ISSN 2347 - 3258
International Journal of Advance Research and Innovation
National Conference on Modern Trends in Analytical & Environmental Physics (Hindu College, Moradabad)

Path Towards 25% Efficient Solar Cells and Beyond

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Article Info
Article history:
Received 02 April 2017
Received in revised form
20 May 2017
Accepted 28 May 2017
Available online 15 June 2017

Keywords: Solar cell, tendem device, band gap

Abstract

Tandem solar cells have shown efficiencies beyond the single-junction Shockley–Queisser limit which has led researchers to develop thin film tandem solutions for high performance low cost solar cells. These solar cells have recently emerged as a promising candidate for photovoltaics. In addition to ease of fabrication and good efficiencies, a particularly attractive feature is their tunable band gap between 1.48 and 2.3 eV. Early experimental results and modeling indicate that efficiencies beyond 25% are within reach. In this paper we review the most relevant design strategies of tandem solar cells for enhanced solar spectrum harvesting. Tandem solar cells offer for the first time the unique combination of high efficiency at high (and tunable) band gap, coupled with relatively low processing temperature that does not impair the functionality of the bottom absorber. This dramatically extends the range of design possibilities of high-efficiency tandem solar cell.

1. Introduction

To meet the global demand of energy, existing energy networks are not adequate. Finding sufficient supplies of clean energy for the future is one of the most daunting challenges of the society [1]. Photovoltaic energy is one of the most promising possible solutions to the power shortage and oil dependency of the World.
Shockley Queisser Efficiency Limit or SQ Limit refers to the maximum theoretical efficiency of a solar cell using a single p-n junction to collect power from the cell. The limit places maximum solar conversion efficiency around 33.7% assuming a single p-n junction with a band gap of 1.34 eV (using an AM 1.5 solar spectrum) that is, of all the power contained in sunlight falling on an ideal solar cell (about 1000 W/m²), only 33.7% of that could ever be turned into electricity (337 W/m²). [1-3]
The most popular solar cell material, silicon, has a less favourable band gap of 1.1 eV, resulting in a maximum efficiency of about 32%. Despite of the state of development, no single junction technology can realistically overcome the Shockley–Queisser limit of about 33%. The use of multi-junction solar cells, where two or more absorbing photovoltaic cells are monolithically connected on top of one another, allows higher efficiencies to be reached. However, multi-junction or tandem (when the number of junctions equals two) solar cells have found only a limited range of product applications due to issues with either cost, inadequate efficiency or material and process compatibility.[3-4]

2. Tandem Device Classification

Multi-junction or tandem solar cells use photovoltaic materials such as crystalline silicon, CdTe and CIGS. [5]
There are only two available technologies to develop monolithically integrated two-terminal tandem devices viz.
A- Amorphous silicon based which is relatively low-cost and low efficiency solar cell. [5-7]
B- The III–V multi-junction solar cells that hold the current efficiency record of 46% using GaInP/GaAs; GaInAsP/GaInAs, were the first to surpass the SQ limit and are currently the standard solution for highest efficiency concentrator and PV applications in space.
For the better optimal absorption, p–n junctions with a higher band-gap are stacked on top of those with a lower band-gap. [7-9]
There are several types of tandem solar cells depending on the fabrication sequence and interconnection scheme used. These are classified as type A and B based on the number of transparent conductive electrodes (TCEs) and the number of their contact terminals that ranges from two to four. [9]

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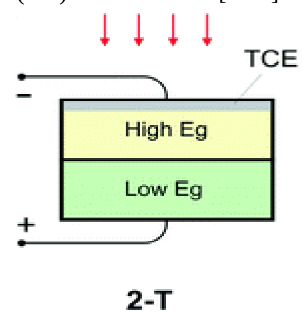
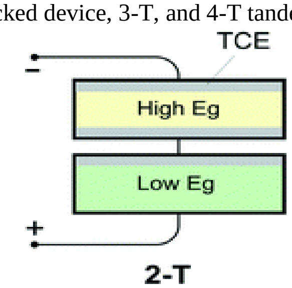
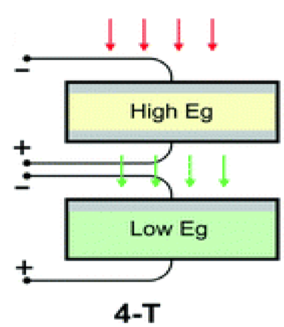
Type A tandem is a monolithic series interconnected device grown on a single substrate that employs one TCE, which implies that it is a two-terminal (2-T) tandem device.[9-11]



This is the configuration almost exclusively used in commercial products because it involves a minimum number of processing steps, substrates, layers and interconnections. [11-12]
Type B tandem solar cell uses additional transparent conductive layers and substrates; this type includes a 2-T (two terminal) mechanically stacked device, 3-T, and 4-T tandems. [12]





This way the individual devices from the stack can be fabricated independently, thereby also significantly expanding the processing tolerance window as well as simplifying the full device characterization [10-12].

Naturally type-A solar cells is extremely challenging because it requires compatibility of every processing step with all preceding layers and interfaces as well as precise optical and current matching between individual devices. On the other hand type-B solar cell is the configuration of choice for most research focused on non-traditional tandem solar cell concepts.

3.Conclusions

As a conclusion it can be said that the unique combination of high efficiency, tunable band gap and soft processing temperature of tandem solar cells has made them popular in just a couple of years. Significant progress has been achieved with both monolithic and stacked device configurations, the latter already reaching over 25% efficiency.

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