Technische Universität Braunschweig

Institut für Physikalische und Theoretische Chemie

Biomimetic Engineering of High Efficiency Light-Harvesters

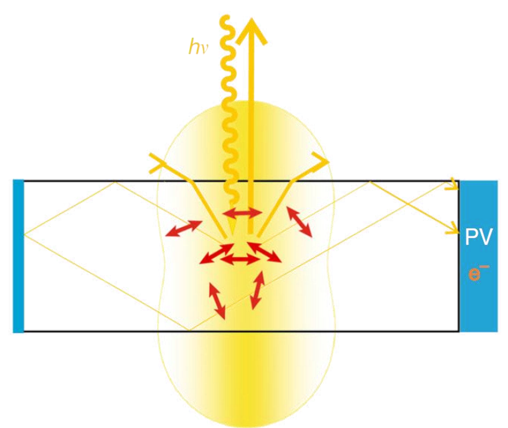
A. Brennecke, A. Pieper, M. Hohgardt, M. Willich, D. A. Gacek, N. Hafi, D. Pfennig, A. Albrecht, P. J. Walla
Technische Universität Braunschweig | Institut für Physikalische und Theoretische Chemie
a.brennecke@tu-braunschweig.de | Telefon +49 (0) 531 391-5393

Motivation

Conventional silicon photovoltaic cells are restricted to a theoretical highest efficiency of 30%.[2] More efficient photovoltaic cells with e.g. gallium arsenide (GaAs) have already been developed but are still highly expensive.[3] Harvesting sunlight with affordable solar concentrators and redirectioning it onto smaller areas of these expensive photovoltaic cells reduces the overall costs and makes it even possible to collect diffuse light.[1] Previously, these systems are still suffering from intrinsic loss mechanisms outweighing their benefits. Here, we present a high efficiency light-harvester allowing for efficient collection of light without these intrinsic loss mechanisms.

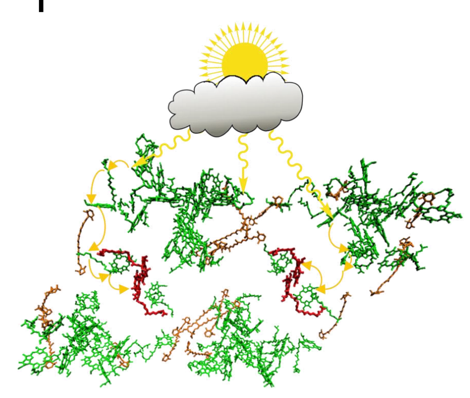
Intrinsic Loss Mechanisms

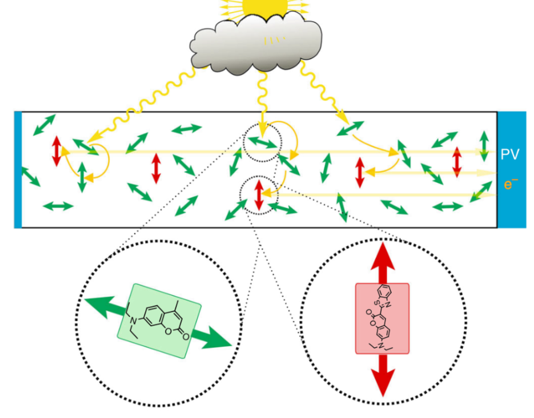
In artificial light-harvesters, sun light is absorbed by randomly orientated fluorophores, reemitted and directioned onto the photovoltaic cell by total internal reflection (TIR) waveguiding. However, the light is mostly emitted in angles which are not suitable for TIR. As a consequent, the light is not reflected at the waveguide-air boundary and can escape from light-harvester.[4] Another problem is the reabsorption of emitted light: Because of the high concentrations necessary for full absorption the light is reabsorbed on its way to the photovoltaic cell, losing energy with every absorption process.[5]

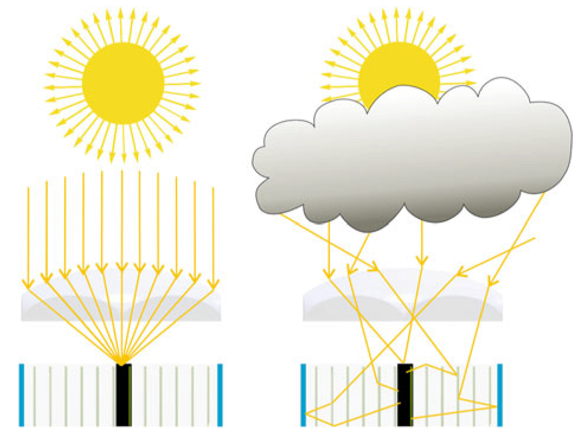


Improving Efficiency

Nature has developed an exceptional efficiency in harvesting light: in antenna complexes, diffuse sunlight is captured and funneled towards the reaction center.[6] Using a similiar concept to funnel light towards photovoltaic cells allows for a removal of intrinsic losses in a simple but efficient way.





