Fabrication and Optical Characterization of a Quasi-2D Perovskite-based Luminescent Solar Concentrator

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ABSTRACT— **Renewable energies particularly solar concentrators, have been increasingly utilized in photovoltaics. Recently, organic-inorganic perovskite materials have gained significant attention due to their exceptional properties, such as high quantum efficiency and broad absorption band. Among these materials, two-dimensional and quasi-two-dimensional perovskites have been of particular interest to researchers. In this experimental work, a luminescent solar concentrator based on quasi-two-dimensional perovskite $OA_2MA_3Pb_4Br_{13}$ was fabricated and characterized. Results show that the relative efficiency increased to 116.7%, making these materials suitable for use as luminescent materials in concentrators.**

KEYWORDS: Luminescent Solar Concentrator, Optical properties, Quasi-Two-dimensional perovskite.

I. INTRODUCTION

Among the various perovskite structures, organic-inorganic perovskites have garnered significant attention in recent years due to their unique optical and electrical properties, making them excellent candidates for use in optoelectronic devices. These materials offer several notable advantages, including broad solar absorption, long carrier diffusion lengths, and tunable bandgaps, along with low-cost, scalable, and straightforward fabrication processes. Together, these features make organic-inorganic perovskites highly promising for a wide range of optoelectronic applications.

In addition to their applications in photovoltaics, three-dimensional (3D) organic-inorganic perovskite materials have also been widely explored for use in light-emitting diodes (LEDs), photodetectors, sensors, and fluorescent imaging [1]-[3]. The structure of 3D hybrid halide perovskites, schematically illustrated in Fig. 1, follows the general formula ABX_3, where A is a monovalent cation, B is a divalent metal cation, and X represents a halide anion.

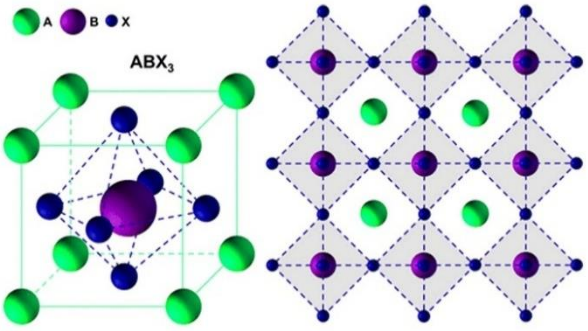

Fig. 1. Schematic illustration of the perovskite crystal structure.

The general formula for the two-dimensional layered perovskite structure is $R_2A_{n-1}B_nX_{3n+1}$ where R is a bulky organic cation and n represents the number of inorganic layers [4].

Layered perovskites show different properties depending on the number of inorganic layers. The alternating organic and inorganic layers lead to unique physical effects, one of the most important being dielectric confinement. This effect originates from the periodic contrast between the low dielectric constant of the organic layers and the high dielectric constant of the inorganic layers. Since the inorganic layers have a smaller bandgap than the organic layers, a quantum-well structure is naturally formed, where the organic layers act as barriers and the inorganic layers serve as wells. As a result, layered two-dimensional perovskite structures offer stronger photoluminescence (PL) and higher thermal stability than three-dimensional perovskites, leading to better device performance [5]-[9].

With a growing respect for nature and an increasing demand for energy, urban perspectives are increasingly focused on green buildings that can generate their own power. Luminescent solar concentrators (LSCs) represent a promising technology for photovoltaic systems, offering the ability to be seamlessly integrated into building environments [10], [11]. The primary motivation for using an LSC is to replace large and costly areas of photovoltaic cells with more affordable light-harvesting concentrators [12].

In this work, quasi-two-dimensional perovskite with octylamine (OA) cation and n=4 was chosen because of its superior PL performance [7]. A LSC was then fabricated based on quasi-2D perovskite and characterized in terms of its optical and photovoltaic properties.

II. EXPERIMENTAL PROCEDURE

A. *Materials*

Methylamine (MA, 40wt% in water), octylamine (OA, ≥98%), hydrobromic acid (HBr, 48wt% in water), lead bromide (PbBr2, ≥98%), and N, N-dimethyl formamide (DMF, ≥99.9%) from Merck are used to synthesize quasi 2D perovskite. Methyl methacrylate (MMA, 99%), polymethyl methacrylate (PMMA, Mw = 996000), and diphenyl (2, 4,6 −trimethylbenzoyl) phosphineoxide (TPO) are used in the fabrication process of the LSC polymeric matrix.

