Parallel Integrated Solar Circuits for Split Solar Spectrum Light Source

Y. Li[*,**] and F. Shi[**]

[*]Texas A&M University, College Station, TX, USA, yingfeng@ece.tamu.edu
[**]Solar Energy Research Park and Academy, Northern New Mexico College, NM, USA, fshi@nnmc.edu

ABSTRACT

Among the various solar energy application technologies, the photovoltaic technology is, in particular, the most desirable technology for large-scale applications due to the fact that solar energy in optical form is directly transformed into electrical energy in a quite simple way. The parallel integrated multiple solar cell circuits for split solar spectrum light source presented in this paper takes a different approach. It manipulates the incident solar radiation by splitting the broad-band solar spectrum into narrow band components through optical instruments which are easily integrated into the photovoltaic system, and then guides the components onto the parallel integrated multiple solar cell arrays for different solar cells to convert each of the components with different photon energy. This approach processes concentrated solar radiation first, then converts the processed components respectively with parallel integrated solar cell array and collects photon-induced current in integrated electrode circuits. This approach adapts integrated circuitry to deal with concentrated sunlight thereby significantly reducing the area of the semiconductor and therefore greatly lowering the consumption of materials.

Keywords: solar cell, circuit, high efficiency, low cost

1 INTRODUCTION

As a clean, abundant and widely distributed renewable energy source, solar energy appears to be one of the most promising alternatives to fossil energy. However, photovoltaic technology suffers from low conversion efficiency and high cost per unit of energy production[1]. The drawback stems from the intuitive properties of solar energy itself and the current technical approach to photovoltaic conversion. As shown in Fig. 1[2], solar radiation is present in a broad band of spectrum extending from wavelength 0.25 μm to 2.5 μm corresponding to the photon energy 0.5 ev to 4 ev, which is a wide range of energy. Current photovoltaic technology mainly employs semiconductors to absorb solar radiation and separate the photon-exited electron-hole pairs to generate electricity. As shown in Fig. 2, the photon absorbed by the semiconductor with a fixed band gap must have energy equal to or greater than the band gap of the semiconductor to exit electron-hole pair, while it should not have energy greater than band gap as the photon-exited electron-hole pair would thermally relax to the band gap energy and dissipate the extra energy. For the broad solar spectrum, it is clear that no devices made of a single semiconductor with fixed band gap such as Ge, GaAs and GaInP shown in Fig.1 can efficiently convert solar energy into electricity.

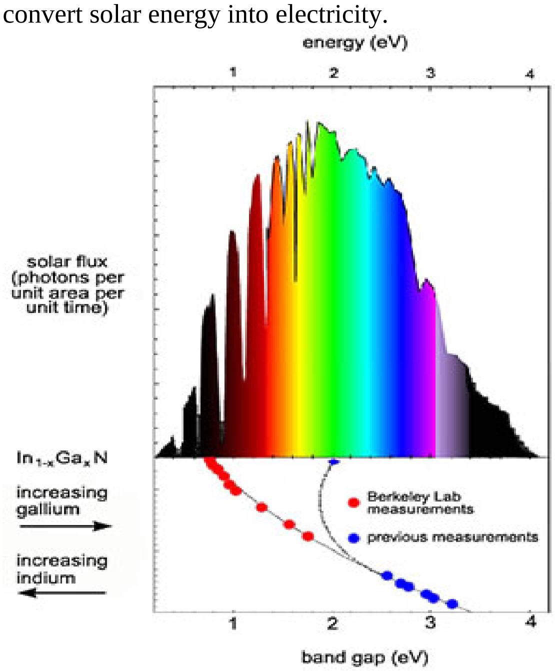

Figure 1: Air-mass-1.5 solar spectrum. The gap energies of conventional MJ solar cell materials (Ge, GaAs, and GaInP) and InGaN alloy system are also shown in the right-hand panel for comparison.

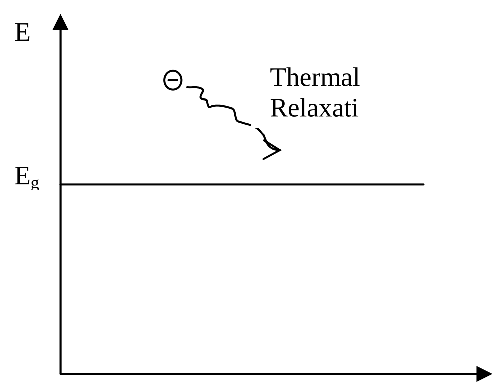

Figure 2: The electron in semiconductor materials is exited by photons with energy greater than the band gap of the semiconductor materials and then thermally relaxed to the band gap level for dissipating energy.

