Up-Converters and their Role in enhancing Conversion Efficiency of Solar Cells

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Abstract The Silicon solar cells used for extraction of solar radiations generally have a low spectral conversion efficiency. It is because of the spectral mismatch between the energy distribution of sunlight and band gap of solar cell material. A generic approach for improving efficiency of solar cell is to manipulate sunlight prior to conversion by solar cell. Spectral conversion or spectral modifications can be carried by using spectral converters, like Up-converters UC's (absorbs high wavelength photons and emits into low wavelength photons) down converters (absorbs low wavelength photons and emits high wavelength photons) respectively. The present paper reviews the UC's their properties, mechanism and role in modifying solar spectrum

***IndexTerms* – Upconverter, solar cells**

I. INTRODUCTION

The range of solar radiation available on the surface of earth ranges from 280 to 4000 nm. The harnessing of these radiations by solar cells for different applications have many limitations arising from sub-band gap losses of cell. The major reason for it is spectral mismatch between energy of radiations available to energy which can be absorbed by solar cells. The Silicon solar cells used for mining of solar energy are reported to have low spectral conversion efficiency because of the incongruity between the energy distribution of sunlight and band gap of solar cell material [1]. In the case of photons with energies more than the band gap energy, dissipation of the excess amount of energy as heat takes place. Whereas if the solar radiation photons incident on material have energies less the band gap then radiations are not absorbed consequently no electron hole pairs are created [2]. For optimal energy conversion the majority of the solar spectrum needs to be used [3]. A generic approach for improving efficiency of solar cell is to manipulate sunlight prior to conversion by solar cell. This can be done by modifying the photon energy of the spectral content of incident sunlight so that more photons with energy equivalent to the band gap are directed into the solar cells. Incident solar radiation can be modified by using a spectral converter, which absorbs (i) high wavelength photons and emits into low wavelength photons called Up-converters (UC's) and (ii) absorbs low wavelength photons and emits into high wavelength photons called Down-Converter (DC's). Efficiency of cell can be achieved by designing UC's/DC's materials, which can be passively used along with available solar cells to maximize the use of sunlight in the infrared, ultraviolet and visible spectral regions

2. SPECTRAL CONVERSION

Spectral modification refers to modulation of the available solar radiations, for its efficient harvesting. Different ways of achieving spectral conversion are:(a) upconversion (UC), in which absorption of low-energy (sub-bandgap) photons results in creation of high-energy photon; (b) downshifting takes place when high energy photon is converted into one lower energy photon; and (c) quantum cutting or downconversion, is other way of spectral conversion in which absorption of one high-energy photon is followed by emission of two lower energy photons.

3. UPCONVERSION PRINCIPLES

Upconverter's comprises of an active ion having a long lived excited intermediate states, a host material, in which the active ion is incorporated. The mechanisms involved for the upconversion process involves (i) Energy transfer UC (ETU), which is prominent when two types of luminescent centers, termed as activator and sensitizer, are used. On absorbing photons of lower energy, the color centres activators and sensitizer would be excited. A non radiative energy transfer from the sensitizer to the adjacent activator results in sequential excitation of the activators to the higher excited states, followed by radiative emission (ii) by absorbing one low energy photon, transition of electron from ground to intermediate metastable states takes place, followed by absorption of a second photon resulting in promotion of electron to a higher excited state.

When a transition to the ground state is radiative, the UC emission is observed. Auzel discovered that higher excited states of ion might be populated through successive energy transfer steps from a neighboring ion. Whereas, Forster and Dexter showed that the energy transfer in RE–doped samples are mostly by means of electric multipole interactions. Since the spectral features and the overall efficiency of the UC process strongly depend on the host material and dopand electronic levels, a lot of effort has been done to produce efficient upconverter materials by considering these influencing factors.

4. UP-CONVERTERS

As mentioned earlier UC's are composed of a host material doped with optically active sensitizer and activator ions [4-7]. In principle, an UC material must have its absorption range towards higher wavelength relative to the band gap of the solar cell material and, radiative emission slightly above the band gap, where the cell has its maximum absorption.

