Comparison of Different Solar Cell Designs for Efficiency Improvement

Nidhi Sinha[1], Varun Chandra[2]

[1]Research Scholar,M.Tech VLSI Design, [2]Research Associate

Poornima University, Jaipur(Raj)

Abstract* — This paper concludes the study of various design methodology related with solar cell and their efficiency improvement under different operating condition. As solar cell efficiency is a function of short circuit current density (I_{sc}), open circuit voltage (V_{oc}), fill factor (FF), and maximum power output (P_{max}). Overall solar cell efficiency is the product of absorption efficiency, dissociation efficiency, transport (charge) efficiency and Collection efficiency ($\eta_{eff} = \eta_{abs} \times \eta_{diss} \times \eta_{tans} \times \eta_{col}$). Overall efficiency is the function of no. of junctions of different material such that more of the light can be absorbed to increase the absorption efficiency hence conversion efficiency. Many inorganic hetro-junction design such as intermediate band solar cell (IBSC) design[33], InGaP/Ge(3J)[29], GaInP/GaAs/Ge[10] AlGaAs/GaAs/Ge:Ge[28], InGaP/GaAs/InGaAs/Ge (4J) or nitride cascade quantum well design as (InGaP/GaAs/MQW/Ge[11] etc were presented. This paper presents the comparative analysis of proposed designs methodologies concerning with different design issue with process involved and output results. Among these maximum theoretical estimated efficiency of 50 % was claimed by IBSC design using highly periodically silicon nanodisc array using 3D FEM and MQW(Multi-Quantum-Well) technique in AM1.5(500 sum) but only 42% in 1 sun condition[33]. Although on system design modification lateral optical system integrated with cell design i.e designed for portable application operates on 50% efficiency and splitting solar cell assemblies shows photoelectric conversion efficiency of 38% under 2.8 SUN radiation condition[1].

Keywords: Photovoltaic (PV), Short circuit current (Isc), Open circuit voltage (Voc), Short circuit current density (Jsc), Fill factor (FF), Efficiency (η)

I. INTRODUCTION

A **solar cell**, or **photovoltaic cell**, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels. Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.The operation of a photovoltaic (PV) cell requires 3 basic attributes:

- The absorption of light, generating either electron-hole pairs or excitants.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit. In contrast, a solar thermal collector supplies heat by absorbing sunlight, for the purpose of either direct heating or indirect electrical power generation from heat. A "photo electrolytic cell" (photo electrochemical), on the other hand, refers either to a type of photovoltaic cell (like that developed by Edmond Becquerel and modern dye-sensitized solar cells), or to a device that splits water directly into hydrogen and oxygen using only solar illumination.

Fig.1.1 A Conventional Crystalline Silicon Solar Cell. Electrical Contacts Made From Bus bars (The Larger Strips) and Fingers (The Smaller Ones) are Printed On The Silicon Wafer

Development of clean energy resources as an alternative to fossil fuels has become one of the most important tasks assigned to modern science and technology in the 21st century. As was well recognized after the Kyoto Protocol, the reason for this strong motivation is to stop air pollution resulting from the mass consumption of fossil fuels and to maintain the ecological cycles of the bio-systems on the earth. The influences of the industrial developments of the energy revolutions since James Watt built the steam engine in the 18th century are examined and discussed. The evolution of the main energy resources from coal (solid), oil (liquid) and LNG, LPG (gas) are closely related not only to the economy of mass production, storage, and transportation but also to environmental issues.

A. THEORY

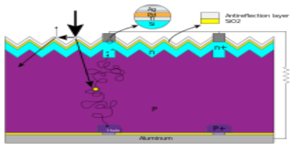

Fig.1.2 Working mechanism of a solar cell

The solar cell works in several steps:

- Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
- Electrons are excited from their current molecular/atomic orbital. Once excited an electron can either dissipate the energy as heat and return to its orbital or travel through the cell until it reaches an electrode. Current flows through the material to cancel the potential and this electricity is captured. The chemical bonds of the material are vital for this process to work, and usually silicon is used in two layers, one layer being bonded with boron, the other phosphorus. These layers have different chemical electric charges and subsequently both drive and direct the current of electrons.
- An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.
- An inverter can convert the power to alternating current (AC).
- The most commonly known solar cell is configured as a large-area p-n junction made from silicon.