In principle, multi-junction solar cells made of band gap tunable materials such as $In_{1-x}Ga_xN$ shown in Fig. 1 on the right panel might lead to a solution to this problem, However, due to the theoretical limitations of junction tunneling and fabrication complexity, the benefit of adapting multiple junctions is limited in a minor range by the bottleneck of the total current of this type of solar cell. In fact, more than three junction solar cells are too complicated to be fabricated economically.

In U. S. Patent No. 2,949,498 to Jackson (1960), a solar energy converter is disclosed that splits the solar spectrum by stacking photovoltaic cells. A high band gap photovoltaic cell is placed in front of one or more photovoltaic cells having successively lower band gaps. High energy photons are absorbed by the first cell and lower energy photons are absorbed by the following cells. This principle of multi-junction photovoltaic cells is developed and implemented in the modern multi-junction structure that is described well by Masafumi Yamaguchi [3]. In a modern multi-junction structure, the photovoltaic cells made of materials with different band gaps are connected with tunnel junctions and buffer layers are adapted to eliminate the stress-induced degradation. Unfortunately, this method suffers from a number of disadvantages:

(a) The method essentially can not significantly improve photovoltaic conversion efficiency. The best achieved efficiency of a single photovoltaic cell is about 28.0%, but the best achieved efficiency of this multi-junction photovoltaic cell is only about 40.7%. Although in principle this method takes care of the efficiency losses due to thermal relaxation and non-absorption by matching the photon energy with appropriate band gaps of photovoltaic materials, and therefore ultra high efficiency can be reached, this approach is severely limited by the photo-generated charge carrier transportation and collection. In reality, it is almost impossible to fabricate multi-terminal tandem solar cells economically, so the assumption that all photogenerated electron-hole pairs contribute power output is not valid. In a normal two-terminal case, during the charge carrier transportation process, only one-Nth (N is number of junctions) of the total charge carriers generated by all the absorbed photons can be output to the two terminals of this type of device because the rest of the charge carriers recombine on the interface of the tunnel junctions.

(b) The materials used for different photovoltaic cells have to be lattice matched otherwise defects and stress will be introduced. Due to the lattice mismatch problem, the photovoltaic materials available for this type of structure are limited.

(c) The photocurrent of each of the photovoltaic cells has to be the same.

(d) Inevitable electrode shading of incident light.

(e) The antireflection layer and back reflector can not be effectively optimized for all the spectrums.

(f) Structure and fabrication processes are too complicated.

(g) This type of cell is not eligible for miniaturization to reduce cell area to save materials due to over heating in the concentrating system.

(h) The design of the electrode grid for collecting charge carriers is not easily optimized to enhance conversion efficiency.

2 SOLAR CELL CIRCUIT DESIGN

In order to significantly improve the photovoltaic conversion efficiency and dramatically lower the cost, we propose a new approach–Parallel integrated multiple solar cell circuits for a split solar spectrum light source. The general idea of this approach is to manipulate the incident solar radiation by splitting the broad-band solar spectrum into narrow band components through optical instruments which are easily integrated into the photovoltaic system, and then guide the components onto the parallel integrated multiple solar cell arrays for different solar cells to convert each of the components with different photon energy [4]. This approach processes concentrated solar radiation first, then convert the processed components respectively with parallel integrated solar cell arrays and collect photon-induced current in integrated electrode circuits.

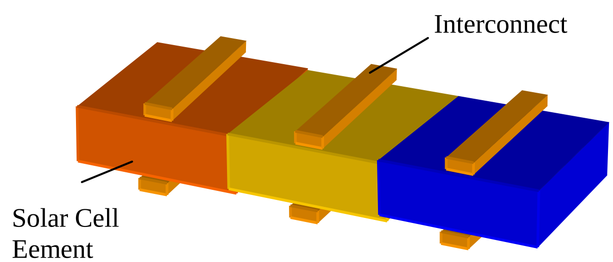

Figure 3: Parallel integrated solar cell circuits. Each element has the same structure, but is made of materials with different band gaps to match the incident photon energy in its area. The elements are grouped by using interconnects to output electric energy.

