PROGRESS IN PHOTON MANAGEMENT FOR FULL SPECTRUM UTILIZATION WITH LUMINESCENT MATERIALS

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1 INTRODUCTION

Photon management aims for higher efficiencies by full solar spectrum utilization. The underlying idea is to split or modify the solar spectrum before the photons are absorbed in a solar cell. In this paper we investigate the concept of fluorescent concentrators which allows for spectral splitting and concentration without tracking systems.

2 FLUORESCENT CONCENTRATORS

Fluorescent concentrators are a concept well known since the late seventies [1] to concentrate both direct and diffuse radiation without tracking systems. In a fluorescent concentrator dye molecules in a matrix absorb radiation and emit light with a longer wavelength. Most of the emitted light is internally totally reflected and therefore trapped and guided to the edges of the concentrator, where it is utilised by solar cells. The design of an advanced fluorescent concentrator system is shown in Figure 1. Key features are spectrally matched solar cells, new materials and a photonic structure, which increases the fraction of light guided to the edges of the concentrator.

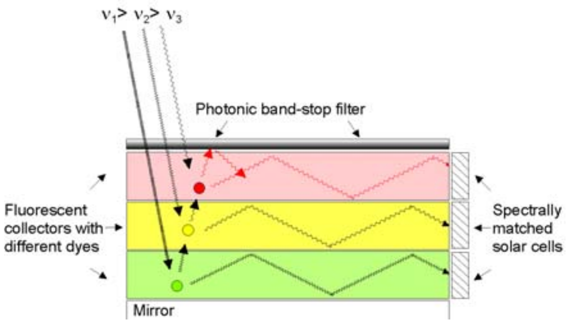

Figure 1: An advanced fluorescent concentrator system design.

A set of optical measurements allows determining directly the fraction of light which is guided to the edges [2]. This data was used to select promising materials, which were used to realise systems out of fluorescent concentrators and solar cells. Also combinations of two materials were tested. The fluorescent concentrators were all 3mm thick and had an area of 4cm². GaInP solar cells were attached to one side of the concentrators and the stacks, respectively. These solar cells were produced specifically for the use in these systems. The solar cells have geometric dimensions fitting to the edges of the concentrators. Their height is 3 or 6mm and the widths are 21 and 34.5mm, respectively. They were equipped with a single layer antireflection coating of 65nm Ta_2O_5, which is optimized for the emission range of the dyes between 550 and 650nm. The solar cells were then bonded to a copper base to give mechanical stability. The solar cells were attached to the edges of the fluorescent concentrators with an acrylic colour extender. It has nearly the same refractive index as PMMA and therefore provides a good optical coupling of solar cell and fluorescent concentrator. The used solar cells with 3mm height all had efficiencies of 14.4±0.1%, and the solar cells for the stacks with 6mm height had efficiencies of 15.4±0.1% to make the system measurements comparable (the given accuracy is for relative comparisons, the absolute uncertainty is bigger) White bottom reflectors were placed under all systems. Figure 2 displays the efficiencies of the systems. The material denoted BA241 shows the highest efficiency of 2.5% in reference to the 4cm² area of the concentrator. The combination with a second material increases the efficiency. Such a system reached an efficiency as high as 3%, although it utilises only the light leaving the concentrator on one side. From this stack a system with four solar cells, one at each edge of the fluorescent concentrator, was built. This system had an efficiency of 6.7%.

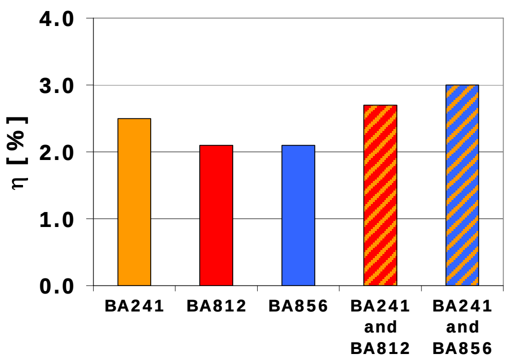

Figure 2: Efficiencies of systems consisting of a fluorescent concentrator (area 4cm², thickness 3mm) with one GaInP solar cell attached to one edge, and combinations of two different fluorescent concentrators with one GaInP solar cell of 6mm height attached to the edges of both concentrators. A white bottom reflector was placed under all systems.