B. CELLS, MODULES, PANELS AND SYSTEMS

Multiple solar cells in an integrated group, all oriented in one plane, constitute a solar photovoltaic panel or solar photovoltaic module. Photovoltaic modules often have a sheet of glass on the sun-facing side, allowing light to pass while protecting the semiconductor wafers. Solar cells are usually connected in series in modules, creating an additive voltage. Connecting cells in parallel yields a higher current; however, problems such as shadow effects can shut down the weaker (less illuminated) parallel string (a number of series connected cells) causing substantial power loss and possible damage because of the reverse bias applied to the shadowed cells by their illuminated partners. Strings of series cells are usually handled independently and not connected in parallel, though (as of 2014) individual power boxes are often supplied for each module, and are connected in parallel. Although modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity, using independent MPPTs (maximum power point trackers) is preferable. Otherwise, shunt diodes can reduce shadowing power loss in arrays with series/parallel connected cells.

C. MATERIALS

Solar cells are typically named after the semiconducting material they are made of. These materials must have certain characteristics in order to absorb sunlight. Some cells are designed to handle sunlight that reaches the Earth's surface, while others are optimized for use in space. Solar cells can be made of only one single layer of light-absorbing material (single-junction) or use multiple physical configurations (multi-junctions) to take advantage of various absorption and charge separation mechanisms.

i) Crystalline silicon

By far, the most prevalent bulk material for solar cells is crystalline silicon (c-Si), also known as "solar grade silicon". Bulk silicon is separated into multiple categories according to crystallinity and crystal size in the resulting ingot, ribbon or wafer. These cells are entirely based around the concept of a p-n junction. Solar cells made of c-Si are made from wafers between 160 to 240 micrometers thick.

ii) Monocrystalline silicon

Monocrystalline silicon (mono-Si) solar cells are more efficient and more expensive than most other types of cells. The corners of the cells look clipped, like an octagon, because the wafer material is cut from cylindrical ingots, that are typically grown by the Czochralski process. Solar panels using mono-Si cells display a distinctive pattern of small white diamonds.

iii) Polycrystalline silicon

Polycrystalline silicon, or multicrystalline silicon (multi-Si) cells are made from cast square ingots—large blocks of molten silicon carefully cooled and solidified. They consist of small crystals giving the material its typical metal flake effect. Polysilicon cells are the most common type used in photovoltaics and are less expensive, yet less efficient than those made from monocrystalline silicon.

iv) Thin film

Thin-film technologies reduce the amount of active material in a cell. Most designs sandwich active material between two panes of glass. Since silicon solar panels only use one pane of glass, thin film panels are approximately twice as heavy as crystalline silicon panels, although they have a smaller ecological impact (determined from life cycle analysis). The majority of film panels have 2-3 percentage points lower conversion efficiencies than crystalline silicon. Cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and amorphous silicon (a-Si) are three thin-film technologies often used for outdoor applications.

v) Silicon Thin Film

Silicon thin-film cells are mainly deposited by chemical vapor deposition (typically plasma-enhanced, PE-CVD) from silane gas and hydrogen gas. Depending on the deposition parameters, this can yield:

- Amorphous silicon (a-Si or a-Si:H)

- Protocrystalline silicon or

Nanocrystalline silicon (nc-Si or nc-Si:H), also called microcrystalline silicon.

vi) Multi-Junction SolarCell

Multi-junction cells were originally developed for special applications such as satellites and space exploration, but are now used increasingly in terrestrial concentrated photovoltaics (CPV), an emerging technology that uses lenses and curved mirrors to concentrate sunlight onto small but highly efficient multi-junction solar cells. By concentrating sunlight up to a thousand times, *High concentrated photovoltaics (HCPV)* has the potential to outcompete conventional solar PV in the future.

Multi-junction cells consist of multiple thin films, each essentially a solar cell grown on top of each other, typically using metalorganic vapour phase epitaxy. A triple-junction cell, for example, may consist of the semiconductors: GaAs, Ge, and GaInP each layers have a different band gap energy to allow it to absorb electromagnetic radiation over a different portion of the spectrum.

On Solar cell design, various paper has been published between 2001 to 2015 that is undertaken. The paper reviewed by me mainly consisting two issues for efficiency improvement:

i. Solar cell design modification
ii. System/Module modification

D. SOFTWARE USED:

- TCAD (Two-dimensional Computer aided tool)
- Silvaco (ATLAS)
- PC1D (One dimensional solar cell simulator)

II TECHNIQUES USED

A. Multi-Juntion Solar Cell

i) Two-Junction Solar Cell

a) A hetro-junction solar cell of n-ZnO/p-cSi and p-ZnO/n-cSi with the help of two dimensional numerical computer aided design tool (TCAD) was designed. That shown great potential alternative from the viewpoint of performance efficiency, simple and low temperature processing steps and hence low cost candidate. In future ZnO can also be used to reduce the cost.

