A Review on Preparation Techniques of Charge Transport Layer for Organic and Inorganic Perovskite Solar Cells

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Authors' contributions

Review Article

ABSTRACT

The fascinating behavior of charge transport layer in organic and inorganic perovskite solar cells has piqued the interest of designers of semiconductor SnO_2 nanoparticles (PSC). The goal of this research is to look at several techniques for manufacturing SnO_2 films for use as charge transport layers in PSC. To comprehend the link between the attribute of nanostructured SnO_2 films and the efficiency of solar cells, special attention is devoted to the production and properties of the SnO_2 thin films. The spin-coating deposition of SnO_2 nano fluids generated via surface modification of nano-colloids composed of SnO_2 has been one of the key techniques for obtaining SnO_2 layers. It has also been reported that preparing SnO_2 nanoparticles using Tin (IV) salts results in a high-quality SnO_2 film. Light-to-electricity conversion efficiency of about 25.5% has been claimed in many PSC papers [1]. One benefit of adopting SnO_2 materials is that they have substantially greater conductivity than TiO_2. This work also discusses the production of SnO_2 nanoparticles, a

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different method of generating SnO_2 charge transport materials that may be accomplished by the process of freeze-drying precursors known as Tin (IV). SnO_2 crystal formation may be regulated at temperatures as low as 70^0C.

1. INTRODUCTION

The availability of fossil fuels has declined over the last several decades while the world's energy needs have grown, causing more harm to the environment. As a result, the development of renewable energy sources has increased. Solar power is one of the most promising options since solar energy provides the most definitive solution to the problem of a sustainable energy supply. Solar thermal systems, both passive and active are the two most used methods for producing solar power. When it comes to solar cells for electric power production, there are many methods for harvesting solar energy, the most popular of which are traditional solid-state solar panels. The disadvantages of these silicon-based solar panels include their high manufacturing costs and bad environmental effects. Different types of solar cells have appeared in recent years, each promising cheap manufacturing costs, minimal environmental impact, and great efficiency, solar cells made of perovskite, for example (PSC) [2] and dye-sensitized solar cells (DSSC) [3].

"Perovskite solar cells are a relatively new type of photovoltaic technology that has been produced since 2009" [4]. They're a collection of compounds that share the same crystal structure as calcium titanate (CaTiO3) and have the generic formula ABX3. Anions are usually accommodated at the X site, while inorganic cations of various valency ionic radii are commonly accommodated at the A and B sites (halogen or oxygen).

"They're a class of materials that share the same crystal structure as calcium titanate (CaTiO3) and have the generic formula ABX3. The A and B sites are often used to accommodate inorganic cations of various valency ionic radii, while the X site is used to accommodate anions (halogen or oxygen)" [6]. "They're a collection of materials that have the same crystal structure as calcium titanate (CaTiO3) and the generic formula ABX3. Anions are usually accommodated at the X site, while inorganic cations of different valency ionic radii are commonly accommodated at the A and B sites (halogen or oxygen)" [4]. The crystal structure of these materials has an octahedrally coordinated lead (Pb) atom with corner-sharing halogens and A-site organic ligands. The precise position of the organic ligands in crystallographic data is currently unavailable.
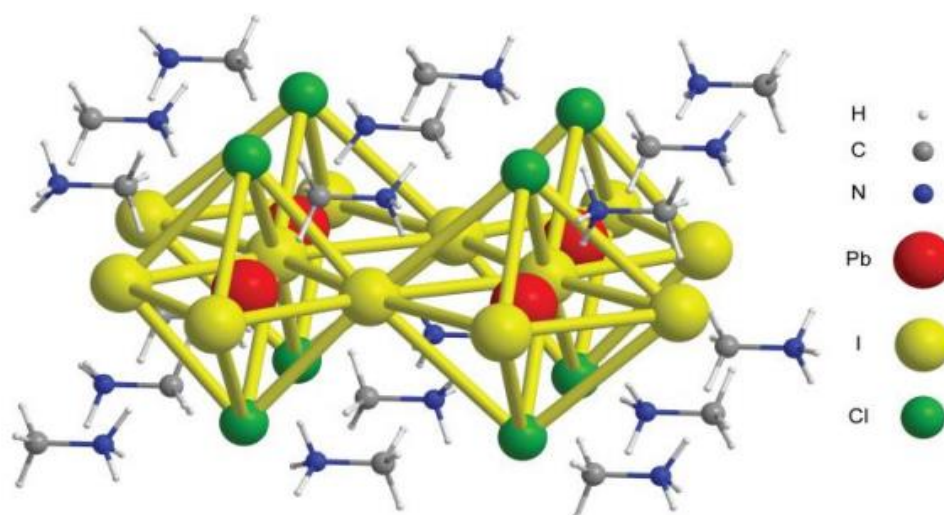
Fig. 1. Possible crystal structure of the hybrid perovskite CH₃NH₃PbI₃-xClx [5]

