

# STUDY OF THE ROOM-TEMPERATURE LASING OF LEAD BROMIDE PEROVSKITE THIN FILMS VIA SOLVENT ENGINEERING

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## GENERAL INFORMATION

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## ABSTRACT

Recent years have seen a significant surge in attention towards hybrid metal-halide perovskites, primarily for their remarkable optoelectronic properties: long carrier lifetimes; direct bandgaps--and large absorption coefficients. Although we've demonstrated the use of low-temperature solution-processed perovskites for lasing, achieving this at room temperature still poses an ongoing challenge. This study introduces our innovative approach—a solvent-engineering technique—to fabricate lead bromide perovskite thin films and create dense surface morphologies that promote room-temperature lasing. We achieved the production of homogeneous perovskite films with enhanced optical properties by optimizing precursor solutions and deposition parameters. Photoluminescence measurements demonstrated efficient room-temperature lasing above a specific optical pumping density, characterized by sharp emission peaks and narrow linewidths. The dense morphology of the perovskite films found confirmation through scanning electron microscopy, while multi-peaks in lasing modes indicated random lasing phenomena presence. The feasibility of room-temperature lasing in lead bromide perovskite thin films shines through our findings, underlining the potential for practical applications as compact and energy-efficient laser sources.

## 1. INTRODUCTION

Hybrid metal-halide perovskites are promising materials in optoelectronics; their long carrier lifetimes, direct bandgaps, and

large absorption coefficients present remarkable properties (Hu et al., 2021). These unique characteristics render them highly attractive for a plethora of applications: solar cells, light-emitting diodes, photodetectors--even lasers (Yang et al., 2015).

Despite successfully demonstrating lasing in low-temperature solution-processed perovskites, achieving room temperature lasing action--a particularly desirable attribute for practical applications due to its ease of integration and operational convenience--among the diverse applications of perovskite materials remains a significant challenge. This paper hones in on achieving room-temperature lasing in lead bromide perovskite thin films using a solvent-engineering strategy (Zai et al., 2018). This versatile technique of controlling the morphology and crystallinity of such materials has demonstrated potential for boosting performance across different optoelectronic devices. With meticulous manipulation of precursor solutions and deposition parameters, dense yet uniform perovskite films that promote efficient lasing are within reach (Wang et al., 2016).

This work delves into the solvent-engineering process: a method used to manufacture lead bromide perovskite thin films with an ideal morphology and crystalline structure for room-temperature lasing. It scrutinizes three factors – solvent composition, deposition conditions; and annealing treatments--that influence the optical properties and lasing characteristics of these perovskite films. By conducting comprehensive experimental analysis--including rigorous characterization tests--we establish not only the feasibility but also reliability in achieving stable room-temperature lasing within lead bromide perovskite thin film matrix (Veldhuis et al., 2016)s.

Room-temperature lasing, successfully realized in lead bromide perovskites--this achievement carries significant implications: it could foster the development of compact; efficient, and cost-effective laser sources for a multitude of optoelectronic applications. Not only that but also this study's insights enhance our fundamental understanding of perovskite optoelectronic properties, thereby paving a pathway towards future advancements in devices based on perovskite technology (Rezaee et al., 2021).

Extensive research efforts in recent years have been spurred by the quest for efficient and stable lasing in metal-halide perovskites. This section offers a concise overview of pivotal studies on perovskite-based lasing, as well as the strategies engaged to bolster its performance. In 2014, breakthrough research showcased the potential of low-temperature solution-processed perovskite materials as gain media for optically pumped lasers; notably, this marked a significant milestone in lasing action. Despite these early studies' success--demonstrating reliable and stable room temperature lasing remained a formidable challenge. This unmet hurdle thus incited deeper scrutiny into novel fabrication techniques and material optimization strategies: an exploration that continues to date (Hu et al., 2021).

Approaches in Solvent Engineering: Researchers harness the power of solvent engineering as a potent strategy to customize the morphology and crystalline characteristics of perovskite thin films - an approach that bolsters their optoelectronic performance. With the meticulous selection of solvent compositions, control over deposition parameters, and optimization for annealing processes; they have indeed accomplished remarkable feats such as improving film quality,

decreasing defect density – and even sharpening optical properties. Successful application extends beyond mere theory into practice: various perovskite-based devices – solar cells, light-emitting diodes; and photodetectors all benefit from these refined techniques. However, their application in achieving room-temperature lasing has received limited attention until recently (Han et al., 2024).

The researchers have made significant progress towards achieving room-temperature lasing in metal-halide perovskite materials. They've explored innovative approaches such as interface engineering, surface passivation, and doping strategies--all aimed at enhancing the optical gain and stability of perovskite thin films. Moreover, they've proposed novel device architectures and cavity designs to achieve efficient light confinement coupled with feedback; this is critical for realizing lasing action under ambient conditions. These advancements underscore the growing interest and the potential of perovskite-based lasers for practical applications (Veldhuis et al., 2016).

