Novel Wavelength-Shifting Materials for Improving the Efficiency of Solar Cells

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INTRODUCTION TO WLS

Current photovoltaic systems generally display a rather poor response to short wavelengths, thus missing out on the most energetic part of the solar spectrum; furthermore, high losses take place when light reaches the surfaces of a photovoltaic system. Wavelength-shifting materials (WLS) appear to be very promising means to tackle these problems [1]. The goal is the enhancement of the energy response of the photovoltaic cell due to the absorption of the most energetic component of the solar spectrum [2]. In particular, we aim at collecting incident light in the wavelength range 350-500 nm and shift it to the range 450-1000 nm, where silicon cells have a high sensitivity (see figure 1).

In this work we report some results coming from the study of two luminescent dyes embedded in different matrices that can be suited as WLS materials. The tested dyes are BBOT (2,5-bis(5-tertbutyl 2 benzoaxoazolyl thiophene) and 3HF (3-hydroxyflavone). The molecular structure of the two dyes is shown in figure 2.

BBOT has a light absorption peak at around 390 nm and re-emits at 450 nm, featuring a high quantum efficiency (more than 90 %) and light emission stability. 3HF was chosen because of its very wide Stokes Shift ($\Delta \lambda \approx 180 \text{ nm}$): as a matter of fact, when the molecule is excited by light with a wavelength of 350 nm, the re-emitted light has a higher wavelength than 500 nm. The large Stokes shift can strongly enhance the efficiency of the system by minimizing re-absorption losses.

The chosen dyes were incorporated in parylene films and in polysiloxane samples. The choice of these two matrices was due to their high transparency and chemical durability, radiation hardness and easy processability.

EXPERIMENTAL RESULTS

Samples with dye-containing parylene were deposited with a Labocoater LC3000 from PPCS (Germany). The chamber was customized for the co-deposition of dye and parylene monomer. BBOT was evaporated at different temperatures ranging from 160° to 180°C, while 3HF was evaporated at the temperature of 115°C.

Polysiloxane was synthesized from the polyaddition of two components: the first was a vinyl-terminated polydimethyl-diphenyl siloxane and the second was a hydride-terminated polyphenylmethylhydrosiloxane. The fluorophores were mixed in the first component at 50°C for 12 hours; Pt-divinyltetramethyldisiloxane catalyst was later added in order to speed up the vulcanization reaction, and finally the second resin was added [3].

FT-IR spectra of dye-containing parylene films were studied to establish that there was no interaction between the evaporated molecules and the parylene film. Increasing the concentration of BBOT molecules (increasing the temperature of evaporation, the rate of evaporation increases) typical BBOT peaks become visible in the IR spectrum (see figure 3).

Fig. 1. Solar spectra and efficiency of InGaP and Si solar cells.

Fig. 2. Molecular structures of BBOT and 3HF.
Fig. 3. FT-IR spectra of undoped (a) and BBOT-containing parylene films deposited at increasing crucible temperature: (b) 160°C; (c) 170°C and (d) 180°C. The asterisks highlight the BBOT peaks.

As can be seen, the typical peaks of parylene appear in all the spectra of doped films: this was also true for the 3HF-containing films, thus confirming that the dye incorporation does not change the chemical structure of the polymer matrix. On the other hand, in the BBOT-containing parylene films some new peaks appear in the spectra at increasing sublimation temperature: the most evident ones are at 1578 cm\(^{-1}\), 1480 and 1270 cm\(^{-1}\), 1030 and 811 cm\(^{-1}\) (both of them appearing as shoulders of parylene peaks), and the peak at 718 cm\(^{-1}\). The appearance of these peaks, which are the most intense features of BBOT molecule, shows the successful incorporation of this dye in the parylene matrix.

Comparing the absorption spectra [4] of the BBOT molecule in solution (CHCl\(_3\)) and the spectra of the samples, a shift of the most intense peak can be observed from 378 nm in solution to 360 nm in the film; this suggests that a different state of aggregation is present in the film (see figure 4). Increasing the concentration in the film some re-absorption takes place.

3HF has an absorption band that extends from 280 nm to 380 nm with a maximum at 347 nm, and an emission spectrum contained between 500 and 600 nm. This large Stokes shift can minimize re-absorption losses. 3HF is well embedded in parylene matrix and high concentrations are reached without aggregation. In polysiloxane very high concentrations have to be used (some percent) due to the interaction of the molecule with the platinum catalyst used.

This phenomenon involved many molecules causing a structure transformation which prevents the tautomeric form, as shown by the appearance of a peak due to the normal form. This peak is four times lower than the peak typical of the tautomeric form at an excitation wavelength of 350 nm. This makes parylene a better matrix to embed 3HF molecules with respect to polysiloxane.

Fig. 4. Optical absorption spectra of (a) undoped parylene film, (b) BBOT dissolved in CHCl\(_3\), (c) BBOT-containing and (d) 3HF-containing parylene film. Optical emission spectra of (e) BBOT dissolved in CHCl\(_3\), (f) BBOT-containing parylene film (\(\lambda_{ex}=380\)nm) and (g) 3HF-containing parylene film (\(\lambda_{ex}=350\)nm).

CONCLUSIONS

From our preliminary studies the wavelength-shifting properties of the two tested dyes look extremely promising. BBOT in particular displays a high luminescence, while 3HF displays a large Stokes Shift. The two matrices are also very good in transparency, radiation hardness and easy processability. Further experimentation is in progress to study their photostability under solar irradiation. Attempts are under way, moreover, to employ multiple dyes in order to enlarge the absorption band and extend the total shift.