The efficiency has increased from 3.8% to 25.5% in the last nine years [1, 8]. The devices are made of halide perovskite with a p-i-n structure. The excellent energy conversion efficiency allows it to compete with gadgets from the first two generations. The perovskite solar cell, unlike classic dye-sensitized solar cells based on a solid-liquid interface, is entirely solid-state, lowering encapsulation costs. The main challenge preventing perovskite solar cells from being commercially viable is their instability [9]. The stability of perovskite materials is influenced by light, oxygen, and moisture. The bulk of electron transport materials employed, on the other hand, are less stable than perovskite materials, which might be considered a bottleneck for further reducing device stability. Furthermore, moisture and oxygen can penetrate through the electron transport layer (ETL) and interact with the perovskite layer, therefore improving the electron transport layer stability is critical for device stability [7]. One of the electrodes in these solar cells is composed of nano-crystalline substances, such as titanium dioxide and/or stannous oxide creating the semiconductor layer for the photon-charge transfer process. The nano-crystalline substance is often used. To put over a clear conducting glass to create a high surface coverage of light-absorbing materials, which is required for high-performance devices.

1.1 Charge Transport Layer

"Tin (IV) oxide, also known as SnO_2, has lately been examined as a potential alternative to titanium dioxide (TiO_2) in terms of its ability to transport charges. SnO_2 possesses been extensively explored, for example, concerning perovskite solar cells (PSCs), owing to their advantageous properties such as high charge mobility (100-200 cm^2 V^{-1} s^{-1}) and a broad bandgap of 3.6 eV compared to 3.2 eV for TiO_2" [10]. The high mobility may facilitate quicker charge transit, lowering the likelihood of photoinduced charge recombination. Furthermore, SnO_2 creates a homo-junction with the FTO substrate, which eliminates the high contact resistance reported in hetero-junctions created with other oxides such as TiO_2. Despite the obvious benefits over TiO_2, there are several problems about utilizing SnO_2 as a charge transport layer, the primary one being that it degrades at higher temperatures. Much research has been conducted to demonstrate that the efficiency of solar cells may be boosted even further by employing SnO_2 instead of TiO_2. This study describes important breakthroughs in the fabrication of SnO_2 thin films, as well as the unique properties of SnO_2 as charge transport layers in PSCs (Tables 1 and 2).

Table 1. Provides an overview of the typical method of deposition of SnO_2 films and the performance of PSC. Specifically, the acronyms MA and FA stand for the ions of methylammonium and Formamidinium, respectively.

