Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Supplementary File:

Phosphine oxide based semiconducting small molecule as an additive and an electron transport layer enables efficient and stable perovskite light emitting devices

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Keywords: Perovskite LED, PO-T2T small molecule additive, Methylammonium lead bromide ($MAPbBr_3$), Stable PL, Higher EL lifetime stability

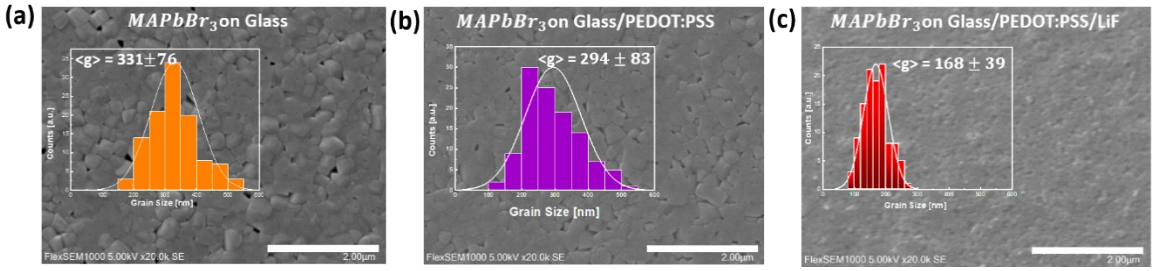
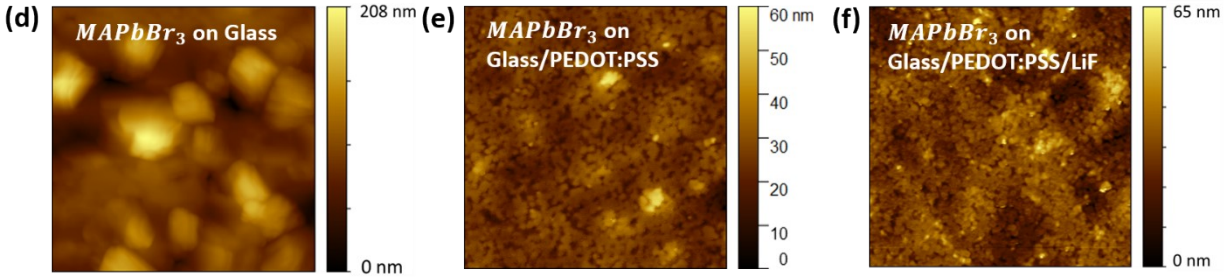


Figure S1. *SEM images [Top row] and AFM images [Bottom Row] of $MAPbBr_3$ films on top of Glass,*



Glass/PEDOT: PSS and Glass/PEDOTPSS/LiF. The scale bar for SEM is 2um and AFM images are of scan size 5×5 *um*

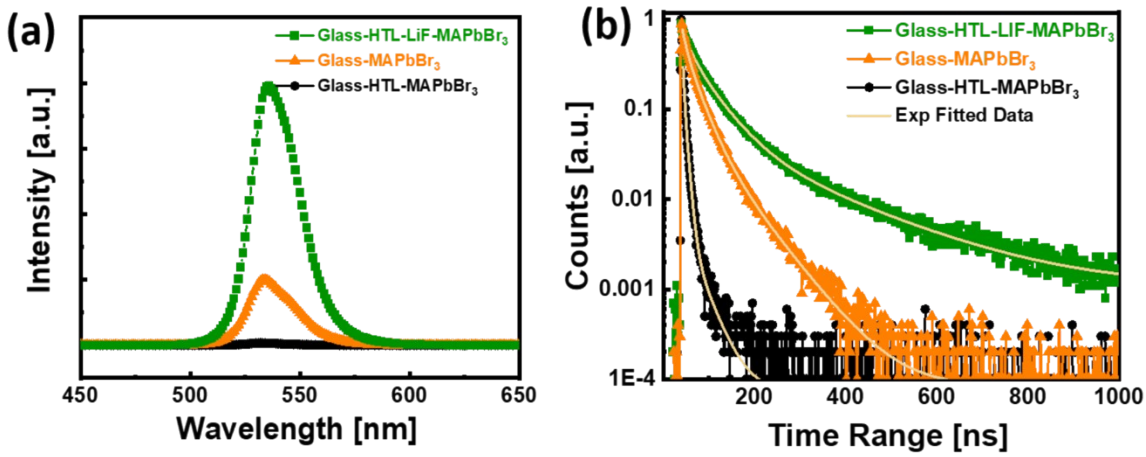


Figure S2. (a) Steady state photoluminescence spectra (b) Time resolved photoluminescence spectra of $MAPbBr_3$ films deposited on Glass, on Glass/PEDOT:PSS and on Glass/PEDOT:PSS/3 nm LiF.