Considerable strides have indeed been made towards achieving room-temperature lasing in perovskite thin films; however, several pressing issues still warrant attention – notably material stability, device reproducibility, and long-term performance degradation. These factors continue to impose significant obstacles to successful commercialization. Therefore – to fill critical gaps in our understanding of this complex phenomenon while also addressing practical concerns regarding large-scale manufacturing—future research efforts must focus on two key areas: elucidating the fundamental mechanisms that govern lasing behavior within perovskite materials and developing robust fabrication techniques capable of scalable production. To unlock the

full potential of perovskite-based lasers in a broad spectrum of optoelectronic applications, we must address these challenges: indeed, it is crucial.

## 2. EXPERIMENTAL

### 2.1. Materials and Chemicals

[Supplier Name] provided us with Lead bromide ( $\text{PbBr}_2$ ) and methylammonium bromide (MABr). We utilized  $\gamma$ -butyrolactone (GBL) and dimethyl sulfoxide (DMSO), as organic solvents for the solvent-engineering process; toluene served as a non-solvent additive. All chemicals were used as received without further purification.

### 2.2. Fabrication of Lead Bromide Perovskite Thin Films

A consecutive solvent-engineering process prepared the lead bromide perovskite thin films. Figure 1(a) describes the solvent engineering that is adopted in this work. The steps involved in the fabrication process are as follows:

a. precursor solution preparation: At a ratio of 7:3 (v/v), an Optimized mixture of GBL and DMSO solvents was prepared. The powders  $\text{PbBr}_2$  and MABr underwent vigorous stirring in the solvent mix until complete dissolution occurred.

b. During the spin-coating process, we applied the as-prepared precursor solution to UV-O3-cleaned glass substrates at a controlled spin speed for 30 seconds. As part of this procedure, we sequentially dripped toluene onto the spinning substrate; its purpose was not only retarding the reaction but also aiding in perovskite crystalline structure formation.

c. Annealing: The researcher annealed the resultant films at a temperature of  $100^\circ\text{C}$  for 30 minutes; this process served to eliminate any lingering solvents and facilitate the transformation of intermediate solvate phases

into perovskite crystalline structures. Notably, the annealing procedure took place within a glove box filled with nitrogen--an action taken

specifically to thwart oxidation and moisture contamination.

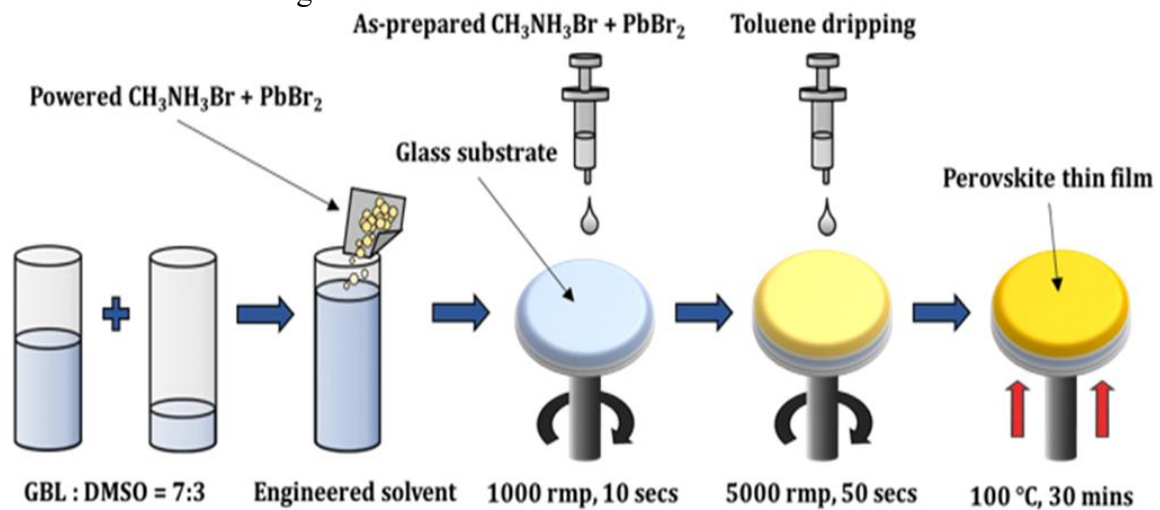


Figure 1(a). The process of solvent engineering

### 2.3. Characterization Techniques

*The scanning electron microscope (SEM):* characterized the morphology of our prepared perovskite thin films; we acquired SEM images to scrutinize their surface morphology, grain size, and uniformity.