A method for the deposition of tin oxide	Perovskite	Jsc (mA/cm^2)	Voc (V)	FF	η (%)	Ref.
Sol-gel process (Spin-coating of Tin salt, Annealing)	$CH_3NH_3PbI_3$	22.83	1.11	0.64	16.02	[11]
Deposition of SnO_2 colloidal solution (Spin- coating)+ Annealing	$(FAPbI_3)_{0.97}(MAPbBr_3)_{0.03}$	24.87	1.09	0.74	20.27	[12]
Deposition of SnO_2 colloidal solution (Spin- coating)+ Annealing	$FA_{0.95}Cs_{0.05}PbI_3$	24.57	1.11	0.79	21.60	[13]
Deposition of SnO_2 colloidal solution (Spin- coating)+ Annealing	$(FAPbI_3)x(MAPbBr_3)_{1-x}$	24.1	1.1	0.78	21.30	[14]
Sol-gel process (Spin-coating of Tin salt, Annealing)	$MAPbI_3$	22.66	1.07	0.72	17.61	[15]
Deposition of SnO2 colloidal solution (Spin- coating)+ Annealing	MAPbI3	24.28	1.15	0.76	21.38	[16]
Electrodeposition (Tin salts)+Annealing	$MAPbI_3$-xClx	18.65	1.02	0.79	14.97	[17]
Annealing followed by the deposition of a colloidal solution of Tin Oxide (Spin-Coating)	$CH_3NH_3PbI_3$	20.11	1.11	0.64	14.36	[18]
Magnetron sputtering	$CH_3NH_3PbI_3$	21.94	0.99	0.67	14.63	[19]
Atomic layer deposition	$Cs_{0.05}(MA_{0.17}FA_{0.83})_{0.95}Pb(I_{2.7}Br_{0.3})$	22.1	1.07	0.75	17.80	[20]

Table 2. Examples of SnO_2/TiO_2 film deposition techniques and PSC performance.

Deposition technique	Perovskite	Jsc (mA/cm^2)	Voc (V)	FF	η (%)	Ref.
SnO_2 nanoparticles that have been coated with amorphous TiO_2 (Spin-coating)	$CsI+(FAPbI_3)_{0.87}(MAPbBr_3)_{0.13}$	22.51	1.168	0.776	20.40	[24]
Three-step chemical bath	$(FAPbI_3)_{0.3}(MAPbI_3)_{0.7}$	23.38	1.122	0.778	20.40	[25]
The process involves magnetron sputtering (TiO_2), deposition of a colloidal solution of SnO_2 (spin-coating) and annealing (SnO_2).	$Cs_{0.05}(MA_{0.17}FA_{0.83})_{0.95}Pb(I_{0.83}Br_{0.17})_3$	23.28	0.980	0.670	15.39	[14]

2. SYNTHESIS OF TIN OXIDE LAYER AND PEROVSKITE SOLAR CELLS APPLICATIONS

SnO_2 electrodeposition on FTO was proved to be a viable option for use in planar heterojunction perovskite solar cells by Ko et al. [17]. A chrono-voltammetry technique was developed for the electrodeposition of Sn nanospheres on FTO substrate using a three-electrode setup (working electrode: FTO, counter electrode: platinum plate, reference electrode: Ag/AgCl electrode) using a water-based solution of $SnCl_2 2H_2O$ and nitric acid. The nanospheres were successfully deposited using this method. To turn the nanospheres into SnO_2, they were heated in air for thirty minutes at 400 °C. $TiCl_4$ treatment was also applied, with the substrates drying in the air at 150 °C after 30 minutes in a $TiCl_4$ solution at 70 °C. The perovskite layer was formed by spin-coating a mixture of PbI_2 and $PbCl_2$ diluted in N, N-dimethylformamide over the SnO_2-coated FTO in a glove box and drying it at 70°C. After spin-coating a methylammonium iodide solution, it was annealed for 75 minutes at 105°C in the open air. A poly[bis(4-phenyl)(2,4,6-trimethylphenyl)amine solution served as the HTM. The device's PCE was 9.11% after 150 seconds, or around 2.5 minutes, of deposition. Its fill factor, open-circuit voltage, and short-circuit current density were 17.84 mA/cm^2, 1.03V, and 0.496, respectively. The superior Jsc produced a higher PCE of 10.0% even after extending the deposition period to 180 s. The PCE is decreased by using a 210-second deposition duration (8.22 %).

