IMPROVEMENTS IN SOLAR CELLS

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ABSTRACT

To enable solar electricity from photovoltaics to be competitive with, or cheaper than, present fossil fuel electricity costs likely requires devices that operate above he existing performance limit of energy conversion efficiency of 32% calculated for single-junction cells. At present, the best single junction solar cells have efficiencies of 20-25%. New concepts, structures, and methods of capturing the energy from sunlight without thermalization of carriers are required to break through this barrier and enable solar cells having efficiencies of greater than 50%

INTRODUCTION

A grand challenge for photovoltaic is the development of high efficiency, low cost photovoltaic structure that can reach this ultimate thermodynamic efficiency limit. Several paths exist towards the realization of photovoltaic device with efficiency greater than 50% including multiple junctions solar cells (tandems) optical spectrum shifting, multiple electron/ excition generation, multiple energy level and hot carrier solar cells. The development of solar cells based on such principles would revolutionize photovoltaic by allowing high efficiency, cost effective solar cells, and further, contribute directly to the fundamental scientific advances.

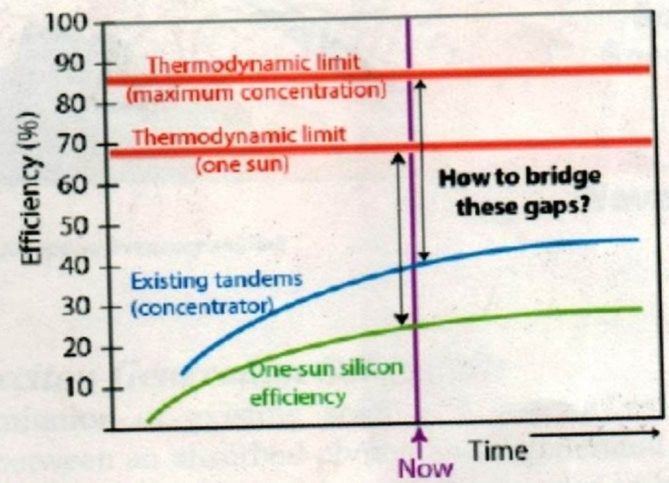

Figure-1 A grand challenge of photovoltaics: How to bridge the gap between existing photovoltaic devices and the efficiency limits?

Multiple Junction Solar Cells

Multiple junction solar cells, or tendem solar cells, consist of multiple, single junction solar cells joined together or stacked upon each other, with each solar cell absorbing the part of the solar spectrum closest to its band gap. Existing tandem devices have achieved efficiencies over 37% (1) at a concentration of 173 suns, and further efficiency- increase can be achieved by increasing the number of different junctions.

Optical Frequency Shifting

Optical frequency shifting cells involve the transformation of the solar spectrum from one with a broad range of energies to one with the same power density but a narrow range of photon energies (Figure 2). One central feature fo these approaches, which include up and down convesion (2,3) is that the transformation of the solar spectrum is done separately with a material that is not a part of the actual solar cell, thus increasing the efficiency of an existing solar cell structure via additional coatings or external element.

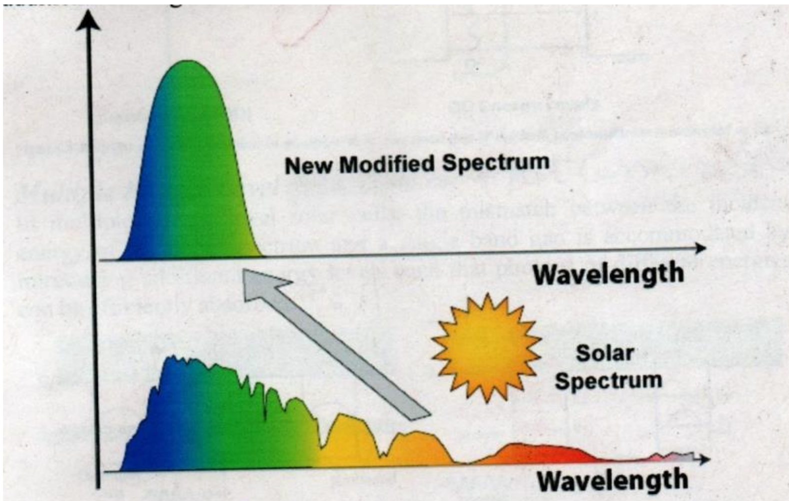

Figure-2 Schematic for optical frequency shifting

Multiple Excition Generation

A central limitation of existing various solar cell approaches is the one to one relationship between an absorbed photon and a generated electron hole pair. The process of impact ionization known for decades in bulk semiconductor crystals, allows the conversion of single high energy photons to multiple electron hole pairs, but with relatively low efficiency. Recent experimental reports of multiple exciton generation (MEG) in nano-sized (quantum dot) semiconductors indicate much more efficient generation of multiple electron hole pairs compared to bulk materials (see Figure-3) (4,5)