As shown in Fig. 3, the goal of the proposed circuit is to parallel integrate solar cell elements with different band gaps. Each of the elements has the same structure, as shown in Fig. 4, the n-type substrate, intrinsic amorphous germanium-silicon layer and p-type micro-crystalline silicon layer are used to construct the p-i-n structure, where the band gap of the i layer is tunable by adjusting the germanium concentration in the alloy, and consequently specify the band gap for each of the solar cell elements. The

NSTI-Nanotech 2009, www.nsti.org, ISBN 978-1-4398-1784-1 Vol. 3, 2009

Indium Tin Oxide layer is coated on the top as transparent and conductive electrode and antireflection layer as well.

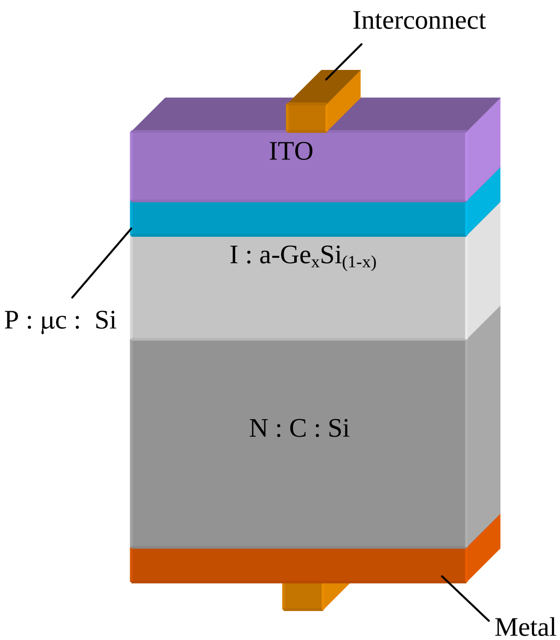

Figure 4: Solar cell element structure on n-type crystalline silicon (N:C:Si) substrate. An intrinsic amorphous Germanium-Silicon (I:a-$Ge_xSi_{(1-x)}$) alloy layer is deposited and followed by a p-type micro-crystalline Silicon (P: μc:Si) layer, then on the top of the solar cell a transparent conductive layer of Indium Tin Oxide (ITO) is coated. Finally the back electrode and interconnects are fabricated on both sides of the solar cell.

3 FABRICATION PROCESS

Conventional integrated circuit fabrication process is adapted to fabricate the proposed parallel integrated solar cell as shown in Fig. 5. PECVD is used to deposit the intrinsic GeSi layer, and Etch is used to remove the selected area of thin film. The solar cell arrays with different band gaps are patterned by alternatively operating these two processes over many iterations. Step (4) shows that PECVD is used to deposit *p* doped amorphous silicon thin film and that RTP is used to anneal it to form a micro-crystalline layer after the deposition. In step (5), PVD is used to coat ITO and Etch is used to remove selected area to form thin films with appropriate thicknesses for antireflection of corresponding spectral components. The interconnect pattern is formed by using PVD and ECP. As shown in Fig. 5, the key processes are PECVD, Etch and RTP. Since it is necessary to deal with dielectric, semiconductor and metal materials, it is desirable to configure three chambers on Etch systems used for wafer fabrication.

