

# A Review of Progress in Electron Transport Layers in Perovskite Solar Cells.

Author's Details:

A.S. Yusuf<sup>1,2\*</sup>, T. M Anderson<sup>2</sup>, K. Prasad<sup>3</sup>

<sup>1</sup>Department of Physics, Federal University of Technology, P.M.B 65, Minna, Nigeria.

<sup>2</sup>Department of Physics and Astronomy, Auckland University of Technology, New Zealand.

<sup>3</sup>Department of Electrical and Electronics, Auckland University of Technology, New Zealand.

E-mail of Corresponding Author: ayusuf@futminna.edu.ng

## Abstract:

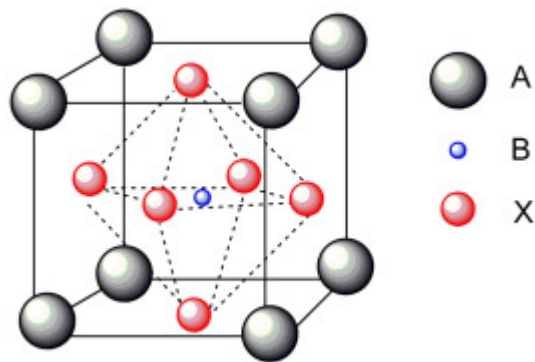
The energy industry is currently very interested in designing and developing next-generation photovoltaic systems using organic-inorganic perovskite hybrid solar cells. They represent the most promising materials for high Power Conversion Efficiency (PCE), low-cost solar cells. They can also come up with answers to the global dilemma and the current energy requirements of civilization. Over the past few years, the power conversion efficiency of perovskite solar cells (PSCs) has rapidly increased, going from 3.8 to 24.2 %. The review, however, focuses on the most recent developments in the electron transport layer as perovskite solar cells are the most important element for enhancing the performance and stability of the device. These summaries include designs, electron transport (ETL) layers and perovskite active layers for efficient perovskite solar cells. The performance and stability issues with organic-inorganic halide perovskite solar cells are also covered in this article. Finally, recommendations for additional research on the ETL and perovskite active layer were offered.

*Keywords: perovskite, doping, active layer, electron transport, mesoporous.*

## 1.0 Introduction

The energy sector is particularly interested in organic-inorganic perovskite hybrid solar cells for the design and development of next-generation photovoltaic systems to meet society's present demand for inexpensive and environmentally friendly electricity. Organic-inorganic hybrid perovskites are therefore intriguing materials for highly efficient and inexpensive solar cells. The PCE of perovskite solar cells (PSCs) has rapidly increased in recent years, rising from 3.8 to 24.2

% (Kojima et al., 2009; Tang et al., 2019). The power conversion efficiency for the most effective organic-inorganic red perovskite solar cells exceeds 20%. These materials offer great light absorption with a small band gap, extended charge carrier lifetimes, high carrier mobility, and long diffusion lengths, among other excellent optoelectronic properties. They are also quite appealing due to their superb charge transport properties (Ahn et al., 2015; Chen et al., 2015). The crystal structures of the perovskite have a general formula of  $AMX_3$  as shown in Fig.1 where “A” is an organic cation such as methylammonium ( $MA^+$ ) or formamidinium ( $FA^+$ ), “M” is a metal cation (e.g.,  $Pb^{2+}$  or  $Sn^{2+}$ ) and “X” stands for the halide anion (e.g.,  $Br^-$ ,  $I^-$ ,  $Cl^-$ ) or a mixture of them. Methyl-ammonium lead iodide and bromide ( $MAPbBr_3$  and  $MAPbI_3$ ) were utilized as sensitizers in dye-sensitized solar cells by Miyasaka and coworkers in 2006 and 2009, and their devices displayed a 3.13 % and 3.81 % efficiency, respectively (Kojima et al., 2009; Lachore et al., 2021). Additionally, in 2011, Park and colleagues showed how to use  $CH_3NH_3PbI_3$  quantum dots (QD) placed on a nanocrystalline  $TiO_2$  surface to create a highly effective quantum-dot sensitive solar cell with a power conversion efficiency of 6.5%. However, due to their device's unstable design, 80% of the sensitizer deteriorated after 10 minutes (Im et al., 2011). To increase conversion efficiency, Spiro-OMeTAD substituted a solid hole transport layer for the liquid electrolyte in the dye-produced solar cell with a  $TiO_2$  electron transport layer.



