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Effects of self-absorption in Quantum Dot Solar Concentrators with partially overlapping absorption and emission spectra of type-II quantum dots

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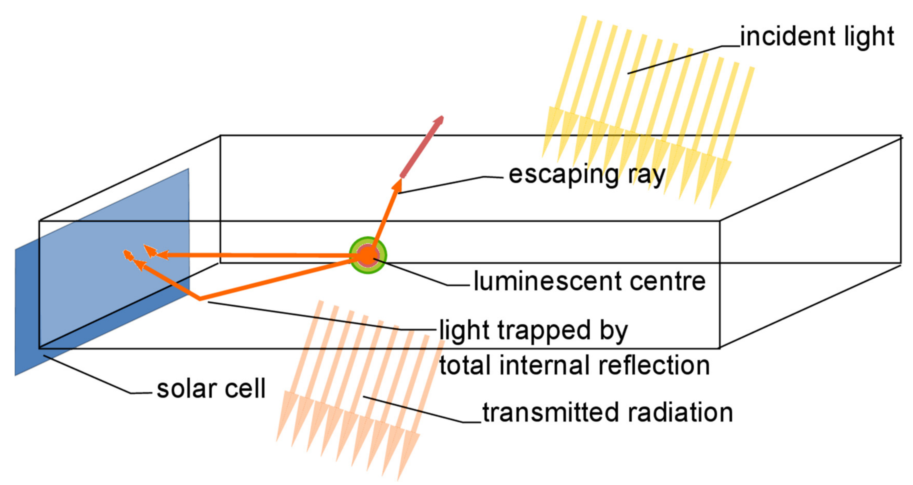
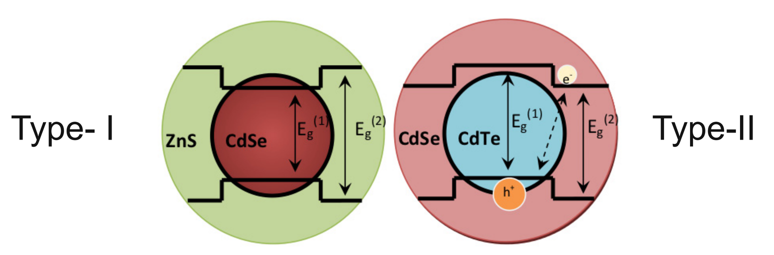
Introduction

Development of luminescent solar concentrators (LSCs) started in the 1970s as an alternative approach to lower costs of photovoltaic (PV) technology [1].

LSCs consist of transparent polymer sheets doped with luminescent species, i.e., organic dye molecules (narrow absorption bands), semiconductor nanocrystals (broad absorption bands).



Efficiency low due to several loss processes: self-absorption is important [2]. Self-absorption has been shown to be correlated with Stokes' shift [3]. Semiconductor nanocrystals with large Stokes' shift are potential candidates to overcome self-absorption [4]. However, synthesis of these nanocrystals with high luminescent quantum efficiency is difficult.



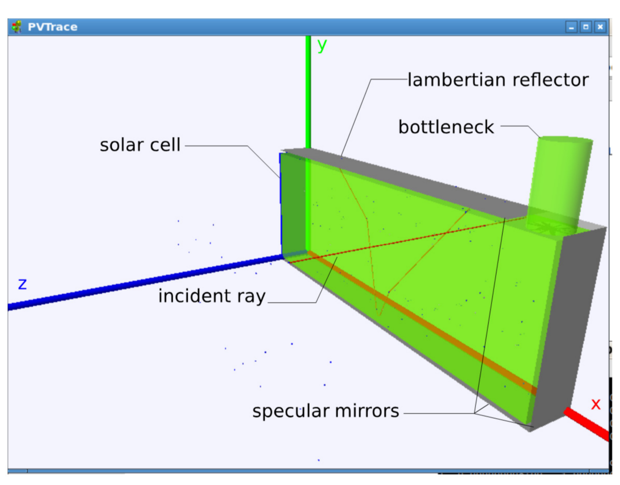
The synthesis of highly luminescent nano-particles with a small but not negligible spectral overlap promises to be less complicated [5]. In this work we investigate the suitability of such nano-particles to circumvent the self-absorption problem in LSC devices by means of experimentally validated combined ray-tracing and Monte-Carlo simulations.

