

Chemical Vapor Deposition Growth of 2D Lead-Based Perovskite (PEA₂PbI₄) Films and Their Low-Temperature Random Lasing Properties

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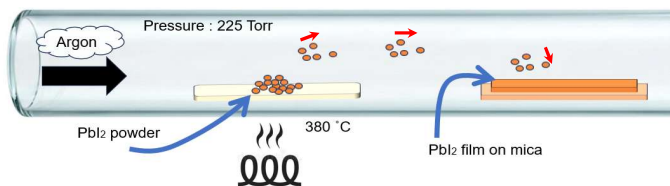
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Introduction

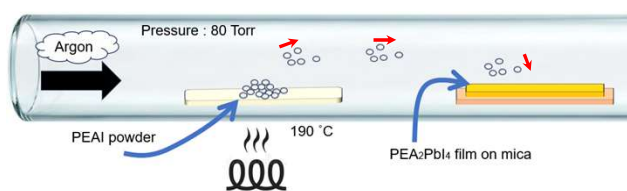
Perovskite materials possess outstanding optical properties, such as high photoluminescence quantum yield (PLQY), low lasing thresholds, and broad spectral tunability, demonstrating extensive application potential in optoelectronic fields like LEDs, photodetectors, and lasers. [1] Compared to their 3D counterparts, 2D organic-inorganic halide perovskites incorporate organic ligand layers, which not only significantly improve moisture resistance and structural stability but also induce strong dielectric and quantum confinement effects. [2] Regarding film fabrication, Chemical Vapor Deposition (CVD) provides a more stable approach to growing high-quality single-crystalline films compared to traditional space-confined and solution spin-coating methods. [3] Therefore, in this work, we utilize a two-step CVD method—depositing a PbI₂ film first, followed by vapor conversion using PEA₂I—to demonstrate the excellent quality and optical properties of 2D perovskite films fabricated via the vapor-phase approach.

Sample Fabrication

Step 1 : PbI₂ deposition

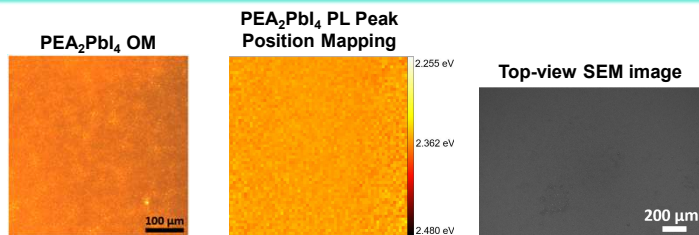


Step 2 : PEA₂I deposition



Result & Discussion

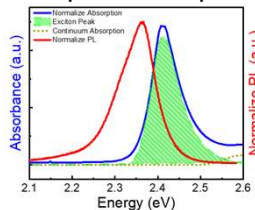
Structural and Morphological Properties



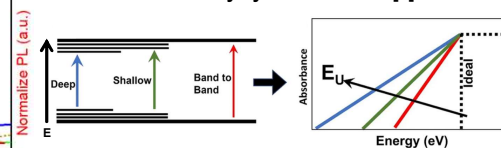
□ PL mapping and SEM images demonstrate excellent film uniformity.

Optical Properties

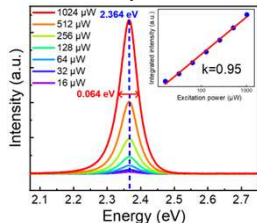
Absorption and PL Spectra



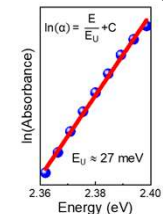
Schematic of band tails caused by system disorder [4]



Power-dependent PL



Urbach Tail Fitting



□ Elliott Formula :

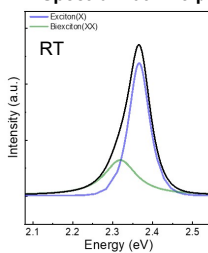
$$\alpha(E) = \alpha_{cont}(E) + \alpha_{exc}(E)$$

- High exciton binding energy of 227 meV ensures stable excitons at room temperature.
- Low Urbach energy (E_U) implies a low defect density within the film.
- A k-value of 0.95 indicates that the emission is dominated by excitonic recombination.

