Highly efficient visible colloidal lead-halide perovskite nanocrystal light-emitting diodes

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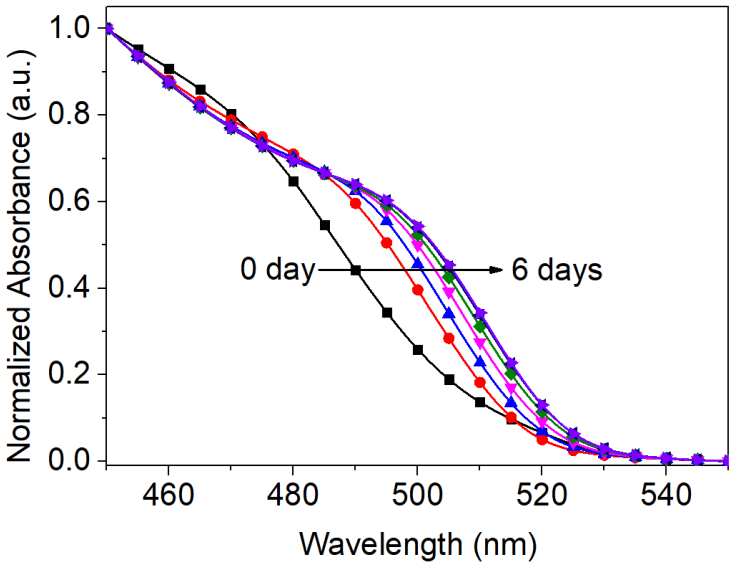

Figure S1. The absorption edge migration of as-synthesized colloidal MAPbBr3 PeNCs solution aging for 6 days. Absorption bands redshift, 510.5-516.8-519.0-521.5-523.1-524.3 nm.

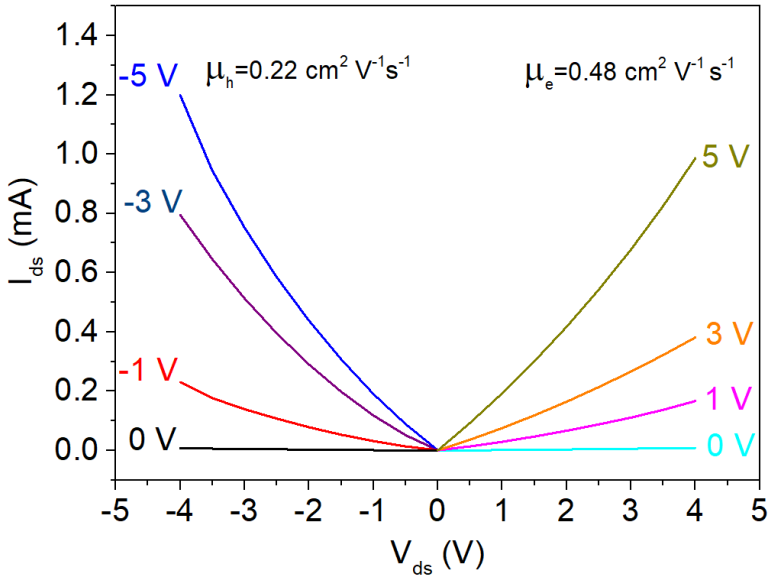

Figure S2. Electron and hole mobility derived from the field effect transistor using $MAPbBr_3$ PeNCs film as the active layer.

