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INNOVATION IN ACTION: TURNING IDEAS INTO REALITY

Chapter 36

Perovskite Solar Cells for Energy Harvesting in Low-Light Environments

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ABSTRACT
The transition from fossil fuels to renewable energy is critical to reducing air pollution and mitigating climate change. Solar energy, as a clean and sustainable alternative, has gained significant attention, with perovskite solar cells emerging as a promising technology. These cells offer several advantages over traditional silicon-based photovoltaics, including higher efficiency potential, lower production costs, and simpler manufacturing processes. Recent research highlights the feasibility of perovskite solar cells for indoor and low-light energy harvesting, demonstrating their versatility beyond conventional outdoor applications. In this study, a solution-processed perovskite solar cell was fabricated and tested under room building light conditions. The device achieved an impressive open-circuit voltage of 1.49V and a short-circuit current density of 5.15 mA/cm^2, with a maximum power conversion efficiency of 18.67%. These results underscore the potential of perovskite solar cells to efficiently generate electricity even in ambient lighting, making them ideal for powering IoT devices, smart sensors, and other low-energy electronics indoors. The cost-effective production and high efficiency of perovskite solar cells position them as a key player in the renewable energy transition. Their ability to perform well under varied lighting conditions expands their applicability, supporting decentralized energy generation and reducing reliance on fossil fuels. Further advancements in stability and scalability could accelerate their commercialization, contributing to a more sustainable energy future. By harnessing indoor light, perovskite

technology complements traditional solar panels, enhancing energy accessibility and driving the shift toward cleaner power solutions.

Key Words: air pollution; solar cells; perovskite; efficiencies; ambient light.

1. INTRODUCTION

The increasing use of fossil fuels for power generation causes significant environmental, health, and social problems, necessitating cleaner alternatives. Burning them drives climate change, pollution, and land degradation with the Intergovernmental Panel on Climate Change (IPCC) urging immediate emission reductions. Fossil fuel plants release harmful pollutants, posing health risks. The limited supply also necessitates a shift to alternatives like solar energy. Solar power offers a clean, renewable solution that can significantly cut emissions and improve air quality. It has no toxic operational emissions and uses little water (Mehmood, 2021).

2. LITERATURE REVIEW

Traditional silicon solar cells work poorly indoors, limiting urban solar energy use. A study explores cost-effective perovskite cells for indoor electricity generation, using specific materials to boost low-light efficiency. Perovskites are a key advancement in affordable renewable energy (Yan et al., 2022), with solution processing showing high efficiency potential. Research aims to improve their efficiency, stability, and applications (Zhang et al., 2022), also using non-toxic materials (García-Mendoza et al., 2023).

3. METHODOLOGY

The perovskite solar cell production process starts with measuring 1.5 g of titanium dioxide (TiO_2) for the electron transport layer. TiO_2 is combined with polyethylene glycol (PEG) and ethanol to create a paste. The solution is deposited onto fluorine-doped tin oxide (FTO) glass (Figure 1), heated at 200°C for 10 minutes to form a strong TiO_2 layer. The glass then cools to room temperature, solidifying the TiO_2 layer.

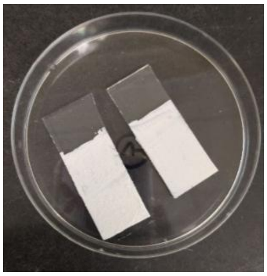


Figure 1: TiO_2 particles deposited on FTO glass.

The dye solution, prepared by mixing deionized water and nickel phthalocyanine-tetrasulfonic acid tetrasodium salt (NiTsPc), was applied to pre-coated FTO glass overnight (Figure 2).

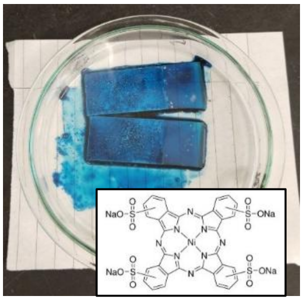


Figure 2: FTO coated glass with TiO_2 layer immersed in NiTsPc overnight (insert: NiTsPc molecular structure).

After long immersion, the FTO glass is removed from the solution, purified to enhance solar cell efficiency, and then annealed at 90°C for 20 minutes (Figure 3) until fully dry.

Figure 3: Annealing process of the FTO coated glass with TiO_2 and NiTsPc at 90°C.

