



香港城市大學  
City University of Hong Kong

專業 創新 胸懷全球  
Professional · Creative  
For The World

## CityU Scholars

### Towards next generation white LEDs optics-electronics synergistic effect in a single-layer heterophase halide perovskite Rogach, Andrey L.

**Published in:**  
Light: Science and Applications

**Published:** 01/01/2021

**Document Version:**  
Final Published version, also known as Publisher's PDF, Publisher's Final version or Version of Record

**License:**  
CC BY

**Publication record in CityU Scholars:**  
[Go to record](#)

**Published version (DOI):**  
[10.1038/s41377-021-00488-8](https://doi.org/10.1038/s41377-021-00488-8)

**Publication details:**  
Rogach, A. L. (2021). Towards next generation white LEDs: optics-electronics synergistic effect in a single-layer heterophase halide perovskite. *Light: Science and Applications*, 10, [46]. <https://doi.org/10.1038/s41377-021-00488-8>

#### Citing this paper

Please note that where the full-text provided on CityU Scholars is the Post-print version (also known as Accepted Author Manuscript, Peer-reviewed or Author Final version), it may differ from the Final Published version. When citing, ensure that you check and use the publisher's definitive version for pagination and other details.

#### General rights

Copyright for the publications made accessible via the CityU Scholars portal is retained by the author(s) and/or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights. Users may not further distribute the material or use it for any profit-making activity or commercial gain.

#### Publisher permission

Permission for previously published items are in accordance with publisher's copyright policies sourced from the SHERPA RoMEO database. Links to full text versions (either Published or Post-print) are only available if corresponding publishers allow open access.

#### Take down policy

Contact [lbscholars@cityu.edu.hk](mailto:lbscholars@cityu.edu.hk) if you believe that this document breaches copyright and provide us with details. We will remove access to the work immediately and investigate your claim.

NEWS & VIEWS

Open Access

# Towards next generation white LEDs: optics-electronics synergistic effect in a single-layer heterophase halide perovskite

Andrey L. Rogach <sup>1</sup>

## Abstract

A novel concept of the *heterophase optics-electronics synergistic effect* has been demonstrated in a single-layer  $\alpha/\delta$ -heterophase perovskite CsPbI<sub>3</sub> in order to realize white LEDs featuring only one broadband emissive layer.

Light sources have been under steady development all the way throughout the human existence, from ancient times to the modern technology, and sources of lighting experienced changes from fire to electricity. Since the dawn of the first semiconductor light-emitting diodes (LEDs), these devices showed many advantages over traditional incandescent or fluorescent lighting, such as high luminous efficiency, energy saving, and color quality<sup>1</sup>. Traditional approach to realize white LEDs (WLEDs) relies on the down-conversion of light emitted by a combination of red (R) and green (G) phosphors excited by blue (B) light, or on electrical excitation of RGB emitters arranged into LED arrays<sup>2,3</sup>. However, the use of the rare-earth elements in down-conversion devices faces issues of high cost and scarcity, and the most common blue-emitting component of such LEDs (GaN) is fabricated through rather expensive epitaxial growth techniques. Thus, exploring new technologies for lighting which may lead to more cost-efficient WLEDs is highly desired.

Halide perovskites have recently attracted a lot of attention as promising monochromatic bright emitters able to offer high-quality light in LEDs<sup>4</sup>. External quantum efficiencies (EQE) of perovskite-based green and red LEDs already exceeded 20%<sup>5,6</sup>. Despite a great progress on monochromatic perovskite LEDs, development of perovskite WLEDs has been rather slow, so far, and mostly relied on the doping with other elements<sup>7,8</sup>. High rate of

anion diffusion in mixed-halide perovskite materials, combined with non-balanced degradation under working conditions severely hinder the use of the LED arrays due to the rapid change of emission color<sup>9</sup>. Moreover, efficiencies and stabilities of blue perovskite LEDs still lag behind their red and green counterparts<sup>10</sup>, so that more efforts are needed for their development. Very recently, Chen and co-workers used an advanced device structure that could efficiently suppress the trapped optical modes<sup>11</sup>. It comprised a layer of red-emitting perovskite nanocrystals acting as a down-converter, coated on a blue perovskite LED with an ultrathin transparent top electrode. An efficient extraction of the trapped waveguide mode and surface plasmon polariton mode in the blue LED was realized, leading to over 50% improvement in a light-extraction efficiency, and also efficient blue-to-red light conversion, resulting in a complementary white light emission with a high EQE of 12%.

