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Boosting Perovskite Tandem Solar Cell Efficiency

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***Abstract*—**To minimize losses in perovskite-silicon tandem solar cells, we apply optical modeling techniques that require precise optical constants obtained through methods like spectrophotometry and ellipsometry. Our research focuses on validating optical properties to reduce losses, thereby improving overall efficiency compared to single-junction cells. Recent developments have highlighted perovskites with wide bandgaps. Achieving current matching in two-terminal devices is essential due to interference effects in multi-layered tandems. Extensive modeling investigated varying bandgaps and pyramid heights to attain current matching, demonstrating that a 1.7 eV bandgap perovskite can achieve high efficiency. Reducing losses can further enhance performance.

***Keywords*—** Perovskite, Solar Cells, Efficiency.

I. Introduction

Rising population and improving lifestyle standards have led to an unprecedented rise in the demand for energy [1]. In fact, an increase in energy consumption leads to global warming and its dire attendant consequences. To restrain some of these issues, it is imperative to shift to abundant and eco-friendly fossil free alternatives as resources of energy [2]. Out of all available options, the strongest candidate for electricity generation is solar energy. Currently, Silicon solar cells have retained their monopolistic position in the photovoltaics industry, making up about 90- 92% of installations. Over time, these silicon-solar-cells have shown an efficiency of about 20 percent, with some even attaining 27 percent [3]. These efficiencies are still very close to the theoretical limit S-q-limit for single Junction solar-cells. However, in order to further improve the efficiency of photovoltaics and widen its scope, scholars are doing active research towards different materials. Perovsikite solar cells (PSC) have shown a lot of potential as an alternative because they are inexpensive to manufacture and simple to process [4]. The efficiency for energy conversion of perovskite cells has improved dramatically from 3.8% to 25% (Laboratory, 2019). It remains the very much recognized, widely used solar-cell technology worldwide. Therefore, silicon-cells are significant for their long lifespan of around 20 years and decreasing fabrication costs due to large-scale industrial manufacturing [5]. There are challenges associated with silicon solar cells such as the high-temperature requirements during the production. The development of solar tandems using perovskite materials carries much promise for getting higher efficiencie.

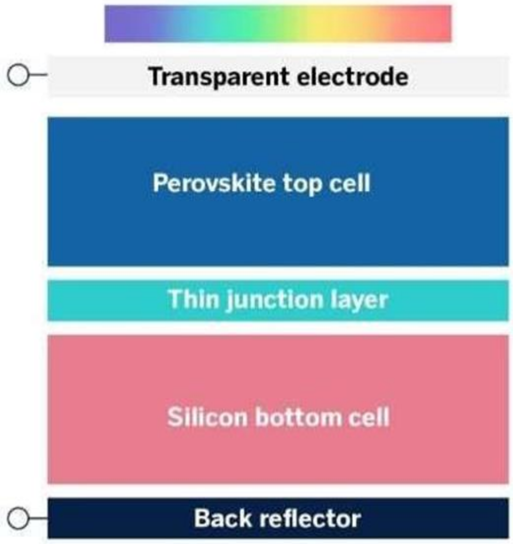

Figure 1: Silicon/ perovskite tandem [6].

Perovskites are emerging as an innovative technology in the field of solar-cell research. Perovskite solar cells demonstrate efficiencies that are relatively close to those of crystalline silicon-solar-cells [7]. They can be fabricated easily without requiring high-temperature processing. The first perovskite solar cell, manufactured in 2009, achieved a modest conversion efficiency of 3.8%. However, researchers have made significant progress since then, reaching an efficiency of 21.0% in 2015. Despite these advancements, the instability at high temperatures is a challenge that impacts their overall efficiency [8]. This indicates ongoing research and development opportunities to further improve efficiency. By addressing the stability and durability challenges of perovskite solar cells while further enhancing their efficiency, this technology holds great potential for revolutionizing the field.

II. Literature Review

This Perovskite-based solar cells have demonstrated impressive progress in recent years, achieving a power

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conversion efficiency (PCE) of over 21.2%. However, their practical application is still hindered by durability issues, as the current processes yield relatively short lifetimes. To make perovskite solar cells commercially viable, it is crucial to develop economically feasible devices with extended lifetimes [1-2]. In 2009, Miyasaka et al. introduced the concept of perovskite solar cells with a design based on dye-sensitized solar cells and a thin layer of perovskite on mesoporous TiO2 as the electron collector. This initial design achieved a modest PCE of 3.8 %. In 2012, the stability of perovskite solar cells was improved by incorporating spiroMeOTAD as a solid-state hole transport material (HTM), resulting in longer lifetimes [8]. Another approach to enhancing stability involved subjecting the cells to long-term light soaking at a temperature of 450°C, which improved stability over 500 hours [9]. However, the use of organic HTMs like spiroMeOTAD, PTAA, or P3HT in perovskite solar cells can pose challenges for long-term stability measurements (around 1000 hours) [3-4].

These organic HTMs can degrade the photovoltaic (PV) performance due to morphological deformation, metal diffusion, and movable additives. Researchers have explored alternative HTMs such as CuI, CuSCN, and NiOx to improve stability [10]. For instance, CuI-based solar cells exhibited a PCE of approximately 6.0% and demonstrated improved open-circuit voltage compared to devices using spiroMeOTAD. CuSCN has also shown promise, achieving considerably high PCE values. The utilization of NiOx as an HTM in PSCs has led to optimal PCE of 16.47% by spin coating a high-quality NiOx nanoparticle solution [11]. Recent advancements have focused on inorganic HTMs, including copper oxide and nickel oxide, which have achieved efficiencies of around 17%. These inorganic HTMs demonstrate better stability compared to spiroMeOTAD. For instance, CuSbS2 has been explored as a potential inorganic HTM, offering abundant and available materials and high open-circuit voltage. By optimizing the thickness of CuSbS2, perovskite solar cells achieved a conversion efficiency of 23.14% with acceptable VOC and JSC values.