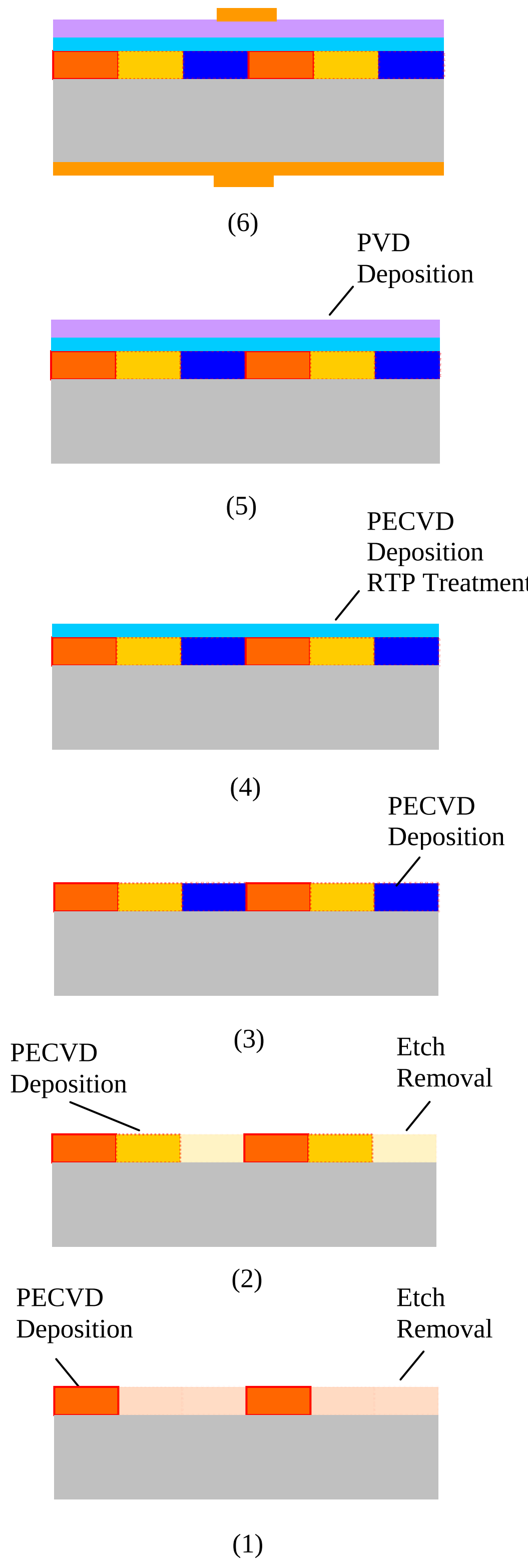

Figure 5: Parallel integrated solar cell circuits fabrication processes. (1)-(3) fabricate GeSi i layer, (4) fabricate p-type micro-crystalline Si layer, (5) fabricate ITO, and (6) fabricate back electrode and

4 DICUSSIONS

From the description above, we conclude that the advantages of this parallel integrated solar cell circuits for spliced light source are:

(a) The effective conversion area of the photovoltaic cells is greatly reduced, and thus the consumption of photovoltaic materials is substantially reduced.

(b) The structure of the element cell is significantly simplified, and the fabrication processes are dramatically simplified.

(c) The frame of the system structure enables all of the advanced integrated circuit technology to be used in photovoltaic device fabrication.

(d) The broad solar spectrum can be spliced as many components as possible without limit. Resulting in dramatic increases in conversion efficiency.

(e) Many photovoltaic cells with incident photon energy matched band gaps can be employed to convert the spliced components without limit.

(f) Any type photovoltaic materials can be used to fabricate photovoltaic cells without limit.

(g) The electrode grids and antireflection layers can be particularly optimized to improve the cell conversion efficiency.

(h) The electronic circuits can prevent the damage of solar and improve the total performance of the whole system.

(i) The whole system can be easily packed into a compact package instead of a large area module. The result in more efficient utilization of available space for system placement.

This approach is based on existing silicon integrated circuit technology. The different solar cells with materials such as amorphous silicon, amorphous silicon and germanium alloy, and so on are fabricated on silicon substrate. The main wafer fabrication systems needed for this solar cell fabrications are PECVD, Etch, and RTP. A PECVD chamber is used for growing thin films, dry Etch is used for fabricating parallel integrate solar cells, and RTP is used for treating thin film materials fabricated on silicon substrates.

This approach adapts integrated circuitry to deal with concentrated sunlight so that it significantly reduces the area of the semiconductor and therefore greatly lowers the consumption of semiconductor materials. Because each of the components of the solar radiation is matched with specific solar cell made of materials with the exact band gap as the incident photon energy, this approach results in extremely dramatic improvement in the photovoltaic conversion efficiency.

REFERENCES

[1] Solar cell efficiency table http://www.pv.unsw.edu.au/documents.

[2] http://www.lbl.gov/Science-Articles/Archive/MSD-full-spectrum-solar-cell.html.

[3] Mary D. Archer and Robert Hill, “Clean Electricity from Photovoltaics, Series on Photoconversion of Solar Energy,” Vol. 1, Imperial College Press, 347-375, 2001.

[4] F. Shi and Y. Li, “Parallel Integrated Solar Cell Circuits for Spectrally Spliced Light Source”, US patent application # 11/716905, 2007.