	τ_1 [ns]	B_1 [%]	τ_2 [ns]	B_2 [%]	τ_3 [ns]	B_3 [%]	τ_{ave} [ns]	χ^2
Glass/ $MAPbBr_3$	8.24	11.11	26.47	62.15	67.63	26.74	35.45	0.7850
Glass/PEDOT: PSS/ $MAPbBr_3$	2.34	47.71	6.63	48.02	31.86	4.27	5.66	0.6284
Glass/PEDOT: PSS/LiF/ $MAPbBr_3$	15.88	12.22	51.93	60.09	194.80	27.70	87.10	0.9513

Table S1. TRPL decay curve fitting and average lifetime calculated from tri-exponential fit for $MAPbBr_3$ films on 1) Glass 2) Glass/PEDOT:PSS 3) Glass/PEDOT:PSS/LiF .

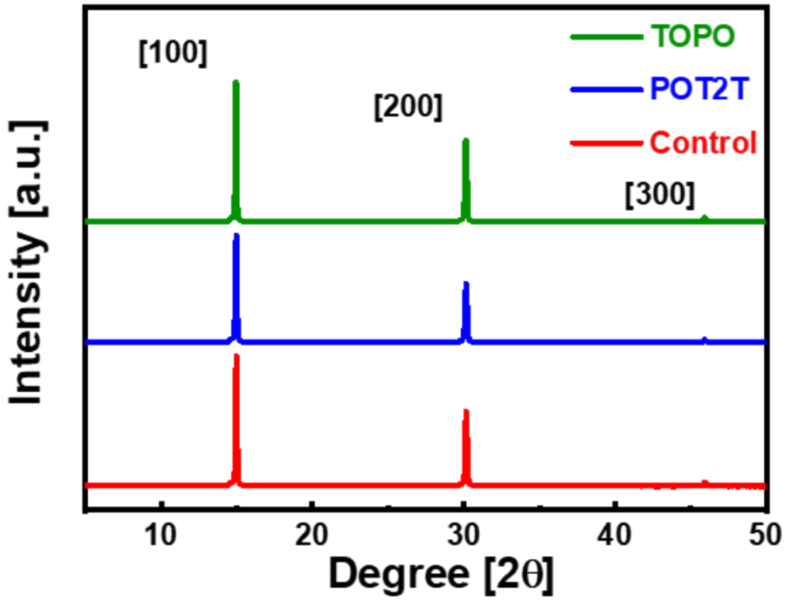


Figure S3. XRD spectra of $MAPbBr_3$ polycrystalline films with different additives (films made on HTL [Glass/PEDOT:PSS/3 nm LiF]

$MAPbBr_3$ films made on Glass/PEDOT: PSS/3 nm LiF with below mentioned additive	[hkl]	Position $[2\theta]$ (degree)	FWHM (degree)	Lattice Constant (Å)	Intensity (A.U)	Strain
Control (no additive)	[100]	14.96	0.11	5.91	135311	0.054
	[200]	30.14	0.15	5.92	77832	
	[300]	45.90	0.18	5.92	3913	
TOPO	[100]	14.94	0.11	5.92	145579	0.053
	[200]	30.14	0.15	5.92	85020	
	[300]	45.90	0.18	5.92	4595	
PO-T2T	[100]	14.96	0.13	5.91	111167	0.042
	[200]	30.14	0.16	5.92	61762	
	[300]	45.90	0.18	5.92	3224	

Table S2. Summary of XRD measurements on $MAPbBr_3$ films with different additives

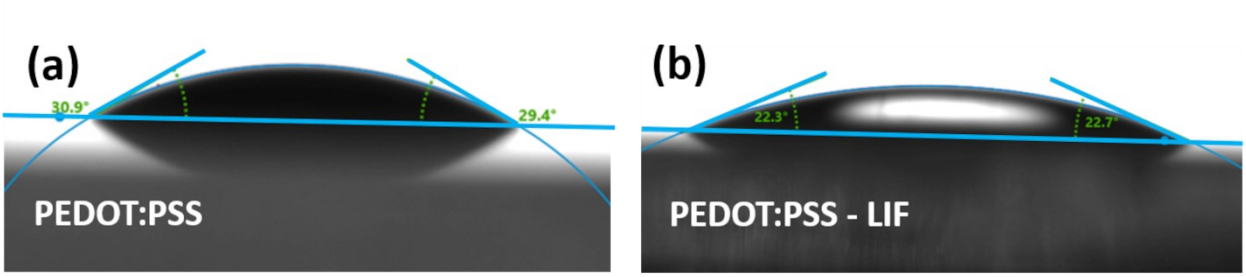


Figure S4. Contact angle of water measured (a) On glass/PEDOT:PSS layer (b) On glass/PEDOT:PSS/3 nm LiF layer

