A Stable and Cost-Effective Perovskite-Based LSC Fabricated via Epoxy Resin

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ABSTRACT— With the increasing demand for optoelectronic devices, luminescent solar concentrators have emerged as a promising solution to reduce the cost of solar cells. Additionally, the use of perovskites with mixed cations and halides as luminescent materials has significantly improved the stability of perovskites in optoelectronic devices, attracting the interest of many researchers. Given that conventional polymerization techniques for fabricating luminescent solar concentrators, such as thermal and photopolymerization methods, are time-consuming and costly, a luminescent solar concentrator based on low-cost polyamide epoxy resin was fabricated using a triple-cation perovskite. This concentrator, with a simple fabrication process and no need for specific environmental conditions, was produced in customizable dimensions and exhibited a 170% increase in relative efficiency.

KEYWORDS: Epoxy resin, Luminescent Solar Concentrator (LSC), Optical properties, Triple-Cation Perovskite.

I. INTRODUCTION

In recent years, organic-inorganic perovskites have attracted significant attention due to their unique properties. These materials follow the general formula ABX_3, where A is an organic cation, B is a metal cation, and X is a halide anion. Perovskites have become the focus of extensive research for various applications, including light-emitting diodes (LEDs), lasers, photodetectors, luminescent solar concentrators (LSCs), and photovoltaic cells [1, 2].

Despite their promising properties, perovskite materials suffer from substantial structural and thermal instabilities. Studies have shown that incorporating mixed cations and halides can significantly enhance the stability of perovskites. In fact, different cations can combine the advantages of each component while minimizing their drawbacks. It is expected that the combination of FA, MA, and Cs cations, along with I and Br anions, can lead to the formation of high-quality, stable perovskite films [3].

LSCs represent a promising approach for enhancing the efficiency of photovoltaic (PV) systems by concentrating sunlight onto a small-area solar cell placed at the edge of the device. Beyond their potential in energy harvesting, LSCs offer versatile applications, including integration into solar noise barriers (SONOB) along highways, greenhouse panels to support plant growth, and automotive windows for on-board energy generation [4], [5].

Structurally, LSCs consist of highly transparent polymeric waveguides embedded with luminescent materials. These materials absorb incident sunlight and re-emit it at longer wavelengths. A large portion of the emitted light is trapped inside the waveguide through total internal reflection and is guided to the edges, where it is collected by attached solar cells [6].

Among the various luminescent materials explored, perovskites stand out due to their ease of synthesis, broad absorption spectra, and high photoluminescence quantum yield (PLQY). Prof. Ahmadi's research group has conducted extensive investigations in the field of LSCs. In this study, an epoxy resin-based LSC incorporating the triple-cation perovskite $Cs_{0.15}MA_{0.10}FA_{0.75}Pb(Br_{0.17}I_{0.83})_3$ was successfully fabricated, and its optical properties were thoroughly investigated.

II. EXPERIMENTAL PROCEDURE

A. *Materials*

Methylamine (MA, 40 wt% in water), hydrobromic acid (HBr, 48 wt% in water), lead bromide (PbBr2, ≥98 %), Lead (II) iodide (PbI_2, 99 %), Formamidinium iodide (FAI, ≥99 %), Cesium iodide (CsI, 99.9%), Diethylether (>99.7%) and N, N-dimethyl formamide (DMF, ≥99.9%), Dimethylsulfoxid (DMSO, 99%) from Sigma-Aldrich are utilized to synthesize perovskite. Also, the commercially available polyamide-based epoxy resin used in this study (Parlag Paint Industry Co.) is a two-component system consisting of an epoxy base (A) and a hardener (B). It cures at room temperature within 24 hours [7]. All chemicals were used as received, without any purification.

B. *Perovskite Precursors*

In this experimental work, the triple-cation perovskite $Cs_{0.15}MA_{0.10}FA_{0.75}Pb(Br_{0.17}I_{0.83})_3$ was successfully synthesized with a weight percentage of 43.25%. To prepare the precursor solution, specified amounts of FAI, PbI_2, MABr, and $PbBr_2$ were first dissolved in 1 mL of a DMF/DMSO (4:1) solvent mixture. Separately, 390 mg of CsI was dissolved in 1 mL of DMSO, and 70 µL of this solution was then added to the initial mixture. The resulting solution was stirred at 75 °C for 2 hours [8].

