Experimental Analysis of Temperature Effect on a Typical Perovskite Silicon (Si) Tandem Solar Cell

[1,2]Md Maroof, Md Nayeem, [1]Dr.Hamesh Babu Nanvala

[1]Babasaheb Naik College of Engineering, Pusad, Maharashtra, India

[2]Anjuman-I-Islam's Kalsekar Technical Campus Panvel, Maharashtra, India

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Abstract

Solar energy is the most plentiful source of renewable energy on the globe; nevertheless, the potential of solar cells now available on the market has not been fully tapped in an effective manner. Either raising the efficiency of a solar cell or lowering its price would help make solar energy more affordable. This may be accomplished in a number of ways. The purpose of this thesis is to provide numerous strategies for increasing the efficiency of solar systems by meticulous design. These strategies make use of software that is already on the market, namely SETFOS and SCAPS-1D. These methods make an effort to enhance several aspects of solar cells, including their current, voltage, capacity to absorb light, surface recombination, friendliness to the environment, and stability. Last but not least, the perovskite materials' design, which is mechanically layered, solves the problem of the absence of absorption losses, resulting in higher efficiency. In the beginning, the primary emphasis will be placed on finding ways to mitigate the problems that are inherent to thin film devices, such as poor absorption and high surface recombination.

Keywords. Perovskite, Silicon Tandem, Solar cell, Perovskite structure, Improving efficiency.

Introduction:

Solar energy is the collection of the sun's radiated light and heat utilizing a variety of different technologies that are always being improved upon. The process of generating electricity from the sun's rays via the use of photovoltaic cells is known as solar power (PV). Developing cells with many junctions is one method that may be used to effectively achieve high efficiency[1]. Perovskite solar cells that combine organic and inorganic materials have undergone a period of fast growth in recent years. Perovskite materials are good candidates for the development of tandem solar cells because of their superior optoelectronic characteristics and customizable bandgaps[2]. These solar cells would be combined with silicon solar cells, Cu(In,Ga)Se2 solar cells, and organic solar cells. In this article, we will discuss the latest developments that have taken place in the field of perovskite-based tandem solar cells. These cells include perovskite/silicon, perovskite/perovskite, perovskite/Cu(In,Ga)Se2, and perovskite/organic cells. The article concludes with a discussion of the prospects and difficulties associated with perovskite-based tandem solar cells. the energy demands while simultaneously lowering pollution caused by carbon dioxide, increasing employment opportunities, and lowering market instability caused by the geopolitics of fossil resources [3].

Over the course of the last ten years, there has been an upward trend in the level of worry over the effects of excessive levels of greenhouse gases in the atmosphere[4]. When fossil fuels like gasoline, coal, oil, or methane are burnt to provide energy or power vehicles, carbon dioxide is created. This is one of the primary greenhouse gases, along with methane. Wind power, geothermal power, fuel cells, solar power, and carbon sequestration are a few of the alternative energy sources that may be used in conjunction with one another to cut down on carbon dioxide emissions[5]. There have been many different discoveries made about the use of solar electricity. One method is the use of solar panels, in which light is focused onto a surface to excite electrons, which then results in the production of energy. Another method is known as thermal power, and it involves focusing the light from the sun on a single point in order to heat water, which is then put to use in a steam turbine.

I. Literature review:

The primary purpose of this review study is to summaries [6] all of the most recent published methods for transparent photovoltaics with at least 20% average transmission from 2007 forward. This entails not just displaying the materials and procedures used in each technology, but also explaining the benefits and drawbacks of each in terms of performance, aesthetics, and cost. As a result, this research serves as a vital update on what's new in the study of TSCs.

