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Loss Analysis of Market Available Solar Cells and Possible Solutions

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Abstract— The Sun is the pure power source, by which we can theoretically satisfy the entire electricity demand of the whole earth. Due to the limitation of our solar cell technology, harnessing solar power in full efficient way is still on progress. On commercial basis, it is also promising but not up to the mark. Somehow, researchers are still on the flow to make the solar cell technology much efficient to harness the entire energy on optimum cost. In todays market available solar cell, there are still more criteria to be taken care of to improve the efficiency. The use of Graphene, Multi-Junction Cells and Quantum Dot Cells will increase the rate of recent research flow. This paper visualizes the loss analysis of recent market available solar cells and possible solution to overcome those.

Index Terms— Solar Cell Efficiency, Graphene, Multi-Junction, Quantum Dot Cell, Cell Efficiency Improvement, Loss Analysis, Absorptivity, Transparency, Voltage Loss, Fill Factor Loss, Optical Loss, Electrical Loss, Low Energy Photon, Excess Energy Photon, Sub-Band Gap, Recombination Loss, Resistive Loss, Encapsulation, MPPT.

1 INTRODUCTION

SOLAR Energy is the most unlimited energy among other available renewable sources. According to the US Department of Energy, the amount of power from the sun in a single hour that strikes the Earth is more than the entire world consumes in an year. Each hour 430 quintillion Joules of energy from the sun hits the Earth. In comparison, the total amount of energy that all humans use in a year is 410 quintillion Joules. Where, 430 Exajoules (EJ) is equal to 119444444 GWh and 410 EJ is equal to 113888888 GWh.

On the Other Hand, The MIT Physics Professor Washington Taylor explained that A total of 173,000 terawatts (trillions of watts) of solar energy strikes the Earth continuously. That's more than 10,000 times the world's total energy use. And that energy is completely renewable until The Sun’s Lifetime. It is still in acceptable that, this Energy source has still 5 billion more years to be utilized**.**

However, fully harnessing the total amount of energy hits the earth per square feet, is a great challenge over material, efficiency, cost, technology. But at any cost to maintain a clean environment for the future, making the solar efficiency higher in every aspect, should be the main concern.

Normally, Mono-crystalline cell is around 20% efficient commercially. It is usually shaped as single hexagonal size for scaling criteria. But, theoretically it achieved around 29% efficiency. Amorphous thin film is 10% efficient and it is good for its transparency along with low cost. Poly-crystalline is around 15% efficient at lower cost category. Considering the space congestion this type of cell is designed in square shape. Reaching 16.5% efficiency, CdTe thin film cell is popular for its lower expense and large number of array deployment facility [1]. CdInGa Selenide thin film cell is around 20% efficient.

Hybrid Solar Cell with Perovskite has the efficiency range around 29% to 32% [2]. GaAs Multi-Junction Cell, having maximum 42.4% efficiency is used for expensive commercial purpose [3] [4] [5]. Adjusting doping level and the size of emitter-base layers, the efficiency of multi-junction cell can be improved [6] [7].

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2 POWER LOSS ANALYSIS

2.1 Introduction

Solar cell is not achieving around 100% efficiency due to several loss factors [8] [9]. Depending on some criteria, power loss analysis has been done to avoid this efficiency loss. Maximum Power Point Tracking (MPPT) System cannot be achieved for numerous reasons.

2.2 Low Energy Photon

According to $E = hf$ and $f = c/\lambda$, energy should be increased due to frequency increase. For this case, if the incident photon is of low energy, then it cannot excite the solar cell. These energy gets lost due to non-conversion.

There must be at least a two-level system, where electrons can make a transition from the lower (relaxed) to the upper (excited) energy state when they absorb light. Such a two-level system can absorb sunlight only with a certain photon energy, Eg (at a certain wavelength). A two-level system (as figure)

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can absorb light only at a certain energy (or wavelength). With an increasing number of energy levels (toward the right of the figure), a broader energy (or wavelength) range of light can be absorbed.

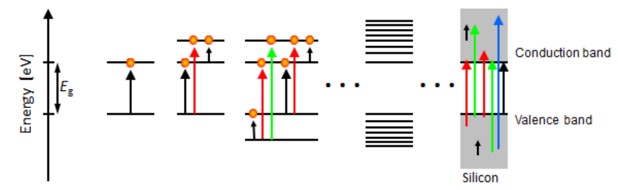

Fig. 1. A two-level system where light absorption happens only at a certain energy.

