Comparison of Fluorescent Down-Shifting Layers for Increasing the Efficiency of CdS/CdTe Solar Cells

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Abstract

The poor spectral response of some Cadmium Sulfide/Cadmium Telluride (CdTe/CdS) solar cells in the UV/blue part of the spectrum can be improved through down-shifting of light using fluorescent dyes [1]. A fluorescent down-shifting structure absorbs UV/blue light and emits it at a longer wavelength where the External Quantum Efficiency (EQE) of the solar cell is significantly higher. This study compares fluorescent structures with different dyes different concentrations, and some benefiting from resonance energy transfer [2]. The results indicate that the application of a down-shifting structure is effective in increasing the EQE of the solar cell in the UV/blue light region, and can also be used to concentrate light from a larger area onto the solar cell. A theoretical model is being developed and the first results have been compared with experimental spectroscopic results, with a satisfactory agreement.

1. Introduction

Increasing the efficiencies of thin film devices such as CdTe/CdS solar cells remains one of the urgent goals of photovoltaic technology. These thin film devices are seen to have poor spectral response to the blue part of the solar spectrum due to absorption of light by CdS [1]. Fluorescent structures placed on top of the solar cell have been proposed as a method to down-shift light from low quantum efficiency wavelength regions to wavelengths where the performance of the solar cell is better [1,2]. An important benefit of this method is that it avoids changes to solar cell processing as it can be applied as a layer on top of an existing cell.

This paper presents a comparison of fluorescent structures using different combinations of dyes in order to improve the efficiencies of CdTe/CdS thin film solar cells. The performance of fluorescent structures based on BASF's Violet 057, Yellow 083 and Orange 240 dyes are presented [3]. The first results of a theoretical model under development are also compared with experimental results.

2. Experimental

The fluorescent structures studied consist of thin lavers containing fluorescent dves dissolved in poly(methyl methacrylate) (PMMA). This was deposited on the surface of a 20x20 mm glass substrate by spin coating. The glass thickness is 1 mm. Thick fluorescent layers were required so as to maintain a high absorbance while minimising fluorescence quenching effects associated with high dye concentrations [4]. For this reason a relatively low spin coating speed of 500 rpm was selected. A solar simulator (T.S. Space Systems) with Xenon equipped а lamp approximating AM1.5 spectrum and a filter selection wheel (350-1100 nm, step 50 nm) was used to measure the current output of the CdS/CdTe solar cells with a down-shifting layer on top coupled with optical gel (ThorLabs). The CdTe solar cells were manufactured at CSER, Glyndŵr University [5] and have a surface area measuring 5x5 mm. A crystalline silicon solar cell with known EQE was used as the reference cell. The light source for the solar simulator testing consisted of a 300 W Xenon lamp calibrated to AM1.5. The absorbance of the fluorescent structures was measured using a Bentham spectrometer and an IL1 100 W Halogen light source while the fluorescence was detected using an Avantes spectrometer and an 89 North PhotoFluor II 200 W Metal Halide lamp.

3. Measurements with Solar Simulator

The EQE of the solar cell with and without fluorescent structures can be obtained experimentally with the use of the following equation:

$$QE_{cell} = \frac{QE_{ref}J_{cell}}{J_{ref}} \tag{1}$$

where QE_{cell} and QE_{ref} are the EQE at a particular wavelength of incident light of solar cell and reference the cell respectively, and J_{cell} and J_{ref} are the current outputs of the solar cell and reference cell per unit area of the solar cell surface respectively. The EQE for the CdTe/CdS solar cell with and without a fluorescent structure placed on top was compared. The EQE for a solar cell without a fluorescent structure on top was measured from the output of the solar cell coupled with optical gel to a glass substrate with PMMA deposited on top through spin coating.



Figure 1. EQE comparison of CdS/CdTe solar cell with and without of a fluorescent down-shifting structure: no concentration of light (V: Violet dye, Y: Yellow dye, Or: Orange dye)

This ensured that any effect associated with the PMMA and glass was not taken into account. A selection of results obtained is shown in Figure. 1. These results confirm that the use of these structures can be used to improve the low wavelength spectral response of CdTe/CdS thin film solar cells.

