Modern Progress in the Advance of High-Efficiency Perovskite ($CH_3NH_3PbI_3$) Solar Cell using different Hole Transport Layer

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Abstract— *One viable alternative for creating new clean energy is solar cells, although they might need additional energy sources. The affordable, easily accessible, and greenhouse gas-free nature of a renewable energy source are its defining characteristics. An alternative that can generate power by converting solar photons into electrical energy is a photovoltaic cell. Over the past 20 years, scientific advancements in photovoltaic technology have presented a number of real-world opportunities that have reduced costs and increased solar cell efficiency. In example, perovskite materials are an interesting chemical family with a broad range of applications in the realm of solar energy. Precisely known for their unique crystal structure and adaptable nature, perovskites have a multitude of remarkable qualities and attributes. When utilizing solar cell simulator software (SCAPS) with perovskite materials like CH3NH3PbI3, the hole transport layer (HTL) is crucial to the efficiency of the solar cells. Using various HTL materials, such as cuprous oxide (Cu2O) and copper thiocyanate (CuSCN), quantitative simulation and modeling have been used to determine the electrical characteristics of the MAPbI3 material used for the active layer for a few parameters, including fill factor (FF), short-circuit current density (Jsc), power conversion rate (PCE), and open-circuit voltage (Voc). The capacitance-frequency (C-F) and capacitance-voltage (C-V) of the previously examined perovskite solar cell have been calculated. The simulated findings demonstrate that the* $MAPbI_3$ *has specifications for performance such as FF=44.67, PCE=30.83, Voc=2.6041, and Jsc=26.5066* $mAcm^{-2}$*using CuSCN as a HTL and FF=41.63, PCE=30.93, Voc=2.8041, and Jsc=26.5032* $mAcm^{-2}$*using* Cu_2O *as HTL.*

Keyword—Perovskite solar cell, $CH_3NH_3PbI_3$***, CuI, C-f, C-V, FF,*** V_{oc}***,*** J_{sc}***, PCE, CuSCN and*** Cu_2O***.***

I. INTRODUCTION

The solar energy is a viable option, the development of new clean energy sources may necessitate additional energy sources. A renewable electricity source has no greenhouse gas emissions, is easily accessible, and is reasonably priced. Photovoltaic cells are an effective way to turn photons from sunshine into electricity. Numerous tangible potential for scientific advances in photovoltaic technology have been presented during the last 20 years, leading to lower costs and higher solar cell efficiency. Bell Laboratories developed the first photovoltaic system to achieve 6% efficiency in 1954[1-4]. Often more efficient are single-cell "photovoltaic" silicon solar panels with a 1 eV band gap. Additional benefits of lightweight film solar cells include their low weight and flexibility. Third-generation solar cells frequently include materials like silicon wire, conductive polymers, and organic dye in addition to having bigger band gaps. In the near future, the development of photovoltaic cells is anticipated to be a critical step in the advancement of renewable energy sources. They can be obtained without releasing carbon dioxide and are available indefinitely. The only natural resources needed to provide sustainable energy are the sun, tides, wind, and rain. Solar energy is a healthy and safe choice for homes and businesses. Solar energy may become the main renewable energy source in the future. Solar power is now the most steady and trustworthy source of free energy[5-10].

There are many more components in the perovskite family that could have a significant impact. The other notable benefits are its great transparency in the visible spectrum, ease of production, and chemical stability. Despite processing Cu_2O and CuSCN in solvents, there is a chance that the perovskite layer will degrade. Thus, using p-in arrangements, researchers tried to produce Cu2O and CuSCN -based PSCs. Ye and others. In 2015, an electrodeposited layer of CuI was followed by a fast deposition-crystallization of a $CH_3NH_3PbI_3$ film with X=I, Br, and Cl[11-17].

The mean PCE was 15. A remarkable PCE of 16 and a score of 6%. The small interface resistance to contact and low apparent coarseness of the resulting perovskite films allowed for this. In addition, it has been shown that special, unconventional methods are used to create the perovskite layer. The effectiveness of the holes transport layer (HTL) of CH3NH3PbI_3, X=I solar cells made from perovskite and Cu_2O an CuSCN are investigated.