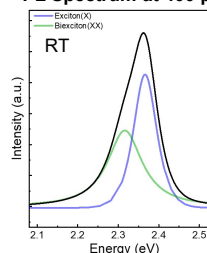
Result & Discussion

Biexciton & Random laser

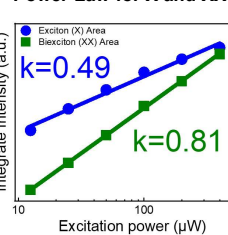
PL Spectrum at 12.5 μ W



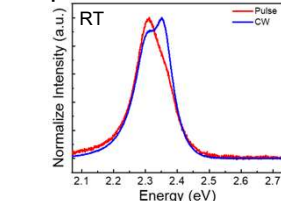
PL Spectrum at 400 μ W



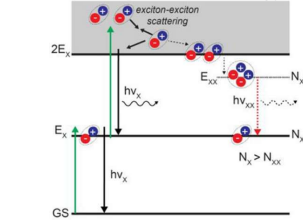
Power Law for X and XX



PL Spectra at Pulse / CW Excitation

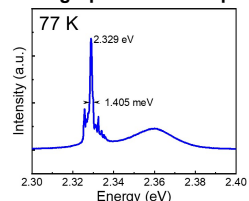


Schematic of biexciton energy levels [7]

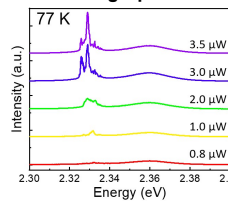


□ PL spectrum shows two peaks with different k-values, suggesting exciton and biexciton recombinations.

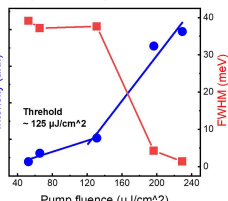
Lasing Spectrum at 3.5 μ W



Lasing Spectra



Light-in Light-out Curve



□ Random laser emission was observed at 77 K with a threshold of ~125 μ J/cm².

Conclusion

- Highly uniform quasi-2D PEA₂PbI₄ films were grown via two-step CVD, exhibiting excellent optical properties (FWHM = 64 meV, E_U = 27 meV) and minimal defect density.
- Power-dependent PL confirmed exciton-dominated emission (k = 0.95) and successfully identified distinct biexciton states.
- Achieved random lasing at 77 K with a low threshold of ~125 μ J/cm², highlighting the strong potential for advanced optoelectronic applications.

Reference

- [1] SU, Zhan, et al. Crystallization mechanism and lasing properties of CsPbBr₃ perovskites by chemical vapor deposition. Chemical Engineering Journal, 2023, 472: 144906.
- [2] HAM, Ayoung, et al. Strategies for chemical vapor deposition of two-dimensional organic-inorganic halide perovskites. Iscience, 2021, 24.12.
- [3] SHENG, Xin, et al. Quasi-2D halide perovskite crystals and their optoelectronic applications. Journal of Materials Chemistry A, 2022, 10.37: 19169-19183.
- [4] SUBHA, T. D., et al. Role of Urbach energy in controlling voltage output of solar cells. Optical and Quantum Electronics, 2023, 55.9: 794.
- [5] ARENDSE, Christopher J., et al. Insights into the growth orientation and phase stability of chemical-vapor-deposited two-dimensional hybrid halide perovskite films. ACS Applied Materials & Interfaces, 2023, 15.50: 59055-59065.
- [6] ZHI, Rui, et al. Direct observation of intragrain defect elimination in FAPbI₃ perovskite solar cells by two-dimensional PEA₂PbI₄. ACS Energy Letters, 2023, 8.6: 2620-2629.
- [7] PARK, Jee Yung, et al. Unraveling the Ultrafast Carrier Dynamics and Lasing Pathways in 2D Tin Halide Perovskites. Advanced Optical Materials, 2026, 14.5: e03289.