**Fig. 1** Configurations of cubic perovskite crystals with the  $AMX_3$  general formula (Liu et al., 2015).

Kim et al. (2,2,7',7'-Tetrakis[N,N-di(4-methoxyphenyl)amino]-9,9'spirobifluorene) and achieved 9.7% PCE (Kim et al., 2012). Planar heterojunction perovskite solar cells with  $TiO_2$  acting as an electron transport layer were described by Liu et al. in 2013 utilizing both vapor deposition and solution treatment methods. Without nanostructure and by substituting the conventional one-step

solution approach, the power conversion efficiency of both methods was 15.4% and 8.6%, respectively (Liu et al., 2013). When compared to typical  $\text{CH}_3\text{NH}_3\text{PbI}_3$ , the first organic-inorganic halide perovskite,  $\text{CH}_3\text{NH}_3\text{PbCl}_3$ -XIX, performed well as a light absorber. As a result, switching to  $\text{Al}_2\text{O}_3$  nano porous scaffolding from  $\text{TiO}_2$  has increased efficiency 7.6 to 10.9% (Lee et al., 2012). To capture the greatest amount of visible light, scientists have been developing more effective photo-absorbing materials, improving the synthesis mechanism and procedures, and tinkering with the electrical structure of the photon-absorbing perovskite active layer. Due to their influence on the cell's ability to capture photogenerated carriers, the electron and hole transport layers have attracted a lot of study to date. To increase the effectiveness of collecting photogenerated charge carriers, proper consideration must also be paid to the interface between the photon absorption layer, electron transport layer (ETL), and hole transport layer (HTL) (Agha & Algwari, 2021; Yang et al., 2016). ETL's primary job is to move photogenerated electrons from the perovskite photon active layer to the contact electrode while blocking the migration of holes to the counter electrode. Due to the type of ETL being utilized, these events improve the charge carrier separation kinetics and decrease electron-hole recombination at the interface (Ahn et al., 2015; Ke et al., 2015). As a result, this review paper gives a brief overview of current developments in PSCs, ETLs, and the dynamics of photogenerated carriers and how the current development of PSCs may affect the stability and effectiveness of inorganic-organic perovskite solar cells.

## **2. 0 Perovskite solar cells**

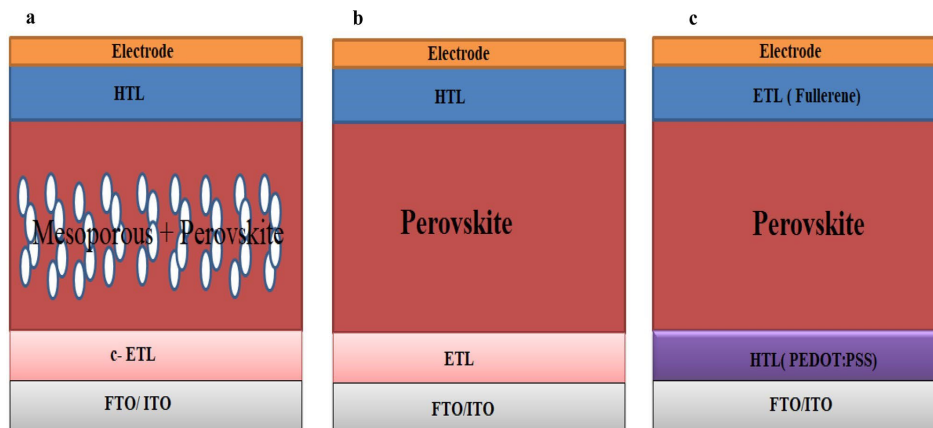
### **2.1 Device architecture**

Like solid-state dye-sensitized solar cells, perovskite solar cells often have similar device designs (DSSCs). Mesoporous, planar, and inverted planar are the three primary architectures of perovskite solar cells, which are depicted in Fig. 2.