The photovoltaic effect, which is how a solar cell, also called a photovoltaic cell, works, is the direct conversion of sunlight into electricity[18]. Here is a condensed description of how a solar cell works:

1. **Sunlight Absorption:** Typically, silicon and other semiconductor-related materials are used to create solar cells. A portion of the photons in sunlight that strike the solar cell's surface are taken up by the semiconductor substance[19].

2. **Creation of Electron-Hole Pairs:** After photons are absorbed, they impart their energy to semiconductor electrons, causing them to reach higher energy states. As a result, electrons become free to migrate and form electron-hole pairs, which leave behind positively charged "holes" in the substance..

3. **Charge Carrier Separation:** The charge carriers are separated by the internal electric field in the semiconductor material, which causes the positively charged holes and free electrons to go in opposing directions[20].

4. **Charge Carrier Collection:** The separation of electrons and holes is made easier by metal contacts that are placed on the top and bottom surfaces of the solar cell. These contacts enable the flow of electrons (current) out of the cell for external electrical applications[21].

5. **Conversion of Light Energy to Electrical Energy:** Electrons can pass through a solar cell's external circuit, producing an electric current. This current can be utilized to power electrical devices directly or stored in batteries for subsequent use[22].

6. **Operation in Closed Circuit:** As long as sunlight is available and the circuit remains closed, the flow of electrons through the external circuit persists. However, when the circuit is opened or sunlight is obstructed, the flow of electrons halts[23].

In essence, a solar cell utilizes sunlight's energy to produce an electric current, offering a renewable and sustainable source of electricity. Multiple solar cells can be interconnected to form solar panels, enhancing the electricity generation capacity for residential, commercial, or industrial applications[25].

2. PEROVSKITE MATERIAL

Perovskite materials are an intriguing class of chemicals that stand out for their many uses, especially in the field of solar energy. Known for their unique crystal structure and adaptable nature, perovskites have several interesting qualities and attributes[24].

Crystallographic ally, perovskites adopt a general formula denoted as ABX_3, wherein the cations 'A' and 'B' vary in size (with 'A' typically larger than 'B'), while 'X' signifies an anion. Their crystalline arrangement can manifest in cubic, tetragonal, or orthorhombic structures, contingent upon environmental conditions.

Their optical absorption capabilities are noteworthy, demonstrating substantial absorption and a modifiable band gap, crucial attributes underpinning their efficacy in photovoltaic applications. Perovskites excel in charge transport, showcasing extended diffusion lengths, ambipolar charge mobility, and elevated carrier mobility, all pivotal for efficient energy conversion. Furthermore, their robust tolerance to point defects contributes to enhanced stability and performance, a trait highly advantageous in various applications[26].

Certain perovskite variants, particularly those incorporating cobalt, exhibit magnetic properties attributable to cobalt's inherent spin. Additionally, through doping—a process involving the introduction of impurities—perovskite properties, both optical and electrical, can be finely tuned to suit specific requirements. These materials are broadly classified into two categories: purely inorganic perovskites, exemplified by compounds like $PbTiO_3$ and $CaSiO_3$, and organic-inorganic hybrid perovskites, typified by compositions such as $CH_3NH_3MX_3$ (where M = Pb or Sn; (X = I)[27].

The Perovskite Solar Cell Market provides The goal of research is to increase scalability and stability for solar energy generation to be widely used. The creation of eco-friendly formulations to alleviate toxicity concerns and increase market acceptance is the goal of the investigation of lead-free alternatives for perovskite. Perovskite materials' diversification into emerging technologies is being researched for uses other than photovoltaics, such as LEDs, sensors, and optoelectronic devices. Integration with Current Infrastructure: In order to maximize synergies and improve performance, efforts are focused on integrating perovskite technologies with well-established semiconductor platforms in a smooth manner[28]. Fabrication of Solar Cell Using Perovskite Material is shown in Figure 1.

