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Universal figure of merit of luminescent dye solar concentrators

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Luminescent solar concentrators (LSC) attracted interest for photovoltaic applications with their potential to reduce costs by concentrating the sunlight onto small area. Commonly LSC structure consist of slabs of glass or plastic doped with dye molecules with relatively strong absorption. The absorbed light is re-emitted as luminescence with characteristic spectrum which is trapped inside LSC and transported towards the edge via total internal reflection. It is expected that the light at the edge is outcoupled to suitable solar cell.

The advantage of using LSC is the possibility of concentrating diffuse sunlight in contrast to conventional concentrators based on parabolic mirrors or Fresnel lenses. However, the performance of LSCs is limited by fundamental losses originating from the reabsorption of emitted luminescence.

Here we propose the universal procedure to evaluate optical efficiency of any square-shaped LSC based on dyes with gaussian shape of absorption/emission bands. Our procedure will rely on approximating the average reabsorption probability, followed by calculations of photon collection probability at the edge of LSC and generalising this approach for any common dye.

Reabsorption emerges from the overlap of dye absorption and emission spectral bands. Once the emitted photons are reabsorbed within LSC, omnidirectional nature of luminescence reemission can breach the original condition for total internal reflection and photons are lost through the front surface escape cone. Probability of reabsorption depends on spectral overlap of absorption and emission band which for most conventional dyes can be simply characterized by a single parameter – Stokes shift E_S. We then associate associate Stokes shift with corresponding linewidths of the bands, using Kazachenko's theory [1]. The theory arises from Stepanov's reciprocity relation [2] between absorption coefficient and emissivity, followed by analytical description of the shape of absorption/emission bands. Assuming the gaussian distribution for bands, Kazachenko derives a relation between width of the absorption/emission band and Stokes shift in the form:

$$\Delta = \sqrt{E_S k_B T} \quad (1)$$

Such a model for absorption and emission bands of perylene BASF R305 dye is shown in figure 1 alongside the measured absorption/luminescence spectra.

To evaluate the average reabsorption probability that photons undertake on their way to the LSC edge, we use modified theory developed by Weber and Lambe [3] and calculate the average reabsorption probability as a function of absorbance ($\alpha.l$). Resulting probabilities are shown in Fig. 2. Figure includes preliminary experimental results of reabsorption probabilities for fluorescent collectors prepared by depositing perylene R305 dye of various concentrations on quartz glass slides. Details of experimental setup and reabsorption evaluation form measured spectra can be found in [4], [5].

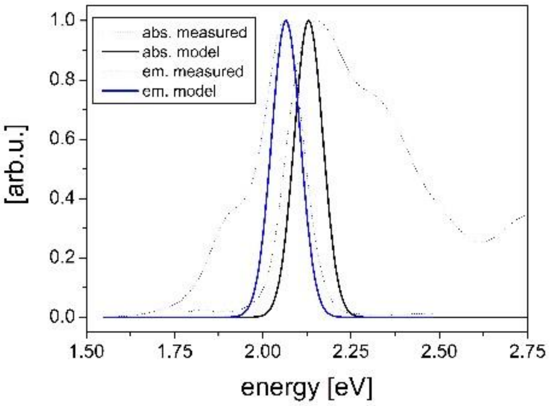

Fig. 1

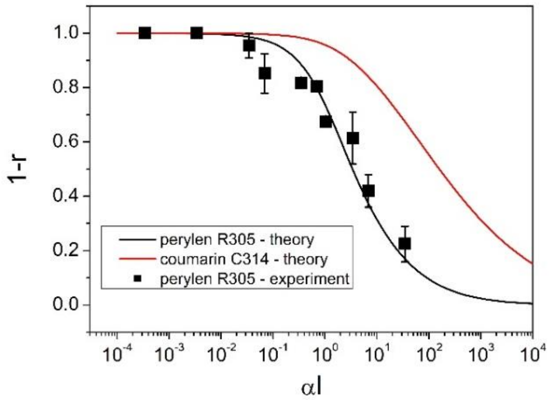

Fig. 2

Photon collection probability can be then calculated from reabsorption probability using approach of Batchelder and Zewail [6]. We aim to establish this process as universal for any dye with gaussian shaped absorption/emission bands by characterising the spectral properties with single parameter. Such a semi analytical approach can find its importance in designing complex spectral conversion systems based on LSC.

References:

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