C. *LSC Device Fabrication*

For the fabrication of the LSC, the two components were mixed in a weight ratio of 7:3. Initially, part A was mixed with the synthesized $Cs_{0.15}MA_{0.10}FA_{0.75}Pb(Br_{0.17}I_{0.83})_3$ perovskite at a concentration of 43.25 wt%, and stirred at 50 °C for 15 minutes using a hotplate stirrer. Then, Part B was added to the mixture. After the solution reached room temperature and became a transparent liquid, it was poured into a pre-designed and fabricated silicone mold. The mold was then subjected to a degassing process using a vacuum pump to remove any trapped air bubbles. Subsequently, it was left to cure at room temperature for 24 h. Then, the fabricated devices were cut into 4cm×5cm×0.15 cm slabs using laser cutter.

D. *Characterization of the LSC*

The Shimadzu UV-2450 spectrophotometer and Jasco FP-6200 spectrofluorometer are the instruments used to measure the optical properties of synthesized triple-cation perovskite. X-ray diffraction (XRD) patterns are used to investigate the structural properties of the samples, obtained from a Siemens D500. The fabricated LSCs are exposed to illumination using an AM1.5 global solar simulator, while their I-V characteristics are measured with a Keithley 2410 source meter. A solar panel (AK5318) with a surface area of 3.8cm×0.5 cm and a rated output of 0.5 V and 160 mA is fixed to the LSC. To prevent direct light from entering the solar cell, all areas except for the interface between the LSC edge and the cell are covered with black tape.

III. RESULTS AND DISCUSSION

To investigate the formation of triple-cation perovskite, XRD analysis was performed to determine its crystal structure. As illustrated in Fig. 1, the XRD pattern demonstrates a strong resemblance to those observed in analogous perovskite structures [9].

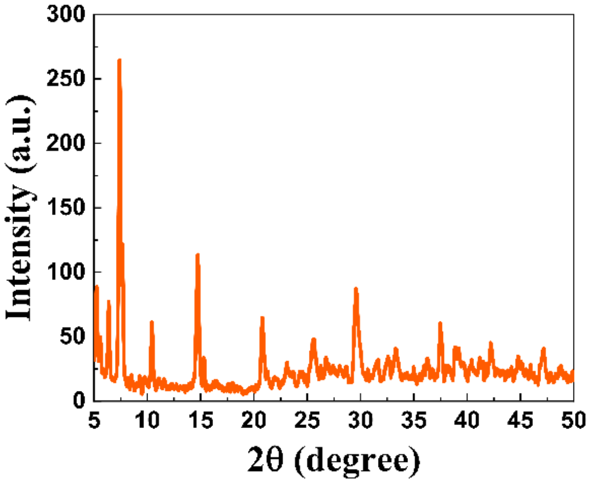


Fig. 1. XRD pattern of the synthesized perovskite.

The optical properties of the synthesized perovskite were investigated using absorption and photoluminescence (PL) spectra. As shown in Fig. 2, the PL peak of the triple-cation perovskite is observed at 590 nm, indicating a reddish emission. The absorption spectrum also exhibits two distinct peaks at 409 nm and 605 nm.

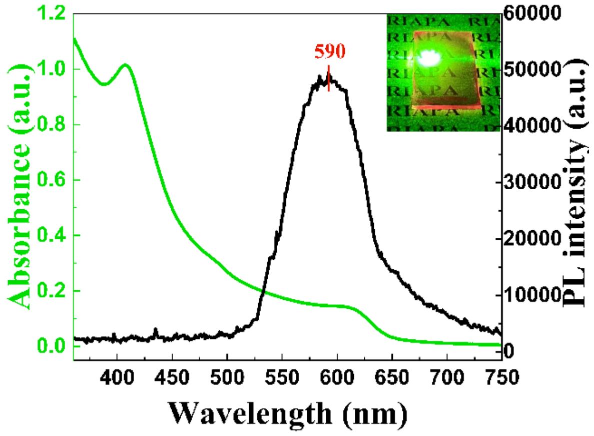


Fig. 2. Absorption and PL spectra of the triple-cation perovskite. The inset shows the perovskite film deposited on a glass substrate under 532 nm laser excitation.

The absorption spectrum of the pure epoxy resin is shown in Fig. 3.

