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Upconversion in Solar Cells Involving Rare-Earth Ions: A Review

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Abstract

Spectral conversion for solar cells is a new idea that has the potential to greatly boost solar cell efficiency. Energy transfer up conversion (ETU) is the most likely and fastest up conversion procedure, and it is frequently employed in practical applications. Rare earth ions are attractive candidates for spectrum conversion because of their high luminescence efficiency and rich energy level structure, which provides for tremendous flexibility in photon up conversion throughout a broad spectral range (NIR-VIS-UV). This research examines the feasibility of employing rare-earth ions as up converters.

Keywords*: - Energy transfer, Up conversion, rare-earth ions*

INTRODUCTION

Given the severe depletion of traditional fossil fuels over the previous two decades, solar energy conversion has emerged as a key alternative. Because about 52% of the sun's energy flow is in the infrared, absorbing low energy photons can boost solar conversion effectiveness by up to 44%. The normal terrestrial Solar Spectrum is seen in Figure (1). The major source of energy loss in the conversion of solar radiation to electricity is referred to as spectral mismatch. While good cell surface texturing, ideal absorber design, and anti-reflective coating reduce reflection losses to improve cell efficiency, absorbing low energy photons remains a barrier [1-2]. Low energy photons are known to be absorbed by solar cells, but high energy photons are inefficiently utilised [3-4]. Adopting the sun spectrum through up conversion is a potential strategy for increasing theoretical efficiency beyond the Shockley-Queisser limit [5]. Up conversion is a third generation photovoltaics technology that is

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expected to boost efficiency over the S-Q limit [6-7]. According to the literature [8,] the possible relative improvement in efficiency for crystalline silica (c-Si) might be 32% and 35% for down and up conversion, respectively, computed for the typical 1000 -W/m2 air mass 1.5 Solar Spectrum.

Spectral Conversion:

Up-converting solar cells try to boost photovoltaic efficiency by catching subband gap photons while keeping the band gap constant. There are several potential up-converting structures, one of which is seen in Figure (2).

