

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

Anita Pashabeygi^a, Tavakkol Tohidi^b, Sohrab Ahmadi-Kandjani^{a,*}

^aPhysics of Optics & Lasers Department, Faculty of Physics, University of Tabriz, Tabriz, Iran.

^bNorthwest Research Complex (Bonab), Radiation Applications Research School, Nuclear Science and Technology Research Institute (NSTRI), Tehran, Iran.

Corresponding author email: s_ahmadi@tabrizu.ac.ir

Received: Sept. 08, 2025, Revised: May 18, 2026, Accepted: June 10, 2026, Available Online: June 12, 2026.
DOI: Will be added soon.

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 $\text{Cs}_{0.15}\text{MA}_{0.10}\text{FA}_{0.75}\text{Pb}(\text{Br}_{0.17}\text{I}_{0.83})_3$ 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 (PbBr_2 , $\geq 98\%$), Lead (II) iodide (PbI_2 , 99%), Formamidinium iodide (FAI, $\geq 99\%$), Cesium iodide (CsI , 99.9%), Diethylether ($>99.7\%$) and N, N-dimethyl formamide (DMF, $\geq 99.9\%$), 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 $\text{Cs}_{0.15}\text{MA}_{0.10}\text{FA}_{0.75}\text{Pb}(\text{Br}_{0.17}\text{I}_{0.83})_3$ 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 $\text{Cs}_{0.15}\text{MA}_{0.10}\text{FA}_{0.75}\text{Pb}(\text{Br}_{0.17}\text{I}_{0.83})_3$ 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 $4\text{cm} \times 5\text{cm} \times 0.15\text{ cm}$ 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 $3.8\text{cm} \times 0.5\text{ cm}$ 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].

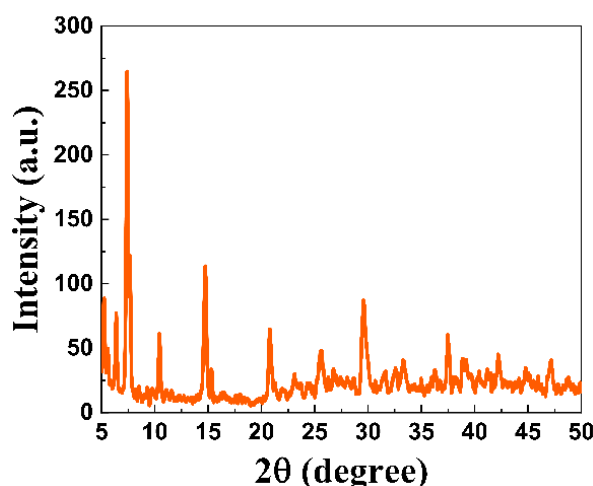


Fig. 1. XRD pattern of the synthesized perovskite.

Figure 1 consists of two panels. Panel (a) is a plot of Absorbance (a.u.) and PL intensity (a.u.) versus Wavelength (nm). The x-axis ranges from 400 to 750 nm. The left y-axis for Absorbance ranges from 0.0 to 1.2. The right y-axis for PL intensity ranges from 0 to 60,000. The absorption spectrum (green line) shows a broad peak around 420 nm. The PL spectrum (black line) shows a sharp peak at 590 nm, indicated by a red arrow and the number 590. Panel (b) is an optical micrograph of the polymer film showing a bright green emission spot.

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

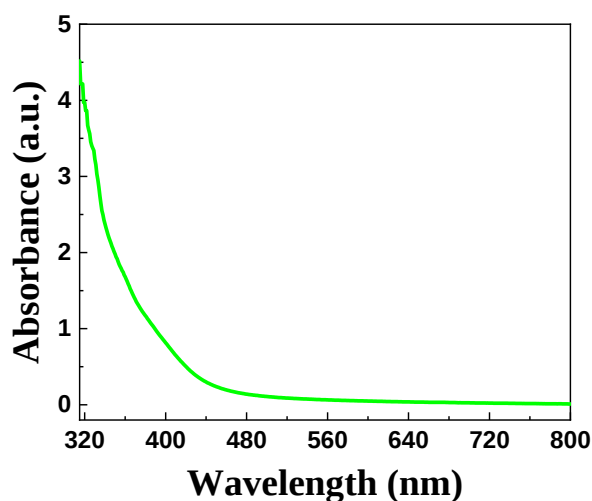
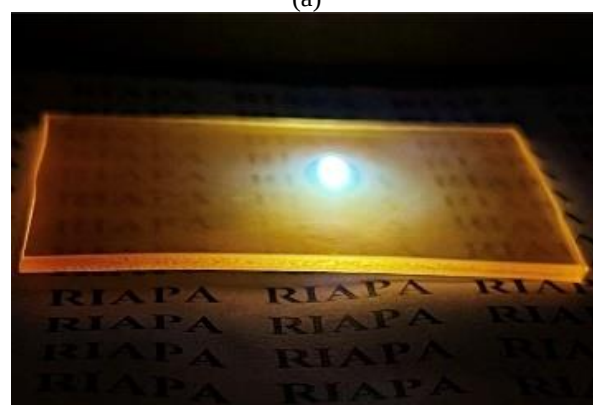