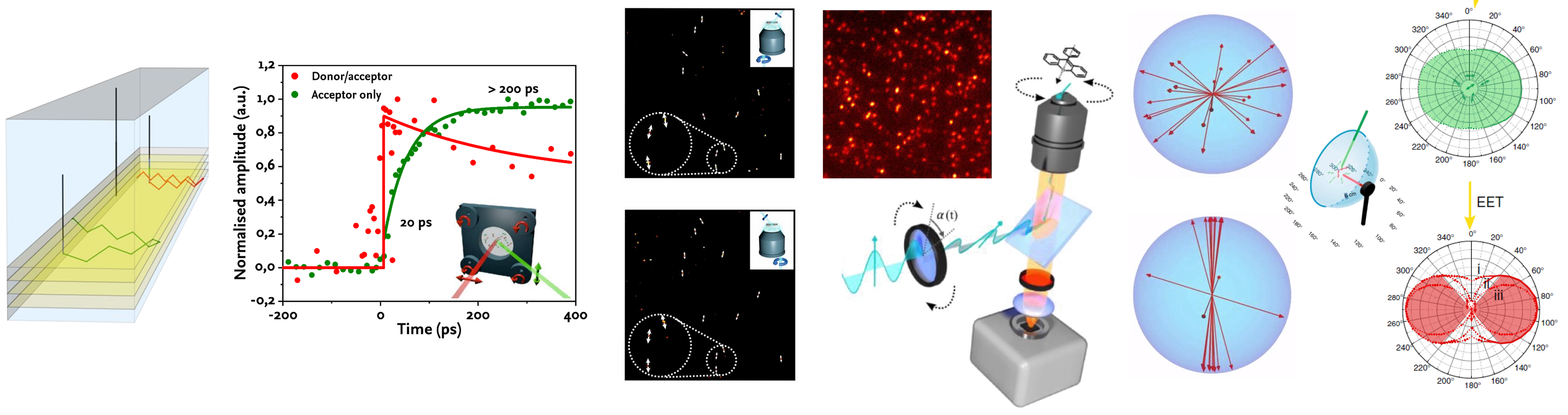


In our concept, we use two pigments: one of them randomly orientated and another with a defined orientation in the waveguide material. The first one (donor) absorbs direct and diffuse sunlight from all directions and transfers the energy radiationlessly to the second one (acceptor). The acceptor can now reemit the light in an angle suitable for TIR because of its defined orientation. By choosing a high concentration of donor, much sunlight can be captured. Reabsorption is avoided by a smaller concentration of acceptor molcules reemitting the redshifted light which can not be absorbed by donor molecules. In 2018, we showed that this system reaches extremely high efficiencies listed in the table below.[1]

Absorption of blue light	Energy transfer & acceptor fluorescence	TIR efficiency	Reabsorption losses
99%	> 90%	> 90%	< 0.5%

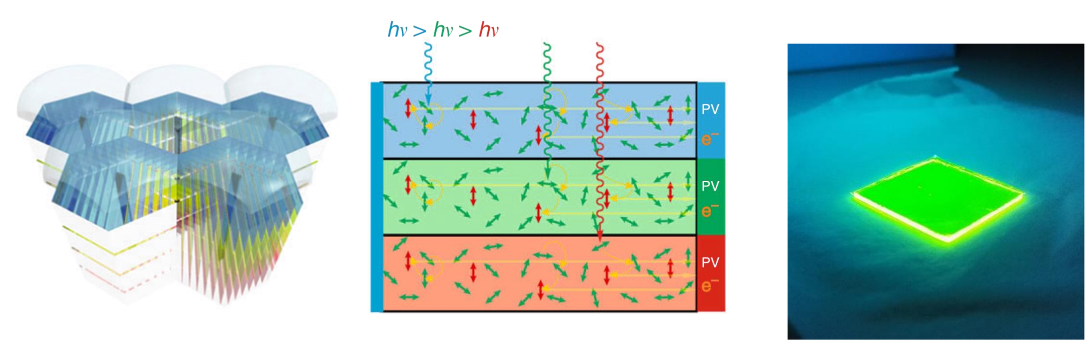
Characterisation

To characetrise the system, we use various methods: Photogoniometry shows how much energy is redirecetd in which angle, a widefield 3D single molecule microscopy allows to analyse the distribution of angles of orientation and pump-probe experiments characterise the velocity of the ultra fast energy transfers. We also use ray tracing simulations to model and analyse different geometries for the light-harvester.



Application

To collect as much of the sunlight as possible, several layers specific for different wavelengths need to be organised in suitable geometries. Currentrly, we are investigating the ideal geometry by computer simulations and the fabrication of different prototypes.



Fabrication

In practice, the way we generate such systems is as simple as effective: We found that there is one class of fluorescent dyes which is aligned by mechanically streching a polymer and another one which remains randomly orientated. By Choosing one from the first class as an acceptor and one of the second class as a donor the desired system can be easily built.[1]

References

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