Crystal structure and photovoltaic performance [7] of CH3NH3PbI3 perovskite solar cells with a basic planar construction were studied at different temperatures. The crystal structure of CH3NH3PbI3 was observed to shift visibly when the temperature was changed, as a result of an increase in lattice parameters and an enlargement of the unit cell. Differences in coefficients of thermal expansion (CTEs) and lattice mismatch between TiO2 and perovskite materials may generate interfacial defects accountable for the decrease in the photovoltaic performance, which was significantly impacted by the crystal expansion. Interestingly, the CH3NH3PbI3 structure's less-distorted angles against temperature variation lead to a hysteresis that is much less in the cubic phase. To sum up, it was shown that the volume of the unit cell of perovskite rises linearly with temperature, and that the divergence in the CTE between CH NH PbI and TiO has an effect on the interfacial connection after heating. From 0 to +55 °C, a large discrepancy may be seen in the J-V measurement between the reverse and forward scan, indicating hysteresis. This, according to the authors, is because the internal rearrangement processes in the perovskite layer are directly influenced by the less distorted Pb-I-Pb angle in the cubic phase (temperature >+55o C). To this end, it may be prudent to pursue the enhancement of interlayer connectivity with selective contact and the better understanding of hysteresis in planar structure perovskite based solar cells as a means to the creation of robust and high-performance perovskite solar cells.

Perovskite solar cells' (PSTSCs) power conversion efficiency (PCE) [8] is discussed in detail in this article. There has been a remarkable rise in the PCE of PSCs, from 3.8% to 23.7%, but on the other hand, inadequate stability is one of the primary aspects that causes a big obstacle in the commercialization of PSCs. In this article, we describe the main causes of and processes for PSC deterioration and offer a brief summary of current attempts to improve PSC stability. In conclusion, studies on the problem of instability have drawn huge interest, coupled with the remarkable increase in the efficiency of perovskite solar cells. Among the many hurdles that must be cleared in the lab before perovskite solar cells may enter mass production is the problem of device instability. Although perovskite's stability has increased from a few minutes to thousands of hours, this is still not adequate for commercial use; the author should increase the lifespan of perovskite solar cells to more than 10 years. Different processes of perovskite solar cell deterioration have been hypothesised, providing both a foundational knowledge and some insight for improving stability.

Among the many materials and methods [9] used to manufacture cheap, efficient photovoltaic cells, inorganic-organic lead halide perovskite materials1-17 stand out as candidates for next-generation solar devices due to their high power conversion efficiency. Methylammonium lead halide materials have been shown to achieve the highest recorded efficiency for perovskite solar cells (1-10). We propose a bilayer solar cell design13 that combines the promising (due to its narrow bandgap) but highly unstable formamidinium lead iodide (FAPbI3) with methylammonium lead bromide

(MAPbBr3) as the light-harvesting unit. The author looked at how the phase stability, perovskite layer shape, hysteresis in current-voltage characteristics, and overall performance varied with the chemical composition. Incorporating MAPbBr3 into FAPbI3 stabilises the perovskite phase of FAPbI3, leading to a power conversion efficiency of the solar cell of about 18% under standard illumination of 100 mW/cm2. These results highlight the adaptability and performance potential of inorganic-organic lead halide perovskite materials for solar applications.

It has taken just around 4 years for perovskite/silicon tandem solar cells [10] to achieve certified efficiency of 28% (on 1 cm2 by Oxford PV), mostly due to the improved design in the perovskite top cell and crystalline silicon (c-Si) bottom cell. In this overview, we will examine how the structural development of monolithic perovskite/silicon tandem solar cells may be used to optimise the bottom cell's design for maximum efficiency. The structural characteristics of c-Si solar cells are first discussed, and then the cells are categorised into silicon homojunction and silicon heterojunction (SHJ) de- vices according to their temperature tolerance. The development of c-Si homojunction and heterojunction bottom devices-based monolithic perovskite/silicon tandem cells is then summarised. Monolithic perovskite/silicon tandem cells, which primarily consist of passivated emitter and rear cell devices, the tunnel oxide passivated contact cell, and SHJ devices, are offered as a suitable contender of the c-Si bottom cell. For the sake of brevity, we'll just say that our evaluation will focus on the various passivation structures for the c-Si bottom cell in perovskite/silicon tandem cells and how they affect the performance of the cells as a whole.

II. Perovskite Solar Cells

Perovskite solar cells have received a great deal of attention in the short period since 2012, and there are two crucial graphs that explain why this attention has been focused on them. The first of these graphs (which uses data taken from the NREL solar cell efficiency chart) illustrates the power conversion efficiencies of perovskite-based devices over the past few years in comparison to emerging photovoltaic research technology as well as traditional thin-film photovoltaics. This comparison is made in light of the fact that perovskite-based devices have been gaining traction in the field of photovoltaics in recent years.