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7. F ABRICATION OF PEROVSKITE SOLAR CELL

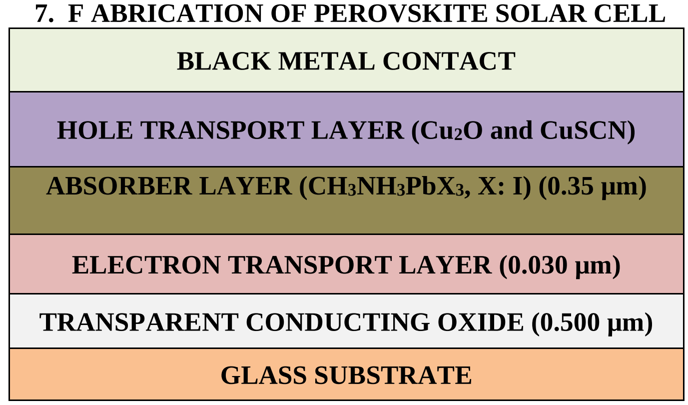

Fig 1 Fabrication of Solar Cell Using Perovskite Material

The "planer heterogeneous junction" structure and perovskite photovoltaic cells (PSCs) have identical configurations. The transport electron layer comprises silicon dioxide (TiO_2), while the glass substratum layer is made of transport conducting oxides (TCO). In perovskite materials, Cu_2O an CuSCN are serves as the hole transport layer (HTL) for the metal reverse contact, while $CH_3NH_3PbI_3$, X=I, serves as the active layer.

The photovoltaic effect, generating electricity from sunlight without emitting gases like carbon dioxide or other pollutants such as sulfur or nitrogen, is fundamental to photovoltaic cells. Solar cells can also indirectly convert solar energy into electricity by first converting it into heat or other forms of chemical energy, without posing risks to the environment or human health[30].

Solar cells are a low-maintenance, durable energy source that can be easily installed in various locations, including homes, workplaces, caravans, tourist attractions, calculators, watches, light meters, and cameras. Solar cells offer an affordable, efficient, and environmentally friendly power source that is non-polluting, non-infectious, and noiseless.

Nowadays, global warming poses a serious threat to humankind and the stability of wildlife on Earth. Sea levels have risen by 10–25 cm, and surface temperatures have increased by 0.3–0.6 during the 19th century due to global warming. Rising sea levels have led to increasingly severe natural disasters and disruptive impacts on human life and other living processes across the planet in the coming years[29].

Solar panels are set up with an enormous array of tiny cells to generate a specific amount of power. The goal of current solar cell technologies is to create electrons and holes in each cell. Cu_2O and CuSCN acts as the HTL for the metal back contact, and CH_3NH3PbI3 from the piezoelectric family makes up the active layer. Cu_2O and CuSCN material serves as the HTL in perovskite solar cells, enhancing the cell's efficiency. Studies indicate that spiro-MeOTAD has a larger fill factor (FF) and lower electrical conductivity than Cu_2O and CuSCN.

The impressive power conversion efficiency (PCE) of 16.6% attained by Cu_2O and CuSCN-based perovskite solar cells (PSCs), surpassing the median PCE of 15.6%, is likely due to the high hole mobility of the Cu_2O and CuSCN hole transport layer (HTL). Additionally, the smooth surface and low interface resistance of the perovskite films significantly contributed to this efficiency. Moreover, specially designed techniques have been effective in minimizing the degradation of the perovskite layer during the synthesis of Cu_2O and CuSCN in the n-i-p PSC solution, where the active layer is $CH_3NH_3PbX_3$ (X=I)..

8. PARAMETERS OF A SOLAR CELL

1. Efficiency: This determines the quantity of sunlight that is turned into useful power. It's one of the most crucial elements since higher efficiency means that for a given amount of sunlight, more power is produced.

2. Open-Circuit Voltage (Voc): When a solar cell is not connected to any load, its maximum voltage can be produced. That voltage is present when there is no current flowing through the solar cell.

3. Short-Circuit Current (Isc): The maximum current that a solar cell can generate when its electrical connections are made short. Voltage between the solar cell is absent when the current is zero.

4. Fill Factor (FF): The theoretical closest point of the solar cell to producing its maximum power output is represented by this value. It is calculated by multiplying the total power of the solar cell by the open-circuit voltage, short-circuit current, and voltage and current at the solar cell's maximum power point[31].