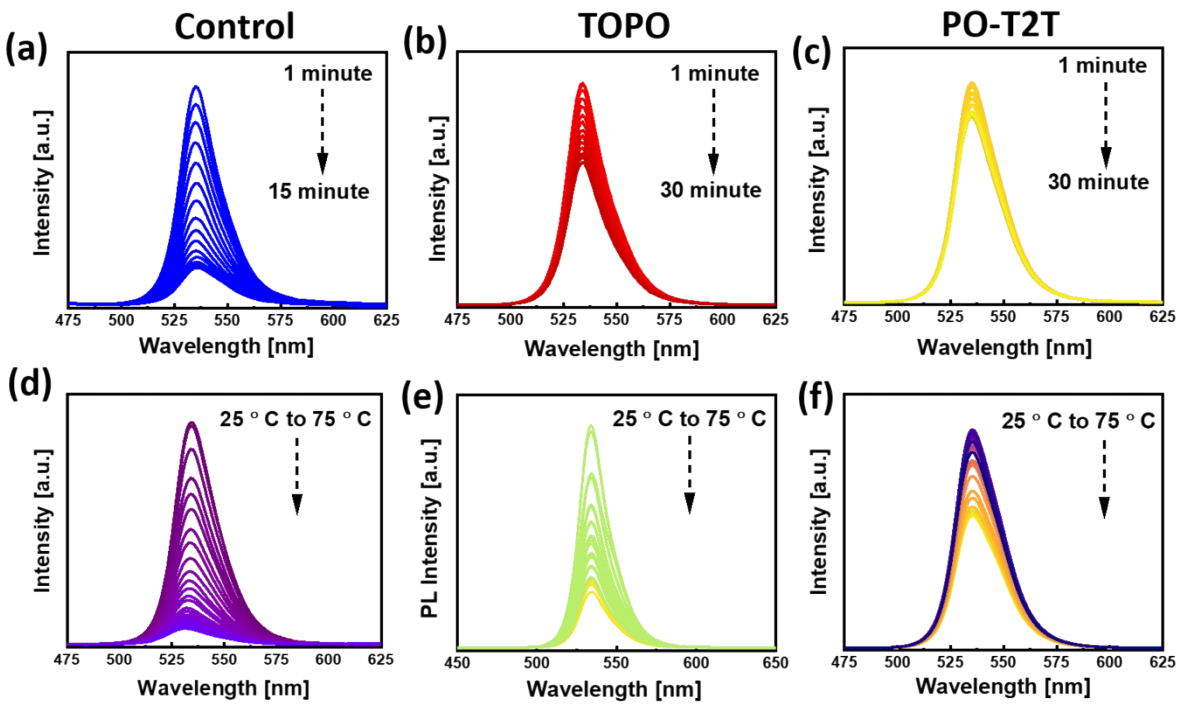


Figure S5. PL spectra recorded as a function of time (a-c) and temperature (d-f) for $MAPbBr_3$ films with control, TOPO and PO-T2T additives. Data is extracted from 2D PL maps shown in **Figure 5**. For control sample PL spectral intensity decreases by 83 %, for film with TOPO as additive there is decrease in PL spectral intensity by 40 % and for film with PO-T2T as additive the decrease in PL spectral intensity is significantly lower (20 %) as a function of time. Similarly, the decrease in PL Intensity for Control, TOPO as additive and PO-T2T as additive is 93 %, 75 % and 40 % respectively as a function of temperature. For all films we monitored the PL spectral intensity changes for 30 minutes and temperature is varied from room temperature to 75-degree C in 2-degree interval

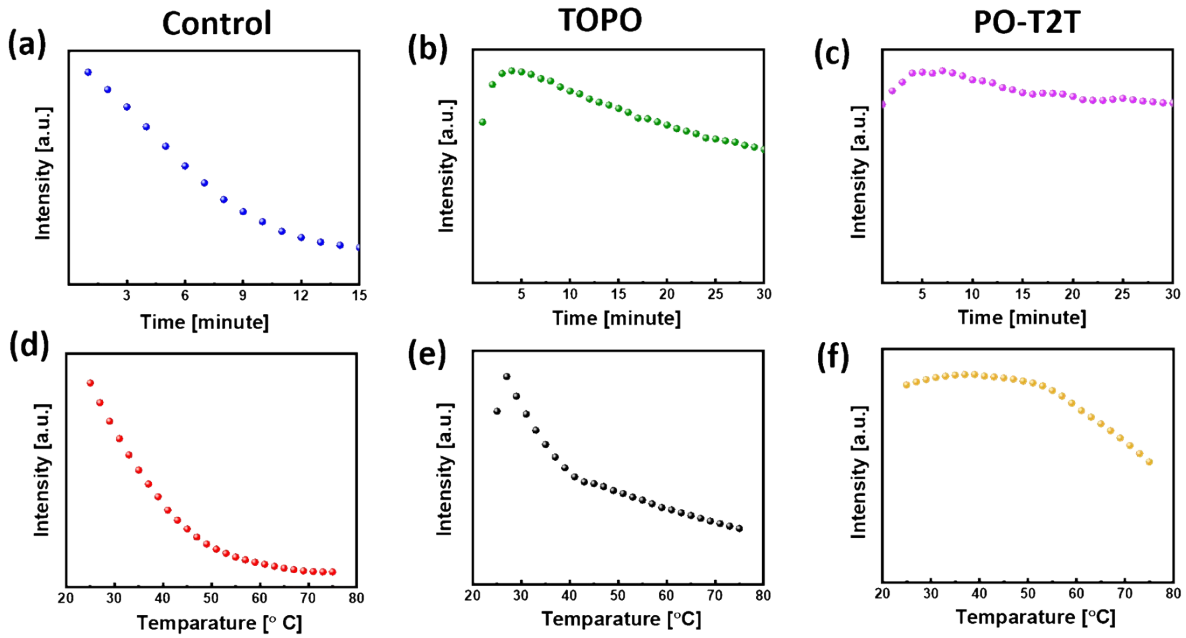


Figure S6. Integrated PL spectra as a function of time (a-c) and temperature (d-f) for $MAPbBr_3$films with control, TOPO and POT-2T additives. Data is extracted from 2D PL maps shown in **Figure 5**.