#### **2.1.1 Mesoporous perovskite solar cells**

Mesoporous materials have been extensively investigated and exploited because of their high porosity and substantial specific surface area. Its large surface area makes it possible to capture more photons per unit of area, which lowers the recombination rate and increases the efficiency

of the solar cell device's charge collection. Methyl-ammonium lead iodide  $\text{CH}_3\text{NH}_3\text{PbI}$  and bromide  $\text{CH}_3\text{NH}_3\text{PbBr}_3$  were used as sensitizers on mesoporous  $\text{TiO}_2$  to introduce mesoscopic perovskite solar cells, and PCE of 3.82 % and 3.13 with an organic liquid electrolyte were attained (Kojima et al., 2006). Kim et al. investigated perovskite mesoscopic solar cells employing the solid hole transportation layer (Spiro-OMeTAD),  $\text{TiO}_2$  as the electrolyte transport layer, and to avoid rapid performance deterioration caused by the dissolving of the perovskite material into the liquid electrolyte (Kim et al., 2012). However,  $\text{TiO}_2$  compact thin film (ETL) and mesoporous materials including  $\text{ZnO}$ ,  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{ZrO}_2$  are utilized most frequently in perovskite mesoscopic solar cells. Mesoscopic perovskite solar cells have reported power conversion efficiencies of more than 20% to date (Guo et al., 2020; Sun et al., 2019; Zhang et al., 2020). In addition, Table 1 provides a summary of perovskite solar cells made from distinct mesoporous perovskite photon-absorbing layers with varying ETL.



**Fig. 2** Various device architectures of perovskite solar cells: **a** mesoporous, **b** planar, and **c** inverted planar device (Pham et al., 2020).

### 2.2.1 Scaffold material in perovskite solar cells

A scaffold material acts as a support layer and frame for perovskite solar cells but is unable to transport electrons into the cells. Smooth electron injection into  $\text{SiO}_2$  and  $\text{ZrO}_2$  is prevented by these materials' large band gaps and conduction band borders, which are significantly higher than those of the perovskite layer. The excited electron consequently spends more time in the conduction band of the perovskite layer. Perovskite solar cells have been reported to use  $\text{TiO}_2$ ,  $\text{ZnO}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Nb}_2\text{O}_5$ ,  $\text{SiO}_2$ , and  $\text{ZrO}_2$  as scaffold materials, with a PCE of about 10%  $\text{SiO}_2$ . (Hwang

et al., 2014), Al<sub>2</sub>O<sub>3</sub> (Niu et al., 2015), and ZrO<sub>2</sub> (Bi et al., 2013). The Al<sub>2</sub>O<sub>3</sub> interlayer was created utilizing the low-temperature procedure sol-gel approach between the Li-SnO<sub>2</sub> (Li<sup>+</sup>-SnO<sub>2</sub>) ETL and the CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> layer, and the Al<sub>2</sub>O<sub>3</sub> layer sits on top of the perovskite layer. Power conversion efficiency has increased to 10%, and the device's performance and stability have also been enhanced. The weak interface contact between the perovskite layer and the carbon counter electrode causes the fill factor to decrease. The Al<sub>2</sub>O<sub>3</sub> layer in the device lowers electron-hole recombination at the interface between the ETL and the perovskite layers, leading to improved perovskite solar cells. A helpful method to raise the short-circuit current density is (Qiang et al., 2020). Xiong and others the interface between the electron transport layer and the perovskite active layer is altered in the reported carbon-based perovskite solar cells with hole-conductor-free associate degraded inclusion of an Al<sub>2</sub>O<sub>3</sub> layer. As a result, electron-hole recombination was prevented at the interface between the ETL, and the perovskite layer and counter conductor leads. This is a great insulating layer that keeps the cathode and anode apart (Xiong et al., 2018). To examine the stability of CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> and the sensitized film under moisture and sunshine, Niu et al. employed aluminum as a post-modification material. Al<sub>2</sub>O<sub>3</sub> shields perovskite solar cells from moisture and UV damage, increasing their stability and effectiveness. Additionally, it lessens spiro-OMeOTAD and the electron-hole recombination at the TiO<sub>2</sub> surface. When exposed to moisture, the gadget after Al<sub>2</sub>O<sub>3</sub> modification showed more brilliant stability than the device before modification. (Niu et al., 2015).