The color of the arrows corresponds to the color of absorbed light (black is infrared) if the energy gap, Eg is the one of silicon (1.12 eV).

In a semiconductor, each atom brings an energy level in, and as there are about 1022 atoms per cm3, these levels form two (nearly) continuous bands. The lower band is called valence band, the upper conduction band. Because the bands are nearly continuous, a semiconductor can absorb sunlight at all photon energies larger than Eg (1.12 eV for Si).

At lower energies than Eg, the light cannot be absorbed, because the electron does not find a state into which it could be excited. This is the reason why silicon solar cells cannot produce much electricity from low-temperature heat alone; they also need visible light.

2.3 Excess Energy Photon

When energy becomes high, the cell gets over excited and heated up. As a result, the open circuit voltage (Voc) increases, which leads to a major loss. These occurs when lower wavelength hits the cell.

No matter what, a silicon solar cell can never generate more than one electron from a single photon. Such harsh quantum realities severely limit the conversion efficiency of photovoltaic cells. Researchers are trying to handle the excitons to force convert on that state, from one photon to double or multiple electrons.

2.4 Voltage Loss

When energy increases, temperature rises. Thus Voc increases linearly with resistivity. We cannot choose randomly a material with a lower band gap. Because, the band gap also determines the strength (voltage) of electric field [10]. And if it is too low, then we can gain some extra current (by absorbing more photons). But on the other hand, we will be introduced to a small voltage also.

It is to be kept in mind that power is voltage times current. The optimal band gap, balancing these two effects, is around 1.4 eV for a cell made from a single material.

2.5 Fill Factor Loss

Injected power by highest possible power output is called filled factor. Fill factor in solar cells is affected by resistive parameters, front and rear metallic contacts resistivities, bulk resistivity, n+ and p+ emitters resistivities and metal-emitters interfaces resistivities. In this case, it is clear that the degradation is due to the bulk (active layer) resistivity. When increasing thickness of the active layer, one must characterize the structural and electrical properties of thick layer. The rise of structural defects like micro-cracks lead to increasing of the series resistivity of the bulk which effect the FF of solar cell.

2.6 Reflection Loss

Reflection loss is around 1.8%. This loss chiefly effect the power from a solar cell by lowering the short-circuit current. Optical losses consist of light which could have generated an electron-hole pair, but does not, because the light is reflected from the front surface, or because it is not absorbed in the solar cell. For the most common semiconductor solar cells, the entire visible spectrum (350 - 780 nm) has enough energy to create electron-hole pairs and therefore all visible light would ideally be absorbed.

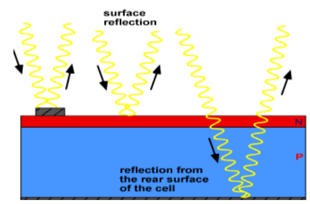

Fig. 2. Reflection criteria.

The reflection of a silicon surface is over 30% due to its high refractive index. The reflectivity, R, between two materials of different refractive indices is determined by as follows. Suppose for Silicon (Si) the reflectivity would be –

$$R = \left(\frac{n_0 - n_{Si}}{n_0 + n_{Si}}\right)^2$$

Where n_0 is the refractive index of the surroundings and n_{Si} is the complex refractive index of silicon. For an unencapsulated cell $n_0 = 1$. For an encapsulated cell $n_0 = 1.5$. The refractive index of silicon changes with wavelength and is given in the chapter on material properties.

2.7 Shadowing Loss

Shadowing loss happens around 0.4%. For non-Tracking situation and solar cell array design shadowing occurs. Shadowing of PV panels causes mismatch losses that can strongly compromise the power output of a photovoltaic power plant.

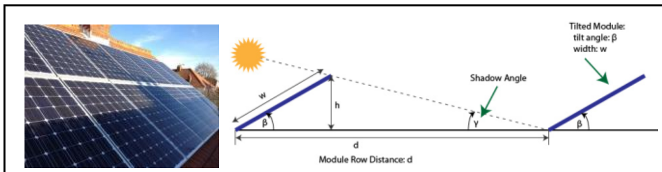

Fig. 3. Several Shadowing Effect.