In another approach, Zeng's group at Nanjing University of Science and Technology (NJUST) in collaboration with D. Ginger at the University of Washington proposed a new concept of WLEDs relying on a *single emissive layer* of CsPbI<sub>3</sub> perovskite which combined  $\alpha$  and  $\delta$ -phases (Fig. 1a)<sup>12</sup>. EQE and current efficiency of these WLEDs which were conveniently fabricated by all-solution processing and featured only one broadband perovskite emitting layer reached 6.5% and 12,200 cd/m<sup>2</sup>, respectively. Importantly, by adjusting the annealing processes of  $\alpha$ -CsPbI<sub>3</sub>, the ratio of the two phases could be controlled to tailor the color temperature of white emission (Fig. 1b).

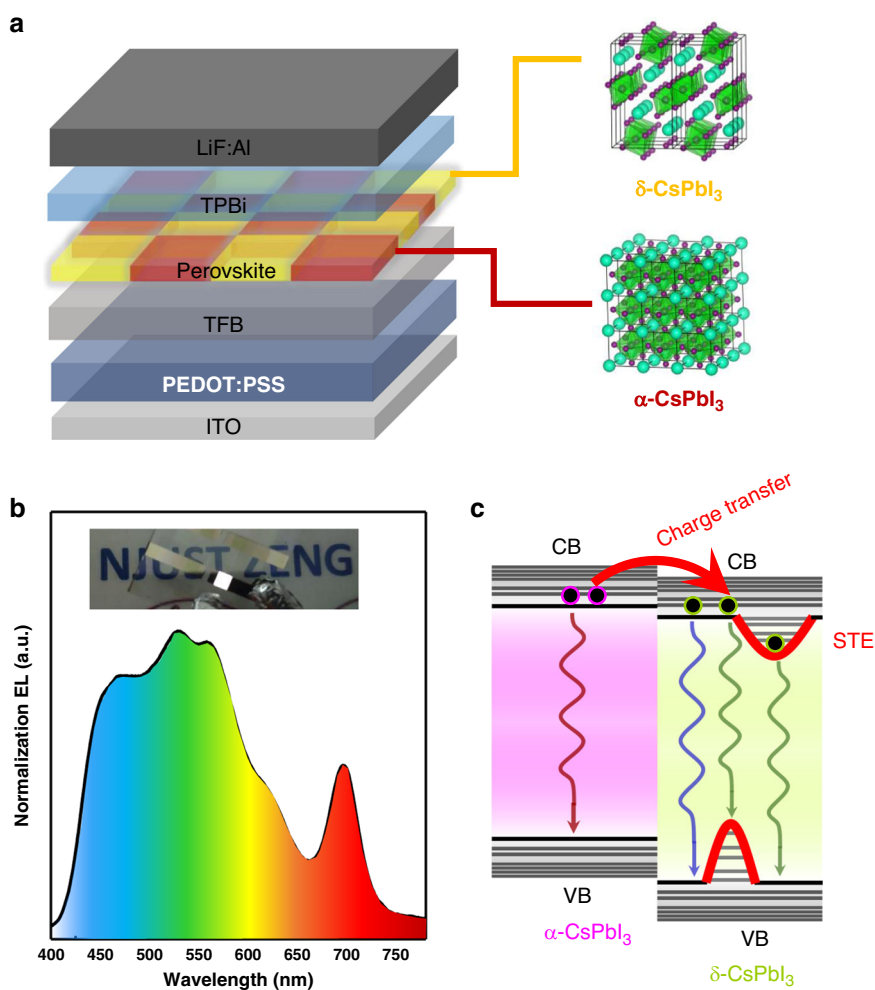
Correspondence: Andrey L. Rogach ([andrey.rogach@cityu.edu.hk](mailto:andrey.rogach@cityu.edu.hk))

<sup>1</sup>Department of Materials Science and Engineering, and Centre for Functional Photonics (CFP), City University of Hong Kong, Hong Kong SAR, PR China