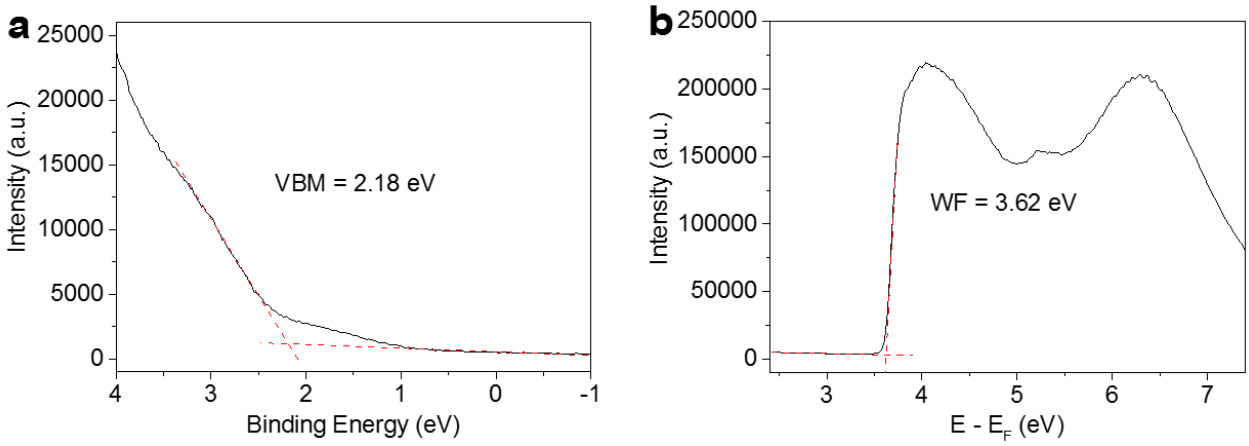

Figure S3. Valence band maximum (VBM) and work function (WF) of PeNCs measured using ultraviolet photoemission spectroscopy (UPS) with a Helium lamp emitting at 21.2 eV. The HOMO of -5.8 eV and LUMO of -3.4 eV were obtained by considering the edge of UV-vis absorption spectrum.

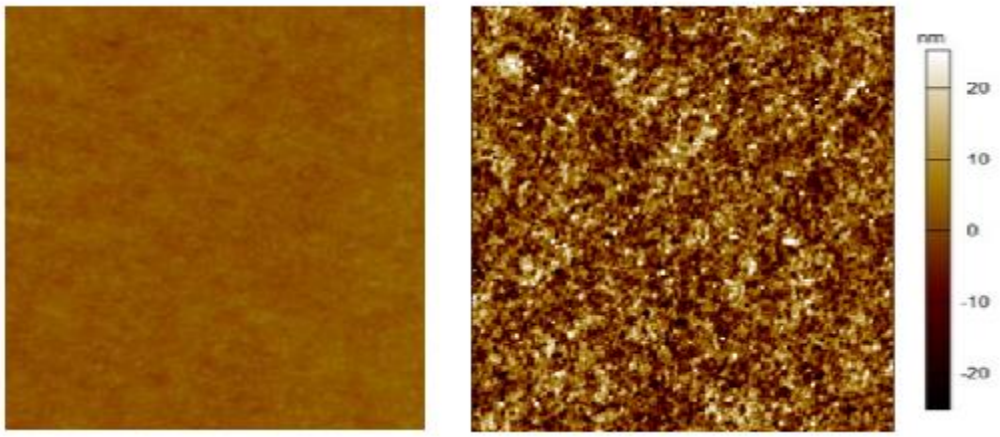

Figure S4. AFM images of the PEDOT:PSS film (5×5 μm^2) and $MAPbBr_3$ PeNCs film (10×10

μm^2) deposited onto PEDOT:PSS layer using colloidal THF solution at a rotational speed of 1,500 rpm. R_a = 0.8 nm and 8.5 nm, respectively.

