Fig 2. below

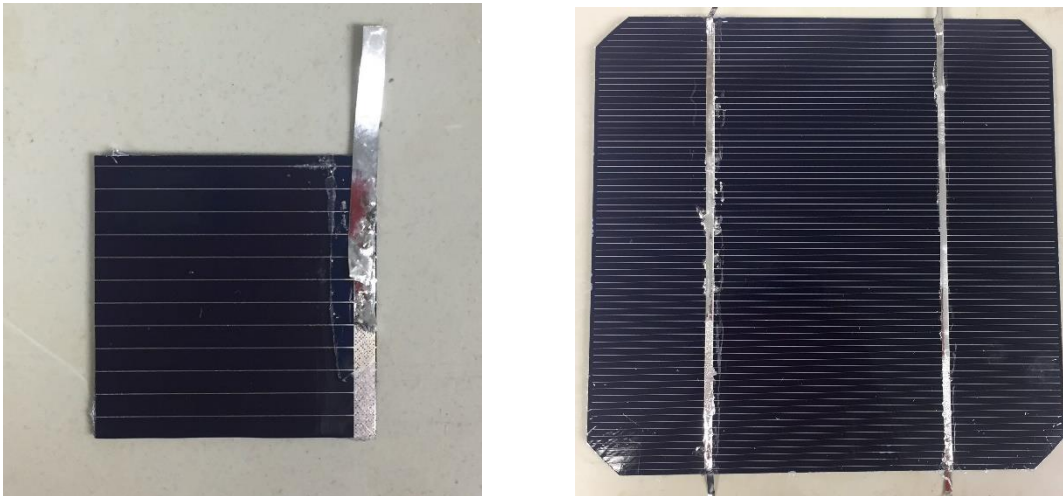


Fig.2 LDS layers with V570 dye

A syringe of 10 ml was used to apply the polymer solution to a 12x12 cm Si solar cell. A spin coater (G3P-12 Systems) technique was used to coat the polymer solution onto the cell at a max speed of 2000 rpm, a ramping time of 25.5 seconds and a dwell time of 180 seconds. The spin coater allows for a more reliable and repeatable results than drop-casting. The purpose of this process ensures that the polymer solution does not begin to polymerise before it can be applied for to the PV cell. The LDS layers produced as shown in Fig. 3 was 20  $\mu\text{m}$ . Fig. 4 below shows the resulting External Quantum Efficiency (EQE) of the cells with an LDS layer using V570 applied. It shows the concentration of 0.2 %wt was slightly more efficient compared to the other concentrations. Not all dyes were more effective than the bare cell however as shown below, due to the dye absorbing light and not allowing the higher energy photons to be

absorbed into the cell under the cell (in the case of 0.3 & 0.4%wt respectively) or not being able to aid in absorbing higher energies (as seen with 0.1%wt) causing more reflection to occur on the surface of the cell.