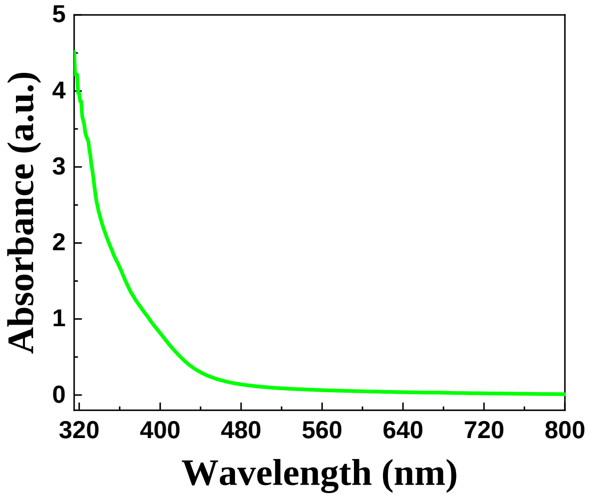
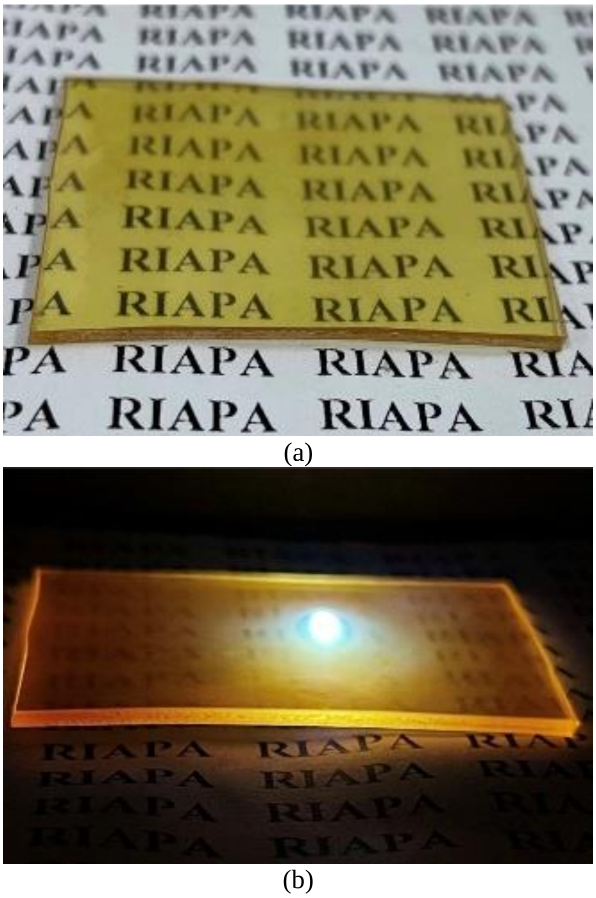


Fig. 3. The absorption spectrum of the pure epoxy resin.

Figure 4 displays the fabricated LSC based on $Cs_{0.15}MA_{0.10}FA_{0.75}Pb(Br_{0.17}I_{0.83})_3$ perovskite under visible light and laser illumination at a wavelength of 532 nm.



(a)

(b)

Fig. 4. Fabricated LSC under (a) visible and (b) laser (532nm) illuminations.

Figure 5 presents the absorption and PL spectra of the LSC based on triple-cation perovskite. The spectrum exhibits a distinc emission peak at 590 nm, indicating red-colored luminescence.

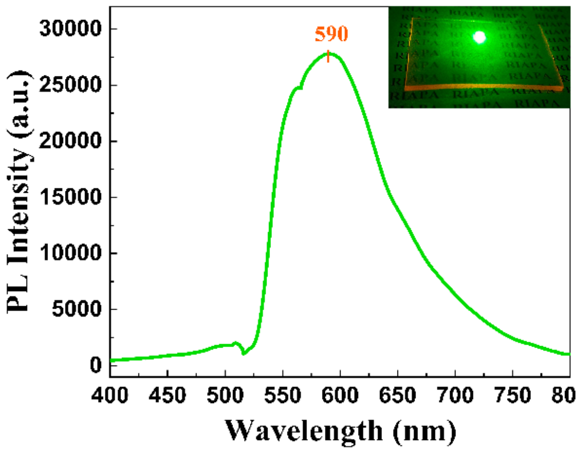


Fig. 5. Emission spectra of LSC. The inset shows the perovskite-based LSC under 532 nm laser excitation.