B. *Perovskite Precursors*

Before initiating perovskite synthesis, it is essential to first prepare the required alkylammonium salts. MABr and OABr can be synthesized by reacting the corresponding alkyl amines with hydrobromic acid (HBr) at molar ratios of 1:1 and 1:2, as reported in [13].

Methylamine (or octylamine) was reacted with hydrobromic acid (HBr) in a 1:1 molar ratio under continuous stirring in an ice-water bath for 2 h. The resulting solution was then transferred to an oil bath at 70 °C and maintained overnight to allow complete solvent evaporation. The obtained dry yellowish powder was subsequently washed three times with 15 mL of diethyl ether for 10 min at 15 °C under moderate stirring, followed by filtration using Whatman filter paper and a Buchner funnel connected to a vacuum pump. Finally, the purified white powder was dried under vacuum and stored for further use in precursor preparation [13].

For the synthesis of quasi-two-dimensional perovskite with n=4 (concentration of 0.2 M) using octylammonium as the spacer cation, 0.1 mmol of OABr, 0.2 mmol of $PbBr_2$, and 0.15 mmol of MABr were dissolved in 1 mL of DMF and stirred overnight at 70 °C for 24 h to obtain a homogeneous precursor solution [7].

C. *LSC Device Fabrication*

A bulk luminescent solar concentrator was fabricated via photopolymerization using PMMA as the polymer matrix.

To prepare the precursor solution, PMMA (20 wt%) was dissolved in methyl methacrylate (MMA, 80 wt%) with continuous stirring at 60 °C in a sealed vessel until a clear and homogeneous solution was obtained. Subsequently, 1 wt% of the TPO photoinitiator was added to the mixture. The synthesized perovskite was then added to the solution at a concentration of 2.4 wt%. The final mixture was poured into a mold with a 5 mm thickness and exposed to UV light (5 W) for 20 hours to initiate polymerization. Finally, samples were cut to dimensions of 5 cm×4 cm×0.5 cm using a laser cutter.

D. *Characterization of the LSC*

The Shimadzu UV-2450 spectrophotometer and Jasco FP-6200 spectrofluorometer are the instruments used to measuring the optical properties of synthesized quasi-2D perovskite. X-ray diffraction (XRD) patterns are utilized to investigate the structural properties of the samples, which are obtained using the Siemens D500. The fabricated LSCs are exposed to illumination using an AM1.5 global solar simulator, while their I-V characteristics are measured using a Keithley 2410 source meter. A solar panel (AK5318) with a surface area of 3.8 cm×0.5 cm and a rated output of 0.5 V and 160 mA is fixed to the LSC.

III. RESULTS AND DISCUSSION

In order to investigate the formation of $OA_2MA_3Pb_4Br_{13}$ perovskite, the synthesized perovskite was analyzed using XRD to determine its crystal structure. The XRD pattern is presented in Fig. 2, where two distinct peaks at 15.06° and 30.22° can be attributed to the (100) and (200) crystal planes, respectively.

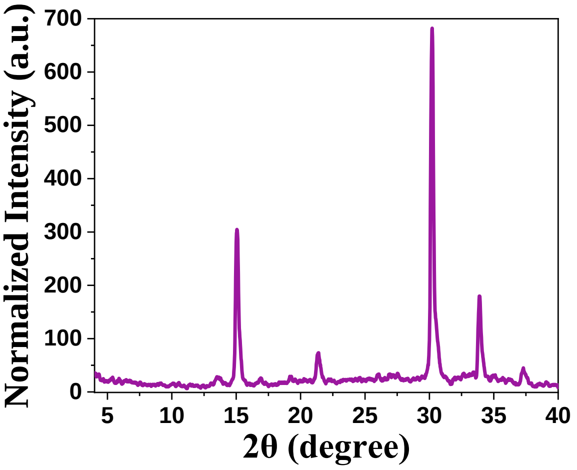

Fig. 2. XRD pattern of the synthesized perovskite.