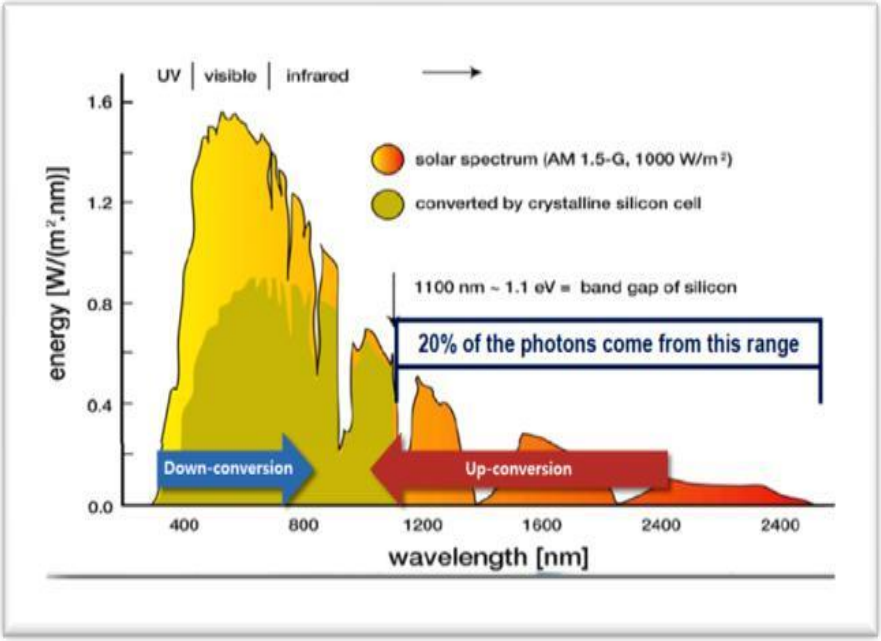


Figure (1): Standard Terrestrial Solar Spectrum

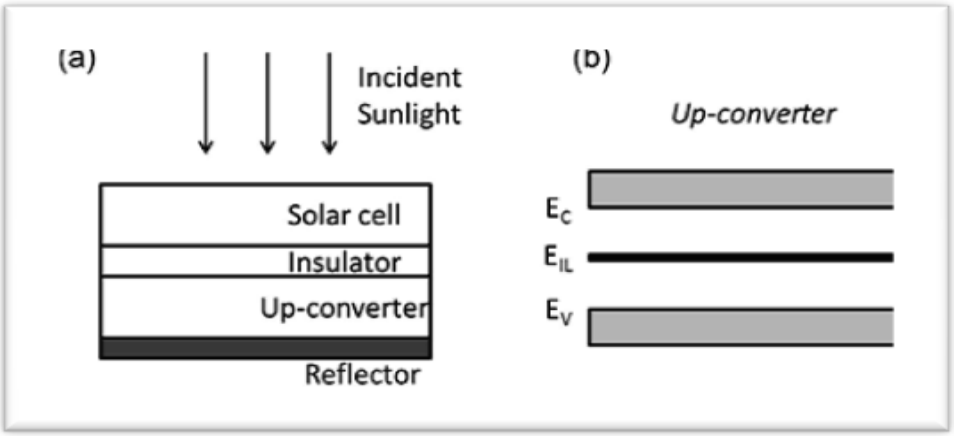


Figure 2: (a) A Schematic of up-converting Solar Cells.

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Because silicon solar cells transmit low energy photons, the up converter should be located in the back. This method avoids the problems involved with light coupling into the cell. To minimise extra recombination of electron-hole pairs via the up converter's energy levels, the up converter should be electrically insulated from the solar cell. The placement of an appropriate reflector behind the up conversion layer guarantees that no useable luminescence escapes out the back of the solar cell.

The up converter consists of a material with a band-gap which equals to the band-gap energy of the solar cell E_g, and contains intermediate levels with an energy E_1 above the valence band edge of the up converter. The absorption of sub-band-gap photons in the up converter leads to the generation of electron–hole pairs via two sequential transitions from the valence band into the intermediate level, and from the intermediate level into the conduction band. These electron–hole pairs recombine via radiative band-to-band transitions, accompanied by emission of photons with energies at the band-gap.

In up conversion, two or more incoming photons generate at least one photon with a higher energy than the incoming photons. These higher photons are directed back to the solar cell and absorbed, thus increasing the efficiency. The number of photons that may be up-converted is limited by the absorption range of the up-converter and the efficiency of up-conversion. If the absorption range of the up-converter can't be increased, one possibility of enhancing the number of photons accepted by the up converter is to use photoluminescence to shift photons with wavelengths longer than the band gap of silicon and less than the absorption range of the up-converter into this absorption range of the up-converter.

Rare –Earth doped Up-Convertors:

For up conversion solar cells, rare-earth ions are ideal candidates. The most impressive feature about the spectra of rare- earth ions in glasses and ceramics are the sharpness of many bands in absorption and emission spectra transitions in VIS-IR region to serve as active centers in the solid state laser materials because of the shielding effect of the outer most electrons [9-10]. Up conversion process can take place within a single type of rare-earth dopant ion, or it can involve energy transfer between two or more types of ions co-doped within the same host

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material. Through several types of up conversion mechanisms exist, the energy transfer up conversion mechanism is the most efficient and fastest one and so widely used in practical applications.

The Energy transfer process of populating E_2 is via sequential excitation from G to E_1 and then to E_2. The required energy to excite the electron from E_1 to E_2 is provided through a non-radiative relaxation process, transferring the energy between two adjacent ions in the system. The exciting ion is called sensitizer and the other one, relaxing to the ground state via a radiation process is called activator or emitter which is as shown in Figure (3).