III. MATERIAL AND METHOD

This study utilizes optical modeling with Sunsolve to enhance efficiency in silicon-perovskite tandem solar cells, requiring accurate optical constants obtained through ellipsometry and spectrophotometry. We will compare these constants to ensure authenticity, while varying parameters such as pyramid height, thickness, and material types in tandem configurations. The focus will be on achieving current matching with bandgaps from 1.56 to 1.8 eV, addressing interference effects in two-terminal structures through detailed modeling of two configurations: configuration-a [txt-ARC/txt/txt/txt] and configuration-b [flat-ARC/flat/txt/txt].

IV. RESULTS AND DISCUSSION

Tandem solar cells represent a highly promising development in solar technology. The light absorbing abilities of perovskites enable them to efficiently trap broad spectrum of light. Silicon has a long term placing in solar industry. Renowned for the stability, reliability, and best performance in conversion to electricity. Therefore, silicon cells have limitations in trapping photon. Structure of perovskite silicon tandem involve very careful consideration of many factors. One important aspects are achieving complementary absorption and electronic properties between the perovskite and silicon layers. This is achieved by optimizing the band-gap with each cell to correspond to energy level of incident photons. To fabricate them the perovskite usually layers on silicon solar cell using techniques such as spin coating. Ensures efficient charge extraction and lessons losses at the perovskite silicon interface. When light enters the tandem many photon are absorbed in perovskites layer. The unique property and strength of solar-cell. The structure gives many benefits to individual cells. They boost the light absorption and facilitates efficient harvesting of photons.

The silicon layer maximize the uses photons thus leading to improved performance and increases PC efficiency. Study focuses on evaluating effect of pyramid height on current-matching short-circuit current density Jsc with two configurations i.e. [ARC-txt/txt/Txt/Txt] and also [ARC-Flat/flat/ txt/Txt]. Pyramid height was optimized to find the achievable current-matching Jsc for each configuration. In the [ARC-txt/txt/Txt/Txt] configuration, the study identified a maximum current-matched Jsc of 21.51 mA/cm². Similarly, for the [ARC-Flat/flat/txt/Txt] configuration. Maximum Jsc obtained was 19.82 m A/cm.

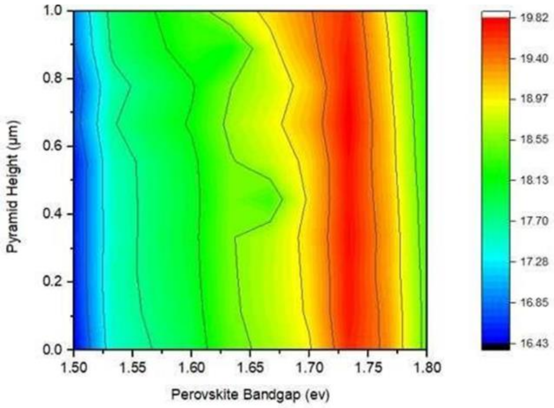

Fig.2 optical constants are used to map the short circuit current density of a textured 2 terminal per/si tandem as a function of pyramid height and bandgap, providing a guide to nearly 19.8 mA/cm2 matched current density with any perovskite bandgap between 1.73 and 1.75 eV

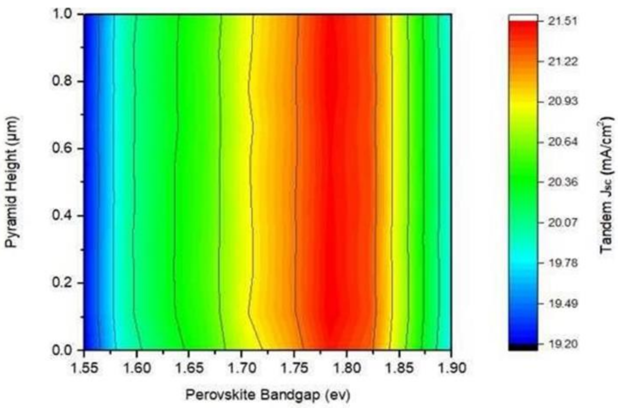

Fig.3. optical constants are used to map the short circuit current density of a textured 2 terminal per/si tandem as a function of pyramid height and

bandgap, providing a guide to nearly 19.8 mA/cm2 matched current density with any perovskite bandgap between 1.76 and 1.83 eV

Pyramid height refers to the height and thickness of the textured-layer with the perovskite/ silicon tandems structure. Study investigates how varying the pyramid height affects the attainment of current-matched condition. Getting matching is important for optimizing tandems efficiency. Results demonstrated that with optimizing the pyramid height, the current-matched Jsc values reached their highest levels for the specific configurations studied. These Jsc values represent the maximum achievable Jsc.

CONCUSLION

This study examines the impact of pyramid height on current-matching short-circuit current density (Jsc) for two configurations: [ARC-txt/txt/Txt/Txt] and [ARC-Flat/flat/txt/Txt]. The goal was to determine the optimal pyramid height for maximizing Jsc. Fine-tuning the pyramid height resulted in peak Jsc values, with the [ARC-txt/txt/Txt/Txt] configuration achieving 21.51 mA/cm^2 and the [ARC-Flat/flat/txt/Txt] configuration reaching 19.82 mA/cm^2. These findings emphasize the significance of optimizing pyramid height to enhance the performance and efficiency of perovskite/silicon tandem structures.

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