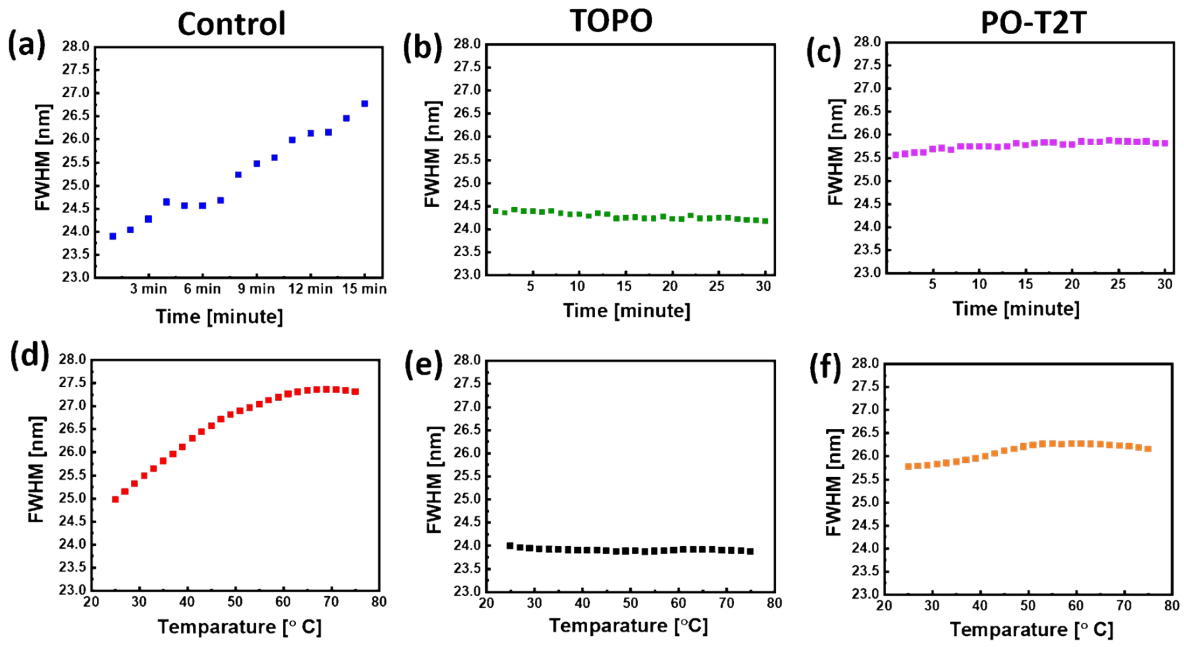


Figure S7. FWHM as a function of time (a-c) and temperature (d-f) for $MAPbBr_3$ films with control, TOPO and PO-T2T additives. Data is extracted from 2D PL maps shown in **Figure 5**.