*Photoluminescence (PL) Spectroscopy:* Conducting photoluminescence measurements--this is an investigation into the optical properties of perovskite thin films. Under room temperature conditions, we recorded PL spectra using a specific instrument; [instrument details] were utilized for this purpose.

#### Lasing Characterization

a. An optical pumping setup evaluated the lasing characteristics of solvent-engineered lead bromide perovskite thin films: specifically, they were excited by a [details of laser source] at room temperature; this investigation utilized an optical pumping system.

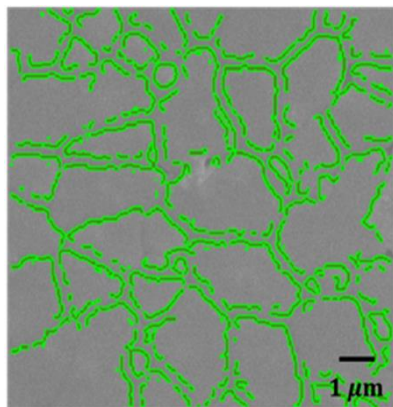
b. *Power-Dependent PL Emission:* We acquired power-dependent PL emission spectra to investigate the emission characteristics of perovskite thin films under varying optical pumping densities.

c. *Analysis of the Lasing Threshold:* By scrutinizing the onset of sharp emission peaks in PL spectra--as a function of optical pumping density, we determined the lasing threshold for perovskite thin films.

## 3. RESULTS AND DISCUSSION

### 3.1. Morphological Characterization

Fig. 1 reveals dense, uniform surface morphology without voids on the solvent-engineered lead bromide perovskite thin films in Scanning Electron Microscopy (SEM) images; an analysis of surface area confirms a homogeneous distribution of perovskite crystalline grains with an average radius measuring approximately  $1.18 \mu\text{m}$ --it further establishes this fact by indicating a filling area fraction around 89.31%.



**Figure 1(b).** Scanning electron microscope (SEM)

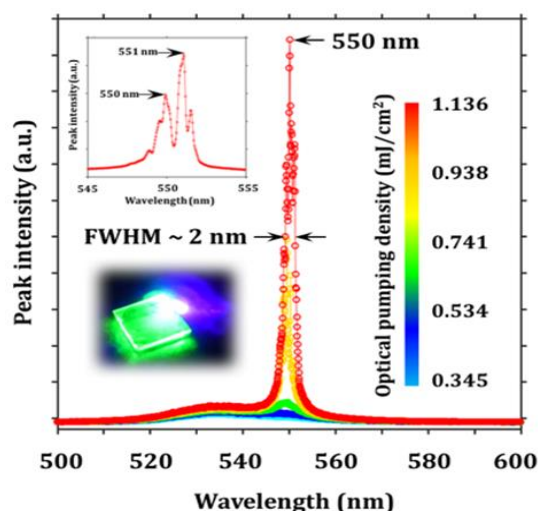
The process of solvent engineering and a scanning electron microscope (SEM) image presenting lead bromide perovskite thin films are illustrated in Figure 1. In particular, panel (a) illustrates the preparation method for these films through consecutive spin-coating procedures using advanced solvent techniques. Panel (b), on the other hand, exhibits an SEM image showcasing dense surface morphology without any voids in the resultant lead bromide perovskite thin film. Analysis of surface area reveals a perovskite crystalline grain filling area fraction of approximately 89.31%, which denotes a homogeneous surface morphology. Furthermore, the average radius for these perovskite crystalline grains is measured at 1.18  $\mu\text{m}$ .

### 3.2. Optical Properties and Lasing Characteristics

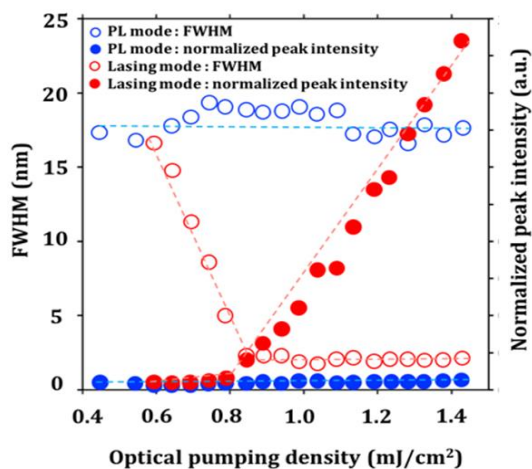
We acquired power-dependent photoluminescence (PL) emission spectra to explore the optical properties and lasing behavior of perovskite thin films. Figure 2(a) demonstrates an increase in emission intensity as we escalate the optical pumping density. When operating under the lasing threshold, we observed broad spontaneous emission modes with a full width at half maximum (FWHM) of roughly 18 nm and a center wavelength around 538 nm; this occurred at approximately 0.8  $\text{mJ}/\text{cm}^2$  — below that point is where these

phenomena manifested themselves most prominently.