Figure 4 displays the fabricated LSC based on $\text{Cs}_{0.15}\text{MA}_{0.10}\text{FA}_{0.75}\text{Pb}(\text{Br}_{0.17}\text{I}_{0.83})_3$ perovskite under visible light and laser illumination at a wavelength of 532 nm.

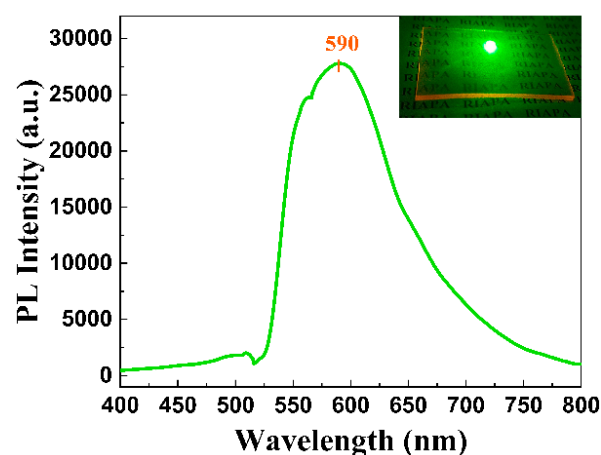


(a)



(b)

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



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:

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

Here, $PCE_{LSC\ with\ perovskite}$ is the measured efficiency of the LSC based on the perovskite material, and $PCE_{LSC\ without\ perovskite}$ 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 V_{oc} is attributed to the enhanced illumination delivered by the LSC, rather than any change in the intrinsic electronic properties of the photovoltaic device [10].

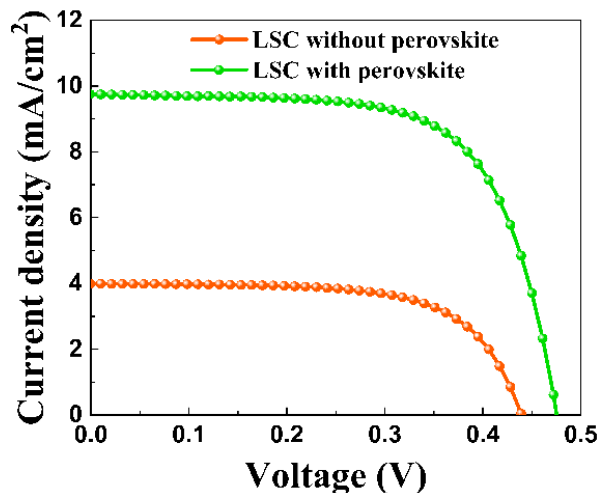


Fig. 6. Current density–voltage (J – V) characteristic curve of the solar cell attached to the edge of LSC.

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.

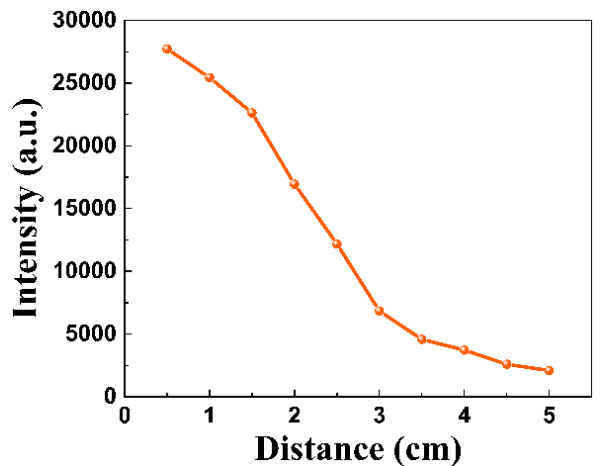


Fig. 7. Reabsorption curve of the triple-cation perovskite based LSC.

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.