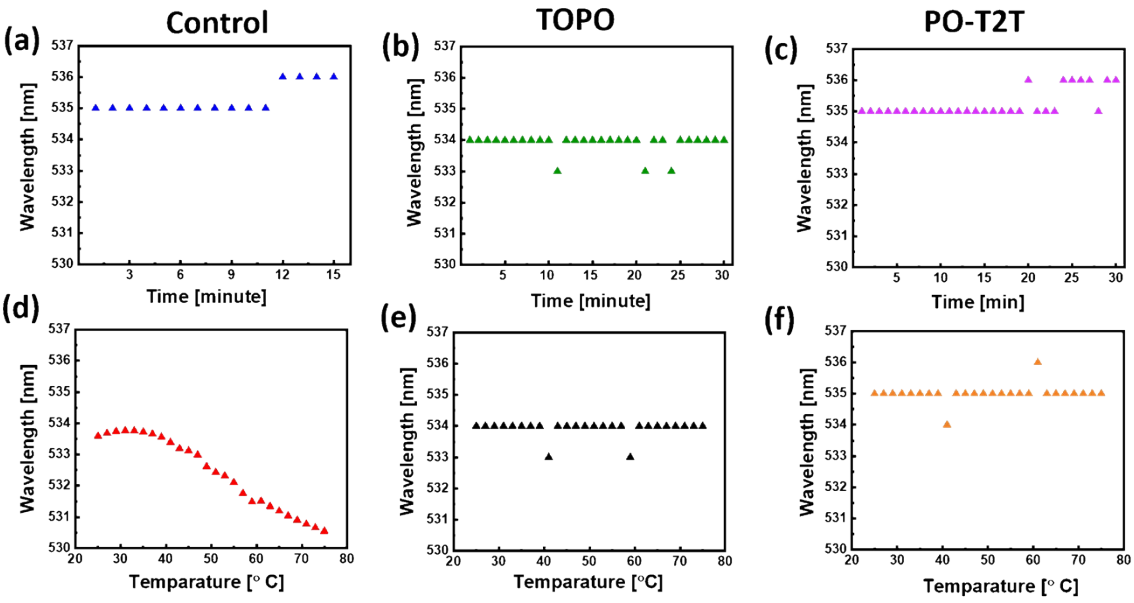


Figure S8. Peak wavelength as a function of time (a-c) and temperature (d-f) for $MAPbBr_3$ films with control, TOPO and PO-T2T additives. Data is extracted from 2D PL maps shown in **Figure 5**.

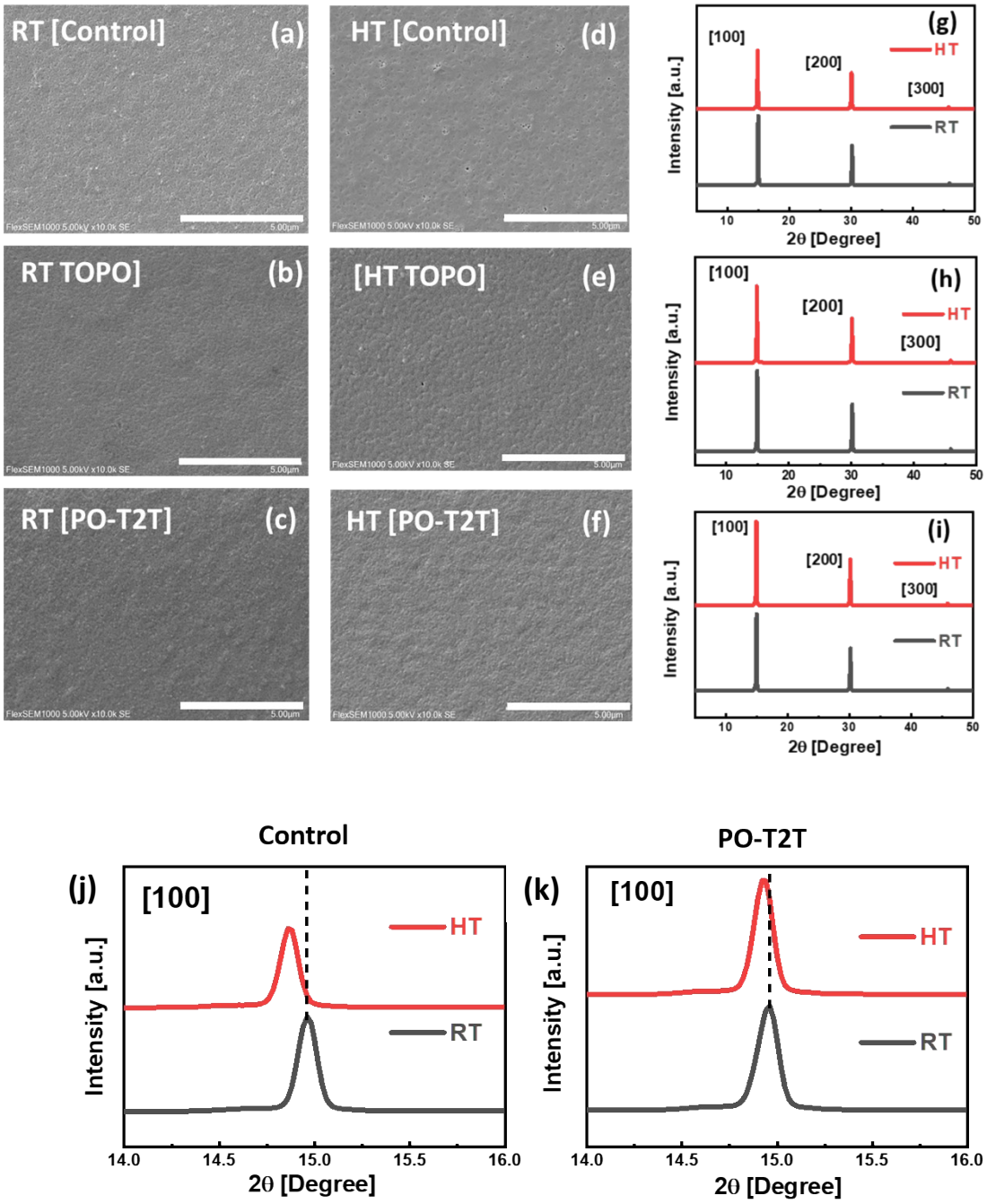


Figure S9. *SEM images of $MAPbBr_3$ films at room temperature (a-c) and high temperature (75 deg) (d-f) for control, TOPO and POT-2T additives. XRD spectra were recorded at room and high*

temperature (75 deg) for control (g), TOPO (h) and PO-T2T(i) additives. Enlarged version of XRD spectra on top of HTL for Control and PO-T2T treated films are shown in Figure (j) and (k).