Method

Combined ray-tracing and Monte-Carlo simulations using *pvtrace* [6]. We have varied the LSC-size and nanocrystal concentration:

QD1: small spectral overlap absorption/emission

QD2: almost complete absorption/emission-separation



LSC dimensions:
  height = 1 cm
  length-to-width ratio = 1 : 0.35

Matrix:
  PMMA, n = 1.5, absorption coefficient = 0.5 m^{-1}

AM1.5G spectrum

Solar cell attached to the smallest side

Perfect mirrors to the 3 other smallest sides (applied with an air gap of 0.5 mm)

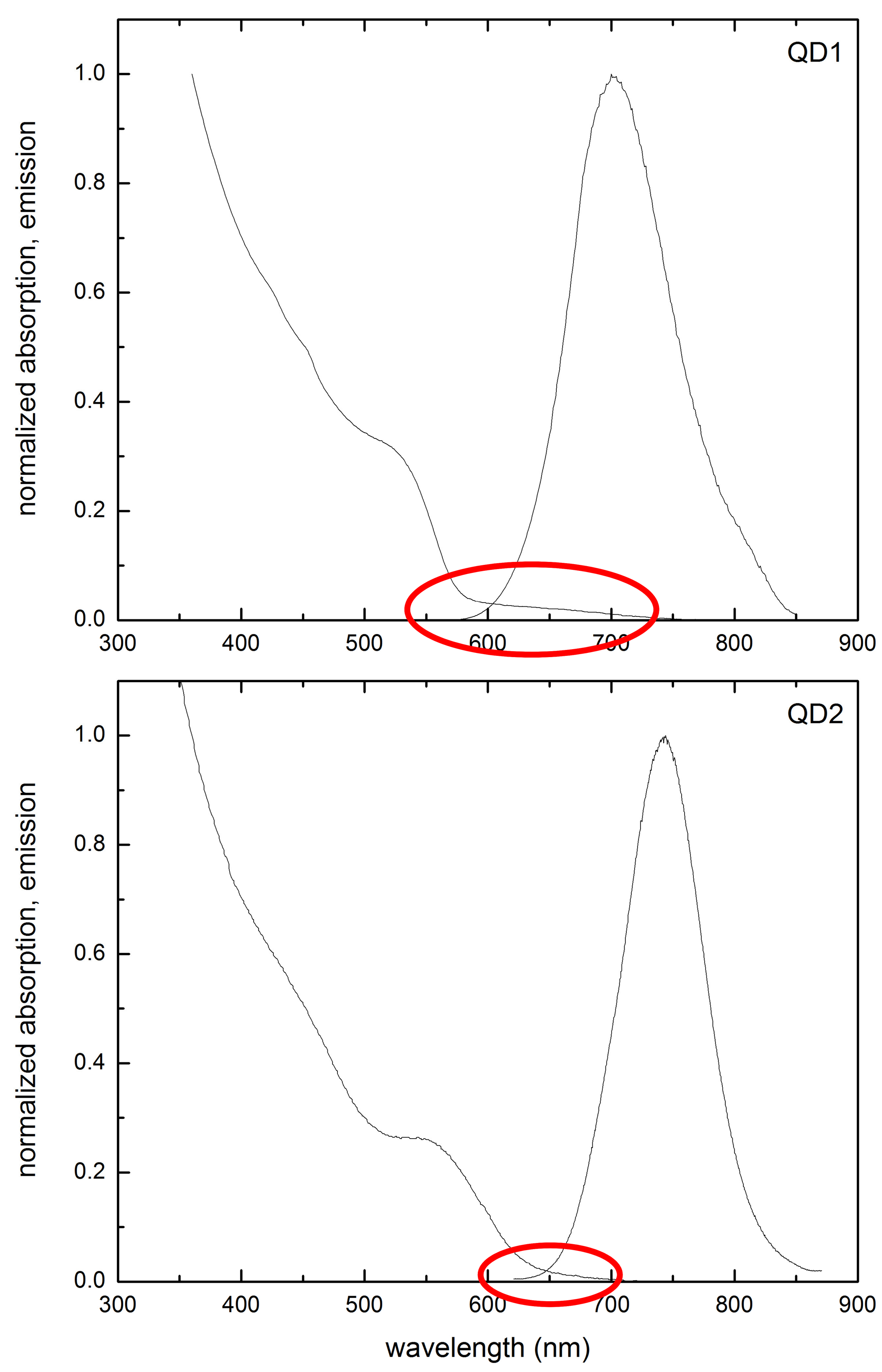
Variation of LSC-size: 1 – 100 cm

Luminophore concentration: simulated as increase in absorption coefficients

Self-absorption $$\sigma_{SA} = \frac{\int_0^\infty F(\lambda)A(\lambda)d\lambda}{\int_0^\infty F(\lambda)d\lambda}$$

