

Efficient Electroluminescence Devices Based on *in Situ* Fabricated Perovskite Nanocrystals

Shuai Chang¹, Haizheng Zhong¹

schang@bit.edu.cn

¹MIIT Key Laboratory for Low Dimensional Quantum Structure and Devices, School of Materials Science & Engineering, Beijing Institute of Technology, 5 Zhongguancun South Street, Haidian District, Beijing, 100081, China

Keywords: perovskites nanocrystals, *in situ* fabrication, electroluminescence, light-emitting diodes.

ABSTRACT

In situ ligand-assisted reprecipitation (LARP) fabrication strategy provides an efficient and convenient way to control the size and dimension of perovskite toward efficient and bright RGB electroluminescent devices for display applications. The role of solvent and ligand effects on the size and quantum-well width distribution are also thoroughly investigated.

1 INTRODUCTION

Halide perovskites are desired light emitters with characteristics of high brightness, tunable and narrow emission bands, which make them potential candidates for display technology. It has been realized that the dimensionality of perovskites plays an important role in determining the carrier transport and recombination as well as the device performance. By introducing organic ligands, both of the molecular and size dimensionality of perovskites can be well-controlled through either *in situ* fabrication on substrates via spin-coating a precursor solution or *ex situ* fabrication via film deposition from colloidal solution. *In situ* fabrication strategy provides an efficient and convenient way to control the dimensionality of perovskite toward efficient and bright devices.^[1,2] Unlike the precipitation process in large volume flask, the *in situ* fabricated perovskite nanocrystals experienced different nucleation and growth process. In this report, we will present our latest findings of the role of solvent and ligand effects on the size and quantum-well width distribution of *in situ* fabricated green, red and blue (RGB) perovskite nanocrystals.

2 RESULTS

Our group has investigated the crystallization of *in situ* fabricated perovskite nanocrystals and illustrate the enhancing role of ligand-assisted reprecipitation (LARP) process in the fabrication of green emissive formamidinium lead bromide (FAPbBr₃) nanocrystals (See Fig. 1).^[3] Highly luminescent and uniform FAPbBr₃ nanocrystals based thin film with photoluminescence quantum yield up to 78% were obtained. Highly efficient pure green perovskite based light-emitting diodes (PeLEDs) devices were achieved with maximum external quantum efficiency (EQE) of 16.3%, which is the record EQE at the time of publication. Interface engineering through oxygen plasma treatment is employed to further

improve the performance and reproducibility of the final electroluminescent devices (See Fig. 2).^[4] The physical changes in film morphology, optical and electric properties, and chemical change of molecular composition for oxygen plasma treated hole injection layer, poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS), is investigated. It is found that the reduced film thickness and PSS-rich surface after plasma treating facilitates the growth of upper layers of FAPbBr₃ nanocrystal films, leading to higher photoluminescence quantum yields.

The solvent effects for the on-chip crystallization during the *in situ* fabrication process of red emissive perovskite nanocrystals is investigated (See Fig. 3).^[5] The formamidinium lead iodide (FAPbI₃) nanocrystals obtained from a precursor solution in γ -butyrolactone (GBL) are smaller than that obtained from N,N-dimethylformamide (DMF) and dimethyl sulfoxide (DMSO), and the relatively weak coordination between GBL and the precursor molecules enables reduced defect states in the resulted perovskite nanocrystals with enhanced photoluminescence properties. An efficient PeLED with peak EQE of 15.8% is obtained with good reproducibility.

For the blue emissive PeLEDs, efficient energy transfer and the subsequent efficient radiative recombination is achieved through ligand engineering to narrow down the quantum-well width distribution of CsPbClBr₂ nanocrystal films (See Fig. 4).^[6] The use of 2-phenylethanamine bromide (PEABr) dominates the formation of small-n domains, while 3,3-diphenylpropylamine bromide (DPPABr) induces the formation of large-n domains. A proper mixing ratio of the two ligands induces a narrower quantum-well width distribution, resulting in precise dimension control with central domination of $n = 4$. Based on such films, efficient blue PeLEDs with a peak external quantum efficiency of 9.0% are achieved at 475 nm.

3 CONCLUSIONS

Our investigations provide effective methods of size, defects and dimension control of *in situ* fabricated perovskite nanocrystals to put forward the development of RGB LEDs for display applications.