b) Design of polymer:fullerene bulk heterojunction (PPV/P3HT:PCMB) solar cell was presented. In which two organic PV cells of two different materials were cascaded together to form a tandem organic solar cell. The efficiency of this photovoltaic cell can be further increased by introducing advance light trapping management. It was simulated using SILVACO (ATLAS).

c) Optimum design of InGaP/GaAs dual junction solar cell design was proposed and simulated using Silvaco ATLAS.

ii) Three-Junction Solar Cell

Two triple junction designs (AlGaAs/GaAs/Ge or InGaP/GaAs/Ge), were proposed that combine high-efficiency, high energy density, and radiation hardness in a manufacturable design. Triple-junction AlGaAs/GaAs/Ge solar cells are highly current mismatched due to the excess current generating capability of the germanium sub cell. That invited a new approach for improving the performance of III-V multijunctions.

iii) Four-Junction Solar Cell

Four junction solar cells (i.e. InGaP/GaAs/MQW/Ge, InGaP/GaAs/InGaNAs/Ge and InGaAs/InGaAsP/$Ga_{0.5}$ $In_{0.5}P$) were presented. A four-junction cell design consisting of InGaAs, InGeAsP, GaAs, and $Ga_{0.5}ln_{0.5}P$ sub cells that could reach 1xAMO efficiencies of 35.4%. A new cascaded quantum well (QW) design whereby a thermally assisted resonant tunneling process is used to accelerate the carrier escape process «30ps) and hence improve the photo generated carrier collection efficiency and named as multi-quantum-well (MQW) solar cell and four junction AlGaAs/GaAs/Ge/Ge device gave benefits of increased open-circuit voltage as contributed by the second Ge sub cell.

B. SPECTRUM SPLITTING TECHNIQUE

Spectrum splitting technique divide the solar spectrum into three sub-ranges of 400-630nm, 630-800nm and after 800nm respectively under the 0.5-6.0 SUN radiation condition that attempted t o overcome the physical limitation. The efficiency achieved through this method was of 38%. Through the measurement and data analysis, author found that the method given in this method will achieve higher conversion efficiency than that of the single junction solar cell.

III COMPARATIVE ANALYSIS OF VARIOUS TECHNIQUE

A. Solar Cell Design Modification

INPUT			PROCESS			OUTPUT					REMARK
Reference Wafer	**Modification done**	**Parameter**	**Irradiation or spectrum**	**Pattern or structure**	**Software/Tech-nique used**	**J_{sc}(mA/cm^2)**	**V_{oc}(mV)**	**I_{sc}(A)**	**FF**	**η (%)**	Low cost
Si-Solar Cell[19]	HYBRID Thin Film Si-Solar Cell Consisting a-Si & poly-Si	Module size	Halogen/Xenon dual light source solar simulator	---	---	--	--	--	--	13.2	Low cost
Point contact Si-concentrator module[9]	Triple jun. III-IV solar cell & a new dense array version of the CUTJ	Size of solar cell array	AM1.5D	Dish shaped module	Concentrated ultra triple junction (CUTJ)design	--	--	--	--	↑ by 46%	High radiability and low cost
Silicon Solar Cell Thin Film[12]	Plasmonic BR based on self assembled silver particle(AgNPs)	Size & shape of nano particle	---	---	---	--	--	--	--	↑	Useful for the nanopatterned Ag-film-based plasmonic BR
Crystalline Si-Solar Cell[1]	Including The Lateral Optical System (i.e inserted in optical path)	Eg of Junction material	1 Sun	---	---	--	--	--	--	50%	Higher Performance Lower Cost
C:Si solar cell[32]	Rsheet fabricated by ion-implantation	Front contact resistance, sheet R, ion-implantation	---	--	T-CAD Simulation	37.63	647	--	79.82%	19.43	FF is limited by contact resistance
Thin film solar cell[22]	Accounting the local defect	Light trapping	1 SUN AM1.5G	2D	Optical & electrical simulation using FEM in T-CAD		7.71	--	76.3	9.54	Can be simulated for 3D structure
Crystalline Si-wafer[38]	Optimized print-on-print technique used	Finger width	---	PoP	---	--	--	--	--	19.13	----
Crystalline Si solar cell[30]	ARC coating & textured wafer	Thickness of ARC coating	400nm to 700nm	---	---	--	580	47	--	9.62	Poor performance due to insufficient BSF
Thin film crystalline Si wafer[37]	Blaze grating along with a metal reflector at rear side	Hight of grating	800nm to 1100nm	2D	Rigrours coupled wave analysis(RCWA) &FEM	--	--	--	--	↑ by 40%	Shadowing of 5%
Crystalline Si solar cell[23]	SiGe hetrojunction thin film solar cell with addition of Ge(i.e Si0.9Ge0.1)	Concentration of Ge	AM1.5	---	Measured with characterization s/m (JASCO, YQ-250Bx)	--	--	--	--	14	Less sensitive to temp. than Si solar cell for real application
Crystalline Si-solar cell[24]	Si with ZnO	Energy gap, n/P doping, refractive index	AM1.5	2D	T-CAD (two dimensional CAD)	--	52.6	47	--	19	Low cost