The performance analysis is illustrated by the J-V curves of a solar cell, as shown in Fig. 6. The epoxy resin-based perovskite LSC exhibited a significant improvement in device performance, exhibiting 170% increase in relative efficiency. This enhancement is mainly attributed to the visible-range PL of the embedded perovskite materials under solar illumination, leading to an increase in the short-circuit current. The relative enhancement in PCE (%) was calculated using the following formula:

$$\Delta PCE = \frac{PCE_{\text{LSC with perovskite}} - PCE_{\text{LSC without perovskite}}}{PCE_{\text{LSC without perovskite}}} \times 100$$

Here, $PCE_{\text{LSC with perovskite}}$ is the measured efficiency of the LSC based on the perovskite material, and $PCE_{\text{LSC without perovskite}}$ is the efficiency of the reference LSC without perovskite material, measured for the same size and dimensions. This method ensures that the reported PCE increase represents the relative improvement due to the perovskite addition.

According to the referenced Study on the Influence of Light Intensity on the Performance of Solar Cells, the open-circuit voltage, short-circuit current, and maximum output power of a solar cell increase with increasing light intensity. In our system, the perovskite based LSC increases the effective light intensity reaching the solar cell. Therefore, the observed increase in Voc is attributed to the enhanced illumination delivered by the LSC, rather than any change in the intrinsic electronic properties of the photovoltaic device [10].

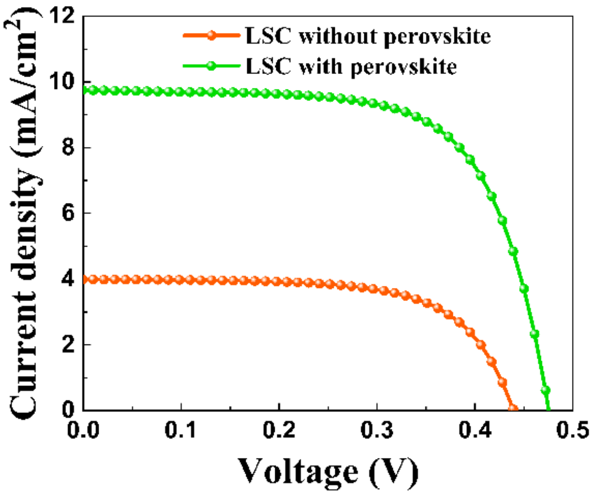


Fig. 6. Current density–voltage (J–V) characteristic curve of the solar cell attached to the edge of LSC.

Additionally, the photovoltaic performance metrics for the fabricated LSC devices are comprehensively detailed in Table 1.

Table 1 The PV cell parameters attached to the LSC based on triple-cation perovskite.

Samples	PCE (%)	FF (%)	V_{oc} (mV)	J_{sc} (mA/cm^2)
LSC without perovskite	1.15	65.8	439.4	3.99
LSC with perovskite	3.11	67.1	475.3	9.75

Figure 7 illustrates the reabsorption loss in the epoxy resin-based LSC incorporating the triple-cation perovskite. As the distance over which light is collected increases, the intensity of the light reaching the edge of the LSC decreases due to reabsorption and escape cone losses.

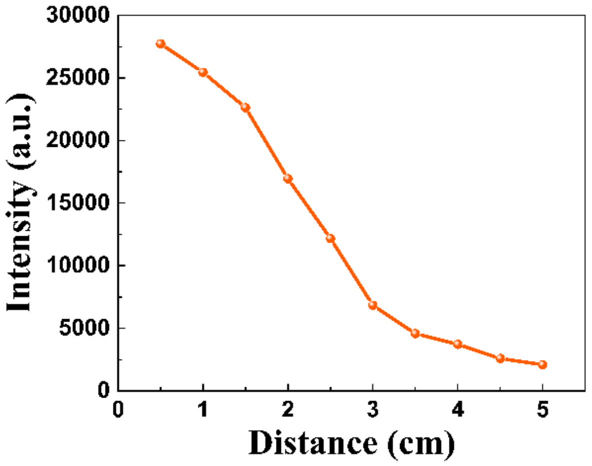


Fig. 7. Reabsorption curve of the triple-cation perovskite based LSC.

IV. CONCLUSION

In summary, a triple-cation perovskite was successfully synthesized, offering improved stability suitable for integration into LSCs. Optical characterization revealed strong absorption and emission in the visible range, confirming its potential as an effective light-emitting material. The fabricated epoxy-resin-based LSC demonstrated a notable 170% enhancement in relative efficiency. Additionally, the device exhibited high transparency, low weight, and good optical uniformity, all of which support its applicability in optoelectronic systems. These findings underscore the potential of triple-cation perovskites as stable and efficient emissive materials for next-generation LSC technologies.

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The author photo was not available at the time of publication.

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