Composition	**[hkl]**	**Position [2θ] (degree)**	**Lattice Constant (Å)**
Control [RT]	[100]	14.96	5.91
	[200]	30.14	5.92
	[300]	45.90	5.92
PO-T2T [RT]	[100]	14.96	5.91
	[200]	30.14	5.92
	[300]	45.90	5.92
Control [HT]	[100]	14.86	5.95
	[200]	30.06	5.94
	[300]	45.82	5.93
PO-T2T [HT]	[100]	14.92	5.93
	[200]	30.12	5.92
	[300]	45.88	5.92

Table S3*: Summary of XRD measurements on $MAPbBr_3$ films with different compositions at different temperatures.*

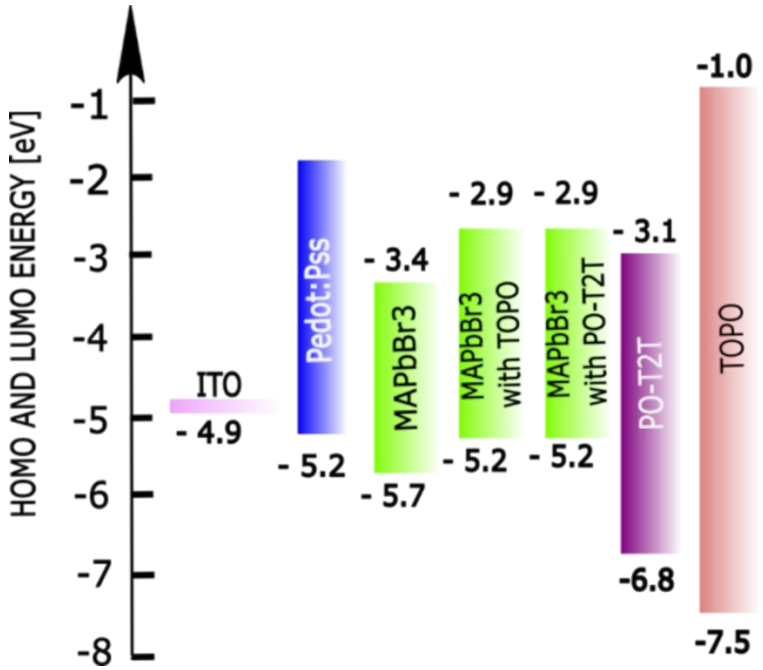


Figure S10. Energy level diagram for Pe-LED device and its components

