Simulation of Fluorescent Concentrators

Solar Energy Research

- cooperation with the Fraunhofer Institute for Solar Energy Systems in Freiburg
- raise efficiency – by concentration of light
- problem: diffuse light
- idea (around 1970): trap light inside medium
- low efficiency → low research interest
- interest increased again in the last years due to improved dyes, solar cells and concepts
What is a Fluorescent Concentrator?

- PMMA (acrylic glass) and fluorescent dye
- Concentrates direct and diffuse light on a solar cell
- Principle:
  - Absorption in dye
  - Re-emittance according to Stokes shift (longer wavelength)
  - Total internal reflection (trap light inside medium)
Absorption and Photoluminescence Spectra

- re-absorption only possible in overlap
Energy Loss Mechanisms

- loss mechanisms have to be analysed for improvement
- experimental testing of new concepts and analysis of physical processes difficult and expensive
- analytical calculations and simulation complex and time-consuming
Simulation Model

⇒ Monte Carlo (MC) method

- ray tracing of single photons (simplest simulation model, least error-prone)
- uni-directional particle transport to avoid problems arising when connecting paths with different wavelengths
- allows to investigate effects isolated from global path
A Photon’s Path through the Concentrator

- sample spectrum AM 1.5 (MC inversion method)
- sample start point
- fix direction
A Photon’s Path through the Concentrator

- calculate intersection with boundary
- calculate reflection coefficient (Fresnel, Cauchy)
- calculate new ray direction (Snell)
A Photon’s Path through the Concentrator

- sample pathlength (*MC inversion method, Lambert-Beer*)
A Photon’s Path through the Concentrator

- estimate absorption event
A Photon’s Path through the Concentrator

- Sample PL-spectrum (*MC inversion method*)
- Sample direction (*MC inversion method*)
- Sample pathlength (*MC inversion method*, Lambert-Beer)
A Photon’s Path through the Concentrator

- calculate intersection with boundary
- calculate reflection coefficient (Fresnel, Cauchy)
- calculate new ray direction (reflection angle equals angle of incidence)
A Photon’s Path through the Concentrator

- sample pathlength (*MC inversion method, Lambert-Beer*)
- estimate absorption event
A Photon’s Path through the Concentrator

- sample PL-spectrum (*MC inversion method*)
- sample direction (*MC inversion method*)
- sample pathlength (*MC inversion method, Lambert-Beer*)
- calculate intersection with boundary
A Photon’s Path through the Concentrator

- estimate absorption event → terminate ray
Experiments and their Simulation

- physical measurement of input parameters: absorption spectrum, photoluminescence (PL-) spectrum, refractive indices and geometry
- several experiments for analysis of fluorescent concentrators
- first step:
  - reproduce experiments “exactly”
  - compare data to verify implementation
  - explain small differences
- second step:
  - simulate experiments without limitations of “real” setup
  - parameter variation
  - evaluate results
Reflection and Transmission Experiment

experiments with integrating sphere

Transmission Spectrum

Reflection Spectrum
Absorption

- Absorption \(\approx 1 - \) Reflection – Transmission
- calculated absorption as input \(\rightarrow\) verification of simulated absorption

Absorption Spectrum

![Absorption Spectrum Graph](image-url)
Angular Experiment
Angular Experiment

- not fully specified → parameter variation: imperfect surface, scattering, properties of the blind, properties of the coupled cylinder
Angular Experiment
Fast Ray Tracing

- several millions of rays to be traced for one graph
- exponentially more (in the number of parameters) needed for parameter variation
- incoherent rays: ray packets/bundles not an option
- ray tracing kernel
  - triangle-based
  - 4-ary BVH
  - SAH-based construction
Visuals

- direct comparison photograph/render
Non-Fluorescent Dragon
Fluorescent Dragon

![Fluorescent Dragon Image]
Future Work

- optimisation:
  - concentrator stacks

- photonic structures, mirrors, additional solar cells
- geometry optimisation
- different dyes (problem: infra-red range)
Summary

- fluorescent concentrators are made for improvement of efficiency and applicability of solar cells.
- testing by simulation possible before (expensive) experimental testing
- fast ray tracing makes automated parameter variation possible
- general Monte Carlo simulation framework for physicists to gain insights in involved processes, for parameter optimisation (dye properties, geometry, ..) and for testing of new ideas

Questions?
Experimental Setup