The graph depicts a meteoric increase in comparison to the majority of other technologies during a period of time that is quite brief. Perovskite solar cells were able to match the efficiency of Cadmium Telluride (CdTe) solar cells, which had been in use for more than 40 years, in only four years after the discovery of perovskite solar cells.

The open-circuit voltage is compared to the band gap for a variety of technologies that compete with perovskites, and this comparison is shown in the second important graph below. This graph illustrates the amount of energy that is wasted during the process of converting light into electrical current.

This is getting very close to the values that can be achieved with state-of-the-art technology (like GaAs), but at a far more affordable price. Crystalline silicon solar cells, which are perhaps the closest comparable to perovskites in terms of efficiency and cost, are already up to 1000 times cheaper than state-of-the-art GaAs. Perovskites are the most efficient and cost-effective solar cells currently available.

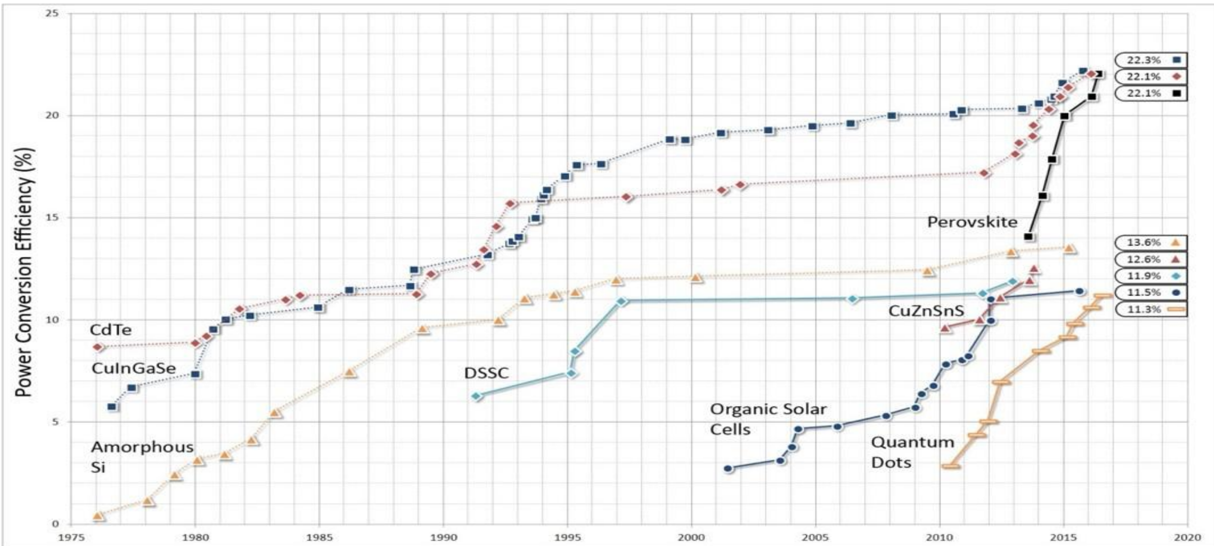

Figure1. ***Perovskite solar cells have increased in power conversion efficiency at a phenomenalrate compared to other types of photovoltaics.***