"Apart from the previously discussed solution-processed SnO_2 film deposition, Li et al. showed the effect that UV treatment of low-temperature processed SnO_2 has on the performance of PSC" [18]. They spun-coated a water-based SnO_2 precursor and then treated it with UV ozone, which resulted in the development of a thick coating. Thin films of SnO_2 were obtained by spin-coating the SnO_2 precursor solution. (Concentrations of 10, 15, 20, and 30%) on ITO substrates, followed by a 50°C drying process. After that, the substrates were cleaned for 60 minutes at 60 ^{0}C using an ultraviolet ozone cleaner. The temperature at which each layer of solar cells was produced was lower than 90°C. ITO/SnO_2/$MAPbI_3$/Spiro-OMeTAD/Au planar hetero-junction PSC were the device designs. At a 20% concentration of SnO_2, the performance peaked with a Jsc of 20.11 mA/cm^2, Voc of 1.11 V, FF of 0.643, and PCE of 14.36%.

Sun et al. [19] also reported "a vacuum film of SnO_2 was created. By using radio frequency reactive magnetron sputtering at room temperature, they were able to generate the film according to their expectations. Compared to the FTO substrate, the surface roughness of the SnO_2 thin films that were produced consequently was lower, which resulted in an improvement in the interface morphology with the perovskite layers. The FTO glass that had not been subjected to sputtering had a roughness of 31.8 nm, while the sample that had been subjected to sputtering had a roughness of 30.2 nm. For reducing faults in interfacial contact, the perovskite coating was smoothed and uniformized using the sputtering process. Planar perovskite cells based on bare FTO displayed very weak Jsc and FF due to their composition and PCE of just 5.08 %. PCE of the device was 12.02 % when reactive sputtering was used to deposit a charge transport layer (Jsc: 20.20 mA/cm^{-2}, Voc: 0.95, and FF: 0.62)".

Kuang et al. reported on "plasma-assisted atomic-layer SnO_2 deposition for PSC [20]. At 200°C, tetrakis (dimethylamino)tin (TDMASn) was used as a precursor to form a SnO_2 film with

a low electrical resistivity of 1.8 1013 cm, a carrier density of 9.6 1019 cm3, and a high mobility of 36.0 cm^2 /V s. As substrates, ITO layers were employed, and SnO_2 layers with a thickness of 15 nm were deposited at temperatures ranging from 50 to 200 °C. Prior to perovskite deposition, the SnO_2 layers were pretreated with O_2 plasma at ambient temperature. Planar PSCs of $Cs_{0.05}(MA_{0.17}FA_{0.83})_{0.95}Pb(I_{2.7}Br_{0.3})$ were created. The top performing devices utilizing 50 and 200 °C-processed SnO_2 attained PCEs of 17.5 and 17.8 %, respectively".

Crystalline SnO_2 nanoparticles have recently been shown for the very first time by researchers that they may be produced via the use of a dry-freezing procedure in conjunction with a low-temperature approach. $SnCl_2$ was used as a starting material for dry freezing, which was performed at temperatures lower than 300 degrees Celsius, to produce the precursor solution of water and methanol combination. The dehydration of them was accomplished using this method. amorphous Sn (II)-containing precursor, resulting in crystalline SnO_2 nanoparticles [23]. Using the transmission charge microscope, it was possible to see nanoparticles that were as tiny as 5 nanometers. The XRD pattern demonstrated that the dry freezing process resulted in the formation of nanocrystals of synthetic manganese dioxide. Now, the development of device applications that make use of SnO_2 as a charge transport layer in PSC is already underway.