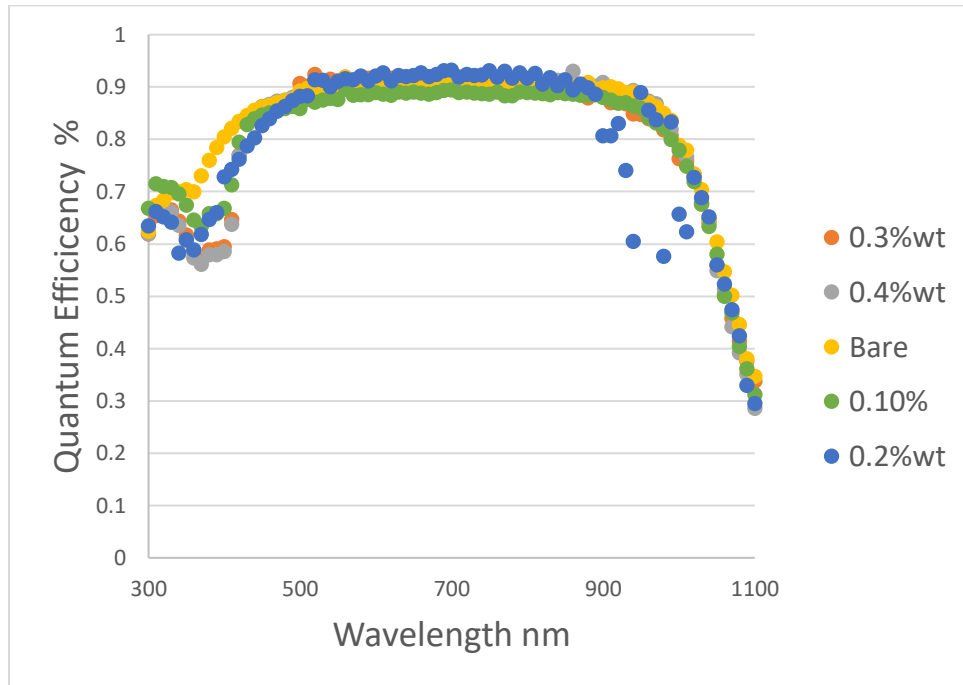


Fig.3 External Quantum Efficiency of V570 dye on solar cell

The speed in which the spin coater would operate had a varying effect on the LDS layer being coated. The final speed was 2000 rpm, if the polymer mixture is applied at a lower speed, the polymer solution would start to polymerise quickly. This led to the LDS not fully covering the cell underneath causing a decrease in efficiency. This was due to the layer being too thick (>20µm) on the section covered, not allowing light to reach the cell underneath, while the uncovered section would only operate as the 'bare' cell in Fig. 4. Once the layer has been made, it must be left to dry for 3-4 hours (more if possible) to make sure the layer has fully dried evenly across the PV cell.

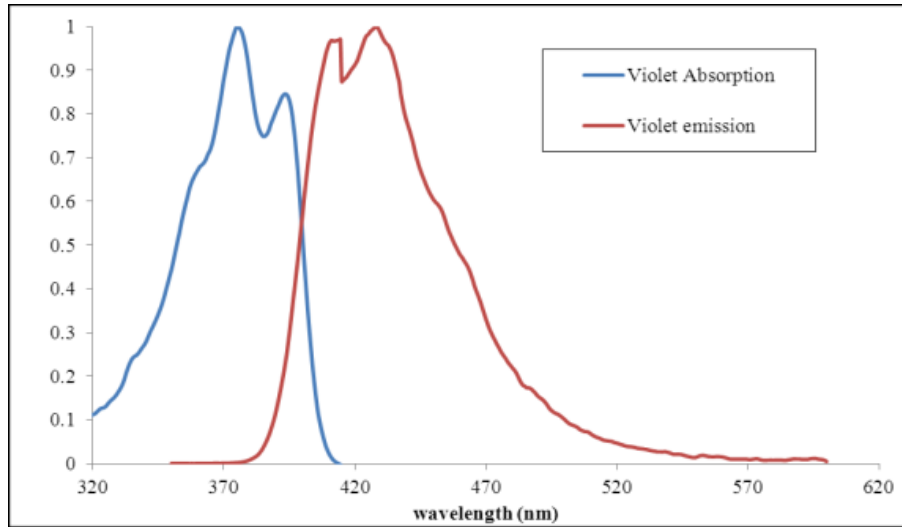


Fig.4 Absorption and Emission of V570 Lumogen dye

Using the same recipe as mentioned previously with the same dye concentration, speed used and volume of solution, a lower ratio of 2.3g of PMMA to 10ml of chloroform would reduce the layer to 5  $\mu\text{m}$ , a reduction of 75%. As mentioned before, a thinner layer would have no absorption benefit but cause extra reflection from the cell.