REFERENCES

- [1] S. Chang, Z. Bai and H. Zhong, "In-situ Fabricated Perovskite Nanocrystals: A Revolution in Optical Materials", *Adv. Opt. Mater.*, Vol. 6, No. 1800380 (2018).
- [2] Q. Zhou, Z. Bai, L. Lu and H. Zhong, "Remote phosphor technology for white LED applications: advances and prospects." *Chin. Opt.*, Vol. 8, No. 3, pp. 313-328 (2015).
- [3] D. Han, M. Imran, M. Zhang, S. Chang, X. Wu, X. Zhang, J. Tang, M. Wang, S. Ali, X. Li, G. Yu, J. Han, Wang L, B. Zou and H. Zhong, "Efficient Light-Emitting Diodes Based on in Situ Fabricated FAPbBr₃ Nanocrystals: The Enhancing Role of the Ligand-Assisted Reprecipitation Process", *ACS Nano*, Vol. 12, pp. 8808–8816 (2018).
- [4] I. Muhammad, D. Han, A. Shmshad, X. Zhang, C. Wang, K. Syed, Y. Chen, S. Chang, B. Zou and H. Zhong, "Gaining Insight into the Underlayer Treatment for In Situ Fabrication of Efficient Perovskite Nanocrystals Based Light-Emitting Diodes", *J. Phys. Chem. C*, Vol. 123, pp. 17353–17359 (2019).
- [5] X. Zhang, D. Han, C. Wang, I. Muhammad, F. Zhang, A. Shmshad, X. Xue, W. Ji, S. Chang and H. Zhong, "Highly Efficient Light Emitting Diodes Based on In Situ Fabricated FAPbI₃ Nanocrystals: Solvent Effects of On-Chip Crystallization", *Adv. Opt. Mater.*, Vol. 7, No. 1900774 (2019).
- [6] C. Wang, D. Han, J. Wang, Y. Yang, S. Huang, X. Zhang, X. Liu, S. Chang, K. Wu and H. Zhong, "Dimension control of in situ fabricated CsPbClBr₂ nanocrystal films toward efficient blue light-emitting diodes", *Nat. Commun.*, In review (2020).

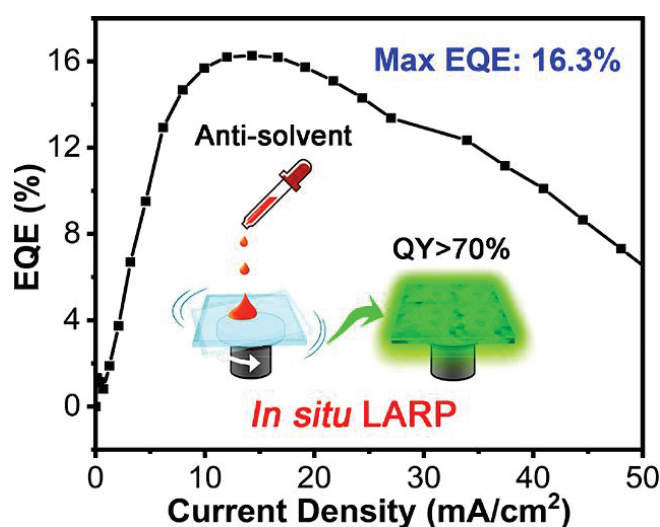


Fig. 1 *In situ* LARP processed green perovskite films for high efficient LEDs

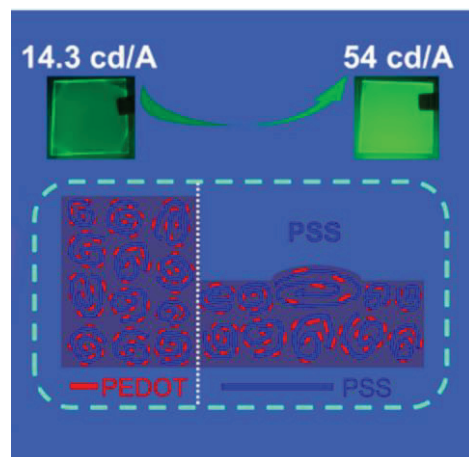


Fig. 2 Oxygen plasma treatment on the hole injection layer to improve the performance and reproducibility of the electroluminescent devices

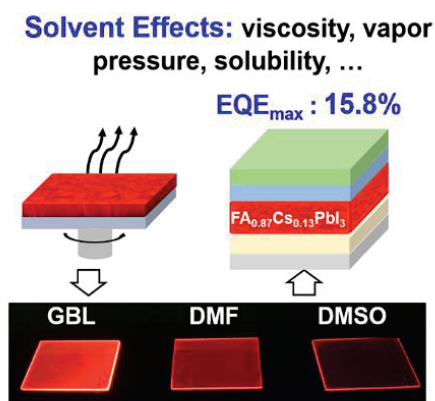


Fig. 3 Solvent coordination effects of the on-chip crystallization

Ligand Effects: quantum-well width distribution

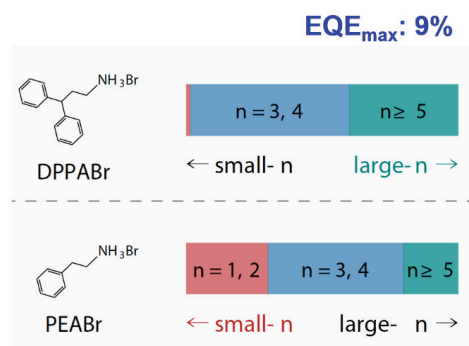


Fig. 4 Dual-ligand engineering for narrowed quantum-well width distribution