4.1 Activators/ sensitizers

Activators are dopands (i.e transition or rare earth ion), with characteristic spectroscopic properties, further the energy levels of these ions are utilized for tuning of the emission and absorption spectra as per the application. Researchers have shown that transition group ions and rare earth ions embedded as impurities (dopands) in the host lattices have the ability to perform light UC due to the richness of their energy level structure. Lanthanides or the trivalent rare earth ions with their electronic configuration 4fn ($0 \leq n \leq 14$) offers as a competent luminescent centres. Their luminescent properties originates from large number of permitted transitions within the 4f electrons. In comparison to the 5s and 5p orbitals the f electrons have a smaller radial extension, hence the susceptibility to crystal field, electron–phonon coupling strength, and exchange perturbations are weakened for rare earth ions. In comparison to rare earth ions transition metal (TM) ions have a smaller orbital shielding so have large ability to interact with their structural environments. This allows optimization of the spectral positions of the absorption and emission peaks by changing the host lattice. The spectral peaks of transition metals ions are broad and intense, which may be due to a strong lattice–host coupling, thus are efficient for UC. Further transition metal ion system follows same up-conversion mechanism as employed by rare earth ions. While designing the upconverter, choice of second constituent (host matrix) and the energy transfer between three is critical. The energy transfer processes between different constituents can be controlled by selecting suitable dopand-host pairs. A dopand with large absorption cross-section at the desired excitation wavelength can be termed as sensitizer in addition it should have resonant energy levels to those of the activators. Among all the RE ions, the absorption cross-section of Yb^{3+} is 9.11×10^{-21} cm^{-2} at 980 nm, which is significantly large among all RE ions, thus is the exclusive sensitizer. Further ,Yb^{3+} is known to have a excited state ($^2F_{5/2}$) that resembles with the f-f transitions of many RE activators, e.g., Er^{3+}, Ho^{3+}, Tm^{3+}, etc. and therefore Yb^{3+} is an excellent sensitizer to transfer energy to other RE ions. For example, the $^2F_{5/2}$ state of Yb^{3+}overlaps the $^4I_{11/2}$ state of Er^{3+}, permitting Yb to Er energy transfer[3]. The energy level structures of, Tm, Ho , and Er ions in their trivalent state are ideal to minimize nonradiative relaxations. Trivalent erbium have a ladder like equally spaced energy levels that are in multiples of the $4I_{15/2}$ to $4I_{13/2}$ and ideally suited for upconversion of near-infrared (NIR) light, the emission spectrum of dysprosium is similar to that of erbium. The Yb^{3+} ion has only one excited state and is an ideal sensitizer for Er^{3+} and Dy^{3+}because of the relatively high oscillator strength of the $2F_{7/2} \rightarrow 2F_{5/2}$ transition and the fact that Er^{3+} and Dy^{3} has a energy state with similar energy ($4I_{11/2}$) which is populated by energy transfer from Yb^{3+}. The upconversion emission can be controlled by minimising the quenching , which can be avoided by keeping, the concentrations of activators low while one or more types of RE ions with high concentration are incorporated as sensitizers. The main objective of an upconverter is to tune the energy of the photons so as to have maximum responseto solar spectrum[4].

4.2 THE HOST MATRIX

The Matrix in which the UC ions are embedded are termed as Host. The varying parameters which distinguishes host matrices from each other are, distance between dopands, energy transfer efficiency and coordination numbers. Thus choice of the host material is significantly important, they should be thermally and chemically stable and to avoid nonradiative relaxations they must possess low-phonon energies. In addition it should have high acceptance for activator and sensitizer ions. The position of spectral lines and their luminescence intensities are different for different host lattices because of their varying inherent optical, and a host–ion interaction. The optical properties of ion under consideration are also influenced by the the electric field at its site which is also termed as crystal field (CF).Further CF influences the optical transitions of metal ions and thereby redefines the splitting pattern and spectral. Thus the choice of host lattice while tailoring a material for spectral conversion should result in a perfect lattice tone permitting the incorporation of impurities without a lattice alteration, and take the host–dopant interaction into account[3-4]. An example is the incorporation of 1% Er^{3+} in Cs3Lu2X9 (X = Br,I,Cl,) lattices, which permits a long–lived $4I_{9/2}$ excited state to attain efficient photon UC processes [5]. For a hosts with low phonon energies a lower non-radiative decay rate is expected, leading to an increase of the emission efficiency.

The specific host materialsin accordance to Phonon energies can be placed as :

Iodide (160 cm^{-1}) < bromide (175–190 cm^{-1}) < chalcogenide, chlorides (200–300 cm^{-1})< fluoride (500–600 cm^{-1}) < silicate (1000–1100 cm^{-1}) < phosphate (1100 cm^{-1}) < borate (1400 cm^{-1}).The probability of non radiative transitions is reported to decrease for hosts with a low phonon energy. Most efficient host for UC phosphors are Halides [5-7].

5 CONCLUSIONS

Luminescent Upconversion (UC) is an efficient way to capture near-infrared (NIR) radiations and improve power conversion efficiency of solar cells.The UC emission can be achieved by tailoring the three constituent of UC materials and their spectroscopic properties by doping ,co-doping and tri-doping. The UC process by sequential absorption of two or more low energy photons into visible or UV, minimizes the optical mismatch in solar cells, resulting in decrease in thermalization loss of solar spectra and increasing the conversion efficiency of the solar cell. However, these numbers may further be increased in forthcoming years, by throughput analysis of combination of transition and rare earth ions embedded in different host lattices.

REFERENCES

[1] X. Y. Huang, S. Y. Han, W. Huang and X. G. Liu, Chem. Soc. Rev., 2013, 42, 173–201..

[2] B. M. van der Ende, L. Aarts and A. Meijerink, Phys. Chem. Chem. Phys., 2009, 11, 11081–11095

[3] M Y. N. Qian, R. Wang, B. Wang, C. Xu, L. L. Xing and Y. L. Xu, Opt. Lett., 2012, 37, 4176–4178

[4] R. M. Rodr´ıguez, S. Fischer, Ivaturi,. Froehlich, K. W. Kr¨amer, J. C. Goldschmidt, S. Richards and A. Meijerink, Chem. Mater., 2013, 25, 1912–1921

[5] A.S Gouveia-Neto, E.B da Costa,, L.A Bueno, S.J.L Ribeiro Optical Materials Volume 26, Issue 3, August 2004, Pages 271–274.

[6] A.Boccolini, R. Faoro, E. Favilla, S. Veronesi, and M. Tonelli·Journal of Applied Physics **114**, 064904(2013).

[7] Yannan Qian, Rui Wang, Biao Wang, Baofu Zhanga and Senpei Gaoa, RSC Adv., 2014, 4, 6652.