Temperature ranges from 400 - 700⁰ C processed TiO_2 was commonly employed as the charge transport layers in high-performance lead halide perovskite solar cells. Ke et al. [21] SnO_2-based perovskite solar cells were the subject of one of the earliest research ever published. The findings of this enquiry suggested that nanocrystalline SnO_2 treated with a solution at low temperatures might be an efficient alternative to TiO_2. This study included the synthesis of SnO_2 using a solution approach, namely spin-coating of SnCl2 precursor, which can be produced at room temperature. The next step was a heat annealing process that lasted for one hour in the air at 180 °C. Before Perovskite deposition, the thin films were exposed to UV-ozone for 15 minutes. The film was composed of nanoscale grains, according to SEM and TEM examination, and the SnO_2 was crystallized. When the FTO substrate was coated with the SnO_2 nanocrystalline film, atomic force microscopy pictures revealed that the surface grew smoother. When tested using the best-performing perovskite cell with a 60 nm-thick SnO_2, $CH_3NH_3PbI_3$ (600 nm), and Spiro-OMeTAD achieved a PCE of 17.21% in a reverse voltage scan (Voc: 1.11 V, Jsc: 23.27 mA cm^{-2}, and FF: 0.67). The PCE, Voc, Jsc, and FF values for a forwards voltage scan of the same cell were 14.82 %, 1.11 V, and 22.39 mA cm^{-2}, respectively. There was extremely little hysteresis in the perovskite solar cells with the SnO_2 layer. The researchers concluded that some of the reduced hysteresis seen in the PSC may be explained by the improved charge transfer, or a speedier charge injection process, at the interface between the SnO_2 and the perovskite. The findings of this study enabled halide perovskite solar cells to operate more effectively.

Jiang et al. [12] exhibited improved charge $HC(NH_2)_2PbI_3$-based PSC with excellent efficiency by SnO_2 extraction. ITO substrates were spin-coated with the commercial SnO_2 colloid precursor, which was composed of 15% tin (IV) oxide dissolved in water. The mixture was then baked at 150 degrees Celsius for 30 minutes on a hot plate with an open atmosphere. A very probable mobility of 1.9 x 10-3 cm^2 $V^{-1}s^{-1}$ for the SnO_2 film was reported. After depositing the SnO_2 charge transport layer, the perovskite layer was created by a two-step spin coating procedure. Before being annealed for 30 minutes at 70°C, PbI_2 in dimethylformamide (DMF) was spin-coated. The PbI_2 was then spin-coated with an FAI:MABr:MACl solution in isopropanol. The best performing device using SnO_2 nanoparticles produced a VOC of 1.09V, Jsc of 24.87mAcm^{-2}, FF of 74.77 percent, and PCE of 20.27 percent during reverse scan (Spiro-OMeTAD was used as a hole-conductor.). When the device was scanned forwards, it registered a V_{OC} of 1.09V, a J_{SC} of 24.88 mAcm^{-2}, an FF of 75.73 percent, and a PCE of 20.54 percent. The expansion of the optical response edge is seen at 820 nm in comparison to $CH_3NH_3PbI_3$. Furthermore, the researchers demonstrated that SnO_2-based devices exhibited superior photostability compared to TiO_2-based devices; nevertheless, the underlying process was not understood.

Another approach that has been shown to be effective for high-efficiency PSC is the use of surface modified tin oxide, generally known as SnO_2. An example of a planar-type perovskite solar cell was recently presented by Yang et al (PSC)with SnO_2 modification utilizing a chelating

chemical, EDTA [22]. In deionized water, EDTA was dissolved.