5. Maximum Power Point (P_{max}): On the current-voltage (I-V) curve of a solar cell, the point at which the product of current and voltage achieves its maximum. It shows the solar cell's maximum power output under specific conditions..

6. Temperature Coefficient: This metric indicates how temperature variations affect the solar cell's performance. Generally, efficiency drops with increasing temperature.

7. Shunt Resistance (R_{sh}): The resistance measured in this manner is parallel to the p-n junction of the solar cell. It is an illustration of the solar cell's leakage current route.

8. Series Resistance (R_s): This resistance is determined by measuring it in series with the p-n junction of the solar cell. It takes into consideration the resistive losses in the solar cell.

9. RESULTS AND DISCUSSION

The perovskite cell $CH_3NH_3PbX_3$ (X: I) performance metrics, which include Jsc, FF, Voc, C-F, C-V, and PCE, are listed in Table I. The cell's efficacy has been demonstrated. For the simulation, two illumination settings are used: low and high. The outcomes differ from those reported by previous searchers when employing Cu_2O and CuSCN as a hole transport layer. Every perovskite solar cell material that has been researched has a working point voltage of zero volts in the dark and 0.5 volts in the light. Table I contains a list of the various determined features for the perovskite solar cell under investigation.

TABLE.I The variously computed characteristics of the perovskite solar cell under study (CH3NH3PbX3, X: I)

MATERIAL		PARAMETER			
		V_{oc}(V)	J_{sc}($mAcm^{-2}$)	FF	PCE (%)
$CH_3NH_3PbI_3$	Using CuSCN as HTL	2.6041	26.5066	44.67	30.83
$CH_3NH_3PbI_3$	Using Cu_2O as HTL	2.8031	26.5078	41.62	30.93

By utilizing CuSCN as the HTL, the simulated results indicate parameters for performance such as Voc=2.6041, Jsc=26.5066, FF=44.67, and PCE=30.83 when compared to other researchers' studies on the $CH_3NH_3PbI_3$ perovskite solar cell.
In relation to the studied perovskite solar cell, the cell's specifications are given in figures 2 and 3, where the J-V characteristics are also shown.

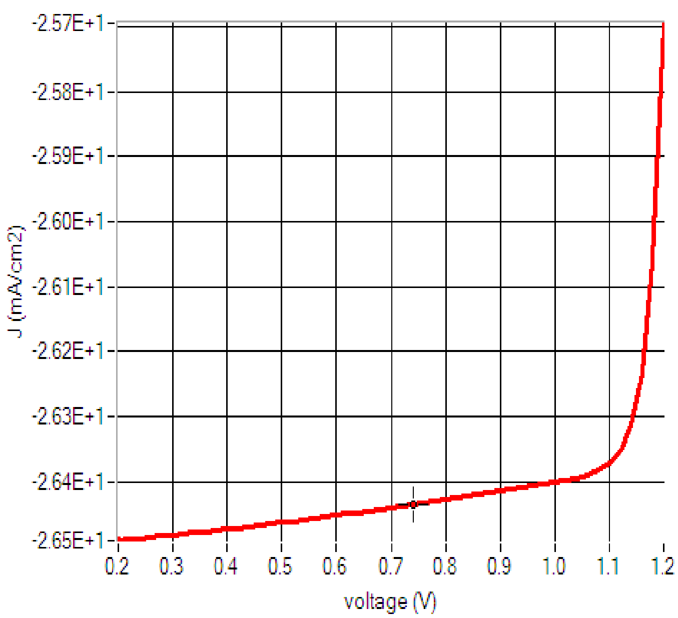

Fig.2.The J-V characteristics for the $CH_3NH_3PbI_3$ perovskite solar cell using CuSCN as a HTL

