PHOTONIC STRUCTURES AND SOLAR CELLS

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Motivation

The aim of photonic concepts is to increase the optical efficiency of photovoltaic systems. In this study we discuss different approaches pursued for this purpose. We will focus here namely on three strategies that may be classified by the optical effect used. These effects are spectral selectivity, angular selectivity and diffractive gratings.

In the examples discussed, we will confine ourselves to the view of the photon. The current objective is to increase the number of photons absorbed and to use the maximum efficiency of each photon.

The first way to achieve this is to use spectral selectivity. Spectral selectivity is applied, for example, to split the spectrum and guide different parts of the spectrum to different solar cells [1]. Or it is used to trap light after a spectral shift. This happens, for example, in fluorescent concentrators [2] or upconverting materials [3].

A second way is the use of angular selectivity. Angular confinement affects a photovoltaic system in several ways: for diffuse internal radiation, angular selectivity constitutes a very efficient light trapping mechanism [4]. Furthermore, angular confinement affects the balance of radiation exchange with its surroundings, and may be used to create a conservative system (conservation of Étendue).

The third method we want to discuss is the use of diffractive gratings. These gratings are used to achieve a defined change of the direction of the internal radiation. This results in a pathlength enhancement of the internal light, and consequently in an increased absorption and quantum efficiency [5]. For all of these concepts, photonic crystals provide an opportunity to create optical elements with the desired properties. However, since the properties of photonic crystals depend on the ratio of the incident wavelength to the lattice constant, it must be taken into account that the desired properties are only obtained for a certain spectral and angular range. One task, therefore, is to find and to optimize suitable optical elements. In the next section, we will introduce examples in which the discussed photonic concepts are realized. Theoretical and experimental results are given in the subsequent section.

Photonic Concepts

Figure 1 shows an example of how spectral selectivity is used to increase the light guiding efficiency in fluorescent concentrators. A spectral shift occurs inside the concentrator, which allows one to distinguish between light absorbed and emitted by the fluorescent dye. This spectral shift is used to increase the light guiding efficiency. The internal radiation is trapped by a filter, which is transparent for the absorbed light but perfectly reflects radiation emitted by the fluorescent dye.

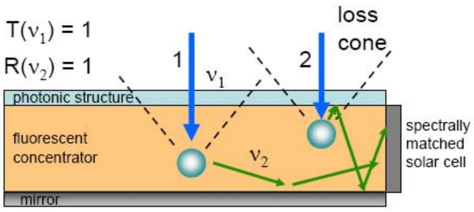

Figure 1: *The fluorescent concentrator: an example of how spectral selectivity is used to increase the efficiency of a photovoltaic system. The spectral shift of light inside the fluorescent concentrator is used. The light is trapped via the application of a filter which is transparent for the spectral absorption range of the fluorescent dye and is a perfect mirror for the dye's emission range.*

Figure 2 displays a sketch of a concept using angular confinement. An angularly selective optical element is placed on top of a photovoltaic system, inside which scattering occurs. The angular selectivity is defined by an angular acceptance range that is chosen in such a way that all incident sunlight passes the filter, but light with a direction outside the acceptance range is reflected. This allows trapping of most of the internal radiation. Scattering mechanisms are realized in numerous ways in PV systems.

Figure 3 illustrates the basic idea for the diffractive grating concept. The basic idea is to redirect light into a specific direction, preferably parallel to the PV system. The direction into which light is diffracted is defined by the grating period. The intensity which is diffracted into each order is defined by the grove depth. The idea here is to completely suppress the 0th order of diffraction, only allowing a 1st order that contains the complete light. This 1st order is directed into the parallel direction to achieve a maximum pathlength enhancement.

We have performed numerical simulations of realistic gratings using rigorous methods to optimize the current gained in a solar cell by the application of a grating. Results are promising though it is very difficult to achieve a complete suppression of the 0th order of diffraction.

Results

Spectrally selective structures have been used successfully to increase the light guiding efficiency of fluorescent concentrators by 20% [6]. Similar structures are currently used for spectral splitting purposes for very high efficiency solar cells [7]. On the other hand, while the potential of angular confinement was already pointed out some time ago [8, 9], the investigation of suitable structures is still in its infancy.

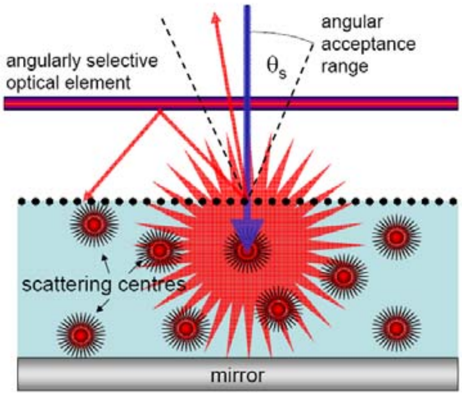

Figure 2: *Schematic sketch of the photonic light trap. An angularly selective optical element is placed on top of the light trap. The angular confinement is defined by an angular acceptance range θ_S. The optical element shall be transparent for all light incident within that range and shall be a perfect mirror for light incident from all other directions. Inside the photovoltaic system, scattering centers diffuse the internal radiation. Because of the angular confinement, the fraction $L=1/\sin^2 \theta_S$ of this diffused light is trapped [9].*

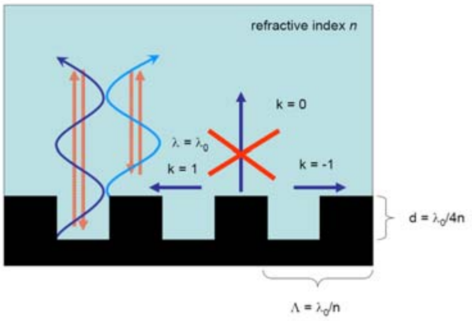

Figure 3: *Schematic sketch of the concept of the reflective $\lambda/4$ grating. In a first scalar approach, this grating should redirect all light with a design wavelength λ_0 into a direction parallel to the photovoltaic system. In a vectoral approach we find that this is not possible, however, the basic idea may be used to design gratings which redirect at least a fraction of the incident light into directions close to parallel.*

Principal considerations about the potential of angularly selective systems show promising results and we have performed preliminary experiments that showed an increased absorption for angularly selective systems (figure 4). The application of diffractive structures is expedited, especially for thin film solar cells [10]. However, for crystalline solar cells as well, the application of diffractive gratings is tested.

The scope of this article is to scrape the surface of what is possible with photonic structures and give a short overview over strategies currently being investigated.

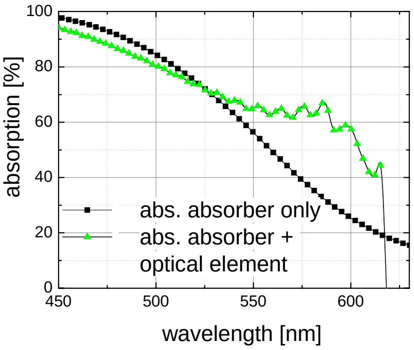

Figure 4: *Obtained absorption for a system with and without angular selectivity. An increased absorption could be verified for a spectral range between λ=540nm and λ=620 nm. The system for which the absorption was tested was a specially fabricated thin layer of non stoichiometric SiC. The photonic structure used was a rugate filter.*

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