2.8 Non-absorbed Radiation Loss

Up to 1.4%. non-absorbed radiation enters the solar cell. For which solar cell gets heated up. Whole range of solar spectrum absorption is needed for this.

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2.9 Ohmic/Resistive Loss

Resistive effect increases if temperature increases. For removing the model complexity one diode parallel PV model is considered. Like this, when shunt resistance increases, series resistance decreases.

2.10 Recombination Loss

For layer by layer junction based solar cell, 2% loss occurs due to recombination effect. In between photon and electron energy transformation time, these kinds of losses occur the most.

A high rear surface recombination will primarily affect carriers generated by infrared light, which can generate carriers deep in the device. The quantum efficiency of a solar cell quantifies the effect of recombination on the light generation current. The quantum efficiency of a silicon solar cell is shown below.

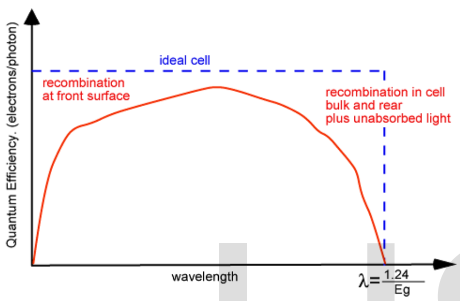

Fig. 4. Quantum η and impact of optical and recombination losses.

A high recombination source close to the junction (usually a surface or a grain boundary) will allow carriers to move to this recombination source very quickly and recombine, thus dramatically increasing the recombination current. The impact of surface recombination is reduced by passivating the surfaces. The net effect of previous trade-offs is shown in the graphs below.

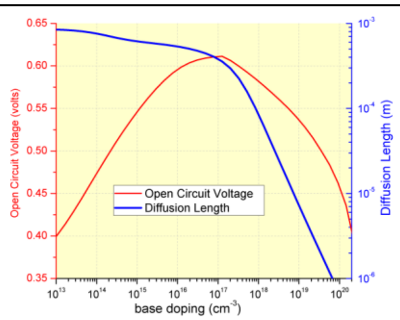

Fig. 5. Effect of doping on diffusion length and Voc assuming well passivated surfaces.

2.11 Temperature Related Loss

In this section, the loss rate is higher. 11% loss occurs for temperature loss effect. Theoretically up to 300 degrees of Celsius mono-crystalline cell can tolerate. But usually it can hold up to 100 degrees of Celsius temperature [10].

In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage. The impact of increasing temperature is shown in the figure below –

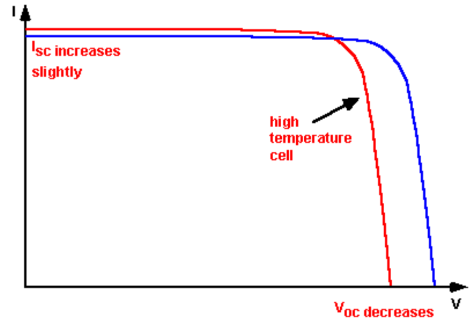

Fig. 6. The effect of temperature on the I-V curve of a solar cell.

The open-circuit voltage decreases with temperature because of the temperature dependence of I0. The equation for I0 from one side of a p-n junction is given by,

$$I_0 = qA\frac{D}{LN_D}BT^3\exp\left(-\frac{E_{G0}}{kT}\right) \approx B'T^{\gamma}\exp\left(-\frac{E_{G0}}{kT}\right)$$

$$\frac{dV_{OC}}{dT} = -\frac{V_{G0} - V_{OC} + \gamma\frac{kT}{q}}{T}$$

For these Calculations, Temperature affects on Silicon based Cell like, Voc decreases by 2.2 mV/°C; Isc increases by 0.0006 A/°C; Pmax decreases by 0.004/°C.

Besides, the heat produces several mechanical and electrical loss also. The operating temperature of a PV module is an equilibrium between the heat generated by the PV module and the heat loss to the surrounding environment. There are three main mechanisms of heat loss: conduction, convection and radiation.

2.12 Wavelength Confinement Loss

The behavior of getting trapped into the solar cell is usually called confinement. Due to specific reason, these confinement behavior gets revoked. This type of loss is called confinement loss.