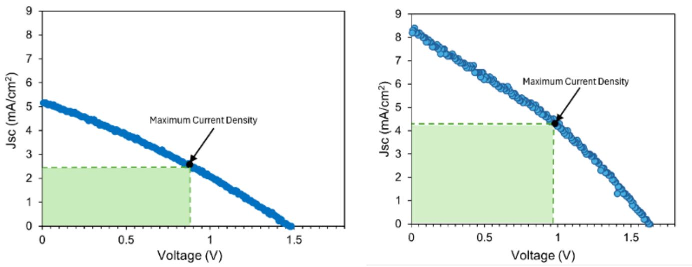
In preparation for the counter electrode, another clean piece of FTO glass is applied with carbon paste to serve as the conductive layer that will facilitate electron collection. The FTO glass with carbon paste is then heated at 100°C for 10 minutes until dry.

Next, the process involves depositing iodine and perovskite solution onto TiO_2 surfaces, then attaching carbon paste-treated FTO glass. The assembled devices (Figure 4) are tested under low and high light intensity to evaluate their functional efficacy. The devices are connected to a source-measure unit to measure efficiency and general function.

Figure 4: The attachment of surfaces of TiO_2, NiTsPc, iodine, and perovskite onto carbon paste-FTO coated glass.

4. RESULTS AND DISCUSSION

Figure 5 shows current density (J_{sc}) versus voltage (V) curves. Under low light, the maximum J_{sc} is 5.15 mA/cm² and the maximum open-circuit voltage (V_{oc}) is 1.49 V. Under 1 Sun intensity, the maximum J_{sc} is 8.3 mA/cm² and the maximum V_{oc} is 1.63 V. The curve's shape indicates the fill factor (FF), with a more rectangular shape signifying a higher FF. The observed linear slope suggests a lower FF, calculated using the FF formula (Equation 1) to be 0.29 under low light and 0.31 under 1 Sun intensity.



(a) (b)

Figure 5: Current density versus voltage (a) under low-light intensity, and (b) under 1 Sun intensity.

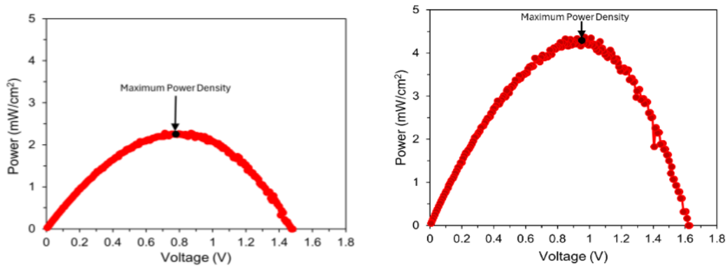
$$FF = \frac{J_{max} \times V_{max}}{J_{sc} \times V_{oc}} \tag{1}$$

To quantify the solar cell's performance, we calculate the power conversion efficiency (PCE), which is given by Equation 2:

$$PCE = \frac{V_{oc} \times J_{sc} \times FF}{P_{in}} \times 100 \tag{2}$$

where V_{oc} is the open-circuit voltage, J_{sc} is the short circuit current density, *FF* is the fill factor, and P_{in} is the incident solar power (mW/cm²).

Figure 6 displays the power density versus voltage curve, derived from Figure 5, with its peak indicating the maximum power point (MPP) and the cell's highest electrical power output. The voltage at this peak is the maximum power point voltage (V_{max}), and the corresponding power value is the maximum power (P_{max}). Under low light intensity, V_{max} is 0.8 V, and the power output reaches about 2.24 mW/cm². Under 1 Sun intensity, V_{max} is 1.019 V, and the power output is approximately 4.21 mW/cm².



(a) (b)

Figure 6: Power density versus voltage (a) under low-light intensity, and (b) under 1 Sun intensity.

The analyzed perovskite solar cell achieved a power conversion efficiency of 18.67% under low light intensity (10 - 12 mW/cm²) and 4.07% under 1 Sun intensity. The efficiency of these cells is highly dependent on the specific perovskite materials used, the fabrication methods employed, and the environmental conditions during testing.

5. CONCLUSION AND RECOMMENDATION

Solution-processed perovskite solar cells can generate energy under ambient light, achieving 1.49 V open-circuit voltage and 5.15 mA/cm² short-circuit current density. Power conversion efficiency reached 18.67% under low light and 4.07% under 1 Sun intensity, showing potential for indoor energy harvesting and sustainable energy. Future research should improve fill factor, explore materials and fabrication, and assess long-term stability.

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