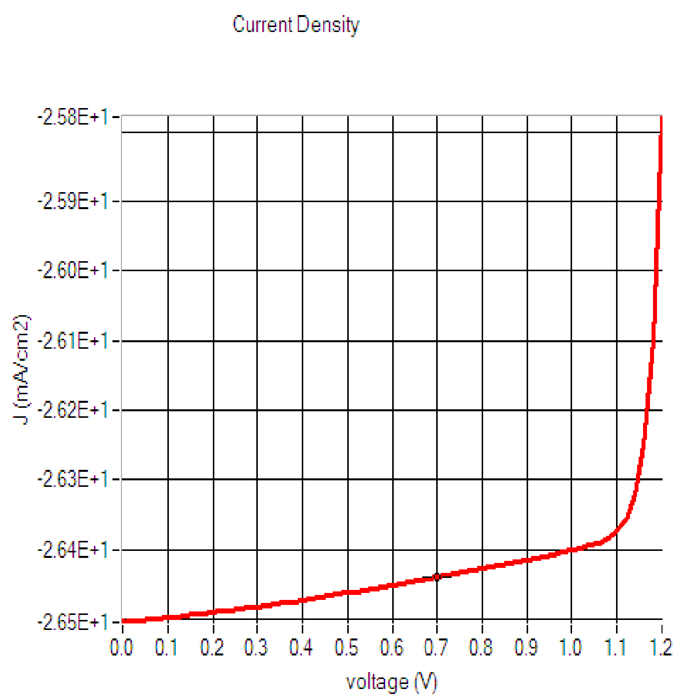

Fig.3.The J-V characteristics for the $CH_3NH_3PbI_3$ perovskite solar cell using Cu_2O as a HTL

For the $CH_3NH_3PbX_3$ (X: I) perovskite solar cell, the current density (JV) characteristics using CuSCN and Cu_2O as HTL were calculated as seen in Figure2 and 3.

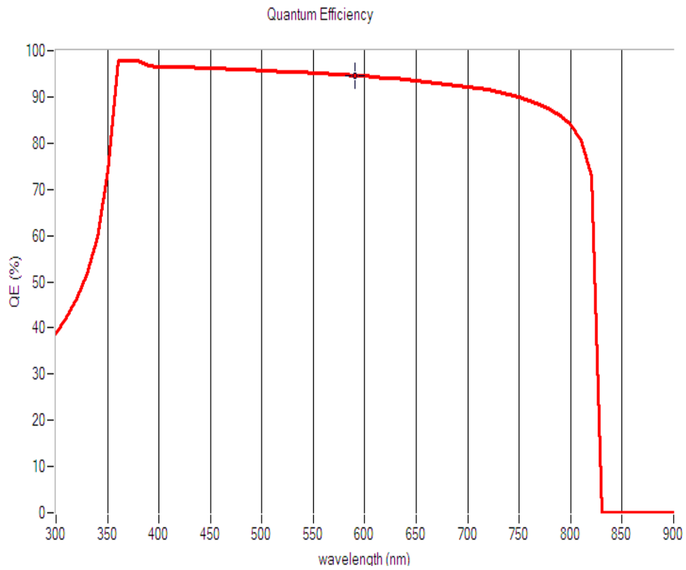

Fig.4. Quantum efficiency of $CH_3NH_3PbI_3$ perovskite solar cell using CuSCN as a HTL

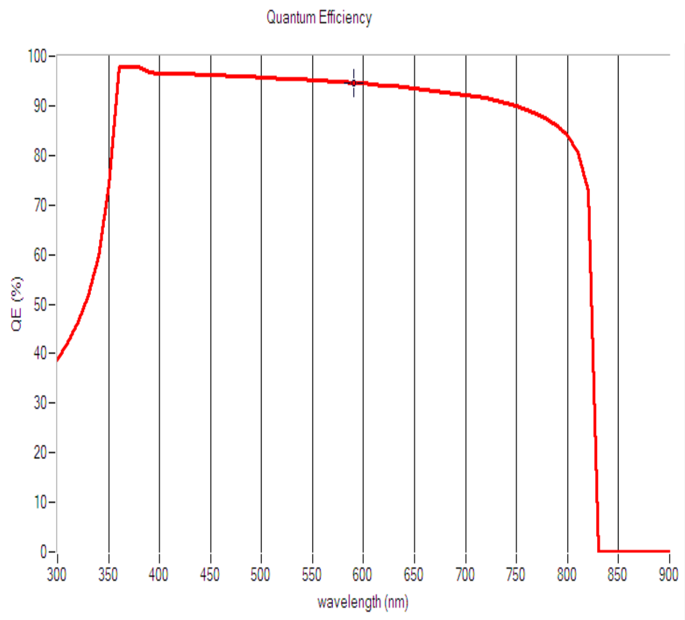

Fig.5. Quantum efficiency of $CH_3NH_3PbI_3$ perovskite solar cell using Cu_2O as a HTL