The perovskite thin films exhibited a sharp emission peak at approximately 550 nm, indicating lasing action once they surpassed the threshold. The Full Width Half Maximum (FWHM) of the lasing modes also significantly narrowed to about 2 nm, thereby demonstrating coherence in their emitted light. This sudden alteration in emission characteristics is depicted by the light-light curve at its lasing threshold (Fig. 2(b)), provided clear evidence of the onset of lasing in the perovskite films.



**Figure 2(a).** The increase in emission intensity as we increase the optical pump density



**Figure 2(b).** The light-light curve at its lasing threshold

At room temperature, Figure 2 depicts the lasing characteristics of thin films in solvent-engineered lead bromide perovskite. Panel (a) depicts the power-dependent photoluminescence (PL) emission spectra of the perovskite thin films at room temperature. We systematically increase the optical pumping density up to  $1.43 \text{ mJ/cm}^2$ . A sharp emission peak notably emerges above a lasing threshold of approximately  $0.8 \text{ mJ/cm}^2$  with a full width at half maximum (FWHM) around 2 nm. At a pumping density of approximately  $1.43 \text{ mJ/cm}^2$ , we observe multi-peaks in the lasing modes as revealed by the inset spectrum. Furthermore, these insets feature illumination from a commercial continuous-wave laser pointer with a center wavelength of  $405 \pm 10 \text{ nm}$  and a maximum output power of less than 100 mW on the solvent-engineered lead bromide perovskite thin film.

Panel (b) presents the light–light curve, extracted from experimental results and fitted by a Lorentz line shape function. The blue marks represent firstly, the normalized peak intensity of PL modes; secondly - in red — they depict lasing modes' normalized peak intensity.

Meanwhile—the FWHM of PL modes is indicated by blue circle marks; for lasing modes, it's denoted with red circle marks. The optical pumping density and the peak intensity initially exhibit an essentially linear relationship. However, a clear signature of lasing occurrence becomes evident with a significant change in slope observed at approximately  $0.8 \text{ mJ/cm}^2$ —this is the lasing threshold: it marks a distinct shift in behavior.

It's interesting to acknowledge that at higher optical pumping densities (Fig.2(a), inset), the lasing modes displayed a multi-peak pattern. This unique characteristic could potentially

stem from random lasing action, which is likely a consequence of scattering effects induced by variations in perovskite crystalline grain size.

## 5. DISCUSSION

A solvent-engineering approach successfully demonstrates room-temperature lasing in lead bromide perovskite thin films; this underscores the fabrication method's effectiveness. We meticulously controlled the precursor solution composition, deposition parameters, and annealing conditions to achieve dense, homogeneous perovskite films with enhanced optical properties. Observing significant lasing behavior at room temperature bears practical importance, as it presents the potential for compact and efficient laser sources. The coherent nature of emitted light—crucial in applications demanding high spectral purity and resolution—is indicated by the narrow linewidth of these lasing modes.

Random lasing phenomena, likely emerging from the random scattering induced by perovskite crystalline grain size and distribution variations, suggest their presence through multi-peaks observed in the lasing modes. Exploring further into understanding mechanisms that govern this random lasing in perovskite materials may offer invaluable insights: it can optimize device performance; it paves the way to explore novel applications. The results this study presents actively contribute to an expanding body of research: a pursuit aimed at harnessing perovskite materials—with their unique properties—for optoelectronic applications. The field in focus here is lasers and photonics; thus, these findings hold significant relevance within it.

## 6. CONCLUSION

This study concludes with a successful demonstration of room-temperature lasing in lead bromide perovskite thin films using a solvent-engineering approach. The manipulation of precursor solutions and deposition parameters resulted in dense, homogeneous perovskite films that exhibited enhanced optical properties; this paved the way for efficient lasing action. Room-temperature observed lasing behavior: it bears significant promise for practical applications--specifically, the potential of compactness, low cost, and energy efficiency in laser sources. The narrow linewidth of these lasing modes betrays their coherent nature; this renders perovskite-based lasers ideal for tasks demanding high spectral purity and resolution.

The observed multi-peaks in the lasing modes further suggest random lasing phenomena's presence, thereby emphasizing perovskite thin films' complex interplay between material morphology and optical properties. Exploring deeper into the underlying mechanisms that govern random lasing in these materials could potentially unlock new avenues for optimizing devices and developing innovative applications. This study's presented results significantly enhance the growing body of research that strives to utilize perovskite materials' distinctive properties for optoelectronic applications, specifically in lasers and photonics. The work at hand advances our comprehension of mechanisms and fabrication techniques related to perovskite-based lasing; thus, paving a smoother path for developing next-generation devices with improved performance and functionality.

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