It was discovered that in addition to serving as an effective electron transport layer, it also aided in the crystallization of the perovskite film beneath, both of which are crucial components of high-performance perovskite solar cells. Additionally, it was discovered that compared to the perovskite/m-TiO<sub>2</sub> film, the perovskite layer on Nb<sub>2</sub>O<sub>5</sub> exhibits fewer pinhole flaws. Consequently, the mesoporous perovskite solar cells enhanced optoelectronic characteristics, and improved photovoltaic efficiency, and stability (Inami et al., 2019). Inami et al. in 2019 saw the publication by Tomulescu et al. of mesoporous TiO<sub>2</sub> films with high-roughness reticulated structures that could be sprayed over huge surfaces in the open air. The average power conversion efficiency was between 10 and 12 % greater than devices with a spin-coated smooth surface mesoporous scaffold in PSCs with small and large active surfaces up to 1 cm<sup>2</sup>. Deposition of a thicker perovskite and an extension of the TiO<sub>2</sub> and perovskite interface, as well as improved photogenerated charge collection and less hysteresis, were all made possible by decreasing charge

losses within the solar cell's most resistive component layer (Tomulescu et al., 2020). As a scaffold for perovskite solar cells, Daneshvar Asl et al. published a thin film in 2020 that had mesoporous nanoparticles, nanorods, and nano branching nanorods. Nano branched nanorods, on the other hand, outperformed nanoparticles and nanorods in photovoltaic performance due to superior optical properties, demonstrating excellent electron transport properties and desired light-harvesting performance, which are desirable features for boosting the efficiency of perovskite solar cells (e Asl et al., 2020). Overall, scaffold materials are crucial in perovskite solar cells because they shield recombination electrons from the electrode and electron transport layer interfaces and increase the efficiency of electron extraction from the electrode to the ETL interface at the perovskite absorber layer interface. Additionally, the pinhole and fracture between the perovskite electrode and the FTO substrate were reduced.

### **3. 0 Electron transport materials in perovskite solar cells**

Overall, scaffold materials are crucial in perovskite solar cells because they shield recombination electrons from the interface between the electron transport layer and the perovskite absorb layer/electrode and increase the ability to extract electrons from the perovskite absorber layer interface to the ETL interface. Furthermore, the pinhole and fracture between the FTO substrate and the perovskite electrode were reduced (Kim et al., 2020). Additionally, to enhance carrier separation and lessen interface electron-hole recombination The efficiency of perovskite solar cells is influenced by ETL characteristics including charge mobility, energy level alignment, trap states, interface, and surface shape. High charge mobility as a result of ETL is crucial for perovskite solar cells to function properly because it promotes effective charge transfer and collecting while preventing charge recombination at the interface (Pan et al., 2020; Yu et al., 2020). Energy level alignment is a further factor that raises the performance of perovskite solar cells. The extraction and transmission of electrons are made simpler when ETL is more properly aligned with the perovskite-absorbed layers. This entails raising the device's open circuit voltage, fill factor, and short-current density ( $J_{sc}$ ) ( $V_{oc}$ ). Charge extraction, transport, and recombination at the interface are important additional characteristics that characterize high-efficiency photovoltaic perovskite solar cells. Trap states, which affect charge extraction and transport and reveal a high recombination rate at the interface, are one of the most important elements in ETL. Interface engineering is one method for enhancing the electron transport layer and the

performance of photovoltaic perovskite solar cells. The surface morphologies of ETL can be improved to increase device performance. As a result, all components contribute to determining the characteristics of the gadget (Chen & Park, 2020; Yu et al., 2020).