III. Perovskite-Silicon Tandem Solar Cells (PSTSC):

Si solar cells are now the most popular kind of photovoltaic device on the market. This is due to a number of factors, including its high efficiency, great stability, well-developed fabrication technology, and relatively inexpensive production costs at the module level. The maximum permitted conversion efficiency (PCE) for Si solar cells has now been measured at 26.7% [13]. The efficiency limit is a consequence of the loss caused by carrier thermalization. It is possible to construct tandem solar cells by combining Si solar cells with PSTSCs in order to cut down on the loss that is caused by thermalization. This idea proposes that a front cell made of PVK with a bigger bandgap would be responsible for absorbing high-energy photons, while a rear cell made of Si would be responsible for absorbing lower-energy photons. The bandgap of PVK is estimated to be 1.70 eV at its theoretical best. PCEs more than 30 percent may be obtained from these PVK/Si tandem cells. At this time, the Helmholtz-Zentrum Berlin (HZB) has reported the best PVK/Si tandem solar cell, which has a PCE of 29.1% and is ranked higher on the NREL Best Research-Cell Efficiency Chart than a single-junction Si or PVK solar cell. [14] Perovskite/silicon tandem solar cells have attained certified efficiency of 28% (on 1 cm2 by Oxford PV) in only around 4 years, mostly driven by the optimised design of the perovskite top cell and the crystalline silicon (c-Si) bottom cell. This was accomplished by Oxford PV. In this study, we will be concentrating on the structural adjustment of the bottom cell based on the structural development of monolithic perovskite/silicon tandem solar cells in order to increase the performance of these cells. To begin, c-Si solar cells are categorised into silicon homojunction and silicon heterojunction (SHJ) devices based on their ability to withstand temperature changes. The structural characteristics that are associated with each of these types of devices are then discussed. Following that is a synopsis of the development of monolithic perovskite/silicon tandem cells based on c-Si homojunction and heterojunction bottom devices. A suitable candidate for the c-Si bottom cell in monolithic perovskite/silicon tandem cells has been presented. This candidate primarily consists of passivated emitter and rear cell devices, the tunnel junction, and the tunnel diode.

SHJ devices and oxide passivated contact cells are included. In a nutshell, this study will stress the significant significance that the c-Si bottom cell plays in perovskite/silicon tandem cells, along with the various passivation structures that may be used. This information serves as a roadmap for improving the tandem cells' overall performance. [15]

IV. Impact of temperature on the efficiency of Perovskite silicon Si Tandem solar cell (PSTSC).

The power conversion efficiency (PCE) of an optimised thick PAL is a variety of temperatures ranging from 300 K to 400 K. Due to the decreasing PCE with rising temperature, the experiment is complete at five distinct temperatures. This is because high temperatures cause damage to PAL layers that are 800 nm thick or thinner. PSTSC devices give a PCE of 12.35% at 300 K temperature, despite the well-known fact that the MAPbI3 begins to bend internally at extremely high temperatures. On the other hand, it reaches 11.18% at 400 K, depicts the temperature gradient of the optimised PSTSC devices at the same time (b). In contrast to earlier results by Rafiq et al.

and Ferouani et al.[95, 96], it is clear that a vertical temperature gradient for the PSTSC device may be generated with a normalised efficiency of 0.012%/K. Inasmuch as more reliable long-term stability is anticipated with a PSTSC device that has a gentler Sagar Bhattarai found that the steeper the temperature gradient, the faster the PAL material would degrade in solar cell applications using perovskite materials.