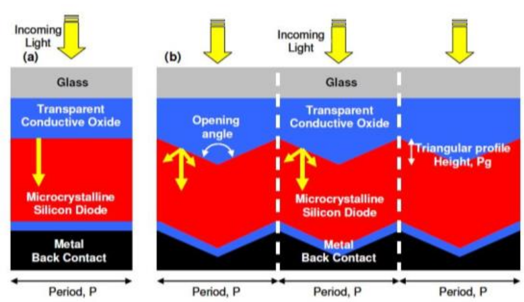

Fig. 7. Light injection on smooth and with triangular textured thin film m-c-si PV cell

Three kind of wavelength can be categorized. Short, medium and high. Infrared, visible light, ultra-violet ranged light are acceptable for PV Cell. Long wavelength like AM, FM, Microwave, causes confinement loss. Also x-rays and gamma

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rays having short wavelength causes confinement loss in solar cell.

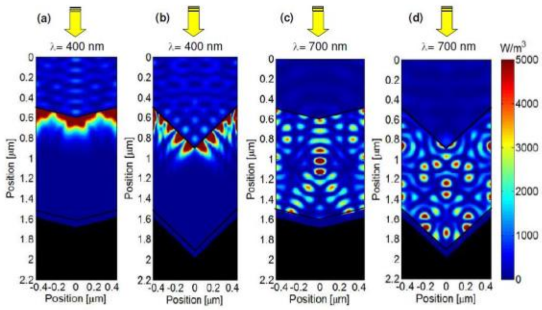

Fig. 8. Simulated Power Loss Profile

2.13 Sub-Band Gap Loss

Up to 10% loss occurs due to sub band gap loss. Material to material band gap defers. That's why use of Multi-junction is getting higher to reduce band gap difference.

2.14 Charge Flow Loss

After energy conversion, electron charge travels to a side thus to load area. In the meantime, these flows sometimes gets resistive behavior due to lack of space shortage in the path of charge flow. For this, access charge gets trapped and create temperature rise in the system [11]. This type of charge flow loss harm the entire PV cell array.

3 Possible Solution Against The Losses

3.1 Introduction

To design a efficient solar cell, solution of the possible losses is mandatory to be taken care of. Loss analysis is the very crucial part for a solar cell. Because, different type of solar cell has different type of loss pattern. Each pattern may react differently in other solar cell. That's why Each Solar Cell has to be cross-checked if there's any heavy loss pattern exist in the model.

3.2 Reduction of 4-R losses

Reduction of Reflection, Radiation, Recombination, Resistive loss are important. For less-reflection thus high refraction, a layer of high absorb rated and refractive glass layer has to be introduced. The refractive index should be nominated as to let every wavelength of the light spectrum. Temperature should be taken care of to reduce recombination loss a little bit and so do resistive loss. If the light intensity increases, the electron carrier increases. thus, resistivity gets reduced also.

3.3 Electron Mobility Accelerator

Electron mobility can be accelerated by injecting photon to the cell to the highest rate of absorption. Short circuit current will also get increased for that purpose, but solar cell will not get heated up due to less resistivity.

3.4 Heat Transfer Ability Development

In solar cell, temperature gets a high rise due to the sun radiation. To reduce this heat, Cavity base high pressurized air was introduced [12]. Water cooling made this step much easier but due to less boiling point level of water, water become non-suitable to transfer the heat from the cell. Accessing several heat transfer systems, some got little bit of efficient. From the analysis, a highly heat transfer system should be introduced to carry the heat from the cell and sink it to the air or other source.

3.5 Quantum Dot Cell Usage

According to the Shockley-Queisser limit, the maximum efficiency of solar energy conversion happens in the material of around 1.34 eV. But from lower band gapped material, we can also harness energy of lower energy photon. Combining these principles, designing of multi-junction with different band gapped materials, energy harness can be harness. Using quantum phenomena, energy levels can be changed and tuned by altering the size. That's why, QDSC Solar cell has better efficiency in that case. However, combining QDSC and several material for different purpose can be sandwiched to get overall better result. These Type of multi-junction solar cell may take the efficiency level to the peak.