B. System/Module Modification

INPUT			PROCESS			OUTPUT					REMARK
Reference Wafer	**Modification done**	**Parameter**	**Irradiation or spectrum**	**Pattern or structure**	**Software/ Tech-nique used**	**J_{sc}(mA/cm^2)**	**V_{oc}(mV)**	**I_{sc}(A)**	**FF**	**η (%)**	
Transparent Si solar cell[7]	Attached it with a material of lower band gap by a dichroic mirror	Concentration, band gap	AM1.5G radiated in 1 SUN	---	---	--	--	--	--	6.4	Better than previously reported η of 5.4%
Si-substrate[15]	4-Junction (InGaAs,InGe-AsP,GaAs,$Ga_{0.5}In_{0.5}$P)	Band-gap of material	1XAM0 15XAM0	---	---	--	--	--	--	35.4 39.8	Can be developed on low cost & Si substrate is mechanically rebust
Boron doped P-type Si substrate[16]	Phosphorous doped N-type Si solar cell buried contact	Doping concentration	One-Sun radiation	Textured front side & planer rear side	IBBC(Interdigited buried back side contact)	37.9 28.4	664 658.8	-- --	0.765 0.775	19.2 14.5	No grid shadowing loss and no co-planar interconnection
Si-solar cell[28]	3 jun. (AlGaAs/ GaAs/Ge) & 4 jun.(AlGaAs/GaAs/ Ge/Ge)	Band gap, thickness range, doping range	AM1.5 One Sun & constant density of 0.1w/cm^2	---	PCID software using trial and error method	--	43.69 68.96	609.8 611.7	2.069 3.336	20.69 33.36	Current mismatch in 3 junction solar cell
Si-Solar cell[4]	InGaN epilayer	Epilayer thickness	AM0	---	---	0.93	1.73	--	--	--	---
Si-solar cell[17]	Back contacted solar cell with Oblique evolution of contacts	Thickness	AM1.5G	--	OECO	--	--	--	--	18.1 17.4	Low cost

IV. FINDINGS

A. Findings For Solar Cell Design Modification:

- Many hetro-junction designs were proposed such as Intermediate Band Solar Cell(IBSC) Design Using Highly Periodical Silicon Nanodisk Array, ZnO/cSi hetrojunction, 3-junction (AlGaAs/GaAs/Ge or InGaP/GaAs/Ge), 4-junction (AlGaAs/GaAs/Ge:Ge or InGaP/GaAs/InGaNAs/Ge or InGaAs/InGaAsP/GaAs/$Ga_{0.5}In_{0.5}P$), Ultra Triple Junction and Nitride Cascade Quantum Well Design(InGaP/GaAs/MQW/Ge), Polymer Based Bulk Hetrojunction (P3HT:PCBM) Tandem solar cell Design etc among them maximum efficiency of 50% was estimated of Intermediate Band Solar Cell(IBSC) Design Using Highly Periodical Silicon Nanodisk Array by using 3D FEM and MQW technique in AM1.5(500 sun) but only 42% in 1 sun.[10][11][28][29]
- Although Dilute Nitride Cascade Quantum Well Design also showed the realistic estimate of efficiency of >40%, ultra triple junction design of 29% and 4-junction solar cell design approached 33.36% whereas 3-junction solar cell only approached only 20.69%.[9][11]
- An Optimized Multi-Junction Solar Cell Design Using Genetic Algorithm for the optimization were proposed and simulated in SILVACO(ATLAS) which resulted the fully optimized Triple Junction(InGaP/GaAs/Ge) efficiency of 32.47% although Quad Juntion(InGaP/GaAs/InGaAs/Ge) resulted fully optimized design efficiency of 34.16%.[11][34]
- 4-Junction(InGaAs/InGaAsP/GaAs/$Ga_{0.5}In_{0.5}P$) solar cell design using Wafer Bonding and Transfer Processes yield practical efficiency of 35.4% for 1xAM0 and 39.8% for 15xAM0 whereas it showed theoretical efficiency of 41.6 for 1xAM0.[15]
- Polymer Based Bulk Hetrojunction(P3HT:PCBM) Tandem solar cell Design was proposed to improve the efficiency of Organic cell i.e ideally 10.73% and further can be improved by introducing advanced light trapping management.[21]