© The Author(s) 2021



**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.



**Fig. 1** WLEDs relying on a single emissive layer of a heterophase cesium lead halide perovskite. **a** Scheme of the WLED structure relying on a synergistic effect of  $\alpha$ - and  $\delta$ -CsPbI<sub>3</sub> perovskite heterophases. **b** Broad electroluminescence spectrum of the WLED; photograph in the inset shows its uniform white emission. **c** Charge transfer and recombination mechanism operative in the  $\alpha/\delta$ -CsPbI<sub>3</sub> heterophase WLED (STE stays for “self-trapped exciton”)

The major idea of operation of these WLEDs relied on a synergistic effect between  $\alpha/\delta$ -CsPbI<sub>3</sub> phases (Fig. 1c): charge carrier injection occurred in the  $\alpha$ -CsPbI<sub>3</sub> phase, which was followed by charge transfer from  $\alpha$ - to  $\delta$ -phases, and white light emission by  $\delta$ -CsPbI<sub>3</sub>. The interfacial states which are energetically closer to the valence band (VB) level of  $\alpha$ -CsPbI<sub>3</sub> assisted hole transfer from  $\alpha$ -CsPbI<sub>3</sub> to  $\delta$ -CsPbI<sub>3</sub>, while the conduction band (CB) alignment between  $\alpha$ -CsPbI<sub>3</sub> and  $\delta$ -CsPbI<sub>3</sub> phases allowed for an optimum electron injection and an efficient radiative recombination. The authors have termed this mechanism “heterophase optics-electronics synergistic effect”.

The strategy used in ref. <sup>12</sup> relying on a single emitting perovskite layer to achieve white emission can greatly decrease the cost of production of WLEDs, and further

push the development of next-generation flexible displays and lighting. This approach, as well as the one suggested in ref. <sup>11</sup> may also have important implications not only for LEDs but for perovskite optoelectronics in general, such as for solar cells and displays.

Published online: 01 March 2021

#### References

1. Cho, J. et al. White light-emitting diodes: history, progress, and future. *Laser Photonics Rev.* **11**, 1600147 (2017).
2. Ma, Z. Z. et al. High color-rendering index and stable white light-emitting diodes by assembling two broadband emissive self-trapped excitons. *Adv. Mater.* **33**, 2001367 (2021).
3. Liu, S. N. et al. A controllable and reversible phase transformation between all-inorganic perovskites for white light emitting diodes. *J. Mater. Chem. C* **8**, 8374–8379 (2020).

4. Song, J. Z. et al. Quantum dot light-emitting diodes based on inorganic perovskite cesium lead halides (CsPbX<sub>3</sub>). *Adv. Mater.* **27**, 7162–7167 (2015).
5. Lin, K. B. et al. Perovskite light-emitting diodes with external quantum efficiency exceeding 20 per cent. *Nature* **562**, 245–248 (2018).
6. Cao, Y. et al. Perovskite light-emitting diodes based on spontaneously formed submicrometre-scale structures. *Nature* **562**, 249–253 (2018).
7. Hou, S. C. et al. Efficient blue and white perovskite light-emitting diodes via manganese doping. *Joule* **2**, 2421–2433 (2018).
8. Sun, R. et al. Samarium-doped metal halide perovskite nanocrystals for single-component electroluminescent white light-emitting diodes. *ACS Energy Lett.* **5**, 2131–2139 (2020).
9. Mao, J. et al. All-perovskite emission architecture for white light-emitting diodes. *ACS Nano* **12**, 10486–10492 (2018).
10. Lu, M. et al. Metal halide perovskite light-emitting devices: promising technology for next-generation displays. *Adv. Funct. Mater.* **29**, 1902008 (2019).
11. Chen, Z. M. et al. Utilization of trapped optical modes for white perovskite light-emitting diodes with efficiency over 12%. *Joule* <https://doi.org/10.1016/j.joule.2020.12.008> (2021).
12. Chen, J. W. et al. Efficient and bright white light-emitting diodes based on single-layer heterophase halide perovskites. *Nat. Photonics* <https://doi.org/10.1038/s41566-020-00743-1> (2020).