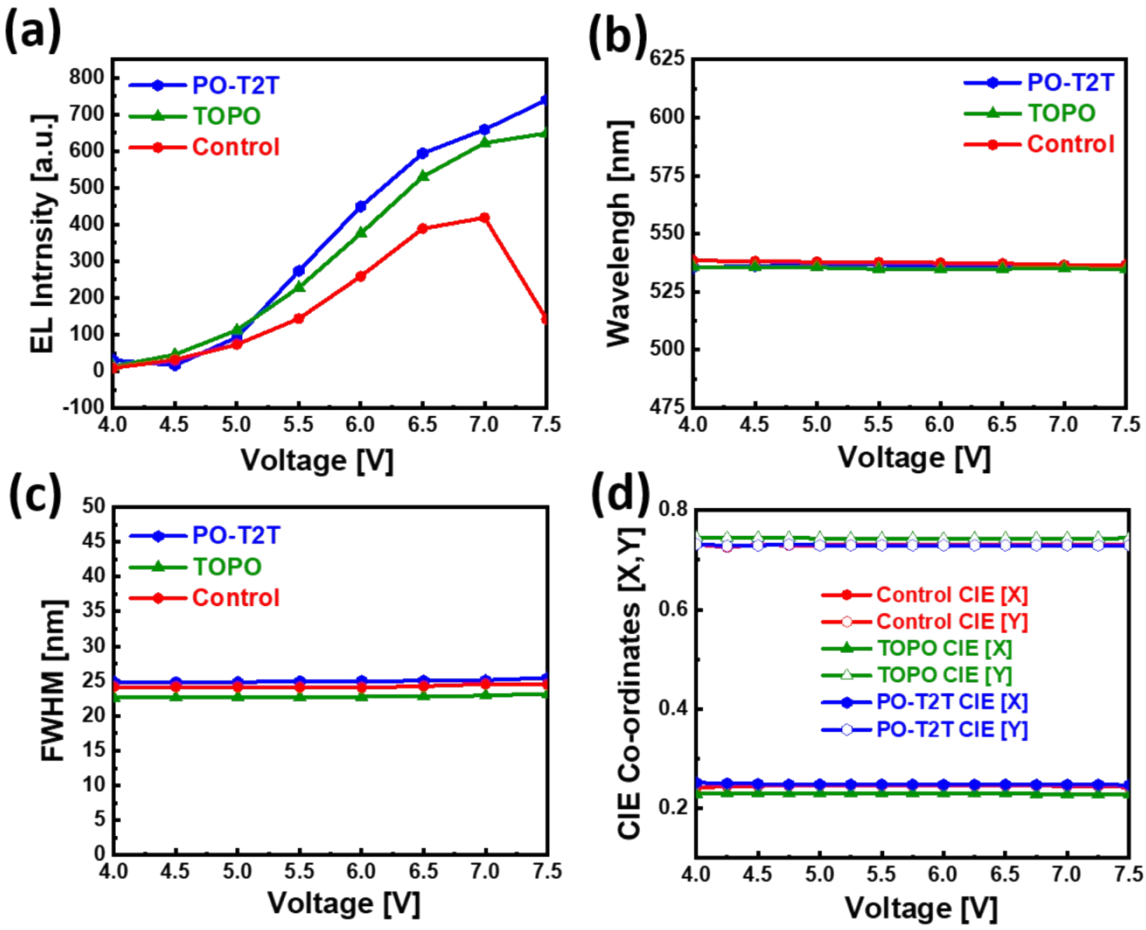


Figure S11. (a) EL intensity (from EL Spectrum), (b) Wavelength, (c) FWHM and (d) CIE coordinate (0.2, 0.7) changes plotted as a function of voltage bias for Pe-LED devices made with control, TOPO and PO-T2T additives

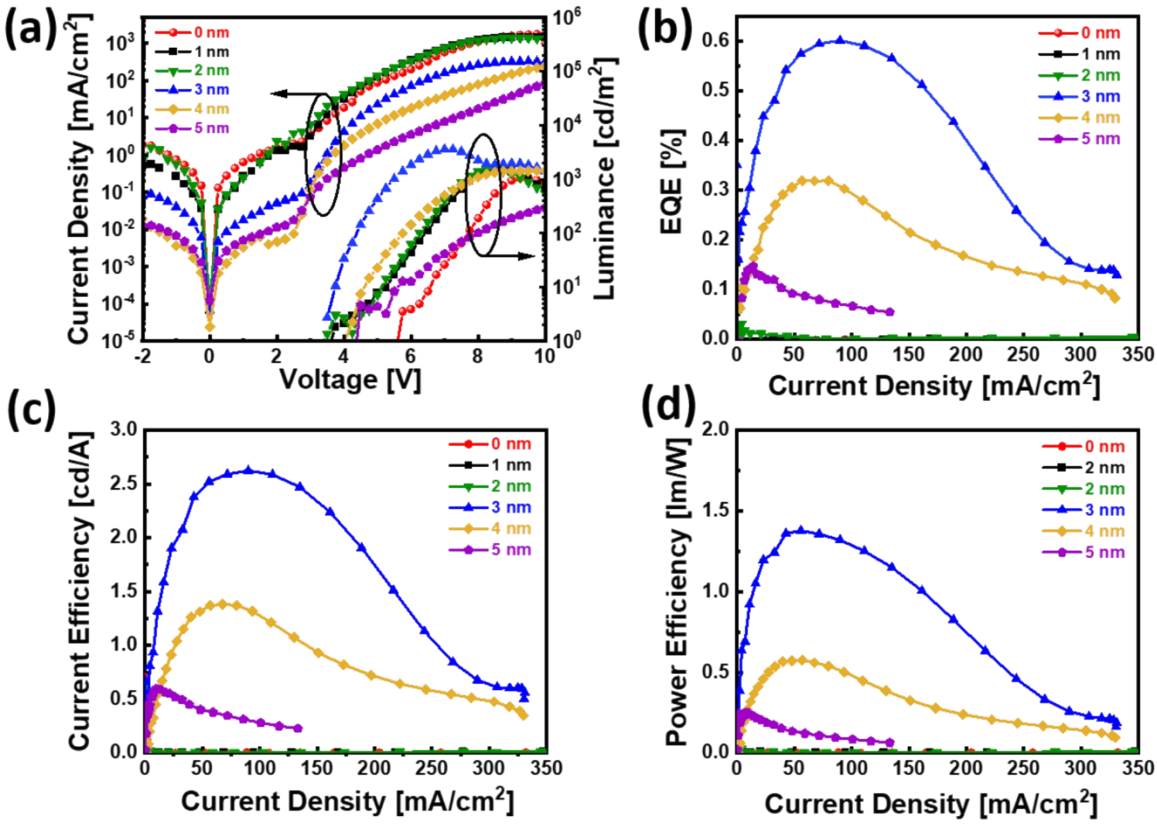


Figure S12. LiF layer optimization: Current Density-Voltage-Luminance [J-V-L] characteristics, EQE vs Current Density, Current Efficiency vs Current Density and Power Efficiency vs Current Density of Perovskite LEDs with different LiF layer thickness from 0-5nm.