The optical properties of the synthesized perovskite were investigated using absorption and photoluminescence spectra. The PL emission of the $OA_2MA_3Pb_4Br_{13}$ perovskite is centered at 540 nm, indicating its green light emission, as shown in Fig. 3.

The absorption spectrum displays three distinct peaks located at 431 nm, 451 nm, and 528 nm, corresponding to the n=2, n=3, and three-dimensional perovskite phases, respectively. Additionally, a shoulder at 473 nm is observed, which can be attributed to the quasi-2D perovskite phase with n=4.

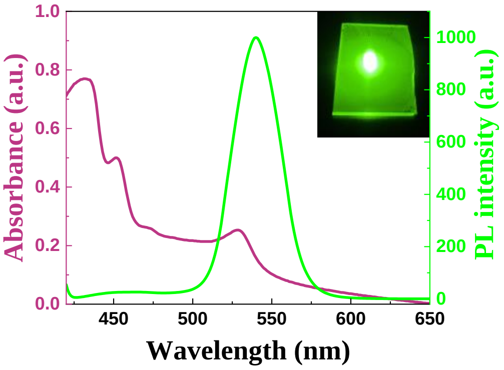

Fig. 3. Absorption and photoluminescence spectra of the perovskite. The inset shows the spin-coated perovskite film on a glass substrate under UV illumination.

Figure 4 displays the fabricated LSC based on quasi-2D perovskite under visible and UV illumination.

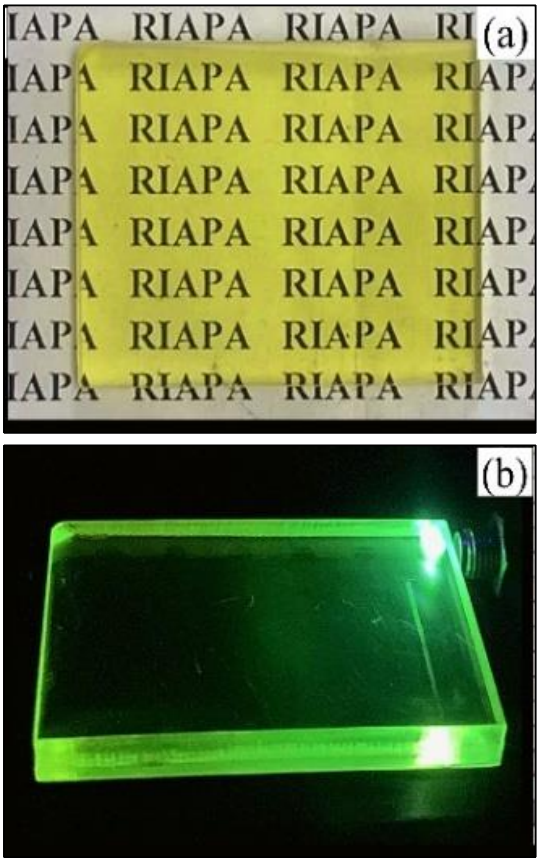

Fig. 4. Fabricated LSC under (a) visible and (b) UV illuminations.

Figure 5 presents the absorption and PL spectra of the LSC based on $OA_2MA_3Pb_4Br_{13}$ perovskite. An excitonic absorption peak appears at 516 nm in the visible range, while a strong PL emission peak is observed at 521 nm, corresponding to the n = 4 phase. The high PL intensity indicates efficient radiative recombination with minimal non-radiative losses. The sharp emission peak confirms good structural ordering within the polymer matrix. These optical properties suggest effective photon waveguiding toward the edges, making this LSC promising for enhanced photovoltaic performance.

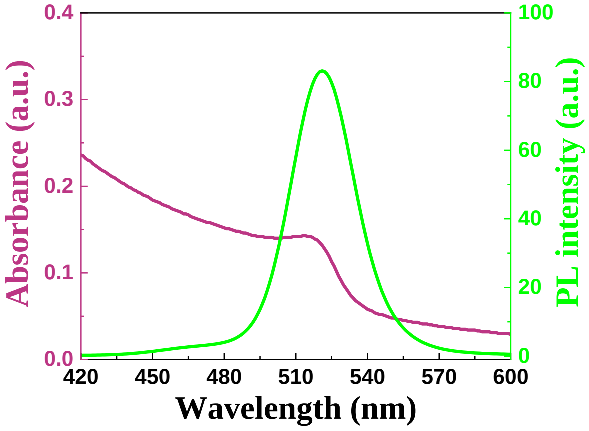

Fig. 5. Absorption and emission spectra of LSC.