B. Findings for System/Module Modification:

- Many system modifications were proposed by researchers such as A New Dense Array Version of the CUTJ (Concentrated ultra triple junction), Splitting Solar Cell Assemblies, Lateral Optical System integrated with solar cell design, Silicon HYBRID Module etc.
- Lateral Optical System integrated with solar cell design (i.e designed for portable application) operates on 50% efficiency whereas Silicon HYBRID Module only provides the efficiency of 13.2% but at comparatively low cost.
  - Splitting Solar Cell Assemblies show photoelectric conversion efficiency of 38% under 2.8 SUN radiation condition whereas Solar Cell Design for Dense-Array Concentrator posses efficiency of 31% under AM1.5D Sun condition.

Comparative analysis on the basis of various parameter has been given below in tabular form. So that comparison of various techniques could be done more effectively. Main objectives is to improve efficiency but at reasonable cost.

C. Strengths***:***

- Ultra Triple junction (UTJ) can improve the cell efficiency up to 28%.[9]
- Back-OECO cells with efficiencies of up to 20 % can be designed.[17]
- MEMS Solar Cell Based on Microcantilever-Photoinduced Bending technology may be used to harvest more energy in ultraviolet band.[20]
- Intermediate Band Solar Cell Design Using Highly Periodical Silicon Nanodisk Array structure breakthroughs the Schockley-Queisser limit in Si solar cells.[33]

D. Limitations:

- Efficiency of Organic solar cell is very less i.e < 15%.
- In HIHT (High intensity & high temperature) environment life of solar cell degrades.
- Electricity cost per unit is high in case of solar cell.

V. SCOPE OF WORK

- In future this structure (solar cell) may be fabricated on a low cost mechanically robust Si substrate.
- Ultra Triple junction (UTJ) can improve the cell efficiency up to 28%.
- Excellent results of the n-type IBBC (Interdigited Backside Buried Contact) solar cells have been designed with efficiency of 19.2%.
- In future Back-OECO cells with efficiencies of up to 20 % can be designed.
- Multi Junction solar cell can be designed using ATLAS (SILVACO).
- Efficiency can be obtained >40% using Multi Quantum Well cell structure.
- MEMS Solar Cell Based on Microcantilever-Photoinduced Bending technology may be used to harvest more energy in ultraviolet band.
- Intermediate Band Solar Cell Design Using Highly Periodical Silicon Nanodisk Array structure breakthroughs the Schockley-Queisser limit in Si solar cells.
- In future simulation model can also be developed on PCID software and a dry process for texturing and improve the device performance by double anti-reflective coating, namely SiN/SiO2 stack.
- Simple and effective structure design considering the manufacturing feasibility can be obtained near in future.

- In future modification in these cell structures can be done to improve the efficiency further because the maximum theoretical efficiency of multi-junction solar cells is 86.8%.

VI. Conclusion

The detailed study of various techniques/approaches has been done with various input-output and process parameters concerning with the solar cell efficiency. Mainly we found two approaches (i) Solar cell design modification and (ii) System/Module modification, for efficiency improvement. In solar cell design modification various material, their heterojunction and the electrical properties has been studied in order to improve the efficiency. In solar cell design modification A four-junction cell design consisting of InGaAs/InGaAsP/GaAs, and $Ga_{0.5}ln_{0.5}P$ sub cells that could reach 1xAMO efficiencies of 35.4% [15] and maximum theoretical estimated efficiency of 50 % can be achieved by IBSC design using highly periodically silicon nano disc array[33]. In System/module modification various techniques such as Spectrum splitting, Combining optical system with solar cell system etc has been studied to improve the performance and efficiency. Spectrum splitting technique divide the solar spectrum into three sub-ranges of 400-630nm, 630-800nm and after 800nm respectively under the 0.5-6.0 SUN radiation condition that attempted to overcome the physical limitation. The efficiency achieved through this method was of 38%[39]. Maximum efficiency of 50% was achieved through the integration of optical design with the solar cell design; this solar cell is named as VHESC (Very high efficiency solar cell) and designed for portable application.[1]

VII. FUTURE SCOPE

The demand of power will always on increase and it cannot be met only by thermal, wind, hydro power plants so Solar cell energy is needed. In future research work can be done in field Organic solar cell to improve its efficiency comparatively at lower cost.