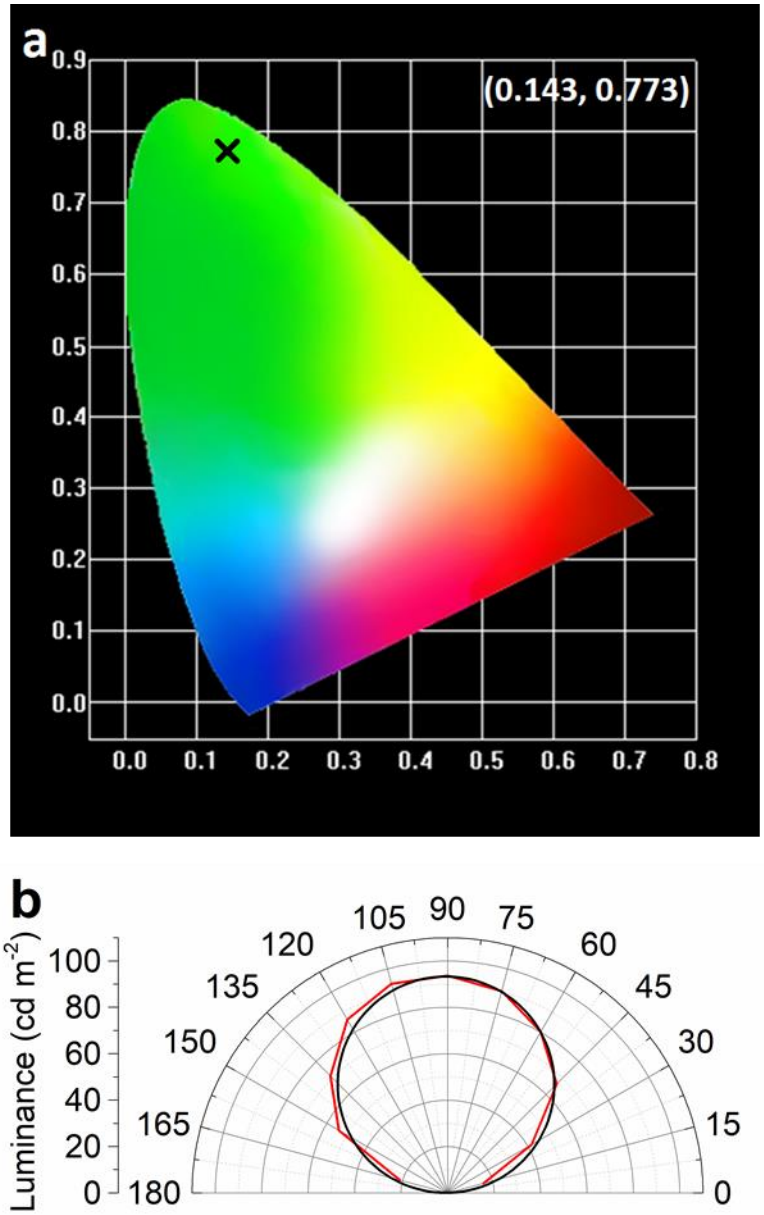

Figure S5. a, CIE 1931 chromatic coordinates of PeLEDs. **b,** Angular luminance profile of PeLEDs (red). The flat panel PeLEDs is close to an ideal Lambertian radiator (black).

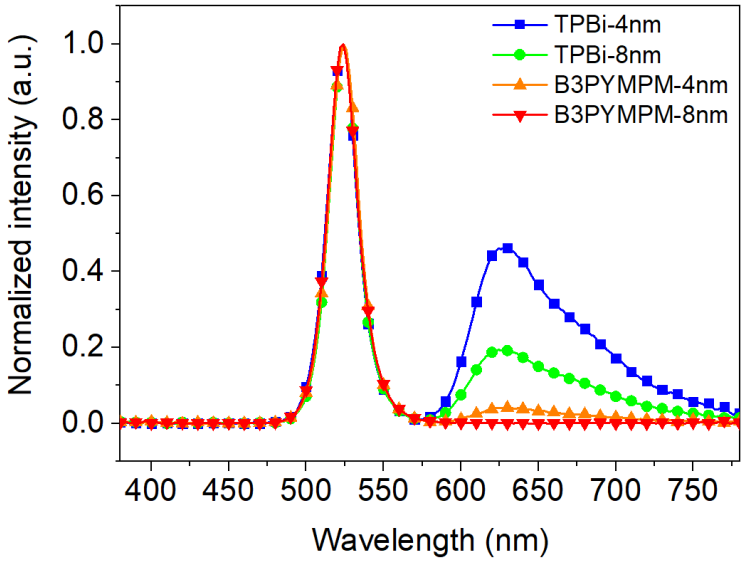

Figure S6. Electroluminescence spectra of $Ir(piq)_2(acac)$ indicator devices at driving current density of 2 mA cm^{-2}. The device structure are as below:

TPBi-4 nm: ITO / PEDOT:PSS (40 nm) / $MAPbBr_3$ PeNCs (40 nm) / TPBi (4 nm) / $Ir(piq)_2(acac)$ (0.3 nm) / TPBi (26 nm) / TPBi: Cs_2CO_3 (10:1 w/w, 20 nm) / Al (100 nm).