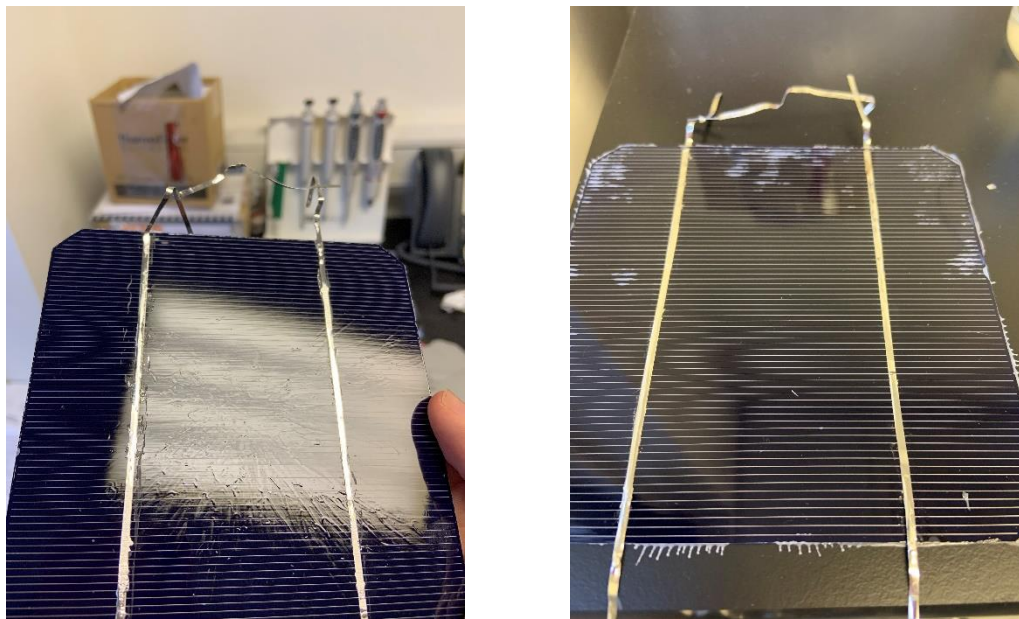


Fig. 5 Effect of volume difference of layer on solar cell

Fig. 6 above shows the effect of change in volume of polymer solution used. The left sample used 15ml of polymer solution while the right sample used 10 ml of solution.

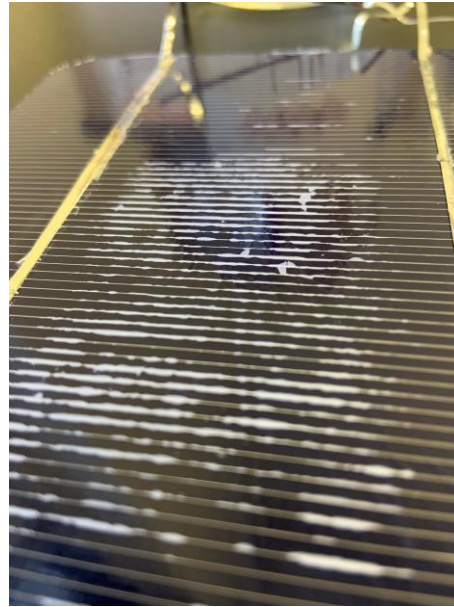


Fig.6 LDS Layer starting to degrade overtime, peeling from base cell

The application of the polymer solution from the syringe onto the cell before being spun. If the solution is not applied evenly and efficiently, as the layer begins to degrade overtime or due to adverse weather affects. The layer can begin to peel and lift from the centre of the cell. This affect can take a long time to present itself and can be missed when applying solution if enough care is not taken. As seen in Fig. 7 above.

#### 4. Conclusion

From repeated testing across different concentrations of dye, ratios of polymer to solution, process of mixing and application process, the characteristics that a LDS layer can demonstrate such as thickness and adhesion can have a varying effect on the efficiency of the base solar cell underneath the layer. During the testing of multiple layers a key component was be found in the repeatability of the PMMA stock solution. Any variation in recipe or methodology resulted in a layer with different properties, either in thickness, PV cell coverage or quality of the LDS layer. However, through those different variations a recipe that produced a consistent thickness, coverage and clean LDS layer was found. From the testing undertaken the areas in production that have a notable impact on the characteristics of the LDS layer have become more evident and allow for further testing with different luminescent dyes and an opportunity for a more optimised and streamlined process.

Add more to this section

#### 5. Acknowledgements

The authors would like to acknowledge the European Research Council grant PEDAL: (639760), H2020 IDEAS (815271) and support funding from Science Foundation Ireland (SFI) and insights from the PEARL PV COST Action Network.

#### References

1. Klampaftis, E., Ross, D., McIntosh, K. R. & Richards, B. S. 2009. Enhancing the performance of solar cells via luminescent down-shifting of the incident spectrum: A review. *Solar Energy Materials and Solar Cells* 93, 1182-1194.



2. Gilligan, S. (2019). *Material Characterization of Luminescent Down-Shifting Layers for Solar Cells Application*. (November).
3. Ahmed, Hind & McCormack, S.J. & Doran, John. (2016). External Quantum Efficiency Improvement with Luminescent Downshifting Layers: Experimental and Modelling. *International Journal of Spectroscopy*. 2016. 1-7.
4. Rahman, W. McCormack, S. (2016). *Modelling and characterization of metal nanoparticles for plasmonically enhanced luminescent devices for solar cells application*
5. Klampafitis, E., Ross, D., ... Richards, B.S., 2009. Enhancing the performance of solar cells via luminescent down-shifting of the incident spectrum: A review. *Solar Energy Materials and Solar Cells*.