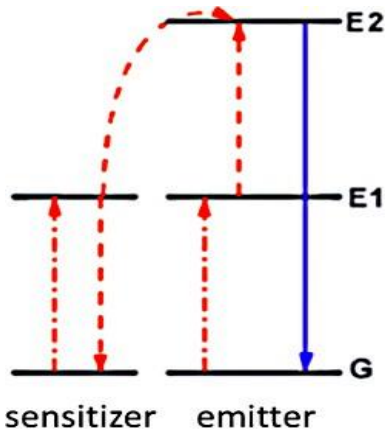


Figure 3: Energy level and energy transfer process in an Energy transfer up conversion

An up converter usually combines an active ion of which the energy level scheme is employed for absorption and a host material in which the active ions is embedded. Up-conversion process has been demonstrated in many systems, mostly consisting of active ions [11-12] in a host material. For silicon solar cells, the trivalent Erbium is a good choice for the active ion [13] because it absorbs at wavelengths lower than that wavelength, which corresponds to the band gap of silicon (1.1μm) and emits within the absorption range of silicon. The width of the absorption range and the up- conversion efficiency are both depend strongly on the host-material. As reported in the literature [14-15], the most efficient up conversion process observed in Yb^{3}+- Er^{3}+ doped rare-earth ions. Figure (4) represents the energy level diagram of Yb^{3}+- Er^{3}+couple.

Yb^{3+} ion which absorbs around 1000 nm and transfers the energy from the $^{2}F_{5/2}$ level to the $^{4}I_{11/2}$ level of Er^{3+}. Subsequent energy transfer from a second excited Yb^{3+} ion to Er^{3+} ($^{4}I_{11/2}$), excites Er^{3+} ion to the $^{4}F_{7/2}$ excited state. After multi- phonon relaxation to the low lying $^{4}S_{3/2}$ and $^{4}F_{9/2}$ states, green and red emission are observed.

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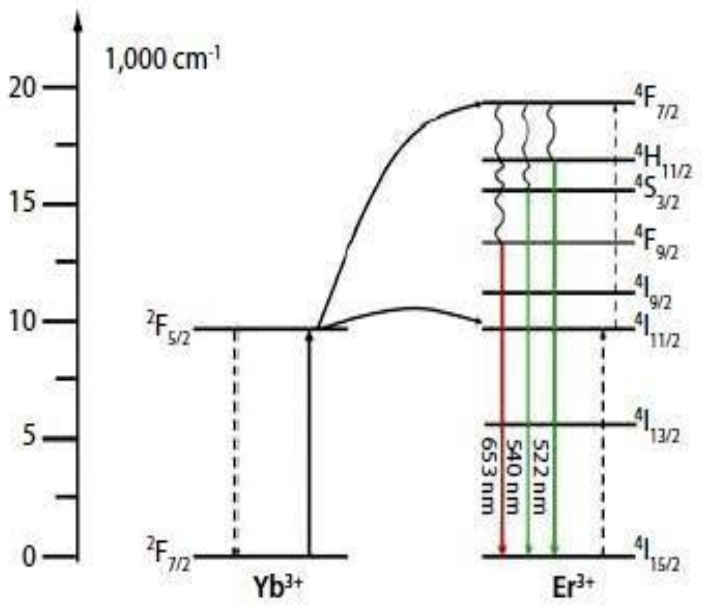


Figure 4: Schematic energy level diagram for the Yb^{3+}- Er^{3+}

CONCLUSION

The contribution of up conversion research to up converter solar cell research is steadily increasing. Up conversion efficiencies are currently poor. Furthermore, broadening the absorption spectrum is critical since the absorption lines for rare-earth up converters are narrow and absorption intensities are low for the parity prohibited transitions inside the 4fn arrangement. A sensitizer having a broad absorption band and a short emission line resonant with the rare-earth absorption line can be used to broaden the absorption spectrum for rare-earth up converters. Sensitization can be accomplished using either an exterior sensitizer (such as quantum dots) or an internal sensitizer (e.g., transition metal ions). Even more difficult are strategies for increasing conversion efficiencies by modulating emission and excitation processes via plasmonic coupling. The application of plasmonic phenomena to up conversion materials is a new and evolving subject with numerous opportunities and problems.

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