TPBi-8 nm: ITO / PEDOT:PSS (40 nm) / $MAPbBr_3$ PeNCs (40 nm) / TPBi (8 nm) / $Ir(piq)_2(acac)$ (0.3 nm) / TPBi (22 nm) / TPBi: Cs_2CO_3 (10:1 w/w, 20 nm) / Al (100 nm).

B3PYMPM-4 nm: ITO / PEDOT:PSS (40 nm) / $MAPbBr_3$ PeNCs (40 nm) / B3PYMPM (4 nm) / $Ir(piq)_2(acac)$ (0.3 nm) / B3PYMPM (26 nm) / B3PYMPM: Cs_2CO_3 (10:1 w/w, 20 nm) / Al (100 nm).

B3PYMPM-8 nm: ITO / PEDOT:PSS (40 nm) / $MAPbBr_3$ PeNCs (40 nm) / B3PYMPM (8 nm) / $Ir(piq)_2(acac)$ (0.3 nm) / B3PYMPM (22 nm) / B3PYMPM: Cs_2CO_3 (10:1 w/w, 20 nm) / Al (100 nm).

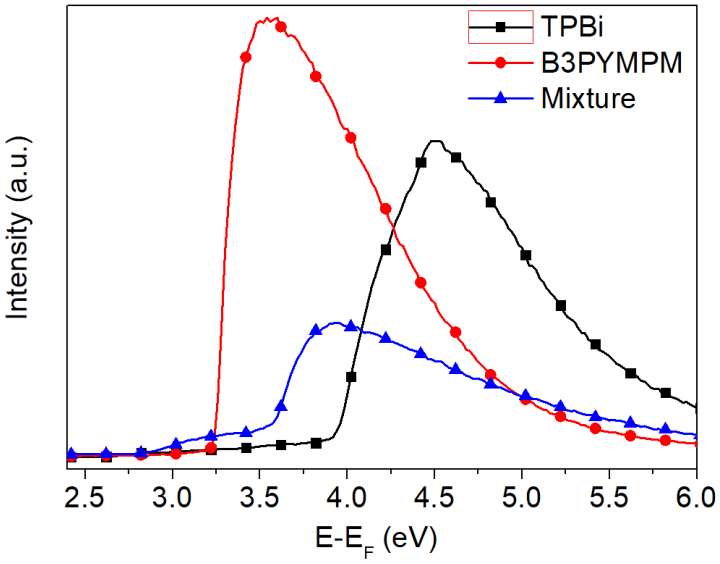

Figure S7. Work function of TPBi (20 nm), B3PYMPM (20 nm), and B3PYMPM:TPBi (1:2, w/w, 20 nm) measured using ultraviolet photoemission spectroscopy with a Helium lamp emitting at 21.2 eV. All films were deposited onto ITO substrates by vacuum thermal evaporation.

