PHOTON MANAGEMENT FOR FULL SPECTRUM UTILIZATION WITH FLUORESCENT MATERIALS

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Motivation

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 dyes 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. Stack designs with several concentrator plates with different dyes allow for a full spectrum utilisation. An additional advantage is the splitting of the solar spectrum, so the different parts can be converted more efficiently with different, bandgap matched cells [1]. This study investigates system designs to maximise the output of fluorescent concentrator systems with today available dyes and solar cells. In addition we explore the possibilities to overcome the principal efficiency limiting problem of the loss cone of total internal reflection, which causes losses of at least 30% [2]. Rugate filters, which serve as a band reflection filter for the emitted light are a promising option to reduce these losses.

Approach

Today organic fluorescent dyes are available, which have quantum efficiencies above 95% for the visible spectrum. There are no such dyes for the infrared. As we have shown in Ref. 3 transmission of typical materials for fluorescent concentrators is high in the near infrared, the spectral range in which the spectral response of a silicon solar cell is the highest. This enables a system design where a silicon solar cell at the bottom of the fluorescent concentrator converts the infrared radiation. Since the spectral response of GaInP solar cells matches the photoluminescence of most dyes, GaInP is the obvious choice for the solar cells at the edges of the fluorescent concentrator. The typical open circuit voltage (V_{OC}) of a GaInP solar cell is in the region

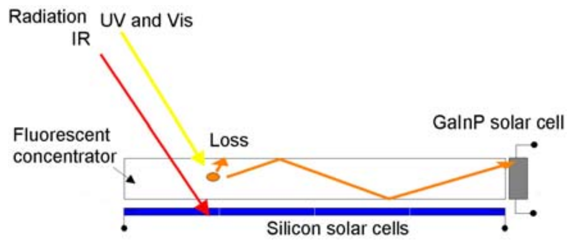

Figure 1: *Fluorescent concentrator system design with silicon bottom cell and GaInP solar cells at the edges of the concentrator.*

above 1300 mV. This compares to a V_{OC} of a typical silicon solar cell of about 600..660 mV. That is, assuming the same fill factor, nearly twice the energy can be utilised if a photon is converted by the GaInP solar cell instead by the silicon cell.

Experimental Results

A first experimental realisation of the system shown in Figure 1 consisted out of one 2x2 cm² back-contact silicon solar cell under a fluorescent concentrator plate of 2x2cm² and 3mm thickness. Four 2x2cm^2 GaInP solar cells were optically coupled to the edges of the concentrator and connected in parallel. The remaining cell area was covered with black material. Figure 2 shows that without the concentrator the silicon solar cell had an efficiency of 16.7%. Under the fluorescent concentrator the efficiency dropped to 14.0%. The parallel interconnection of the four GaInP solar cells had an efficiency of 3.7% in reference to the 4cm² area of the fluorescent concentrator. Therefore the total system efficiency was 17.7%, which is significantly higher than the silicon solar cell alone. Figure 2 b) shows the spectral efficiencies of the system. It can be seen clearly how the fluorescent concentrator system increases the efficiency in the region of 400 to 500nm. We expect much higher efficiencies with optimised GaInP solar cells with the correct geometric dimensions, which are currently in production.