For the $CH_3NH_3PbX_3$ (X: I) perovskite solar cell, the quantum effectiveness (QE) characteristics were calculated and plotted for an absorption coefficient of 10^7 (cm^{-1}) using CuSCN and Cu_2O as HTL, as seen in Figure 4 and 5.

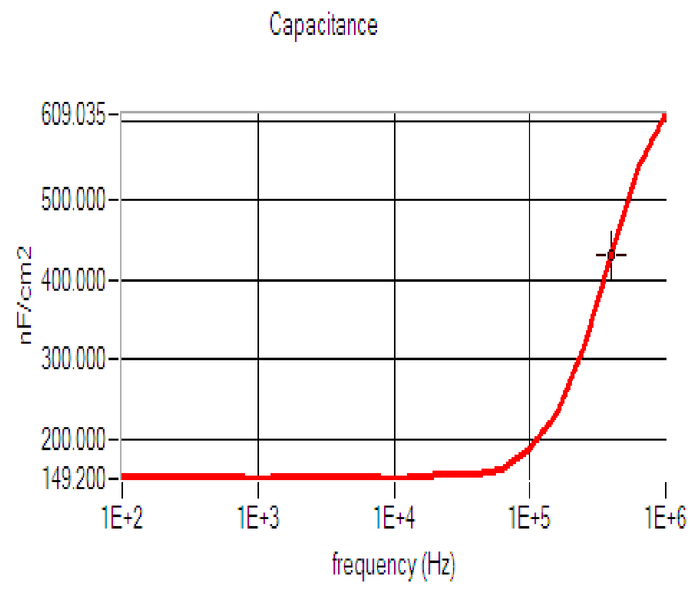

Fig.6. C-f characteristics forCH₃NH₃PbI₃ perovskite solar cell using CuSCN as a HTL

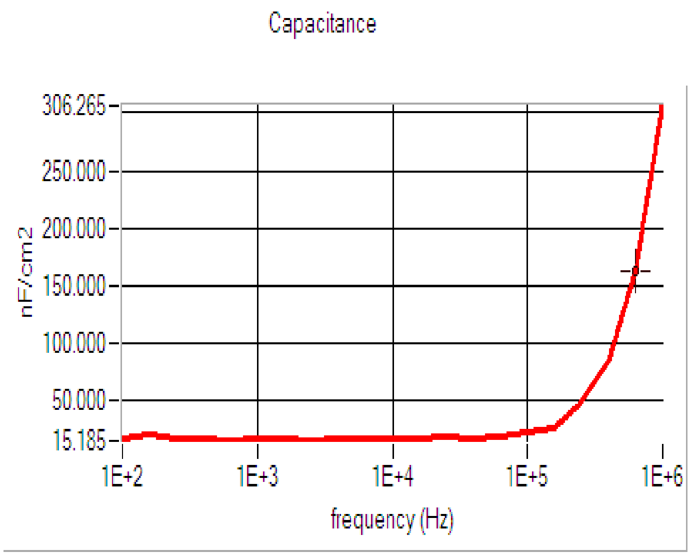

Fig.7. C-f characteristics for$CH_3NH_3PbI_3$ perovskite solar cell using Cu_2O as a HTL

For the $CH_3NH_3PbI_3$ perovskite solar cell under study, the capacitance-frequency (C-f) properties have been determined using CuSCN and Cu_2O as HTL and are displayed in Figure.6 and 7.

By adjusting the alternating current signal frequency during the C-f measurements, capacitance is computed. This demonstrates that $CH_3NH_3PbI_3$ is more responsive to capacitance production at higher frequency ranges.