REFRENCES

[1] Allen Barnett1, Christiana Honsberg1, Douglas Kirkpatrick2, Sarah Kurtz3, Duncan Moore4, David Salzman5, Richard Schwartz6, Jeffrey Gray6, Stuart Bowden1, Keith Goossen1, Michael Haney1, Dan Aiken7, Mark Wanlass3, Keith Emery3," 50% efficient solar cell architectures and designs", 1-4244-0016-3/06/$20.00 ©2006 IEEE.

[2] Amruta P. Joshi*, Mehul C. Raval*, Anil Kottantharayil+, Chetan S. Solanki," Inductively Coupled Plasma Atomic Emission Spectroscopy: A bulk analysis and process monitoring technique for silicon solar cell fabrication", 978-1-4799-3299-3/13/$31.00 ©2013 IEEE.

[3] Atse Louwen_y, Wilfried G.J.H.M. van Sark, Ruud E.I. Schroppzx, Wim C. Turkenburg_ and Andr´e P.C. Faaij, "Cost Analysis of Two Silicon Heterojunction Solar Cell Designs", 978-1-4799-3299-3/13/$31.00 ©2013 IEEE.

[4] Balakrishnam R. Jampana, Student Member, IEEE, Andrew G. Melton, Student Member, IEEE, Muhammad Jamil, Member, IEEE, Nikolai N. Faleev, Robert L. Opila, Ian T Ferguson, Senior Member, IEEE and Christiana B. Honsberg, *Member, IEEE*, "Design and Realization of Wide-Band-Gap (~2.67 eV) InGaN p-n Junction Solar Cell", IEEE Electron Device Letters, Vol. 31, No. 1, January 2010.

[5] B.R. Bathey, J. P. Kalejs, M. D. Rosenblum, M. J. Kardauskas, R. M. Giancola, and J. Cao, "R&D Toward A 15+% Efficiency Solar Cell Manufacturing Line For Efg Silicon Wafers", 0-7803-5772-8/00/$10.00 *0* 2000 IEEE.

[6] C. G. Zimmermann1, C. Nömayr1, M. Kolb2 and A. Caon3," a solar cell design for the bepi colombo high intensity – high temperature mission, 978-1-4244-9965-6/11/$26.00 ©2011 IEEE.

[7] Christopher Kerestes, Yi Wang, Kevin Shreve, and Allen Barnett," Transparent Silicon Solar Cells: Design, Fabrication, And Analysis", 978-1-4244-5892-9/10/$26.00 ©2010 IEEE.

[8] Chunfu Zhang1, Zhenhua Lin1, E.T. Kang2, Chunxiang Zhu1, "Mechanism Investigation And Structure Design Of Organic Solar Cells For Improved Energy Conversion Efficiency", 978-1-4244-5798-4/10/$26.00 ©2010 IEEE.

[9] Geoffrey S. Kinsey1, Raed A. Sherif1, Hector L. Cotal1, Peichen Pien1, Richard R. King1, Randolph J. Brandt1, William G. Wise1, Eduardo L. Labios1, Kam F. Wan1, Moran Haddad1, Jonathon M. Lacey1, Christopher M. Fetzer1, Pierre Verlinden2, John Lasich2, Nasser H. Karam1," Multijunction Solar Cells For Dense-Array Concentrators", 1-4244-0016-3/06/$20.00 ©2006 IEEE

[10] Geoffrey ***S.*** Kinsey, Richard R. King, Kenneth **M.** E:dmondson, Alexander P. Stavrides, Hojun Yoon, Christopher **M.** Fetzer, Peter C. Colter, James H. Ermer, Mark **S.** Gillanders, Peter Hebert, Jennifer E. Granata & Nasser H. Karam, "Ultra Triple- Junction High-EFficiency Solar Cells", E€€ AESSSwrmrr. Uuguiine. March 2WI

[11] Gopi Vijaya, Akhil Mehrotra, Andenet Alemu and Alexandre Freundlich, "Multi-Junction solar cell with Dilute Nitride Cascaded Quantum Wells Design", 978-1·4673-0066-7/12/$26.00 ©2011 IEEE