To get rid of any additional solvent, the SnO_2 aqueous colloidal dispersion was prepared separately. To produce the milky-white 'E-SnO_2' colloidal solution, also known as SnO_2 nanofluid, the EDTA and SnO_2 solutions were mixed with a volume ratio of 1:1. The hot plate was heated to 80 degrees Celsius. Finally, the E-SnO2 films were manufactured by spin-coating, which was then followed by thirty minutes of drying in a vacuum oven at sixty degrees Celsius. Scans performed using an atomic force microscope (AFM) on SnO_2-coated ITO substrates revealed that the E-SnO_2 film had the lowest roughness, measuring 2.88 nanometers. A determination was also made on the alignment of energy bands in perovskites and SnO_2. The Fermi level of E-SnO_2 was found to be quite close to the conduction band of perovskite, according to the scientific community. SnO2 films were shown to have a high average transmittance in the visible region, as indicated by the authors." Furthermore, the charge mobility of E-SnO_2 was 2.27103 $cm^2V^{-1}s^{-1}$, much greater than that of unmodified SnO_2 (9.92104 $cm^2V^{-1}s^{-1}$). $FAPbI_3$ was employed as an active light absorber because of its suitable band gap, with a little quantity of Cs added to increase phase stability. Continuous pinhole-free films were discovered to be generated when electromagnetic radiation was applied to perovskite films. placed on substrates made of SnO_2. Notably, the average perovskite grain size rose to around 828 nm using the E-SnO_2 substrates. The PCE of the EDTA-based device was 16.42%, Jsc was 22.10 $mAcm^2$, Voc was 1.08 V, and FF was 0.687. The device has a PCE of 18.93 percent, Jsc=22.79 $mAcm^2$, Voc=1.10V, and FF=0.755 with an unaltered SnO_2 substrate. The PCE improved to as much as 21.60 percent when E-SnO_2 was used as the ETL (the Jsc, FF, and Voc were increased to 24.55 $mAcm^2$, 0.792, and 1.11V, respectively). Increased charge mobility due to SnO_2 may effectively extract charges, which is why the Jsc and FF were higher. Perovskite and E-lower SnO_2 energy levels might account for the greater Voc.

According to Liu et al., the passivation effect of a fullerene derivative containing 2-hydroxyl anchoring groups impacted the SnO_2 charge transport layer's performance in PSC. By coordinating with Sn, the hydroxyl groups at the end of the lengthy alkyl chain in C9 were added to passivate the oxygen vacancies on the surface of SnO_2. To phrase it another way, the SnO_2 layer's surface flaws may be effectively defected by the fullerene-modifying layer. Using a water-based SnO_2 colloidal solution, an incredibly thin coating of SnO_2 nanoparticles was spin-coated onto the ITO substrate. After that, the coating was annealed for thirty minutes at 150 degrees Celsius. The C9-fullerene derivative was soaked in chloroform and then spin-coated onto the SnO_2 to finish the procedure. The Perovskite film was subjected to further spin-coating in a nitrogen-filled environment. After spreading the perovskite precursor solution on SnO_2, it was spin-coated and heated to 150°C for ten minutes. Using Spiro-OMeTAD as a hole-transport layer, a configuration of ITO/SnO_2/C9fullerene/($FAPbI_3$)x($MAPbBr_3$)1-x/spiro-OMeTAD/Au was investigated. Compared to the control devices made of bare SnO_2, the greatest PCE of the C9-fullerene modified devices was 21.3 % with minimal hysteresis; this was a significant difference (PCE: 20.0 %). Research led to the discovery that materials interface engineering of SnO_2-based PSCs benefited from the use of fullerene derivatives with hydroxyl groups serving as anchors.

Furthermore, it has been shown that the bilayer SnO_2 might serve as a useful charge transport layer for PSC [8]. The formation of a bilayer structure was accomplished by Yi et al. using SnO_2 nanoparticles to fill the pinholes in the sol-gel SnO_2 layer. For the ETL process, a sol-gel SnO_2 precursor solution that included Tin (IV) chloride pentahydrate was spin-coated on ITO inside of a glovebox that was filled with nitrogen and then annealed at a temperature of zero degrees Celsius for sixty minutes at room temperature. A UVO-treated substrate was spin-coated with a SnO_2 colloid dispersion, and then the substrate was annealed at 150 degrees Celsius for thirty minutes. These perovskite films are composed of methylammonium lead iodide. ($CH_3NH_3PbI_3$) were made in a single process. On the surface of the SnO_2 top layer, which had a bilayer structure, there were no pinholes visible, and the surface had an amorphous-like form. Sol-gel SnO_2 was the only kind of SnO_2 film that had pinholes visible in the film. According to the results of the AFM measurement, the rough surface of the double layered SnO_2 ETL was 1.69 nm. The use of thin-layer SnO_2 nanoparticles has resulted in an increase in the average PCE of the Bilayer SnO_2-based PSC from 12.97 % to 16.84 %. The reason that it was the most significant was the rise in FF of 23.7 %. With the disclosure of the bilayer SnO_2 ETL, it is

probable that new opportunities for the creation of highly efficient PSC will become available.