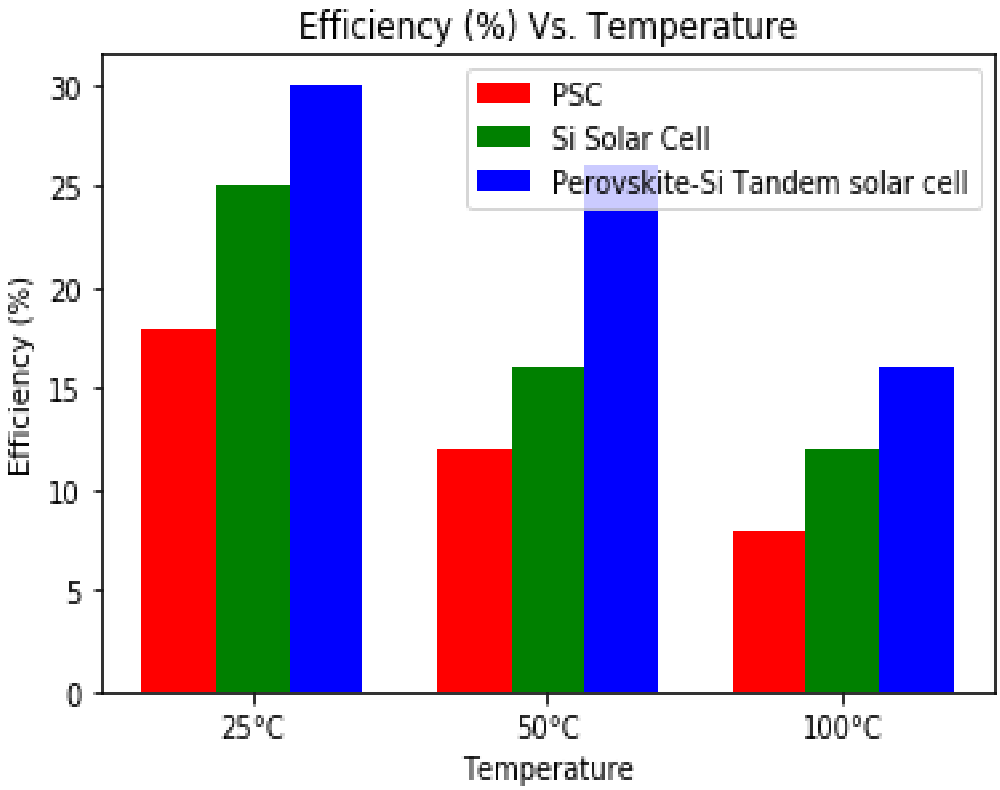

Figure2. Efficiency (%) Vs. Temperature(K)

V. Simulated device structure for Perovskite silicon Si Tandem solar cell

For the purpose of comparison modelling, a lead-free active layer is inserted into a heterojunction perovskite solar cell with structures D1 (FTO/TiO2/ MAPbI3/Spiro-OMeTAD/Au) and D2 (FTO/TiO2/MASnI3/Spiro-OMeTAD/Au). (b). The standard PSTSC device has a 100 nm thick FTO top electrode, followed by a 1 nm thick TiO2 hole blocking layer. This configuration efficiently gathers photo-generated electrons from PVK layers. The PVK materials that sit between the ETL and the HTL in both devices (D1 and D2) are precisely 400 nm and 500 nm in thickness, respectively. Spiro-OMeTAD, with a thickness of only 10 nm, efficiently transfers the hole from the PVK to the anode through a hooping process. The anode is thought to be Au and has a thickness of about 100 nm. The active layer of both PSTSC device architectures (D1 and D2) is doped with a doping density of 3.251019 cm-3 (c). Additionally,the photo-generated electron in PVK is largely injected to ETL and the hole to HTL, and then collected by their respective electrodes. This is because of the energy mismatch in the intermediate organic layer. [99]

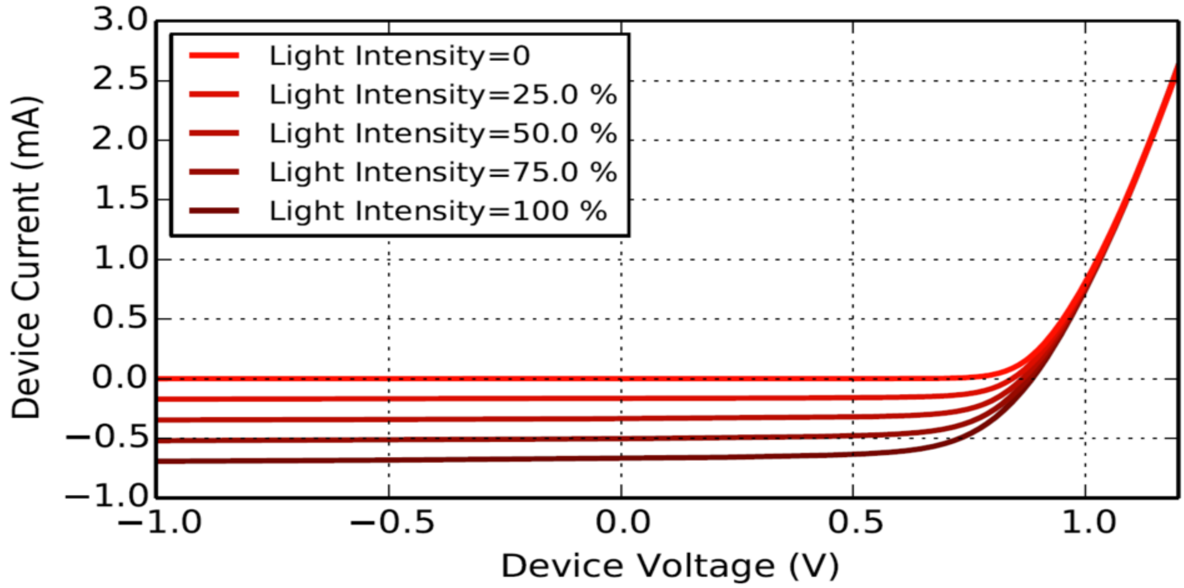

Figure3. Variations in Output V-I Characteristics of Perovskite silicon Si Tandem solar cell