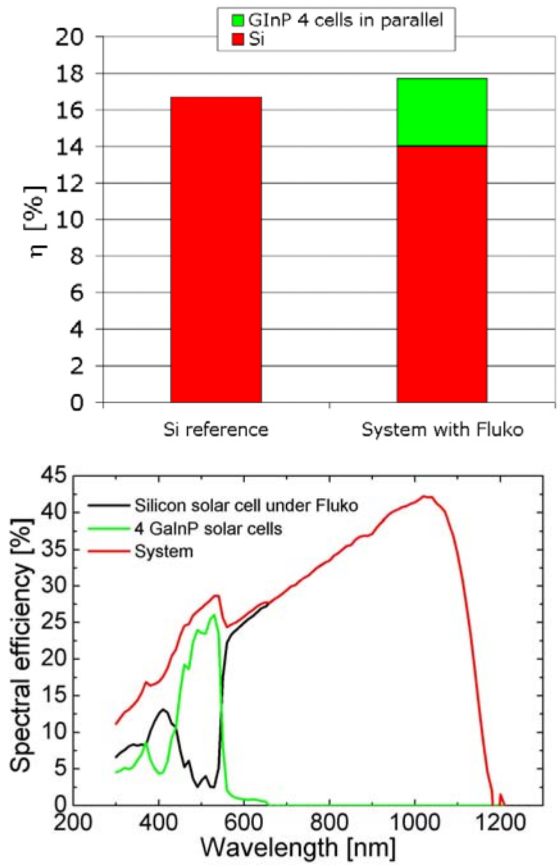

Figure 2: *Efficiencies of a system as delineated in Figure 1 in comparison to a single silicon solar cell*

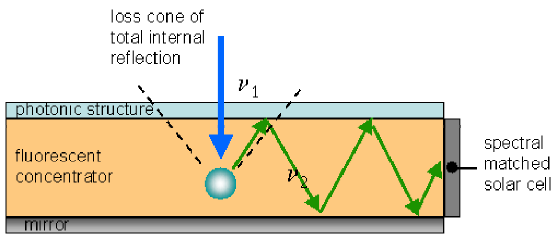

Figure 3: *Another fluorescent collector concept with photonic band-stop filter. The photonic structure helps to minimise losses due to the escape cone of internal reflection. It reflects light in the emission range of the dye but transmits the light in the absorption range of the dyes. Therefore no incoming light is lost in the usable wavelength range*

Rugate filters are multilayer systems with continuously varying refractive index profiles. They can serve as band reflection filters for the emitted light which leaves the fluorescent concentrator in the loss cone of total internal reflection. Because of unwanted reflection in the absorption range of the fluorescent dye (Figure 4) no significant net-increase of system efficiencies could be achieved yet. Weighted with the AM1.5-spectrum and the absorption spectrum of the fluorescent concentrator the losses due to this reflection are 10% of the light being otherwise absorbed by the fluorescent concentrator. Thus the filter effectuated no significant net increase of the efficiency when it was applied to a fluorescent concentrator/ GaInP solar cell system. As the efficiency remained unchanged, it could be calculated that the filter increased the internal light guiding efficiency after the light has been absorbed by 11% at least. Measurement of the angular distributions of the light which is coupled out at the edges of a fluorescent concentrator of 5x5cm² showed also a beneficial effect of the Rugate structure for the collection of light, which is emitted into the loss cone of total internal reflection. Thus, significant efficiency enhancements can be expected from structures without the unwanted reflection in the absorption range

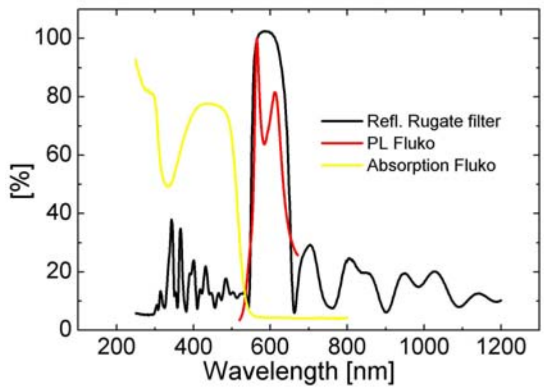

Figure 4: *Reflection spectrum of a so called Rugate filter and the absorption and photoluminescence of the fluorescent concentrator the filter was designed for. The filter was produced at Fraunhofer IST by chemical vapour deposition. The reflection band of the filter very nicely fits the emission peak of the dye in the concentrator. However, there is still some unwanted reflection in the absorption range of the dye.*

References

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