REFERENCES

- [1] A. Pashabeygi, N. Fathalizadeh, and S. Ahmadi-Kandjani, "Flexible luminescent solar concentrator based on epoxy resin: A simple, cost-effective approach for enhanced energy harvesting," *Solar En. Mater. Sol. Cells (SOLMAT)*, Vol. 282, pp. 113420(1-8), 2025.
- [2] N. Fathalizadeh, R.T. Ghahrizjani, S. Shojaei, E. Mohajerani, and S. Ahmadi-Kandjani, "Enhancing metal halide perovskite LED performance by minimizing ion migration through the design of a mixed 2D (RP+ DJ)/3D active layer structure," *J. Alloys Compd.*, Vol. 1010, pp. 177813 (1-11), 2025.
- [3] K. Kranthiraja, M. Parashar, R.K. Mehta, S. Aryal, M. Temsal, and A.B. Kaul, "Stability and degradation in triple cation and methyl ammonium lead iodide perovskite solar cells mediated via Au and Ag electrodes," *Sci. Rep.*, Vol. 12, no. 1, pp. 18574(1-12), 2022.
- [4] M. Kanellis, *Application of luminescent solar concentrators as noise barriers*, M.Sc. thesis, Eindhoven Univ. Technol., Eindhoven, The Netherlands, pp. 1-35, 2016.
- [5] B.S. Richards and I.A. Howard, "Luminescent solar concentrators for building integrated photovoltaics: opportunities and challenges," *Energy Environ. Sci.*, Vol. 16, no. 8, pp. 3214-3239, 2023.
- [6] F.J. Ostos, G. Iasilli, M. Carlotti, and A. Pucci, "High-performance luminescent solar concentrators based on poly (Cyclohexylmethacrylate) (PCHMA) films," *Polymers*, Vol. 12, no. 12, pp. 2898(1-14), 2020.
- [7] Available: <https://parlagpaint.com>.
- [8] A.G. Boldyreva, A.F. Akbulatov, S.A. Tsarev, S.Y. Luchkin, I.S. Zhidkov, E.Z. Kurmaev, K.J. Stevenson, V.G. Petrov, and P.A. Troshin, "γ-ray-induced degradation in the triple-cation perovskite solar cells," *J. Phys. Chem. Lett.*, Vol. 10, no. 4, pp. 813-818, 2019.
- [9] S. Vafaei, M.H. Hekmatshoar, and F. Abbasi, "Poly (3-dodecylthiophene)-grafted multi-walled carbon nanotubes: an additive for improving charge transport properties of triple

cation perovskite solar cells," *J. Mater. Sci.: Mater. Electron.*, Vol. 34, no. 12, pp. 1050(1-9), 2023.

- [10] Z. Li, J. Yang, and P. A. N. Dezfali, "Study on the influence of light intensity on the performance of solar cell," *Int. J. Photoenergy*, Vol. 2021, no. 1, pp. 6648739(1-10), 2021.



Anita Pashabeygi was born in Tabriz, Iran, in 1998. She received her B.Sc. degree in engineering physics from University of Tabriz, Iran in 2020. She received her M.Sc. degree in photonics from the University of Tabriz, Iran, in 2024. Her research focuses on fabrication luminescent solar concentrators doped with a range of additives, synthesis perovskite materials, and device characterization.

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

Tavakkol Tohidi was born in Miandoab, Iran, in 1973. He received his B.Sc. degree in solid state physics from University of Urmia, Urmia, Iran in 1996. He received his M.Sc. degree in solid state physics from the Kharazmi University, Karaj, Iran in 2009. He received his PhD degree in physics from Azarbaijan Shahid Madani University, Tabriz, Iran in 2014. His research focuses on nanostructured thin films.



Sohrab Ahmadi-Kandjani was born in Tabriz, Iran, in 1972. He received the B.Sc. and M.Sc. degrees from the University of Tabriz, Tabriz, Iran, in 1996 and 1998, respectively, and the Ph.D. degree in physics from the University of Angres, France, in 2007. Since 1998, he has been a faculty member with Research Institute for Applied Physics and

Astronomy (RIAPA) and the Faculty of Physics, University of Tabriz, where he is currently the head. He has authored or coauthored more than 120 scientific papers in peer-reviewed international journals. His experimental and theoretical research activities encircle the study of nonlinear optical effects in organic and organic-inorganic perovskite materials, surface relief gratings formation in azo-polymers, self-organized patterns in optics, organic and organic-inorganic perovskite optoelectronic devices, luminescent solar concentrators, computational ghost-imaging, optical sensors based on photonic crystals, SPRs, and LSPRs.