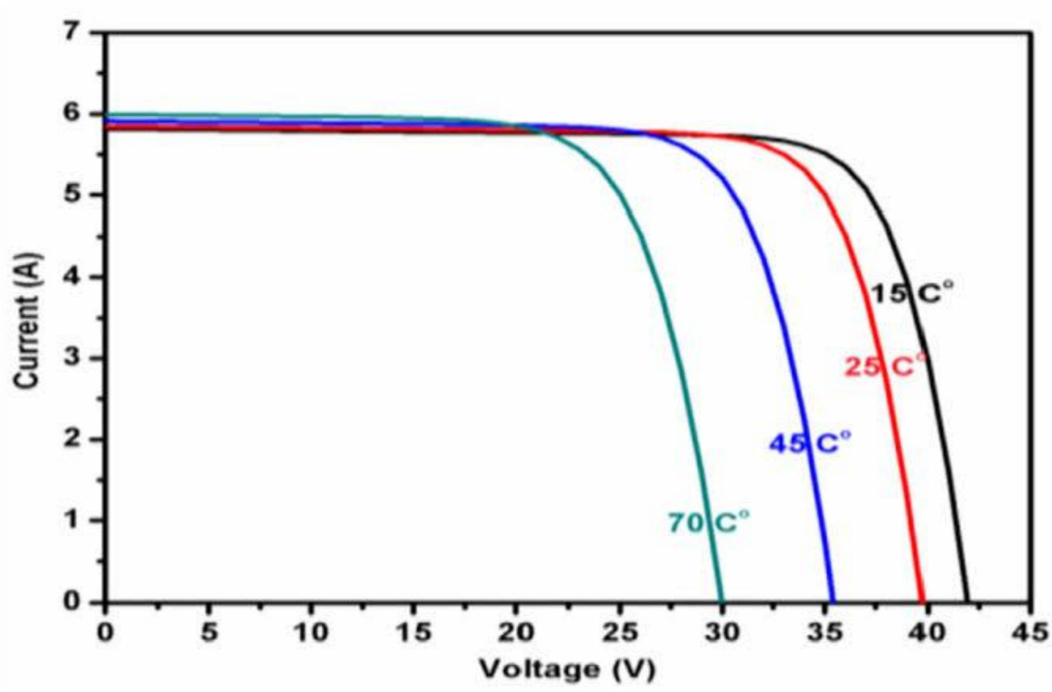

Figure4. Variations in Output V-I Characteristics

VI. Conclusion:

The maintenance and expansion of an affluent and advanced civilization both need a source of energy that is both guaranteed and able to be maintained throughout time. Since the consumption of energy has constantly climbed with the growth of civilization, it is expected that the consumption of energy will continue to rise in the future in order to maintain the present level of human progress. Therefore, solar energy and the technology behind solar cells could be the greatest alternative solution to current energy issue. However, the use of photovoltaic solar cells is restricted because of their poor efficiency and expensive price. Therefore, the most significant obstacle for the researchers is to bring down the cost of solar cells while simultaneously raising their overall efficiency. Perovskite solar cells and the influence temperature has on them When it comes to analysing how temperature rises in relation to the effectiveness of solar panels, using a perovskite structure for generating solar cells offers more advantages than disadvantages. The primary emphasis is placed on enhancing and preserving the efficiency of solar photovoltaic (PV) panels. Having a Perovskite solar cell and keeping the temperature stable are two things that may help improve efficiency. The findings demonstrate the improvement in performance for a PSTSC device with multiple carrier transport layers and a MAPbI3 layer at the ideal thickness of 500 nm, despite the layer's relatively narrow bandgap of 1.6 eV.

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