#### **4. 0 Conclusion and future perspective**

In perovskite solar cells, charge transport layers may act as n-type to connect the halves in a p-n junction, lessen surface recombination at the interface, channel the current to the metal electrode, and enable the amount of incoming light to flow through and reach the absorber layer. We have therefore discussed efforts to enhance the PCE using an ETL, as well as the interface between the ETL and the perovskite absorber layer, in this review. There was a short discussion of how doping affected the characteristics of ETL in perovskite solar cells. Numerous metal oxides have been studied and used in perovskite solar cells, including TiO<sub>2</sub>, ZnO, SnO<sub>2</sub>, WO<sub>x</sub>, and fullerene. The reduced charge carrier recombination at the surface, which improves the layer's ability to conduct current, may be the cause of the better charge collection performance utilizing ETL. Additionally, it was mentioned that improving charge extraction and transportation depends on the interface between the charge transport layers and the perovskite active layer changes with useful self-assembled monolayers (SAMs). Additionally, limiting charge recombination suggests improved performance and stability in perovskite solar cell apparatus. Therefore, careful ETL and interface design is required to utilize the greatest amount of visible light-generated charge carriers utilizing perovskite solar cells. A hysteresis-free perovskite solar cell device was built for commercial use, which may increase efficiency. Therefore, by increasing the current conduction through them to the metal electrode, increasing the quantity of light reaching the photon active layer, and decreasing charge carrier recombination at the surface and interface, ETL will enhance the PCE of perovskite solar cells.

#### **5.0 References**

- Agha, D. N. Q., & Algwari, Q. T. (2021). The influence of the interface layer between the electron transport layer and absorber on the performance of perovskite solar cells. IOP Conference Series: Materials Science and Engineering,
- Ahn, N., Son, D.-Y., Jang, I.-H., Kang, S. M., Choi, M., & Park, N.-G. (2015). Highly reproducible perovskite solar cells with average efficiency of 18.3% and best efficiency of 19.7%

fabricated via Lewis base adduct of lead (II) iodide. *Journal of the American Chemical Society*, 137(27), 8696-8699.

Bi, D., Moon, S.-J., Häggman, L., Boschloo, G., Yang, L., Johansson, E. M., Nazeeruddin, M. K., Grätzel, M., & Hagfeldt, A. (2013a). Using a two-step deposition technique to prepare perovskite (CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>) for thin film solar cells based on ZrO<sub>2</sub> and TiO<sub>2</sub> mesostructures. *RSC advances*, 3(41), 18762-18766.

Bi, D., Moon, S.-J., Häggman, L., Boschloo, G., Yang, L., Johansson, E. M., Nazeeruddin, M. K., Grätzel, M., & Hagfeldt, A. (2013b). Using a two-step deposition technique to prepare perovskite (CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>) for thin film solar cells based on ZrO<sub>2</sub> and TiO<sub>2</sub> mesostructures.

Chen, J., & Park, N.-G. (2020). Materials and methods for interface engineering toward stable and efficient perovskite solar cells. *ACS Energy Letters*, 5(8), 2742-2786.

Chen, W., Wu, Y., Yue, Y., Liu, J., Zhang, W., Yang, X., Chen, H., Bi, E., Ashraful, I., & Grätzel, M. (2015). Efficient and stable large-area perovskite solar cells with inorganic charge extraction layers. *Science*, 350(6263), 944-948.