The approach of Liu et al. [16] was used in order to lessen the hysteresis of the I-V curves seen in SnO_2-based PSC. It was possible to achieve the aqueous SnO_2 colloidal dispersion by swirling it at room temperature. combined with NH_4Cl to generate the NH_4Cl-SnO_2 precursor. The NH_4Cl-SnO_2 layers were fabricated by spin-coating them onto clean ITO substrates and then annealing them to eliminate the solvent after the spin-coating process. The perovskite coating made of MAPbl3 was put on top of the SnO_2 layer. Devices were constructed using ITO/SnO_2/perovskite/Spiro-OMeTAD/Ag as its components. The reference solar cell produced a power conversion efficiency (PCE) of 18.71 % with hysteresis, while the perovskite solar cells that included NH_4Cl-induced coagulated SnO_2 colloids achieved a PCE of 21.38 % with negligible hysteresis. In addition to that, they said that the device's stability might be significantly improved.

3. PEROVSKITE SOLAR CELLS WITH HYBRID LAYERS COMPOSED OF TIN OXIDE AND TITANIUM OXIDE

Tavakoli et al. [24] a mesoscopic oxide double layer (SnO_2/TiO_2) that was employed as an charge selective contact for PSC was detailed via this article. To create this charge selective layer, nanoparticles of titanium dioxide (TiO_2) were coated with amorphous stannous oxide (SnO_2). To change the surface of the mesoporous-TiO_2 material, a SnO_2 precursor solution was used ($SnCl_2$ dissolved in ethanol). After spin-coating this solution on top of mesoporous titanium dioxide, the films were annealed at a temperature of 180 degrees Celsius. The grain size of the perovskite film that was developed on top of the bare mesoporous-TiO_2 layer was found to be slightly larger than the grain size of the perovskite film that was generated on amorphous SnO_2, according to the results of the SEM testing. Because of this, the number of nucleation sites for amorphous SnO_2 was reduced, which led to an increase in the grain size of the perovskite. According to the results of the XRD tests, the spin coated SnO_2 film was amorphous at 180 degrees Celsius, but it underwent a transformation into crystalline SnO_2 after being annealed at 450 degrees Celsius. FTO glass that was coated with a compact coating of TiO_2, a mesoporous-TiO_2 layer that was 150 nm thick, a thin layer of SnO_2,

