

## Electronic Supplementary Information (ESI)

### Bionic electroluminescence perovskite light-emitting device

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## Experimental Section

### Synthesis of CsPbBr<sub>3</sub> QDs

The whole process of synthesis is operated under ambient atmosphere, through rapid mixing of different precursors to achieve a simple and high-quality preparation of quantum dot (QDs). Firstly, 1 mL of Cs precursor (1 mmol CsCO<sub>3</sub> was dissolved in 10 mL octanoic acid (OTAc, 99%)) and 0.5 mL formic acid (FA) precursor (4 mmol formamidine acetate (FA(Ac), 99%) was dissolved in 5 mL OTAc) were injected into 9 mL of Pb precursor (1 mmol PbBr<sub>2</sub> and 2 mmol tetraoctylammonium bromide (TOAB, 98%) are mixed together in 10 mL toluene). After mixing, the reaction immediately started, and the solution produced severe color changes. After 30 s, 0.1 g dodecylbenzene sulfonic acid (DBSA) was applied to the passivate QDs surface, which then was reacted in the open air at room temperature for 2 minutes. 3 mL didodecyldimethylammonium bromide (DDAB, 98%) (10 mg/mL, toluene solution) was added after that for 2 minutes, then added ZnBr<sub>2</sub> and TOAB toluene solution at a molar ratio of 1:2 after 2 minutes. Finally, the ethyl acetate was added at a volume ratio of 2:1 to wash the QDs for twice, the sediment was collected and dispersed in n-octane to yield (Cs/FA)PbBr<sub>3</sub> QDs.

The clarified Pb precursor is in an almost transparent colorless state, containing diversely bonded ionic Pb<sup>2+</sup> and Br<sup>-</sup>. When the Cs precursor is rapidly injected with the FA precursor, Pb<sup>2+</sup> ions are quickly reacted with Cs<sup>+</sup>/FA<sup>-</sup> in the acidic environment under vigorous stirring, forming (Cs/FA)PbBr<sub>3</sub> crystal nuclei; while the solution color immediately turns yellow. During the reaction, there are more and more perovskite QDs gradually nucleating and growing in an overall solution environment, resulting in the color of the solution appearing cloudy yellow.

### Fabrication of PeLEDs

ITO glass substrate is firstly cleared by ethanol and acetone, then treated under UV ozone for 15 minutes. Then, the PEDOT: PSS solution is spin-coated on the ITO glass substrate at 3000 rpm for 45 s and heated at 140 °C for 15 mins, the PTAA (poly(bis(4-

phenyl)(2,4,6-trimethylphenyl) amine)) was spin-coated on it in a glove box in a N<sub>2</sub> environment at 2000 rpm for 45 s and heated at 120 °C for 15 mins, the n-octane dispersion of perovskite QDs was spin-coated on it at 2000 rpm for 45 s. Afterwards, the sample was placed in a high vacuum thermal evaporation system. Finally, TPBi (1,3,5-Tris(1-phenyl-1H-benzimidazol-2-yl)benzene) (5 nm)/PO-T2T (2,4,6-Tris[3-(diphenylphosphinyl)phenyl]-1,3,5-triazine) (35 nm) and LiF/Al (1 nm/100 nm) were deposited under a vacuum of 2\*10<sup>-4</sup> Pa, forming the PeLED.