3.6 Reduction of Encapsulation Layer

Above the solar cell, light transparent dark blue coloured layer is deposited, which increases lifetime and longibility but it decreases solar cell efficiency. It usually saves the cell from getting damaged by radiation. To increase the efficiency, such a material should be introduced which will play both the role of transparent dark blue layer and the layer of solar cell where photon conversion happens or a cathode material.

Since Graphene can be used as super conductor and can be materialized transparent as needed, it can be used in this case to full fill both the desire [13].

3.7 Charge Carrier Efficiency

High Generation of electron and hole pair rises the congestion of charge carriers. As a result, the conversion efficiency reduces rapidly. The analysis for charge carrier separation [14], dynamics, efficiency and stability should be taken care of while designing solar cells [11].

3.8 Utilization of Solar Spectrum

Solar Spectrum utilization is factor that effects the ultimate efficiency. 360 nm to 2.5 μm wavelength is available in solar spectrum. If all wavelength's photon are not being converted on the installed solar cell, then a major output will get lost.

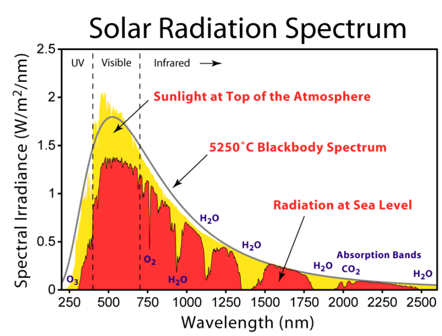

Fig. 9. Available Solar Spectrum

The solar spectrum at sea level contains nearly 2%

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of ultra-violet light (λ ≤ 0.38 μm), 47% is visible light (0.38 μm ≤ λ ≤ 0.78 μm), and 51% of infrared light (0.78 μm ≤ λ ≤ 2.5 μm).

Suppose, a solar cell is design with Silicon having 1.12eV bandgap. That means from 0.38 μm to 1.11 μm wavelength's photon are usable for the cell to convert it to electron hole pair [15]; but other photons (1.12 μm to 2.5 μm) are wasted for the cell. This happens because, for 1.12 eV band gapped material Photons with wavelengths longer than 1.11 μm have less energy than the band-gap energy of silicon (1.12 eV) and Photons with wavelengths shorter than 1.11 μm have more than enough energy to excite an electron.

3.9 Cooling Technology Enhancement

Due to the rise of temperature, solar cell efficiency dramatically reduces. To subdue the phenomena, cooling technique arise the efficiency. According recent analysis, the model temperature reduces significantly if proper techniques are applied [12].

Air cooling can be introduced by heat sink or Air channels, where the corresponding graph would be,

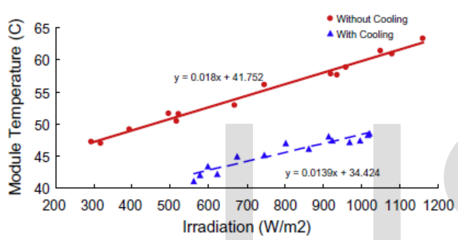

Fig. 10. Module Temperature VS Irradiation (with/without Cooling)

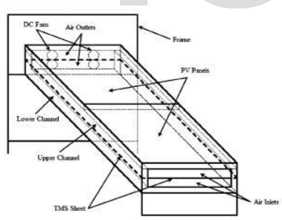

Fig. 11. Air channel based Cooling

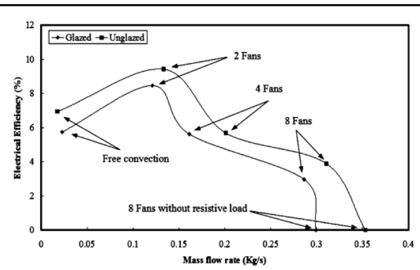

Fig. 12. Effect of air mass flow rate on η (E) of the above system

Water cooling or Heat exchanger can also be introduced. Doing so, the efficiency would be slight better, sometimes even more. The corresponding graph would behave like,

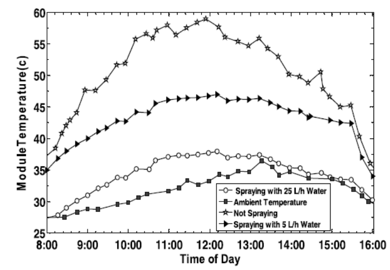

Fig. 13. Effect on temperature for water cooling

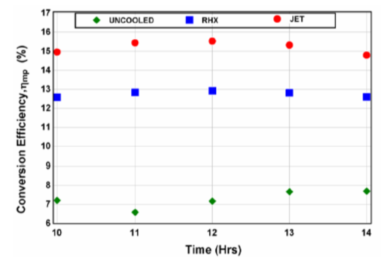

Fig. 14. Conversion η variation for PV with two cooling method.