a perovskite film that was 300 nm thick, a spiro-OMeTAD layer that was 150 nm thick, and gold contact were the components that made up the device. There was a decrease in the amount of hysteresis in the I-V curves of the device, and carrier recombination was also stopped. Consequently, the PCE of mesoporous-TiO_2/amorphous SnO_2 was 20.4 % (Jsc: 22.51mA/cm^2, Voc: 1.168 V, and FF: 77.6 %). The PCE of the reference cell, which used bare mesoporous-TiO_2, was 19.14 % (Jsc: 22.21 mA/cm^2, Voc: 1.098 V, FF: 78.5 %). They The device's I-V curves showed a reduction in hysteresis, and carrier recombination was also inhibited. This resulted in a PCE of 20.4% for mesoporous-TiO_2/amorphous SnO_2 (Jsc: 22.51mA/cm^2, Voc: 1.168 V, and FF: 77.6 %). Using bare mesoporous-TiO_2, the reference cell's PCE was 19.14 percent (Jsc: 22.21 mA/cm^2, Voc: 1.098 V, FF: 78.5 %). Ding et al. [25] the use of SnO_2 nanoparticle modified TiO_2 as the ETL in PSC was reported to inhibit UV degradation of the PSC, resulting in the preservation of 97 % of the original PCE after 60hrs of exposure to UV light. The chemical bath that is mentioned further down was used to produce the SnO_2/TiO_2 layer. To begin, a solution of $SnCl2$ in ethanol was prepared and stored in the freezer at a temperature of 5 degrees Celsius. After mixing $TiCl_4$ with water at a temperature of 0 degrees Celsius, the resulting solution was then frozen at a temperature of 5 degrees Celsius. During the process, the FTO substrate was submerged in an aqueous solution of 2M $TiCl_4$. At 70 degrees Celsius, the glass container was dry. A mixture of ethanol and water was used to wash the FTO substrate before it dried at a temperature of 120 degrees Celsius. After that, the substrate was treated with a solution consisting of water and a 2M aqueous solution of $TiCl_4$ at a temperature of 70 degrees Celsius (the molar ratio was 1:100). Following the chemical coating of the FTO substrate with TiO_2 nanoparticles, the substrate was submerged in the solution that was produced by mixing 2M $SnCl_2$ ethanol with water (the molar ratio was 1:50). The glass was cured at a temperature of seventy degrees Celsius. In the end, the substrate was annealed at a temperature of 140 degrees Celsius. Perovskite solar cells performed well, with average PCEs of 21.27 %, 19.79 %, 17.21 %, and 16.31 % for active surfaces of 0.10 cm^2, 1.13 cm^2, 5.25 cm^2, and 10.56 cm^2, respectively. The outcomes of their investigation indicated that the SnO_2/TiO_2 ETL has the potential to significantly enhance charge extraction and decrease trap states. In

addition, they said that the fact that they could be processed at low temperatures and that they did not have a spin-coating process would make it possible for PSC to be commercialized.

As a charge transport layer for a carbon counter electrode-based planar-heterojunction photovoltaic (PSC), Liu et al. created a bilayer consisting of titanium dioxide and stannous oxide. Radio frequency magnetron sputtering was used to create a titanium dioxide layer. There is a chance that sputtering will completely cover the FTO substrate's surface, passivating its surface imperfections and lowering recombination. A solution of $SnCl_2$ ethanol was spin-coated, and the solution was then heated to 195 degrees Celsius to create the SnO_2 layer. Even while the TiO_2/SnO_2 bilayer had the lowest RMS roughness (9.3 nm), its lowest roughness made it favorable for the deposition of high-quality perovskite films. They used Cu-phthalocyanine in conjunction with a Cs/MA/FA perovskite film as a hole transport layer (CuPc) [26]. The device achieved a PCE of 15.39 % and maintained good stability over 1200 hours.

4. CONCLUSION

Specifically, basic research on SnO_2 nanoparticles has been conducted using PSC's main material, which has advanced the field's understanding of renewable energy systems. Investigating the relationship between PSC performance and the quality of nanostructured SnO_2 films was the aim of this work. The characteristics of SnO_2 particles and films, together with their latest developments in production, were shown. One key technique in the production of SnO_2 layers has been the spin-coating deposition of SnO_2 nanofluids, which is achieved by surface-modifying precursor SnO_2 nano-colloids. According to several studies, PSC converts light into energy with an efficiency of around 20%. In the pursuit of high efficiency, one benefit that may be recognized is SnO_2 substantially better conductivity compared to TiO_2. Another way to lessen hysteresis is to inject charges quickly at the interface where the SnO_2 material and perovskite meet. SnO_2 nanoparticle design approaches, including chemical synthesis and thin-film manufacturing, are still in their early stages and cannot be fully established like TiO_2 nano-crystalline systems for PSC. Gaining further insight into the relationship between SnO_2 nanoparticle microstructures and device performance might be one possible study

direction for future advancement. We have devised dry-freezing technology that can provide a broad range of metal oxides at low temperatures. This is a new method for creating semiconductor nanoparticles. Improving the production of SnO_2 nanoparticles is crucial to improving the materials interfaces of SnO_2 layers in the PSC. Not to mention the improvement already noted. Investigating prospective routes for the low-cost manufacturing of high-efficiency perovskite solar cell modules will be made possible by controlling the creation of SnO_2 crystals.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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