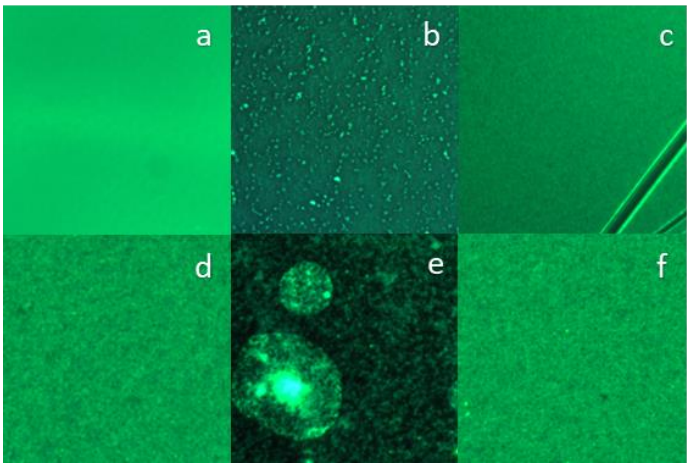

Figure S8. Optical images of $MAPbBr_3$ PeNCs film deposited onto PEDOT:PSS layer using different solutions. A programmable film deposition including two steps; step 1 at 400 rpm for 3 s and step 2 at 1,500 rpm for 60 s. A microscope with integrated UV lamp was used for such observation. **a,** 5× lens, THF solution, image of 600×600 μm^2. **b,** 5× lens, CB solution, image of 600×600 μm^2. **c,** 20× lens, THF:CB (16:1 v:v) solution, image of 150×150 μm^2. **d,** 100× lens, THF solution, image of 30×30 μm^2. **e,** 100× lens, CB solution, image of 30×30 μm^2. **f,** 100× lens, THF:CB (16:1 v:v) solution, image of 30×30 μm^2.

The $MAPbBr_3$ PeNCs can be dispersed uniformly in both THF and CB solvents. A uniform PeNCs film in millimeter scale can be deposited using CB colloidal solution by spin-casting at a rotational speed of 500 rpm. However, such a film was rough in micrometer scale, and there were a lot of brighter emissive dots scatted around the weaker emissive uniform layer. Though the device made from colloidal PeNCs CB solution was low in performance, such dots can give much brighter emission. After considering the high inter-solubility and difference between the two solvents in film deposition, a mixed solvent of THF:CB (Y:1 v/v, with Y=32, 16, 8, 4, 1, 0.25) was systemically studied in film deposition and devices. With Y<8, the PeNCs film represented features more like the pure CB case. When Y=32 the PeNCs film showed a non-uniform pattern as the pure THF case. With Y=16, the champion device shows the best performance.

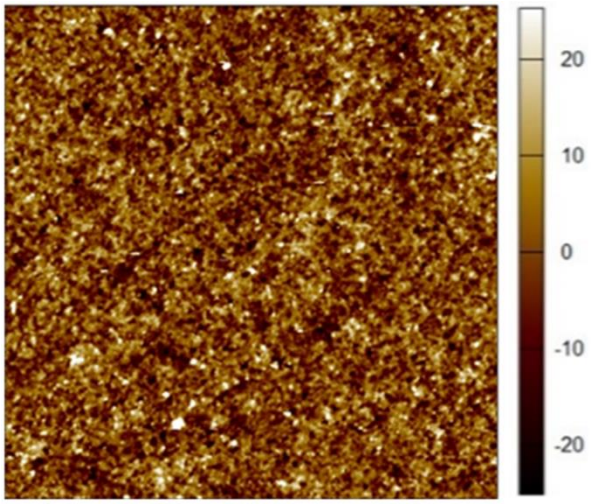

Figure S9. AFM image of $MAPbBr_3$ PeNCs film deposited onto PEDOT:PSS layer using colloidal THF:CB (16:1 v:v) solution. RMS = 8.3 nm. Area of the image is 10×10 μm^2.