[12] Hairen Tan, Rudi Santbergen, Guangtao Yang, Arno H. M. Smets, and Miro Zeman, "Combined Optical and Electrical Design of Plasmonic Back Reflector for High-Efficiency Thin-Film Silicon Solar Cells", IEEE JOURNAL OF PHOTOVOLTAICS 1

[14] Ines Massiot, Clement Colin, Nicolas Vandamme, Nathalie Bardou1, Jean-Luc Pelouard, Pere Roca iCabarrocas3, Christophe Sauvan4, Philippe Lalanne4, Stephane Collin,"Towards High Efficiency ultra-thin solar cells with nanopatterned metallic front contact" 978-1-4799-3299-3/13/$31.00 ©2013 IEEE

[15] James M. Zahler. Anna Fontcubetta i Morral, Chang-Geun Ahn and Hany A. Atwater Thomas J. Watson, "wafer bonding and layer transfer processes for 4 junction high efficiency solar cells", 0-7803-7471-1/02/$17.00 02002

IEEE.

[16] Jiun-Hua **Guo,** Budi **S.** Tjahjono, and Jeffrey E. Cotter, "19.2% Efficiency N-Type Laser-Grooved Silicon Solar Cells", 0-7803-8707-4/05/$20.00 *02005* IEEE.

[17] J.W. Muller, A**.** Merkle, and R. Hezel, "Self-Aligning, Industrially Feasible Back Contacted Silicon Solar Cells With Efficiencies > 18 %", 3rd World Conference on Photovoltaic Energy Conversion May 11-18, 2003 Osaka, Japan.

[18] Lei Hong Rusli, Xincai, Wang, Hongyu Zheng, Hao Wang and Hong Yu Yu,"Design Gidelines for (111)Si Inclined Nanohole arrays in thin film solar cells", 978-1-4673-4842-3/13/$31.00_c 2013 IEEE.

[19] Masashi Yoshimi, Toshiaki Sasaki, Toru Sawada, Takashi Suezaki, Tomomi Meguro, Takahiro Matsuda, Koji Santo, Kazuya Wadano, Mitsuru Ichikawa, Akihiko Nakajima and Kenji Yamamoto Kaneka Corporation, 2-1-1, Hieitsuji, Otsu, Shiga, "high efficiency thin film silicon hybrid solar cell module on 1m2-class large area substrate", 3rd World Conference on Photovoltaic Energv Conversion May 11-18, 2003 Osaka, Japan.

[20] Mazhar B. Tayel and Yahya Ragab," A Novel Design of a MEMS Solar Cell Based on Microcantilever-Photoinduced Bending", 2012 First International Conference on Innovative Engineering systems.

[21] Md. Jubaer Hossain Pantho_, Noor A Junnat and Mohammad Jahangir Alam, "Design and Analysis the Characteristics of A Cost-Effective Polymer Based Bulk Heterojunction Tandem Solar Cell",

[22] Michael G. Deceglie, Vivian E. Ferry, A. Paul Alivisatos, and Harry A. Atwater," Accounting for Localized Defects in the Optoelectronic Design of Thin-Film Solar Cells" 2156-3381/$31.00 © 2013 IEEE.

[23] M. H. Liao and C. H. Chen, Student Member, IEEE," The Investigation of Optimal Si-SiGe Hetero-Structure Thin-Film Solar Cell With Theoretical Calculation and Quantitative Analysis." IEEE TRANSACTIONS ON NANOTECHNOLOGY, VOL. 10, NO. 4, JULY 2011, 1536-125X/$26.00 © 2010 IEEE.

[24] Muhammad Nawaz1,2, E. S. Marstein2 and Arve Hole," Design Analysis Of Znolcsi Heterojunction Solar Cell", 978-1-4244-5892-9/10/$26.00 ©201 0 IEEE

[25] Namjoon Heo , Hyun-Jun Soh , and Jeonghoon Yoo," Reflector Texturing Design of a Thin Film Solar Cell in a Specific Wavelength Range Using Topology Optimization", 0018-9464/$31.00 © 2013 IEEE

[26] Ning-Ning Feng, Jurgen Michel, Lirong Zeng, Jifeng Liu, Ching-Yin Hong, Lionel C. Kimerling, Member, IEEE, and Xiaoman Duan," Design of Highly Efficient Light-Trapping Structures for Thin-Film Crystalline Silicon Solar Cells.", IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 54, NO. 8, AUGUST 2007

[27] Rommel Noufi and Ken Zweibel, "High-Efficiency Cdte And Cigs Thin-Film Solar Cells:Highlights And Challenges", 1-4244-0016-3/06/$20.00 ©2006 IEEE