The use of optical gel to couple the fluorescent structure to the solar cell was to ensure that light from a full hemisphere reaches the solar cell. If a fluorescent collector larger than the solar cell is used, application of optical gel only to areas on top of the solar cell allows light from a larger area to be concentrated onto the solar cell. A uniform application of optical gel, on the other hand, should not produce any concentration effect and is expected to give a lower current output.

To verify this effect, J_{cell} has been measured for both types of optical gel coupling. The results (Figure. 2) confirm

that the current output per unit area of solar cell surface area can be improved further by using fluorescent structures to collect and concentrate light.



Figure 2. Comparison of J_{cell} of a CdTe/CdS solar cell with and without concentration of light using fluorescent structures (CE: Concentration Effect, V: Violet dye, Y: Yellow dye, Or: Orange dye)

4. Theoretical Model

A model is currently being developed to predict the fluorescence emitted from the bottom and top surfaces of these fluorescent structures from absorbance measurements, and this section describes the first results.



Figure 3. Fluorescence structure (collector) placed on top of a solar cell.

Figure. 3 shows a fluorescent structure placed on top of a solar cell. The probability $Q_c(\lambda_{ems})$ that photons emitted at the emission wavelength λ_{ems} could be detected from the up cone or down cone is given by:

$$Q_c(\lambda_{ems}) = \frac{\iint \frac{\Phi(x, y, z)}{4\pi} dV d\omega \exp[-\alpha(\lambda_{ems})L]}{\int \frac{\Phi(x, y, z)}{4\pi} dV 4\pi}$$
(2)

where Φ is the number of photons emitted through fluorescence per unit volume, dVis a small element of volume, $d\omega$ is a small element of the solid angle, $f_1(\lambda_{ems})$ is the normalised first generation fluorescence at emission wavelength λ_{ems} , $\alpha(\lambda_{ems})$ is the absorption coefficient at emission wavelength λ_{ems} and *L* is the distance travelled by the photon before it escapes.

Using this general formula, the reabsorption probability for photons escaping from the top and bottom cones can be calculated:

$$1 - r(\lambda_{ems}) = \frac{2}{P} Q_c(\lambda_{ems})$$
⁽³⁾

where *P* is the fraction of photons in the top and bottom escape cones, and $r(\lambda_{ems})$ is the probability of reabsorption at the emission wavelength λ_{ems} .

The predicted fluorescence spectrum $f_e(\lambda_{ems})$ is obtained from this calculated reabsorption probability and the first generation fluorescence:

$$f_e(\lambda_{ems}) = f_1(\lambda_{ems}) (1 - r(\lambda_{ems}))$$
(4)

In this manner the predicted top and bottom fluorescence have been obtained. The top fluorescence has also been compared the experimental to fluorescence measurements for low dye concentration samples (Figure. 4). The results indicate a satisfactory correlation the model and these between experimental results. For higher dye concentration samples, however, the fluorescence spectrum is observed to be considerably distorted, possibly due to the formation of complexes [4]. The first generation fluorescence spectrum, therefore, cannot be used in order to calculate the fluorescence at these concentrations. Future work will involve developing the theoretical model further so as to include the effects observed at high dye concentrations.



Figure 4. Predicted top and bottom fluorescence (based on theoretical model) and experimentally measured top fluorescence. The fluorescent structure analysed consists of an orange dye with a

concentration of 400 mg/l (an excitation wavelength of 430 nm was selected).

5. Conclusion

We have presented the results of a comparison between fluorescent structures using different dyes and concentrations, with the aim of increasing the low wavelength spectral response of thin film CdTe/CdS solar cells. The use of these down-shifting structures as a method of concentrating light from a larger area onto a solar cell has also been demonstrated. Preliminary results comparing theoretical predictions of the fluorescence emitted from these structures with experimental measurements show satisfactory correlation for low dye concentration samples.

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7. References

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