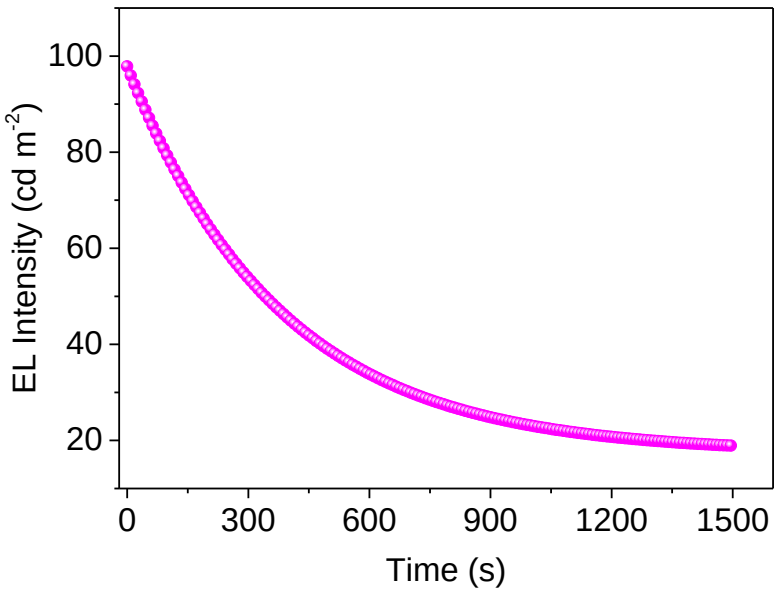

Figure S10. Ageing curve of the champion PeLEDs at a constant driving current density of 0.3 mA cm^{-2}. The half-lifetime of the device (the time frame within which brightness decreases to 50% of the initial value of around 100 cd m^{-2}) was around 6 min.

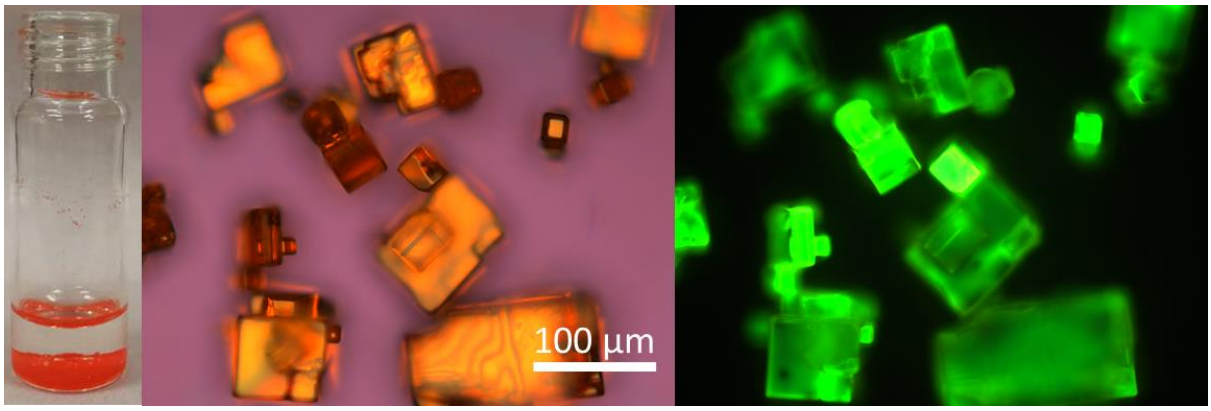

Figure S11. Optical images of $MAPbBr_3$ bulk crystals.

Table S1. NMR results of the as-synthesized PeNCs in 6 days. The amounts of methylamine and octylamine were estimated based on the relative integral intensity of the -CH3 group signal to the solvent residual peak (DMSO).

	0 day	1 day	2 day	3 day	4 day	5 day	6 day
Relative amounts ratio of Methylamine to Octylamine	1 : 0.44	1: 0.44	1 : 0.40	1 : 0.38	1 : 0.39	1 : 0.40	1 : 0.39
Amounts of DMF or gamma-butyrolactone	0	0	0	0	0	0	0

Table S2. Comprehensive comparison of control device I with respect to the various rotational speed of $MAPbBr_3$ PeNCs film deposition.

Rotational speed (rpm)	V_{on} (V)	L_{max} (cd m^{-2})	EQE_{max} (%)
1000	3.4	16,490	4.69
1500	3.3	15,130	5.11
2000	3.3	13,220	4.54
2500	3.2	14,560	4.56

Table S3. Comprehensive comparison of control device III with respect to the various mixing ratio of B3PYMPM:TPBi (1:X, w/w).

Mixing Ratio (X)	V_{on} (V)	L_{max} (cd m^{-2})	EQE_{max} (%)
0.3	2.7	23,520	2.49
1	2.9	32,560	6.72
2	3.0	33,570	7.91
3	3.4	15,480	4.87