Dong, X., Fang, X., Lv, M., Lin, B., Zhang, S., Ding, J., & Yuan, N. (2015). Improvement of the humidity stability of organic-inorganic perovskite solar cells using ultrathin Al<sub>2</sub>O<sub>3</sub> layers prepared by atomic layer deposition. *Journal of Materials Chemistry A*, 3(10), 5360-5367.

e Asl, S. D., Zarenezhad, H., Askari, M., Halali, M., & Sadrnezhad, S. K. (2020). Efficient light harvesting in perovskite layer via three-dimensional TiO<sub>2</sub> nanobranched nanorod scaffold. *Nano Express*, 1(3), 030017.

Guo, Q., Wu, J., Yang, Y., Liu, X., Sun, W., Wei, Y., Lan, Z., Lin, J., Huang, M., & Chen, H. (2020). Low-temperature processed rare-earth doped brookite TiO<sub>2</sub> scaffold for UV stable, hysteresis-free and high-performance perovskite solar cells. *Nano Energy*, 77, 105183.

Hwang, S. H., Roh, J., Lee, J., Ryu, J., Yun, J., & Jang, J. (2014). Size-controlled SiO<sub>2</sub> nanoparticles as scaffold layers in thin-film perovskite solar cells. *Journal of Materials Chemistry A*, 2(39), 16429-16433.

Im, J.-H., Lee, C.-R., Lee, J.-W., Park, S.-W., & Park, N.-G. (2011). 6.5% efficient perovskite quantum-dot-sensitized solar cell. *Nanoscale*, 3(10), 4088-4093.

Inami, E., Ishigaki, T., & Ogata, H. (2019). Sol-gel processed niobium oxide thin-film for a scaffold layer in perovskite solar cells. *Thin Solid Films*, 674, 7-11.



- Ke, W., Fang, G., Liu, Q., Xiong, L., Qin, P., Tao, H., Wang, J., Lei, H., Li, B., & Wan, J. (2015). Low-temperature solution-processed tin oxide as an alternative electron transporting layer for efficient perovskite solar cells. *Journal of the American Chemical Society*, *137*(21), 6730-6733.
- Kim, H.-S., Lee, C.-R., Im, J.-H., Lee, K.-B., Moehl, T., Marchioro, A., Moon, S.-J., Humphry-Baker, R., Yum, J.-H., & Moser, J. E. (2012). Lead iodide perovskite sensitized all-solid-state submicron thin film mesoscopic solar cell with efficiency exceeding 9%. *Scientific reports*, *2*(1), 1-7.
- Kim, T., Lim, J., & Song, S. (2020). Recent Progress and Challenges of Electron Transport Layers in Organic–Inorganic Perovskite Solar Cells. *Energies*, *13*(21). <https://doi.org/10.3390/en13215572>
- Kojima, A., Teshima, K., Miyasaka, T., & Shirai, Y. (2006). Novel photoelectrochemical cell with mesoscopic electrodes sensitized by lead-halide compounds (2). ECS Meeting Abstracts,
- Kojima, A., Teshima, K., Shirai, Y., & Miyasaka, T. (2009). Organometal halide perovskites as visible-light sensitizers for photovoltaic cells. *Journal of the American Chemical Society*, *131*(17), 6050-6051.
- Lachore, W. L., Andoshe, D. M., Mekonnen, M. A., & Hone, F. G. (2021). Recent progress in electron transport bilayer for efficient and low-cost perovskite solar cells: a review. *Journal of Solid State Electrochemistry*, 1-17.
- Lee, M. M., Teuscher, J., Miyasaka, T., Murakami, T. N., & Snaith, H. J. (2012). Efficient hybrid solar cells based on meso-superstructured organometal halide perovskites. *Science*, *338*(6107), 643-647.
- Liu, M., Johnston, M. B., & Snaith, H. J. (2013). Efficient planar heterojunction perovskite solar cells by vapour deposition. *Nature*, *501*(7467), 395-398.
- Liu, X., Zhao, W., Cui, H., Wang, Y., Xu, T., & Huang, F. (2015). Organic–inorganic halide perovskite based solar cells—revolutionary progress in photovoltaics. *Inorganic Chemistry Frontiers*, *2*(4), 315-335.
- Niu, G., Guo, X., & Wang, L. (2015). Review of recent progress in chemical stability of perovskite solar cells. *Journal of Materials Chemistry A*, *3*(17), 8970-8980. <https://doi.org/10.1039/c4ta04994b>