Quantum dot samples

sample	Stokes' shift	σ_{SA}	emission	LQE
QD1	190 nm	0.009	700	48%
QD2	210 nm	0.003	740	48%

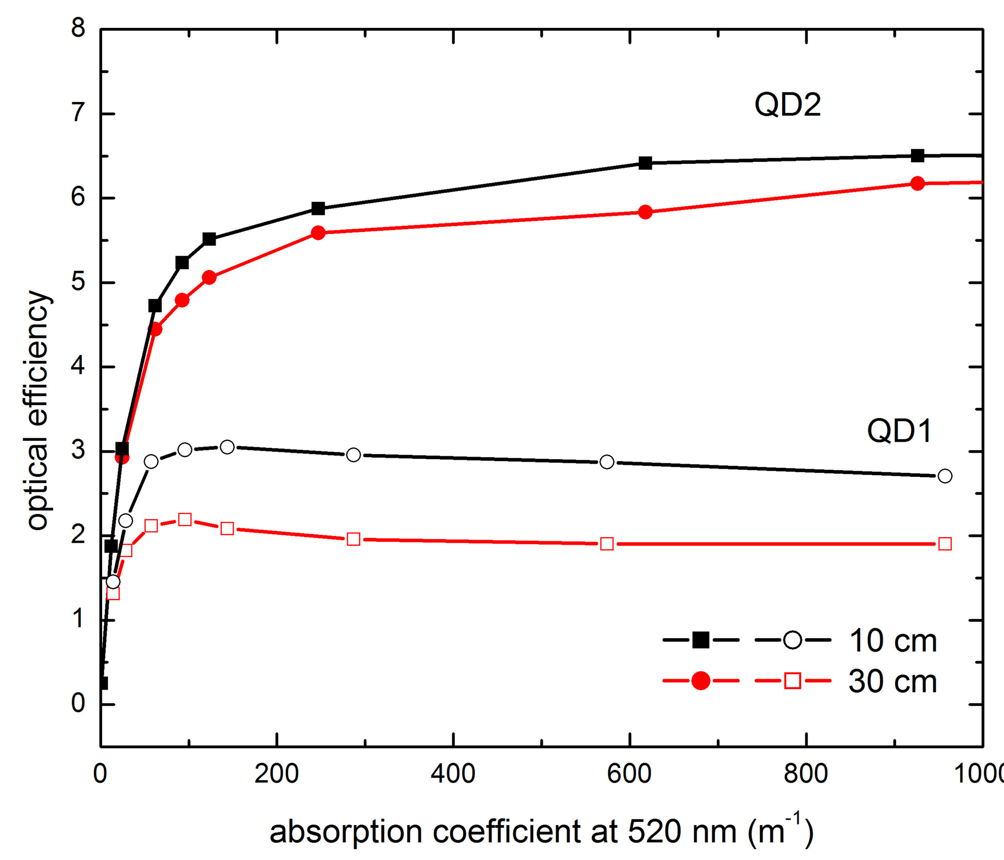


LSC efficiency

Efficiency QD1 < QD2

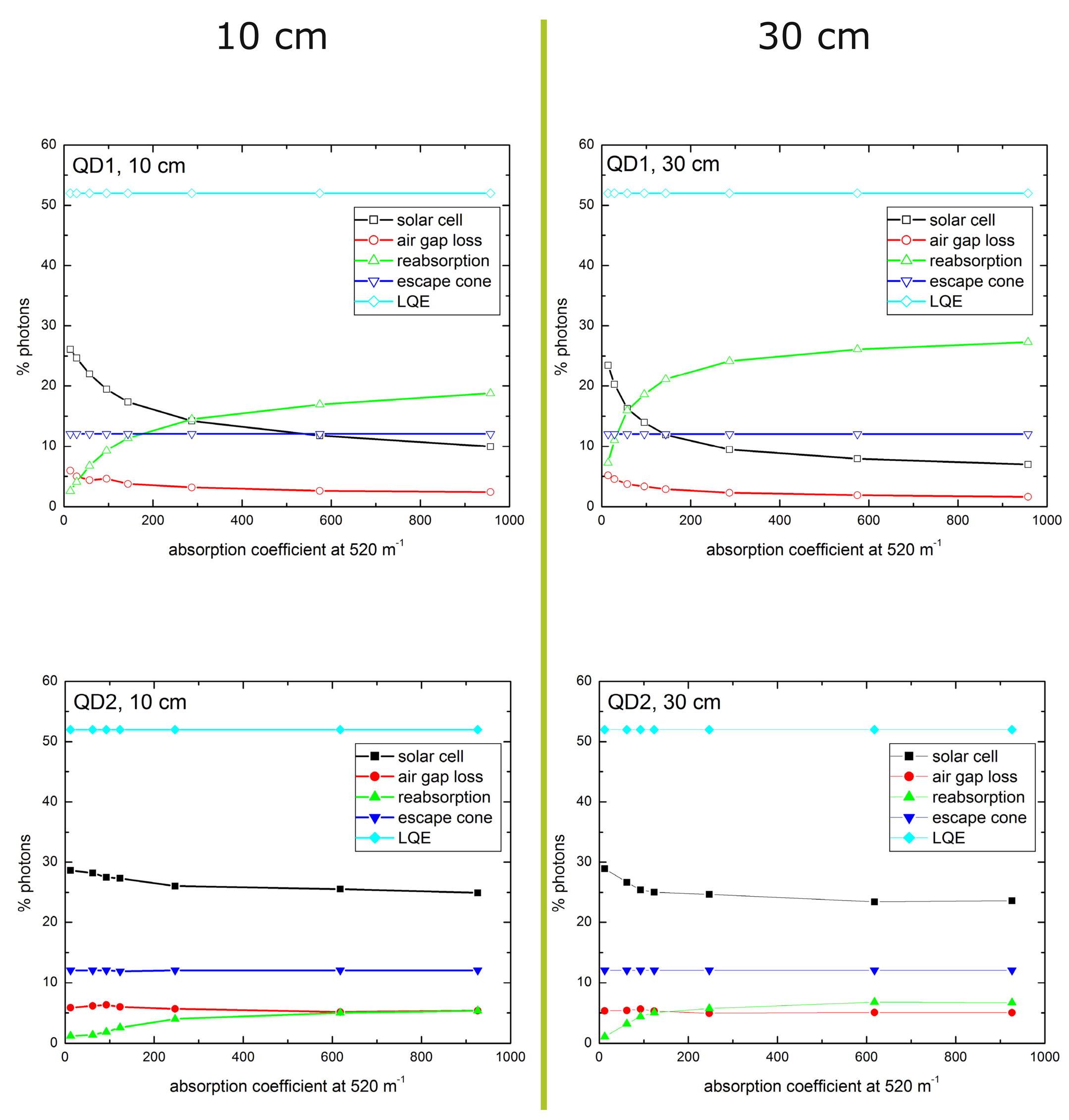
QD1: large LSC device has lower efficiency than small one

QD2: large LSC device has similar efficiency as small one due to 3 times lower self-absorption



What happens to the photons?

Destination of photons as percentage of the absorbed photons for QD1 and QD2 as a function of concentration



- losses due to quantum efficiency are constant at 52%
- losses due to escape cone are constant at 12%
- losses due to escaping through the air gap between the mirror and LSC are low: <5%
- number of photons reaching solar cell clearly competes with reabsorption

The better performance of QD2 can be ascribed to the broader absorption spectrum but foremost by the (much) lower reabsorption losses (see figure above).

The reabsorption losses are caused by the small absorption that overlap with the emission spectrum.

Conclusion

Quantum dot solar concentrator simulated with type-II nanocrystals.

Spectral overlap between absorption and emission determines LSC efficiency and its dependence on concentration. Even small overlap has large effects.

References

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pvtrace: http://github.com/danieljfarrell/pvtrace.