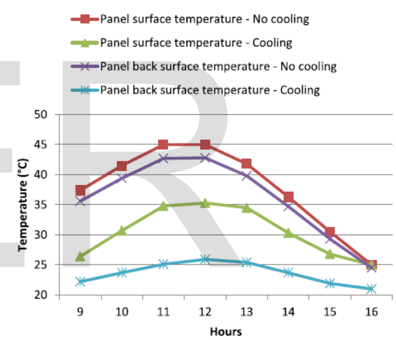

Fig. 15. Temperature variation with cooling and non-cooling situation.

The temperature of the PV cell decreases about 12° C by using heat sink with air cooling. Water spray cooling has a considerable effect on the performance of the PV cell, even for the low flow rate of the water spray the performance of the system enhances remarkably. To be specific that, Graphene has high heat conduction ability. The ability shows the ballistic performance.

3.10 Graphene as multi-purpose efficiency enrichment

Graphene has a unique set of properties which set it apart from other materials. In proportion to its thickness, it is about 100 times stronger than the strongest steel. It conducts heat and electricity very efficiently and is nearly transparent. Researchers have identified the bipolar transistor effect, ballistic transport of charges and large quantum oscillations in the material [16].

Graphene's reduced band gap (nearly zero) makes graphene a wonderful candidate for use in PV cells, for instance, because it can absorb photons with energy at every frequency. Photons of different frequencies of light are converted to electrons with matching energy levels. A material with a band gap

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can't convert wavelengths of light that correspond to the forbidden energy states of the electrons. No band gap means everything is accepted.

Non-covalent functionalized CVD-grown graphene shows a good conductivity and can have up to 0.55 V open circuit voltage, a fill factor of 55% and a PCE of 1.71%. The flexibility of graphene allows the solar cell to bend up to 78° more than pure ITO electrodes [17] [18].

Moreover, Doped Graphene Solar Cell [19], QD Graphene Solar Cell, Graphene Tandem Solar Cell, Graphene Bulk-Heterojunction Solar Cell [20], Graphene Schottky GaAs Solar Cell [21] [5], created an addition to advance research on efficient solar cell technology [22].

4 Market Available Solar Cell and Efficiency

4.1 Introduction

The loss analysis of market available solar cell and possible solution has been mentioned above. To emphasize the necessity of efficiency improvement of market available solar cell, we have to see the past and recent efficient condition commercial solar cell. In this part the linkage between these commercial solar cells and possible solution has also visualized.

4.2 Efficiency Comparison based on SQ Limit

SQ limit is the barrier where maximum solar cell gets stuck to overcome. On the third part of this paper, solution have been given to overcome the SQ limit. But we have to see why we should take the SQ limit under consideration.

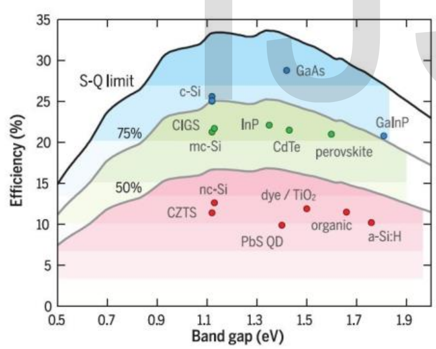

Fig. 16. Theoretical Shockley-Queisser detailed-balance efficiency limit as a function of band gap (black line) and 75% and 50%of the limit (gray lines).The record efficiencies for different materials are plotted for the corresponding band gaps [23].

It is scrutinized that, GaAs, InP, c-Si is leading the edge of SQ limit. And it should be; as it has the ability that are explained on the solution section.