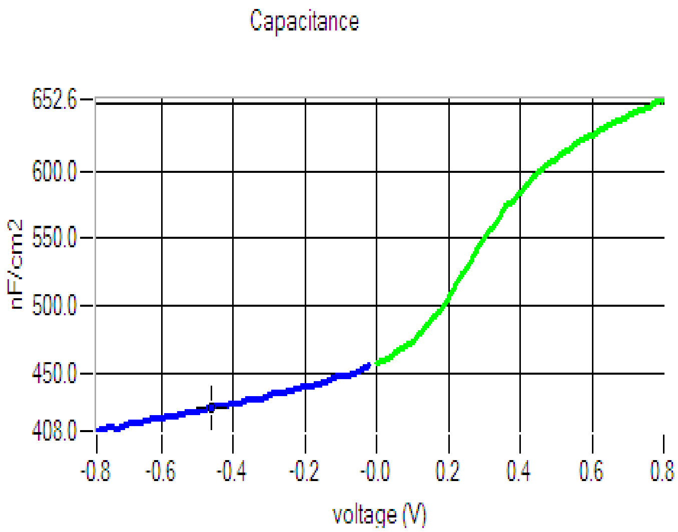

Fig.8.The C-V characteristics of $CH_3NH_3PbI_3$ perovskite solar cell using CuSCN as a HTL

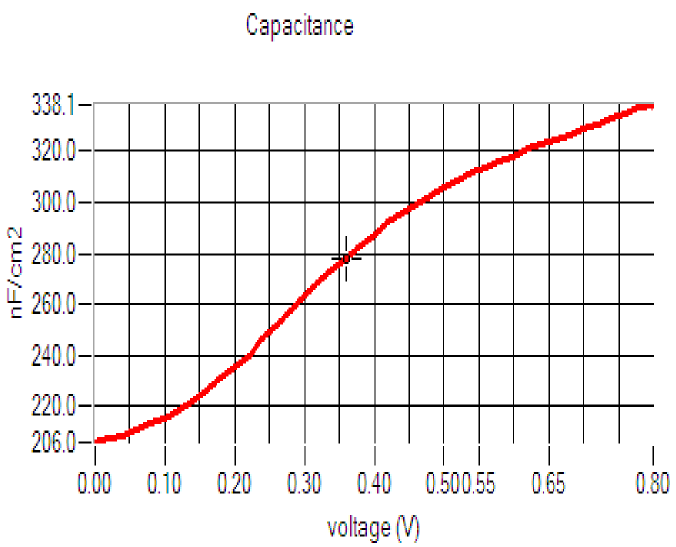

Fig.9.The C-V characteristics of $CH_3NH_3PbI_3$ perovskite solar cell using Cu_2O as a HTL

Figures 8 and 9 in the study illustrate the relationship between capacitance (C) and applied voltage (V) for a perovskite solar cell utilizing $CH_3NH_3PbI_3$ ($MAPbI_3$). The plots show that capacitance increases exponentially with voltage and eventually saturates as voltage increases. These figures provide important insights into the electrical behavior of the solar cell, indicating how its capacitance varies under different voltage conditions. Such information is essential for improving the perovskite solar cell's performance and design in order to increase stability and efficiency.

CONCLUSION

In the research, the hole transport layer (HTL) and the solar cell simulation software (SCAPS) are utilized to assess the efficiency of perovskite solar cells fabricated from CH3NH3PbI3. With an emphasis on variables like fill factor (FF), power conversion efficiency (PCE), short-circuit current density (Jsc), and open-circuit voltage (Voc), quantitative simulation and modeling are utilized to ascertain the electrical properties of the MAPbI3 material used as the active layer. Additionally, the capacitance-frequency (C-F) and capacitance-voltage (C-V) characteristics of the previously analyzed perovskite solar cell have been computed. These analyses provide insights into the electrical behavior and performance optimization of the perovskite solar cells under study. The simulated findings demonstrate that the $MAPbI_3$ has specifications for performance such as FF=44.67, PCE=30.83, Voc=2.6041, and Jsc=26.5066 $mAcm^{-2}$using CuSCN as a HTL and FF=41.63, PCE=30.93, Voc=2.8041, and Jsc=26.5032 $mAcm^{-2}$using Cu_2O as HTL.

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