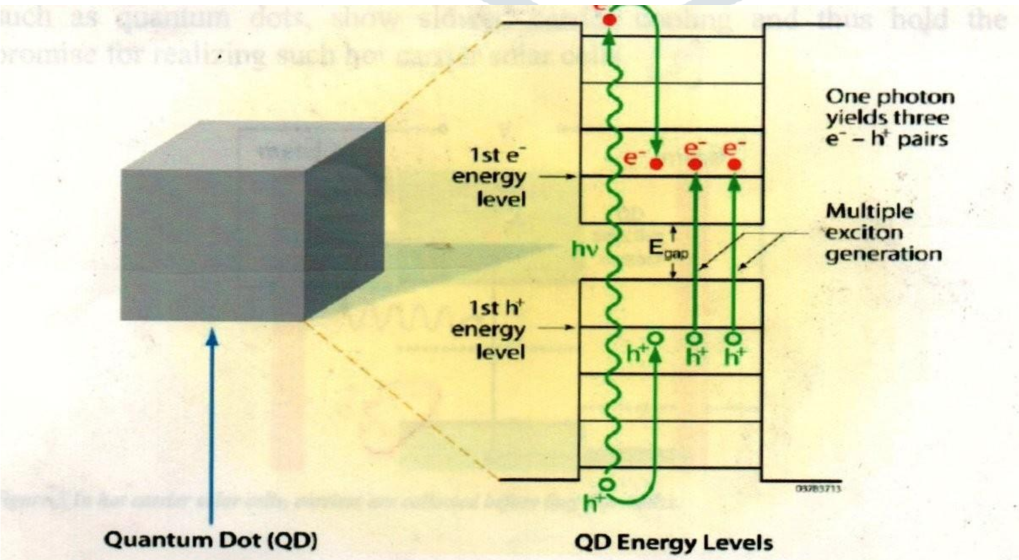

Figure-3 Multiple exciton generation in quantum dots. The band gap of the bulk semiconductor is indicated as Eg.

Multiple Energy Level and Hot Carrier Solar Cells

In multiple energy level solar cells, the mismatch between the incident energy of the solar spectrum and a single band gap is accommodated by introducing additional energy levels such that photons of different energies can be efficiently absorbed (6,7)

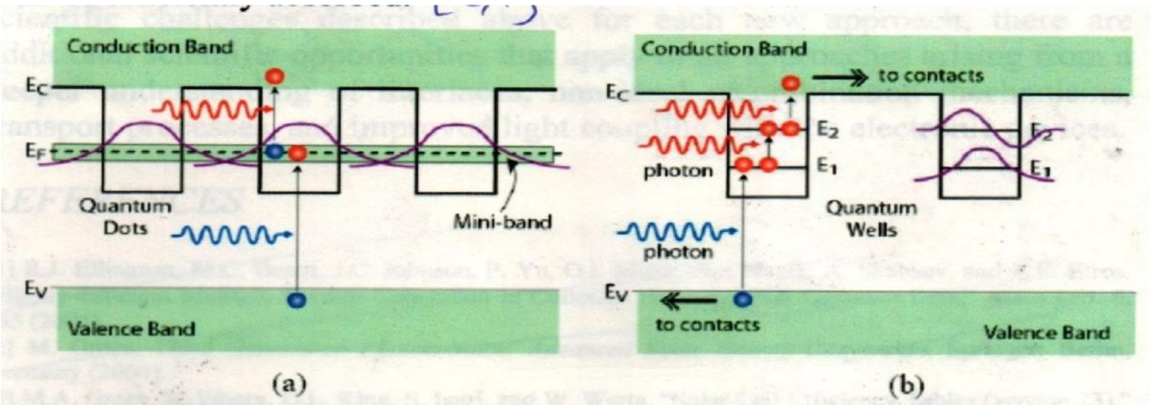

Figure-4(a) Intermediate band solar cell and (b) quantum well solar cell

Hot carrier solar cells utilize selective energy contacts to extract light generated hot carriers (electrons and holes) from the semiconductor regions before they have thermalized with the semiconductor lattice (i.e. converted their excess energy to heat). This allows higher efficiency devices (upto to a thermodynamic limit of 66% at one sun intensity) by reducing the thermalization (heat) losses in single junction solar cells. Specific materials, in particular, materials with low dimensions such as quantum dots, show slowed carrier cooling and thus hold the promise for realizing such hot carrier solar cells. (8)

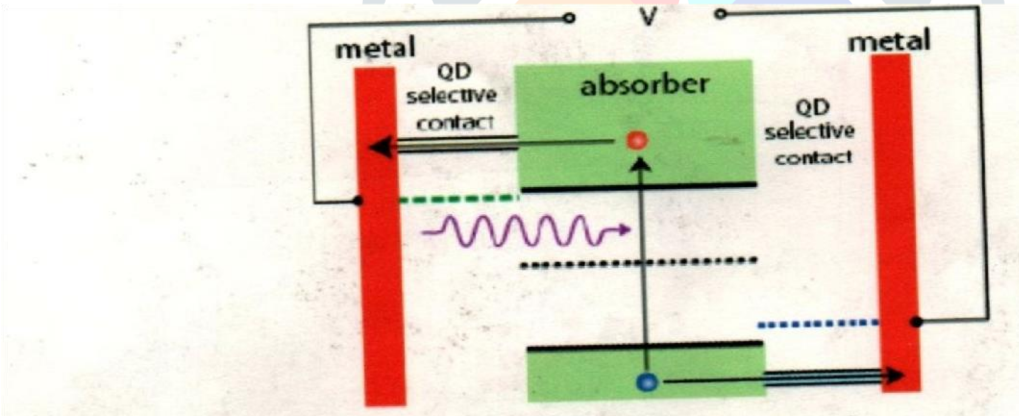

Figure-5 In hot carrier solar cells, carriers are collected before they thermalize.

CONCLUSION

Despite the promise of the new approaches utilizing novel phenomena and materials for energy conversion, substantial scientific challenges exist in understanding and realizing photovoltaic devices that produce > 50% efficiency in cost-effective device structures. In addition to the fundamental scientific challenges described above for each new approach, there are additional scientific opportunities that apply to all approaches arising from a deeper understanding of inter faces, non-ideal recombination mechanisms, transport processes and improved light coupling with the electronic devices.

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