Graphene is an addition to the material for solar cell that will increase the efficiency for its conductivity, transparency, high exciton conversion to electron-hole pair generation. From the solution, based on loss analysis, the multi-junction cell that has GaAs, InP and CdTe can make the efficiency high. Graphene Layer have to binded with these cells for making the efficiency overcome the SQ limit.

The encapsulation layer, electrode, thermo-absorber have to be properly designed. The help of graphene will be the addition for this portion also.

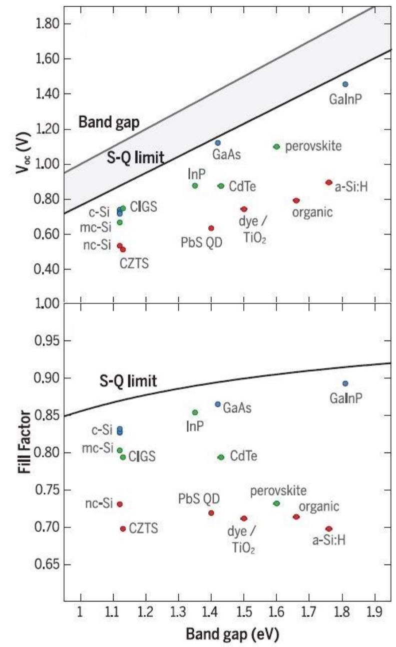

Fig. 17. Bandgap Vs Open Circuit Voltage and Fill Factor [23].

From the above data the previous statement is properly visible. According to the history of Solar Cell research and implementation, GaAs, InP, CdTe are very under rated material that should be used for further multi-junction solar cell manufactures. GaAs and InP can be useful for advanced thin film application also which Silicons' bulk solar cell can not perform. And if graphene enters the manufacturing zone for solar cell, it will reach the revolution.

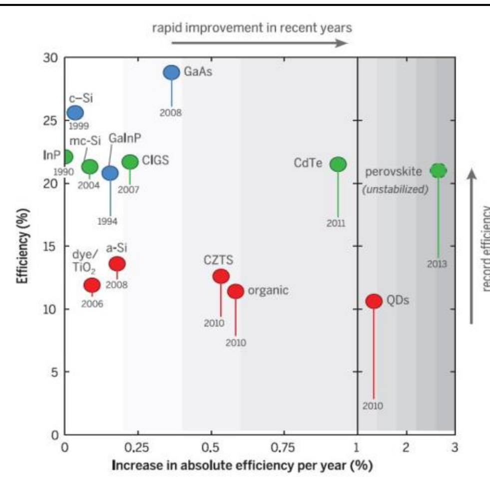

Fig. 18. Yearly comparison of Solar Cell R&D [23].

5 Conclusion

Solution based on the loss criteria works bit more efficiently for the solar cell design. Based on the possible solution facts, solar cell model can be proposed. These proposed solutions will be tested on simulation with several models, which will be the gateway of future high efficient solar cell with the pos-

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sibility of 70 to 90% overall efficiency for commercial aspects. The usage of Graphene and CdTe (for Quantum Dot purpose) with GaAs and InP will create a revolution on upcoming solar cells.

REFERENCES

[1] Vipin Kumar, "Electrical properties of cadmium telluride screen-printed films for photovoltaic applications," Chalcogenide Letters, 5. 2008, pp. 171-176.

[2] M. Bodiul Islam, M. Yanagida, Y. Shirai, Y. Nabetani, K. Miyano, "Highly stable semi-transparent MAPbI3 perovskite solar cells with operational output for 4000 h," Solar Energy Materials and Solar Cells, Volume 195,2019, pp. 323-329.

[3] Wang, X., et al. "Design of GaAs Solar Cells Operating Close to the Shockley–Queisser Limit". IEEE Journal of Photovoltaics. 2013. 3 (2): 737.

[4] Hector Cotal, Chris Fetzer, Joseph Boisvert, Geoffrey Kinsey, Richard King, Peter Hebert, Hojun Yoon and Nasser Karam , "III–V multijunction solar cells for concentrating photovoltaics ," The Royal Society of Chemistry 2009 , Energy Environ. Sci., 2009, 2, pp. 174–192.

[5] Jie W., Zheng F., Hao J., "Graphene/gallium arsenide-based Schottky junction solar cells," App. Phys. Lett., 2013, 103, 233111.

