Phosphors for the improvement of silicon solar cell efficiency: general considerations and examples with new materials - $AgIn_5S_8$/ZnS core-shell nanocrystals and $Cs_2Ag_xNa_{1-x}Bi_yIn_{1-y}Cl_6$ powders

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The maximum efficiency of a single-junction solar cell is calculated from the principle of detailed balance, which reaches 33.7 % with a band gap of 1.4 eV (the Shockley-Queisser limit, s., for instance [1]). For multicrystalline Si with a band gap of 1.1 eV, the maximal value of the power conversion efficiency is estimated to be 29 % [2].

To overcome the efficiency limit, the spectral absorption range of the Si cells can be modified by luminescent materials. The detailed balance calculations done by T. Trupke et al. [3,4] show that the power conversion efficiency of Si solar cells can be improved by using down- and/or up-conversion phosphors, to up to 37 %. Previously, we have analyzed the recent progress in the development of phosphors to utilize the infrared region of solar radiation to improve the solar cell performance with the help of rare-earth (RE) ion-doped up-conversion materials [5]. New trends in RE-ion-doped phosphors are briefly discussed in this paper, among them trivalent RE-ion-doped up-conversion materials for organic solar cell applications.

In addition to the analysis of the given concepts and a review of the best achievements, new experimental results using the concept of UV-down-to-Visible light conversion for the PCE improvement of commercial Si solar cells and modules will be presented. These light-conversion layers are based on highly luminescent $AgIn_5S_8$/ZnS core-shell nanocrystals and double-perovskite $Cs_2Ag_xNa_{1-x}Bi_yIn_{1-y}Cl_6$ powders.

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