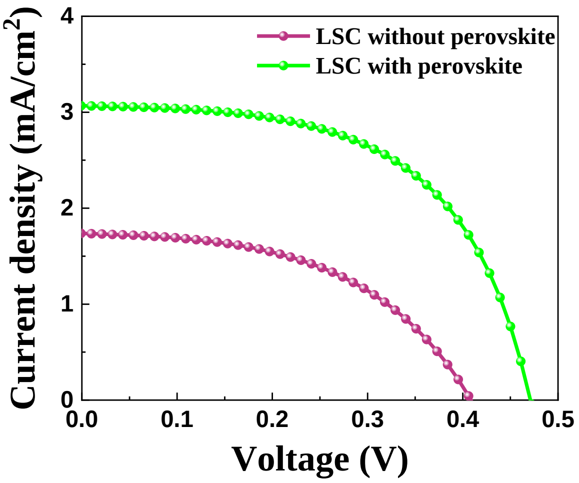

Fig. 6. Current–voltage (J–V) characteristic curve of the solar cell.

Figure 6 shows the current density–voltage (J–V) curves of the solar cell coupled with the LSC, measured with and without the presence of perovskite. To accurately assess the performance of the LSC, any region of the PV cell that extends beyond the LSC's area is covered with black tape. This ensures that only the light guided by the LSC is measured, preventing external light from affecting the characterization results and providing a more precise evaluation of the LSC's efficiency. The relative efficiency increases to 116.7% in the presence of the perovskite material. The PCE was calculated by propagating the measurement uncertainties, yielding absolute uncertainties of ±0.02% for the LSC without perovskite and ±0.05% for the perovskite-based LSC.

Results for this measurement are depicted in Table 1.

Table 1 The PV cell parameters attached to the LSC.

Samples	**PCE (%)**	**FF (%)**	**V_{oc} (mV)**	**J_{sc} (mA/cm^2)**
LSC without perovskite	0.48	55.6	494.1	1.73
LSC with perovskite	1.04	65.3	520.6	3.07

The relative enhancement in PCE (%) was calculated using the following formula:

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

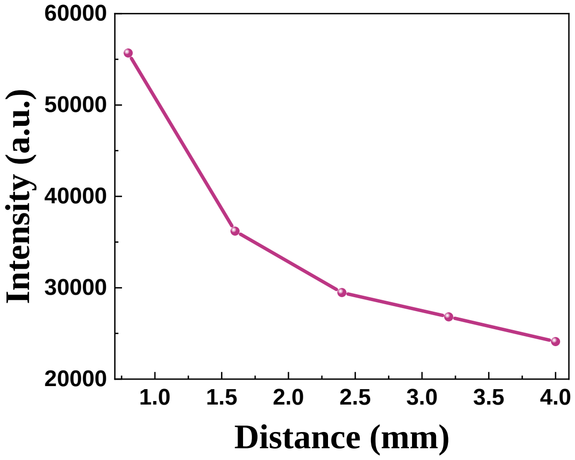

Fig. 7. Reabsorption curve of the perovskite-based LSC.

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.

Figure 7 illustrates the reabsorption behavior in the luminescent solar concentrator based on $OA_2MA_3Pb_4Br_{13}$ perovskite. As the optical path length from the collection point increases, the emission intensity from the perovskite decreases due to reabsorption and escape cone losses, reaching 71.56% of its initial value.

IV. CONCLUSION

The structural analysis of the two-dimensional organic-inorganic perovskite $OA_2MA_3Pb_4Br_{13}$ with n = 4 confirms the successful synthesis of the desired layered structure. The optical characterization of the perovskite revealed suitable absorption and photoluminescence spectra, making it a promising candidate for application in LSCs.

Furthermore, optical measurements of the LSC demonstrated an 116.7% increase in relative efficiency. These findings suggest that such perovskites can serve as effective light-emitting materials in LSC “devices.

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

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