[6] Eli Yablonovitch, Owen D Miller, S. R. Kurtz, "The opto-electronic physics that broke the efficiency limit in solar cells", 2012 38th IEEE Photovoltaic Specialists Conference. 2012 p. 001556.

[7] Roland Scheer, Hans-Werner Schock, "Introduction", Chalcogenide Photovoltaics. 2011. pp. 1–8.

[8] M. Taguchi et al., "24.7% Record Efficiency HIT Solar Cell on Thin Silicon Wafer," IEEE Journal of Photovoltaics, vol. 4, no. 1, 2014, pp. 96-99.

[9] Prabhakaran Selvaraj, Hasan Baig, Tapas K. Mallick, Jonathan Siviter, Andrea Montecucco, Wen Li, Manosh Paul, Tracy Sweet, Min Gao, Andrew R. Knox, Senthilarasu Sundaram, "Enhancing the efficiency of transparent dye-sensitized solar cells using concentrated light," Solar Energy Materials and Solar Cells, Volume 175, 2018, pp. 29-34.

[10] Berthod, C., Kristensen, S. T., Strandberg, R., Odden, J. O., Nie, S., Hameiri, Z., & Satre, T. O. "Temperature Sensitivity of Multicrystalline Silicon Solar Cells", IEEE Journal of Photovoltaics, 2019, pp. 1–8.

[11] Wang, B., Iocozzia, J., Zhang, M., Ye, M., Yan, S., Jin, H., Lin, Z. "The charge carrier dynamics, efficiency and stability of two-dimensional material-based perovskite solar cells," Chemical Society Reviews, 2019, pp. 1-38.

[12] Swar A. Zubeer1, H.A. Mohammed, and Mustafa Ilkan, "A review of photovoltaic cells cooling techniques", E3S Web of Conferences 22, 00205, 2017, pp. 1-2.

[13] Li P., Chen C., Zhang J., Li S., Sun B., Bao Q., "Graphene-based transparent electrodes for hybrid solar cells," Frontiers in Materials, 2014, 1, 26.

[14] U. Würfel, A. Cuevas and P. Würfel, "Charge Carrier Separation in Solar Cells," IEEE Journal of Photovoltaics, vol. 5, no. 1, 2015. pp. 461-469.

[15] K. Masuko et al., "Achievement of More Than 25% Conversion Efficiency With Crystalline Silicon Heterojunction Solar Cell," IEEE Journal of Photovoltaics, vol. 4, no. 6, 2014, pp. 1433-1435.

[16] E. Shinn, A. Hubler, D. Lyon, M. Grosse-Perdekamp, A. Bezryadin, A. Belkin, "Nuclear Energy Conversion with Stacks of Graphene Nano-capacitors". Complexity. 22 October 2012, 18 (3): pp. 24–27.

[17] Tyagi, Pawan "Multilayer graphene as a transparent conducting electrode in silicon heterojunction solar cells," AIP Advances, AIP ADVANCES 5, 2015, 077165.

[18] Huang X., Xiaoying Q., Boey F. and Zhang H., "Graphene based composites," Chem Soc. Rev., 2012, 41, pp. 666-686.

[19] Miao X., Tongay S., Petterson M., Berke K., Rinzler A., Appleton B., Hebard A., "High Efficiency Graphene Solar Cells by Chemical Doping," Nano Lett., 2012, 12(6), pp. 2745-2750.

[20] Li X., Zhang S., Wang P., Zhong H., Wu Z., Chen H., Liu C., Lin S., "High performance solar cells based on graphene-GaAs heterostructures," Nano Energy, 2015, 16, 310.

[21] Ye Y., Dai L., "Graphene-based schottky junction solar cells," J. Mater. Chem., 2012, 22, 24224.

[22] Zongyou Yin, Jixin Zhu, Qiyuan He, Xiehong Cao, Chaoliang Tan, Hongyu Chen, Qingyu Yan, and Hua Zhang, "Graphene-Based Materials for Solar Cell Applications", Advance Energy Material, 4, 1300574, 2014, pp. 1-19.

[23] Albert Polman, Mark Knight, Erik Garnett, Bruno Ehrler, Wim Sinke. (2016). Photovoltaic Materials - Present Efficiencies and Future Challenges. Science. 352. aad4424-aad4424. 10.1126/science.aad4424.