- Niu, G., Li, W., Meng, F., Wang, L., Dong, H., & Qiu, Y. (2013). Study on the stability of  $\text{CH}_3\text{NH}_3\text{PbI}_3$  films and the effect of post-modification by aluminum oxide in all-solid-state hybrid solar cells.
- Pan, H., Zhao, X., Gong, X., Li, H., Ladi, N. H., Zhang, X. L., Huang, W., Ahmad, S., Ding, L., & Shen, Y. (2020). Advances in design engineering and merits of electron transporting layers in perovskite solar cells. *Materials Horizons*, 7(9), 2276-2291.
- Pham, H. D., Yang, T. C. J., Jain, S. M., Wilson, G. J., & Sonar, P. (2020). Development of dopant-free organic hole transporting materials for perovskite solar cells. *Advanced Energy Materials*, 10(13), 1903326.
- Qiang, Y., Xie, Y., Qi, Y., Wei, P., Shi, H., Geng, C., & Liu, H. (2020). Enhanced performance of carbon-based perovskite solar cells with a  $\text{Li}^+$ -doped  $\text{SnO}_2$  electron transport layer and  $\text{Al}_2\text{O}_3$  scaffold layer. *Solar Energy*, 201, 523-529.
- Sun, W., Choy, K.-L., & Wang, M. (2019). The role of thickness control and interface modification in assembling efficient planar perovskite solar cells. *Molecules*, 24(19), 3466.
- Tang, G., You, P., Tai, Q., Yang, A., Cao, J., Zheng, F., Zhou, Z., Zhao, J., Chan, P. K. L., & Yan, F. (2019). Solution-phase epitaxial growth of perovskite films on 2D material flakes for high-performance solar cells. *Advanced Materials*, 31(24), 1807689.
- Tomulescu, A. G., Stancu, V., Beşleagă, C., Enculescu, M., Nemneş, G. A., Florea, M., Dumitru, V., Pintilie, L., Pintilie, I., & Leonat, L. (2020). Reticulated Mesoporous  $\text{TiO}_2$  Scaffold, Fabricated by Spray Coating, for Large-Area Perovskite Solar Cells. *Energy Technology*, 8(1), 1900922.
- Xiong, Y., Zhu, X., Mei, A., Qin, F., Liu, S., Zhang, S., Jiang, Y., Zhou, Y., & Han, H. (2018). Bifunctional  $\text{Al}_2\text{O}_3$  Interlayer Leads to Enhanced Open-Circuit Voltage for Hole-Conductor-Free Carbon-Based Perovskite Solar Cells. *Solar RRL*, 2(5), 1800002.
- Yang, G., Tao, H., Qin, P., Ke, W., & Fang, G. (2016). Recent progress in electron transport layers for efficient perovskite solar cells. *Journal of Materials Chemistry A*, 4(11), 3970-3990.
- Yu, M., Guo, Y., Yuan, S., Zhao, J.-S., Qin, Y., & Ai, X.-C. (2020). The influence of the electron transport layer on charge dynamics and trap-state properties in planar perovskite solar cells. *RSC advances*, 10(21), 12347-12353.
- Zhang, B., Zhang, B., Wang, S., Yao, S., Bala, H., Sun, G., Cao, J., & Zhang, Z. (2020). Applying neoteric  $\text{MgTiO}_3$ -coated  $\text{TiO}_2$  nanoparticulate films as scaffold layers in perovskite solar

cells based on carbon counter electrode for retarding charge recombination. *Electrochimica Acta*, 338, 135884.