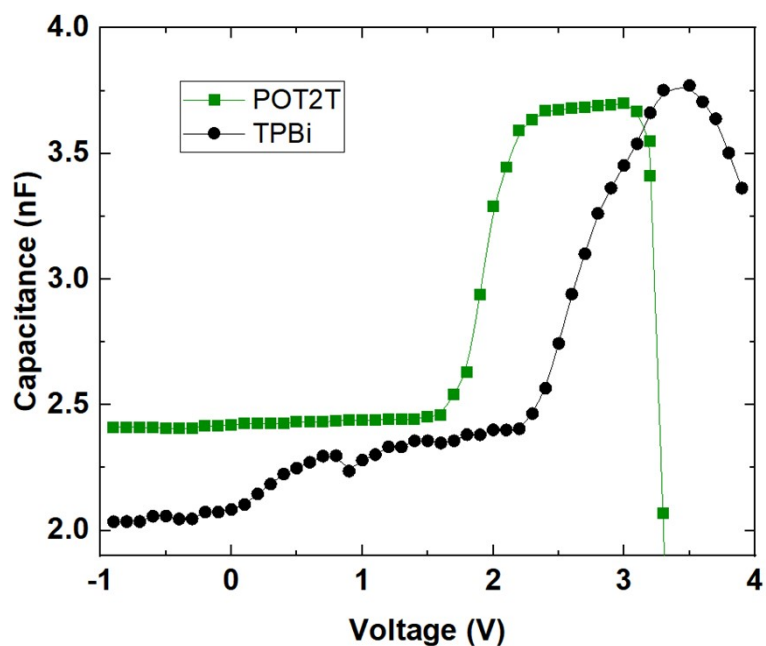
### **Fabrication of FC-PeLED system**

The fluorescent coating (FC) layer was prepared by mixed green, yellow and red phosphor, which can be mixed into brown color. The mixed gel is blade coated onto the outside glass substrate of the PeLED to form a hybrid device (FC-PeLED).

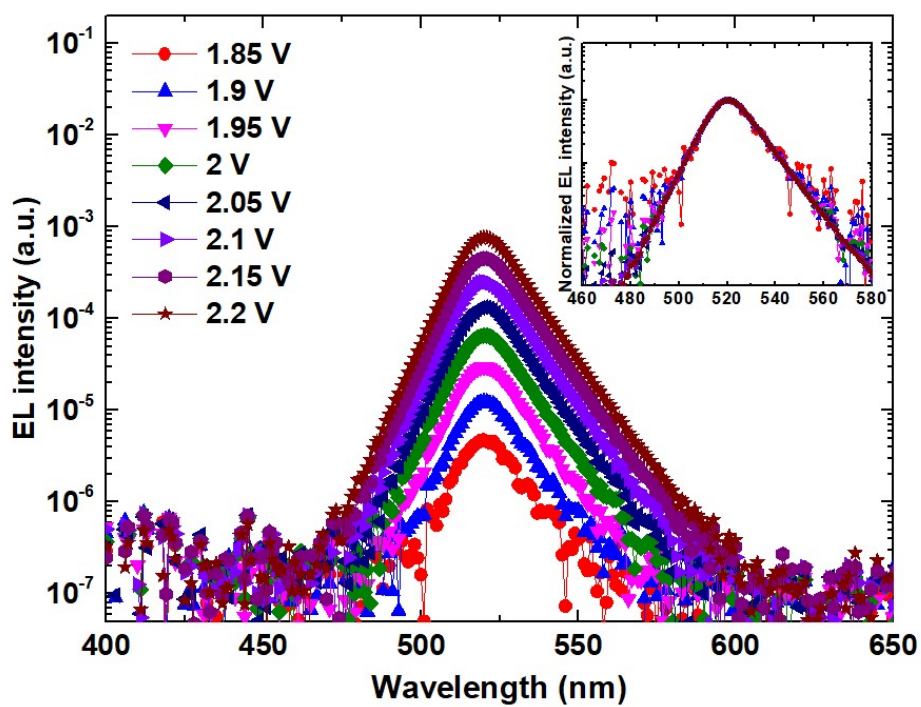
### **Characterization**

The PL spectrum of the QDs and FC layer were obtained by spectrometer (Cary Eclipse, Agilent, Austria). The ultraviolet-visible light absorption spectrum was obtained by Shimadzu UV-3150 UV-vis-NIR spectrometer. XRD pattern of QDs was obtained by a Bruker D8 Advance X-ray diffractometer under Cu K $\alpha$  radiation ( $\lambda=1.5406$  Å). TEM analysis was performed using a JEOL JEM-2100F microscope operated at 200 kV. The characteristics of PeLEDs and FC-PeLEDs were measured by a LED test system (Everfine Photo-E-Info Co., Ltd.), which is mainly composed of Keithley 2400 light source instrument and Konica Minolta CS-2000 spectrometer.

