Fluorescent collectors: trapping light by frequency shift

Tom Markvart
Solar Energy Lab, Engineering Sciences
University of Southampton, UK.

Fluorescent collectors have been under consideration for some time, with the aim of reducing the size – and therefore the cost – of solar cells. We shall show that fluorescent energy collection, possibly with the help of some photonics, can also be used for efficient light trapping. In other words, the path of light inside the photovoltaic structure can be extended, leading to a further reduction in material requirements needed for solar cell manufacture.

Examples of such structures include collectors which direct light onto the edge of the solar cell (Fig. 1). We have shown[1] that similar edge-illumination schemes using a light-harvesting molecular structure combined with a lanthanide fluorescent emitter and a silicon solar cell with nominally 20% conversion efficiency have the potential of reaching overall efficiency of some 17%.

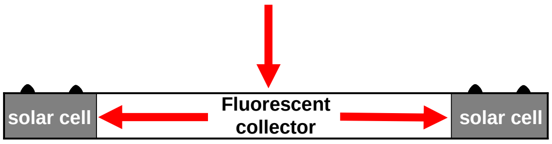

Fig. 1. A fluorescent collector used to illuminate a solar cell from the edge.

A related structure in Fig. 2b uses the fluorescence frequency shift to maximise the photon path length inside the cell, resulting in a novel form of light trapping. We have shown[2] that this structure can extend the average photon path length to

$$\ell = 4n^2 d \left(\frac{\nu_g}{\nu_o} \right)^2 e^{\frac{h\Delta\nu}{k_B T_o}}$$

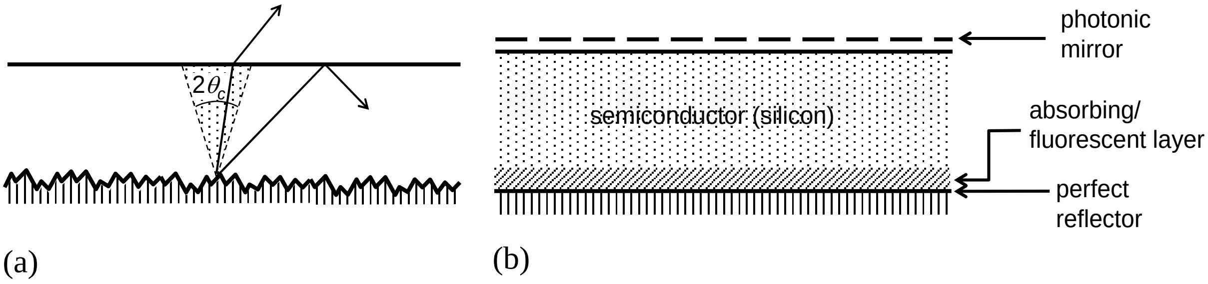

Fig. 2. (a) Geometric light trapping scheme with a Lambertian reflecting rear surface.
(b) Photonic scheme where photons are confined within a thin weakly absorbing layer (such as silicon) by the combination of a highly absorbing layer near the back surface and a photonic mirror at the top.

(1)

where $\Delta \nu = \nu_o - \nu_g$, ν_o and ν_g are the frequencies corresponding to the photonic mirror and the semiconductor bandgap, respectively, and *d* and *n* are the thickness and refractive index of the semiconductor. Equation (1) shows that the path length in the photonic structure exceeds the well known Yablonovitch limit[3] based on surface texturing (Fig. 2a) by approximately the Boltzmann factor corresponding to the frequency shift.

Somewhat surprisingly, the efficiency of solar cell based on the light trapping scheme in Fig. 2b may equal or even surpass the efficiency of the traditional thick solar cells. Indeed, such a scheme, with a photonic mirror corresponding to a wavelength close to 900nm, will not only ensure near-perfect absorption of light below this wavelength (Fig. 3) but also move the effective photonic bandgap closer to the ideal Shockley-Queisser maximum of around 31%, exceeding the maximum possible efficiency of conventional (thick) silicon solar cell.

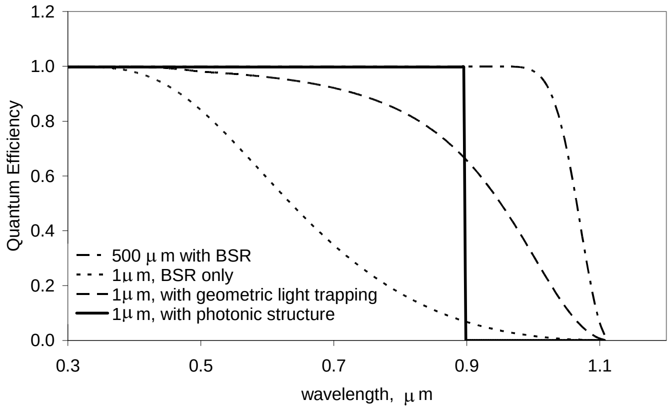

Fig. 3. The quantum efficiency of a c-Si solar cell with the light trapping scheme in Fig. 2b compared with a 500μm c-Si with back-surface reflector, 1μm cell with BSR, and a cell with geometric light trapping (Fig. 2a).

At the fundamental level, photon frequency management can be described as the transformation of a high-temperature solar beam into a low-frequency beam at the room temperature. Unlike geometric concentrators, the energy exchange with the absorbing medium allows the entropy of the captured photon gas to be lowered, reducing the ètendue of the emitted beam or compressing the volume of the photon phase space.

References

[1] T. Markvart and L. Danos, *Proc. 25th European PV Energy Conf*, Valencia, 2010.
[2] T. Markvart, *Appl. Phys. Let.*, in press.
[3] E. Yablonovitch, *J. Opt. Soc. Am.* **72**, 899 (1982)