The escape cone of total internal reflection is a principal efficiency limiting problem. At least 26% of the light is lost [3]. A photonic structure can help to reduce these losses [4]. The photonic structure acts as a bandstop reflection filter. It allows light in the absorption range of the dyes to enter the collector, but reflects light in the emission range. Therefore a larger amount of light is trapped in the collector and guided to the solar cells at the edges. A possible realization of such a photonic structure is a so-called Rugate filter. It features a continuously varying refractive index profile in contrast to the discrete structure of normal bragg reflectors. This results in the suppression of side loops, which would cause unwanted reflection and loss of usable radiation. In this study we used two commercially available filters from mso-Jena optimised for the BA241 material. To investigate how the filters increase the light guiding efficiency of the concentrators we measured the efficiency of a system consisting of fluorescent concentrator with 2x5cm² illuminated area and a GaInP solar cell attached to one edge. We performed two measurements, one with a black material under the concentrator, so no light having left the concentrator would be detected by the solar cell. The second measurement was performed with the filter without antireflection coating under the concentrator and with the filter with antireflection coating on top of the concentrator. Figure 3 shows that the efficiency could be increased by the filters by more than 20% relative

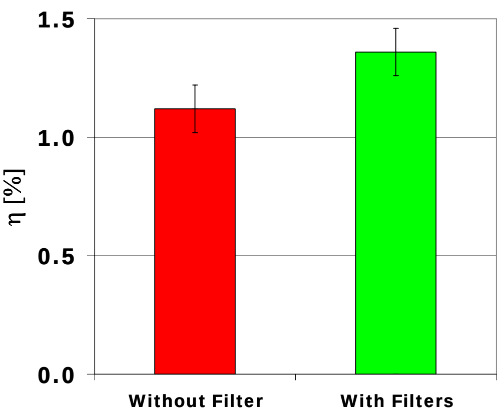

Figure 3: Efficiencies of a fluorescent concentrator system with the dimensions of 2x5cm² with and without selectively reflective structures. The efficiencies were increased by the application of the filters by more than 20% relative.

To deepen the understanding of the effect of the photonic structure we performed LBIC-measurements of the described system with different bottom reflectors and with and without a photonic structure on top. Figure 4 shows an LBIC scan with a white bottom reflector and photonic structure on top. Figure 5 shows linescans perpendicular to the solar cell as indicated by the red line in Figure 4. The linescans reveal that the photonic structure has a different effect close to the solar cell and further away. Close to the solar cell, the collection efficiency drops with the photonic structure. The photonic structure reflects light, which cannot be used by the dye. However, this light can reach the solar cell

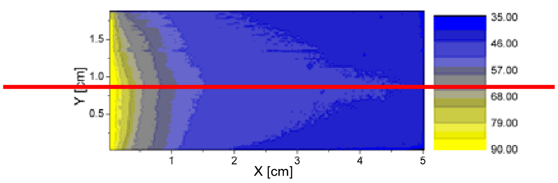

Figure 4: LBIC scan of a fluorescent concentrator with a solar cell attached to one side, a white bottom reflector and a photonic structure on top.

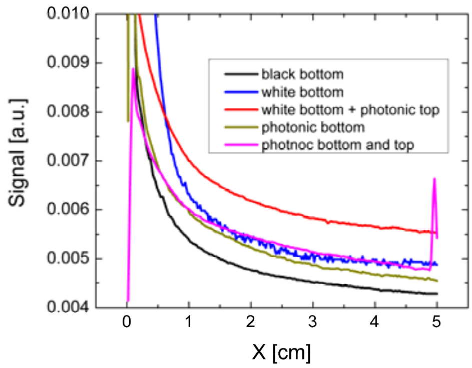

Figure 5: Line scan of the same fluorescent concentrator with different bottom reflectors and with and without a photonic structure on top. The position of the solar cell was at 0cm. The curves were normalised so that the areas under the curves equal the short-circuit currents of the systems.

when it is reflected from the bottom reflector towards the solar cell. This is not very likely further away from the solar cell, but contributes very significantly to the collection efficiency close by. Further away the light has to travel long distances to reach the solar cell making reabsorption and emission very likely, which is associated with additional escape cone losses. Therefore, the photonic structure increases the collection efficiency for the long distances. That is, for larger areas the photonic structure can be a very efficient measure to increase the collection efficiency.

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