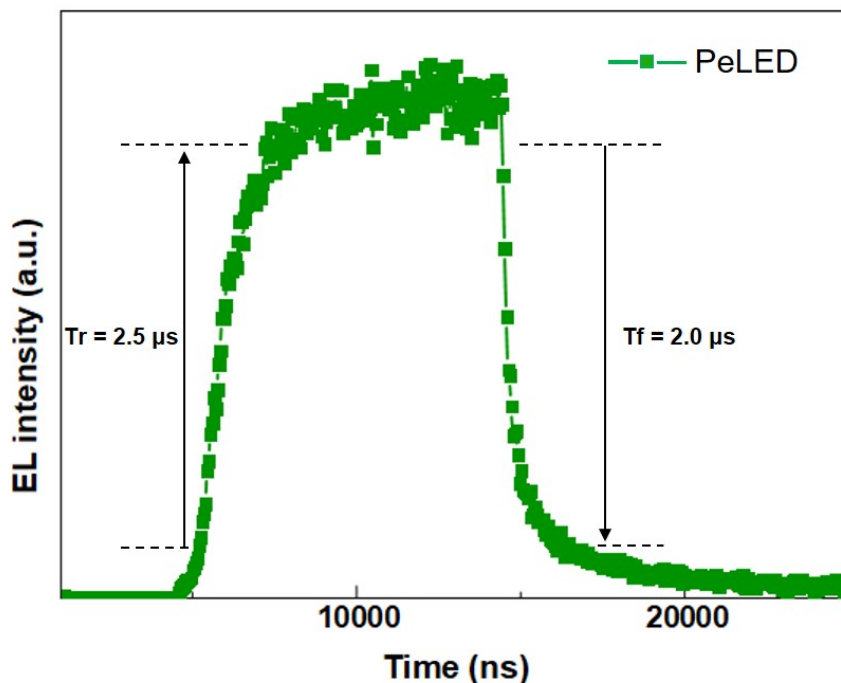
## Supporting Figures



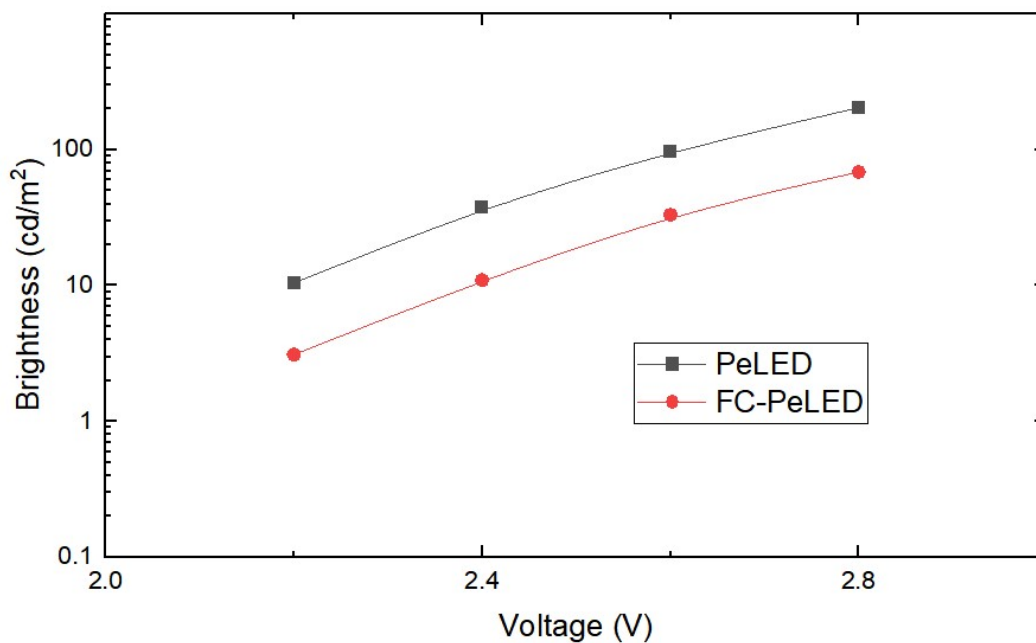
**Figure S1.** Characteristics of capacitance versus voltage of PeLEDs by using POT2T and TPBi as ETL, demonstrating the better carrier injection balance and lower driving voltage on POT2T based PeLED.



**Figure S2.** EL spectrum of PeLED around the turn on voltage (1.85 V - 2.2 V) , the insert picture is the normalized EL spectrum under these voltages.



**Figure S3.** EL intensity-time curve for PeLED shows the response of PeLED. The EL rise time and fall time (defined as the interval between the 10% and 90% amplitude points on the leading edge of a pulse<sup>[1]</sup>) are about 2.5 μs and 2.0 μs respectively.



