

ABSTRACT

Spectral conversion for solar cells is an emerging concept and it has the potential to increase the efficiency of solar cells significantly. Among various up conversion processes, the energy transfer up conversion (ETU) is the most probable and fastest one widely used in practical applications. Rare earth ions are ideal candidates for spectral conversion, due to their high luminescence efficiencies and rich energy level structure that allows for great flexibility in the up conversion of photons in a wide spectral region (NIR-VIS-UV). This paper, reviews the potential of using rare-earth ions as up converters.

KEYWORDS: Up conversion, energy transfer, rare-earth ions

I. INTRODUCTION

Solar energy conversion has become one of the major alternatives to the conventional fossil fuels, considering their drastic depletion over the last two decades. As almost 52% of sun energy flux being in the IR, the solar conversion performance can further be improved if low energy photons are absorbed and enhanced up to 44%.

Figure (1) shows the standard terrestrial Solar Spectrum. The main energy loss in the conversion of solar energy to electricity is related to the so called spectral mismatch. While proper texturing of the cell surface, designing perfect absorbers and anti-reflective coating alleviate the reflection losses to enhance the cell efficiency, the issue of absorbing low energy photons is still a challenge [1-2]. It is known that the low energy photons are not absorbed by solar cell while high energy photons are not used efficiently [3-4]. A promising approach to raise the theoretical efficiency beyond Shockley- Queisser limit [5] is to adopt the solar spectrum through up conversion. Up conversion is a third generation photo voltaics which is predicted to be able to increase the efficiency above the S-Q limit [6-7]. As reported in the literature [8], for crystalline silica(c-Si), the potential relative gain in efficiency could be 32% and 35% for down and up conversion respectively, both calculated for the standard 1000 –W/m² air mass 1.5 Solar Spectrum.

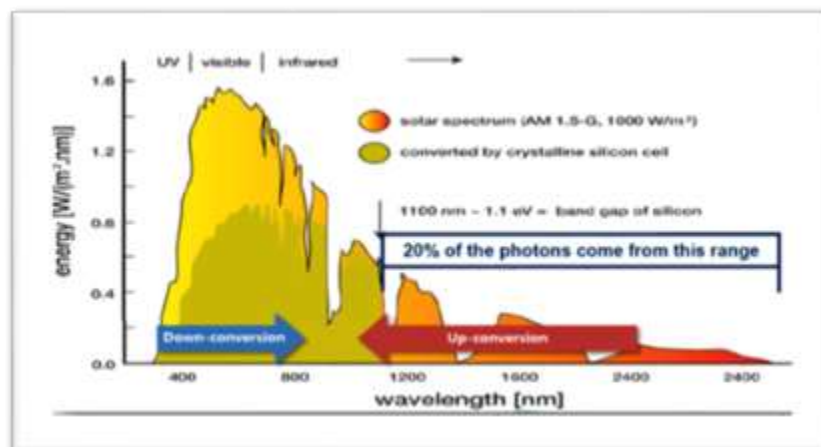


Figure (1): Standard Terrestrial Solar Spectrum

Spectral Conversion:

Up-converting solar cells attempt to increase the photovoltaic efficiency by capturing sub band gap photons without decreasing the band gap. There are a variety of potential up-converting structures, a common one is as shown in Figure (2).

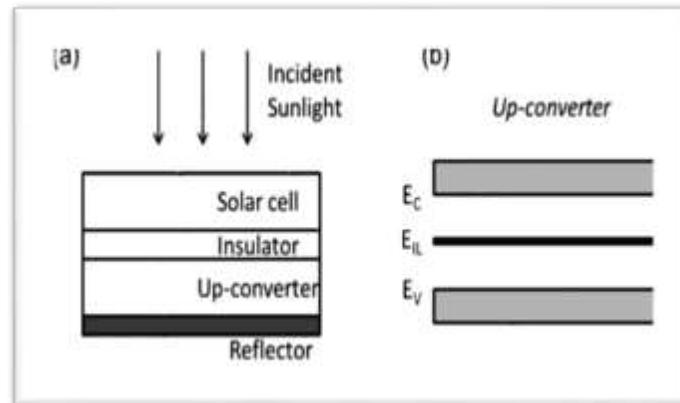


Figure 2: (a) A Schematic of up-converting Solar Cells.

The up-converter absorbs photons with energies less than the band gap of the solar cell, through an intermediate level as shown in the band diagram in (b).

Since low energy photons are transmitted through silicon solar cells, the up converter should be placed on the rear. This has the advantage of avoiding complications associated with light coupling into the cell. The up converter should be electrically isolated from the solar cell to avoid additional recombination of electron-hole pairs via the energy levels of the up converter. The use of a suitable reflector placed behind the up conversion layer ensures that no usable luminescence can escape out the rear 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 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).

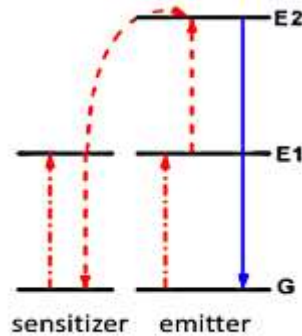


Figure 3: Energy level and energy transfer process in an Energy transfer up conversion

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 (1.1 μm) 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.

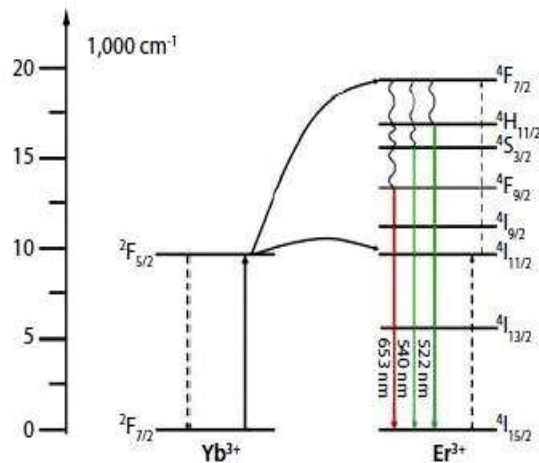


Figure 4: Schematic energy level diagram for the Yb^{3+} - Er^{3+}

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

II. CONCLUSION

An over view of the contribution of up conversion research to up converter solar cell research increases rapidly. Presently, up conversion efficiencies are still low. In addition, it is crucial to broaden the absorption spectrum, as the absorption lines for rare-earth up converters are narrow, and absorption strengths are low for the parity forbidden transitions within the $4f^n$ configuration.

Broadening of the absorption spectrum for rare-earth up converters can be achieved by using a sensitizer with a broad absorption band and a narrow emission line resonant with the rare-earth absorption line. Sensitization can be achieved by an external sensitizer (e.g., quantum dots), or an internal sensitizer (e.g., transition metal ions). Even more challenging are options to enhance up conversion efficiencies by manipulating emission and excitation processes through plasmonic coupling. The use of plasmonic effects with up converter materials is a new and emerging field, with many possibilities and challenges.

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