# UPCONVERSION QUANTUM YIELD OF LANTHANIDE BASED UPCONVERTERS – ITS DEPENDENCE ON LANTHANIDE DOPING AND EXCITATION SOURCES

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The efficiency of solar cells can be increased by spectral conversion of the broad solar spectrum. Especially for single band-gap solar cells the largest losses are due to a mismatch between the solar spectrum and the discrete band-gap energy. For silicon solar cells, roughly 35% of the energy are lost by thermalization of the excessive energy of photons with more energy than the band-gap energy, while photons with less energy than the band-gap energy are simply not utilized. These sub-band-gap photons carry roughly 20% of the total solar energy that reaches the earth's surface. Upconversion denotes the absorption of two or more photons and emission of a photon with higher energy than the previously absorbed ones (see Fig. 2(b)) [1]. Consequently, upconversion of the otherwise unused sub-band-gap photons is a promising concept to expand the usable spectral range of a solar cell further into the infrared and consequently increase the efficiency of the device [2]. The spectral conversion layer, e.g. the upconverter, can be attached to the rear side of the solar cell, as shown in Fig. 1. This is a big advantage of the upconversion concept, because it only demands bifacial solar cells, while the principle properties of the solar cell stay unchanged.

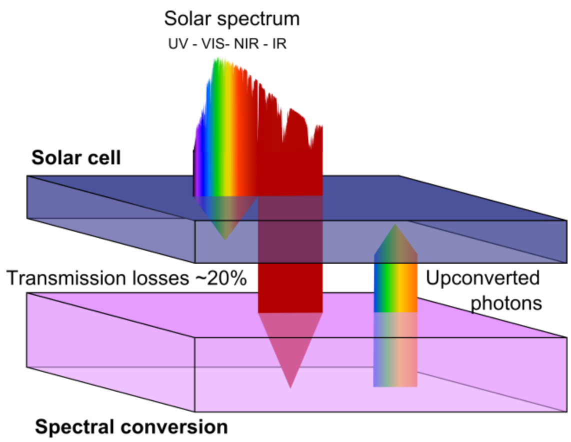


Fig. 1 Schema of an upconversion solar cell device. The sub-band-gap photons are transmitted through the bifacial solar cell and can be absorbed in the spectral conversion layer, generally the upconverter. The upconverted photons can be exploited by the solar cell.

While upconverter materials are commonly characterized under monochromatic laser illumination [3, 4], we investigate upconversion of sub-band-gap photons under the perspective of its application to harvest sun light, i.e. the questions that arise from illumination with a broad spectrum [5-7]. For this purpose, we have adapted our characterization and simulation methods to the needs of solar applications. We measured the upconversion quantum yield (UCQY) of various lanthanide based upconverter materials, and also investigated its dependence on the lanthanide doping, both under laser and low power broad-band excitation. We define the external UCQY (*eUCQY)* as the photon flux of upconverted photons divided by the incident photon flux of the excitation. Comparing different upconversion materials, we will discuss the significant changes of the *eUCQY* between some materials when illuminated under broad-band instead of laser excitation. For the broad-band excitation experiments, the light of a halogen lamp was clipped by several long and short pass filters to investigate the *eUCQY* for four different excitation profiles.

We applied a spectral mismatch correction on the measured *eUCQY* of $\beta$-$NaY_{0.8}Er_{0.2}F_4$ [7] to calculate which efficiency gain can be expected by a silicon solar cell under illumination with sunlight. The investigated upconverter features a large *eUCQY* and a fairly broad absorption spectrum. The excitation spectrum follows the ground state absorption spectrum of $Er^{3+}$ and is shown in Fig. 2 for the emission of photons at 980 nm. Considering the broad-band excitation, we found that much lower solar concentrations are necessary to increase the short-circuit current of silicon solar cells significantly compared to those previously determined for monochromatic laser illumination.

The largest increase of the additional short-circuit current due to upconversion was calculated for the broadest excitation profile. For a comparatively low solar concentration of only 46 suns we determined an increase of the short-circuit current by 1.8 mA/cm$^2$. Changing the erbium doping level alters the UCQY and consequently the impact on the efficiency of the solar cell.

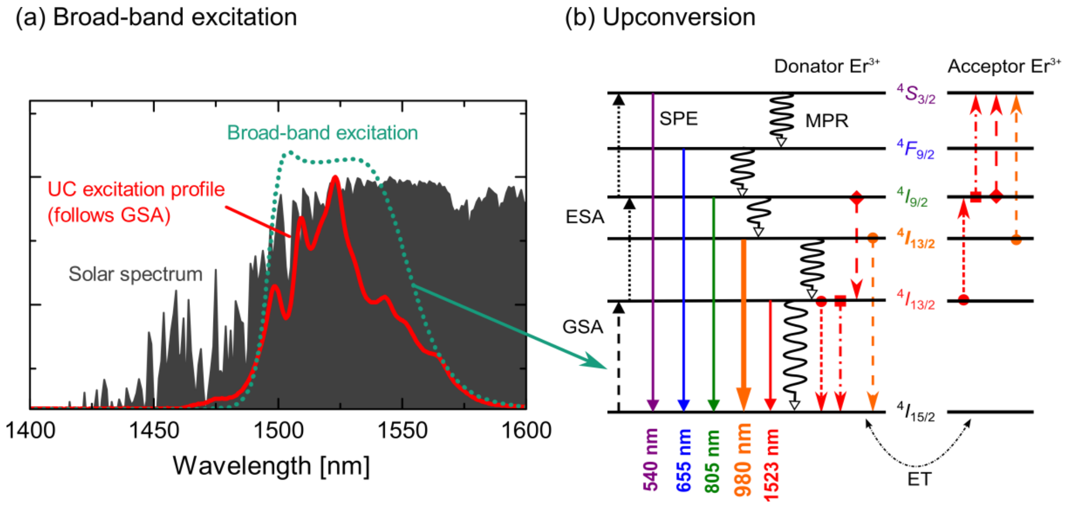


Fig. 2 (a) Broad-band excitation experiments are much more significant to investigate the potential of upconversion for photovoltaics. The upconverter $\beta$-$NaY_{0.8}Er_{0.2}F_4$ shows a fairly broad excitation spectrum for the emission of photons at 980 nm. Hence the fraction of absorbed photons from the solar spectrum AM1.5G is comparatively large. The experimental broad-band excitation spectrum and the solar spectrum show a large overlap with the GSA spectrum of $\beta$-$NaY_{0.8}Er_{0.2}F_4$ (b) Most important energy levels and UC processes of $Er^{3+}$ doped upconverters. Energy transfer (ET) from a donator ion to an acceptor ion is the most important UC process.

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