**Figure S4.** The brightness curves of PeLED and FC-PeLED varies with voltage.

## Supporting Table

**Table S1.** The properties of typical mechanochromism (MC), electrochromism (EC) and mechanochromism (MC) materials.

Approach	Materials	Device or other	Drive Mode	Drive Range	Color Rang	Response Time	Reference
Mechanochromism (MC)	PDGI/h-PAAm hydrogels	/	Compressive stress	3.0 kPa	640-340 nm	0.3 ms	[2]
	$[\text{Cu}_2\text{I}_2\text{L}_2]_n$	Crystal	Pressure	0-0.9 GPa	472-500 nm	None	[3]
	P(AM-co-APA)-PAM-photonic crystal array	Device	Pressure	0-85 kPa	658-467 nm	None	[4]
Electrochromism (EC)	$\text{W}_{18}\text{O}_{49}\text{-V}_2\text{O}_5$ nanowires	Device	Bias	2 V, 0 V, -0.5 V	Orange-green-gray	~ 10 s	[5]
	$\text{WO}_3\text{-W}$ layer	Device	Bias	+3.5 V, -3.5 V, -4.5 V	Bright cyan-blue-deep violet; rose red-pale brown-curry yellow	None	[6]
	Zn-SVO	Device	Bias	0.2 V, 1.2 V, 2.0 V	Orange $\rightleftharpoons$ yellow $\rightleftharpoons$ green	~20 s	[7]
Electroluminescence (EL)	tBCzHDPO-TADF	Device	Bias	3.5-10 V	480-460 nm	None	[8]
	<b>PeLED</b>	<b>Device</b>	<b>Bias</b>	<b>2-3 V</b>	<b>Green-brown</b>	<b>~ 2.5 <math>\mu\text{s}</math></b>	<b>This work</b>

The response time of PDGI/h-PAAm hydrogels is extracted from the high-speed footage.<sup>[2]</sup> The response time of  $\text{W}_{18}\text{O}_{49}\text{-V}_2\text{O}_5$  nanowires and Zn-SVO is defined as the time required to achieve 90% of the maximum optical contrast.<sup>[7]</sup> The response time of the PeLED is defined as the interval between the 10% and 90% amplitude points on the leading edge of a pulse.<sup>[1]</sup> The response time of LED can be as fast as nanoseconds and microseconds<sup>[9]</sup>, and microseconds response has been observed in our tests.



## **Author Contributions**

All the authors contributed to the general discussion and manuscript writing. Weijin Li and Hengyang Xiang conceived the idea and directed the experimental processes and manuscript writing. Hengyang Xiang and Saichao Zhao wrote the first draft of the manuscript with guidance from Jun Liu, Fan Wu, Aming Xie, Weijin Li and Haibo Zeng. Saichao Zhao, Yifei Wang, Run Wang, Xinxin Li, Hao Wang and Gaoyuquan Lai performed the experiments. Jun Liu, Fan Wu, Aming Xie, Weijin Li and Haibo Zeng contributed to the criticism and polishing of the manuscript.

## Supporting References

- [1] L. Zhao, K. Roh, S. Kacmoli, K. Al Kurdi, X. Liu, S. Barlow, S. R. Marder, C. Gmachl and B. P. Rand, *Adv. Mater.*, 2021, **33**, 2104867.
- [2] Y. Yue, T. Kurokawa, M. A. Haque, T. Nakajima, T. Nonoyama, X. Li, I. Kajiwara and J. P. Gong, *Nat. commun.*, 2014, **5**, 4659.
- [3] E. Kwon, J. Kim, K. Y. Lee and T. H. Kim, *Inorg. Chem.*, 2017, **56**, 943-949.
- [4] S. Liu, Q. Li, J. Wang, X. Wang, N. M. Mbola, Z. Meng and M. Xue, *ACS Appl. Mater. Interfaces*, 2022.
- [5] J.-L. Wang, J.-W. Liu, S.-Z. Sheng, Z. He, J. Gao and S.-H. Yu, *Nano Lett.*, 2021, **21**, 9203-9209.
- [6] J. Chen, Z. Wang, C. Liu, Z. Chen, X. Tang, Q. Wu, S. Zhang, G. Song, S. Cong and Q. Chen, *Adv. Mater.*, 2021, **33**, 2007314.
- [7] W. Zhang, H. Li, W. W. Yu and A. Y. Elezzabi, *Light Sci. Appl.*, 2020, **9**, 121.
- [8] C. Han, C. Duan, W. Yang, M. Xie and H. Xu, *Sci. Adv.*, 2017, **3**, e1700904.
- [9] L. Zhao, K. Roh, S. Kacmoli, K. Al Kurdi, X. Liu, S. Barlow, S. R. Marder, C. Gmachl and B. P. Rand, *Adv. Mater.*, 2021, **33**, 2104867.