[28] S.Meenakshi and Dr.S.Baskar, "Design of Multi-Junction Solar cells using PC1D", 978-1-4673-6150-7/13/$31.00 ©2013 IEEE

[29] Sherif Michael, Drew Bates and James Utsler," The Design of Advanced Multi-Junction Solar Cells Using Genetic Algorithm for the Optimization of a SILVACO® Novel Cell Model", 1-4244-0016-3/06/$20.00 ©2006 IEEE

[30] Suhaila Sepeai, M.Y.Sulaiman, Saleem H.Zaidi, Kamaruzzaman Sopian," Enhanced Light Absorption in Bifacial Solar Cells", IEEE-ICSE2012 Proc., 2012, Kuala Lumpur, Malaysia 978-1-4673-2396-3/12/$31.00 ©2012 IEEE

[31] Vikas Kumar, Ammar Nayfeh," Design of Impact Ionization Enhanced Thin Film c-Si HIT Solar Cells", 978-1-4799-4398-2/14/$31.00 ©2014 IEEE

[32] Vikram Bhosle, Basil Tsefrekas, Hans-Joachim L. Gossmann, Christopher E. Dube," Fabricating high efficiency solar cells with high sheet resistance emitters by ion implantation and contact resistance modeling", 978-1-4799-3299-3/13/$31.00 ©2013 IEEE

[33] Weiguo Hu1,2, Makoto Igarashi1,2, Ming-Yi Lee3, Yiming Li3,4,*, and Seiji Samukawa1, 2, 4,*," 50% Efficiency Intermediate Band Solar Cell Design Using Highly Periodical Silicon Nanodisk Array", 978-1-4673-4871-3/12/$31.00 ©2012 IEEE

[34] Wen-Tsung Huang, Chieh-Yang Chen, Yu-Yu Chen, Sheng-Chia Hsu, and Yiming Li*," Multiobjective Evolutionary Approach to Silicon Solar Cell Design Optimization", 978-1-4799-1314-5/13/$31.00 ©2013 IEEE

[35] Wolfgang Neu' , Steffen Kelle?, Barbara Terheiden," process development for back contact power silicon solar cells with emitter wrap through design", 3rd World Conference on Photovoltaic Energy Conversion May 11-18, 2003 Osaka, Japan

[36] Xuesong Lu1†, Martin Diaz1, Nicole Kotulak1, Robert L. Opila2 and Allen Barnett1,"Quantum Efficiency Model Driven Design for Wide Band Gap Gallium Phosphide Solar Cells", 978-1-4244-9965-6/11/$26.00 ©2011 IEEE

[37] Yih-Peng Chiou, Shin-Yi Wu and Cheng-Yen Chen, "Blaze Gratings As Light Trapping Structures For Enhancing Cell Efficiency Of Thin-Film Crystalline Silicon Solar Cells", 978-1-4244-5892-9/10/$26.00 ©2010 IEEE

[38] Yu-Hsuan Chang, Wei-Ming Su, Po-Sheng Huang and Li-Wei Cheng," Improvement of the Solar Cell Efficiency by Fine Line Print on Print Technology", 978-1-4799-3299-3/13/$31.00 ©2013 IEEE

[39] Yuan Zhao, Ming-Yu Sheng2,3, "Design of Spectrum Splitting Solar Cell Assemblies",

[40] Zhenjiao Wang, Peiyu Han, Oinglei Meng, Hongqiang Oian, Jiaqi Wu, Yongfei Jiang, Ning Tang, Hongyan Lu, Haidong zhu, Rulong Chen, Peter Yang, Jingjia Ji, Zhengrong Shi1, Adeline Sugianto, Stuart Wenhem, "20.3% efficiency rear passivated silicon solar cells with local back contact using commercial P-Cz wafers", 978-1-4673-0066-7/12/$26.00 ©2011 IEEE

AUTHOR'S PROFILE

Nidhi Sinha is pursuing M.Tech. in VLSI Design. She has completed his B.Tech. in Electronics & Communication Engineering from Govt. Womens Engg College Ajmer, Rajasthan. Her area of research includes Inorganic / Organic Solar cells deisgn, low power devices.

Varun Chandra is pursuing M. Tech. (Power System) + Ph.D. integrated course. He received the B. Tech. degree from Dr. MGR University, Chennai in 2009. He also completed Post Graduate Diploma in Power Plant Engineering from Joint Venture of JSWECE Bellary and MSRIT Bangalore. He has four years of rich industrial experience in thermal power plant. His area of interest includes solar photovoltaic's system design, power system, and optimization of electrical system.