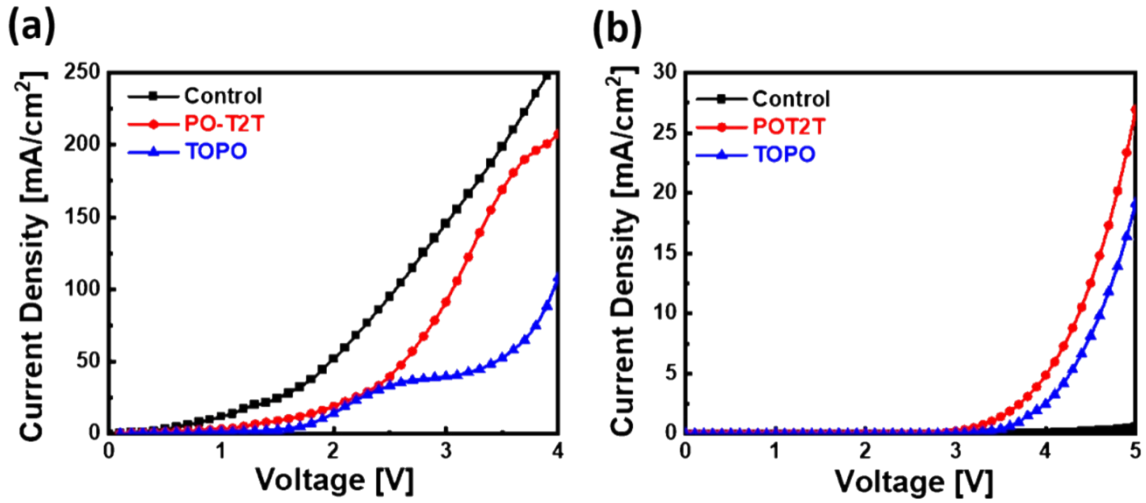


Figure S13. Current density-voltage plots for (a) Glass/ITO/PEDOT:PSS:LiF/ $MAPbBr_3$ with different Additives/LiF/Al (b) Glass/ITO/ $MAPbBr_3$ with different Additives/TPBi/LiF/Al.

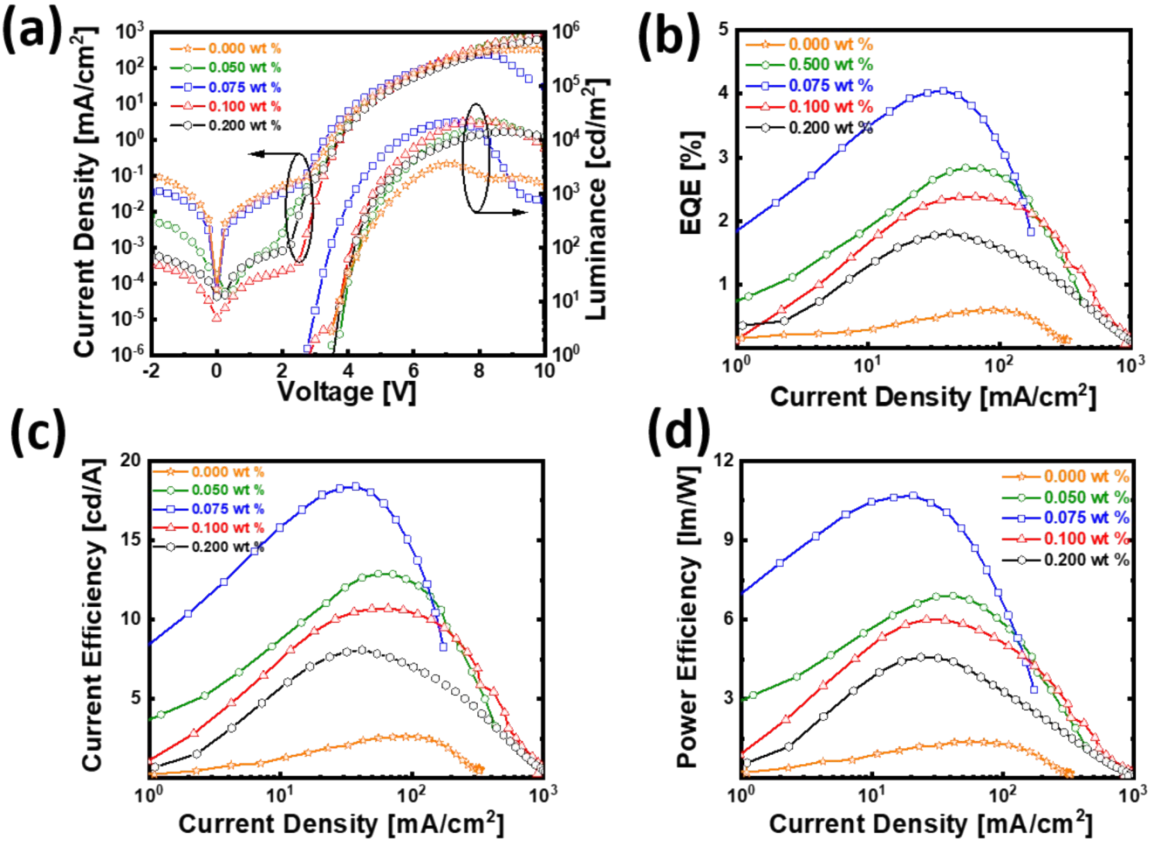


Figure S14. Optimization of PO-T2T in anti-solvent treatment for forming $MAPbBr_3$ films

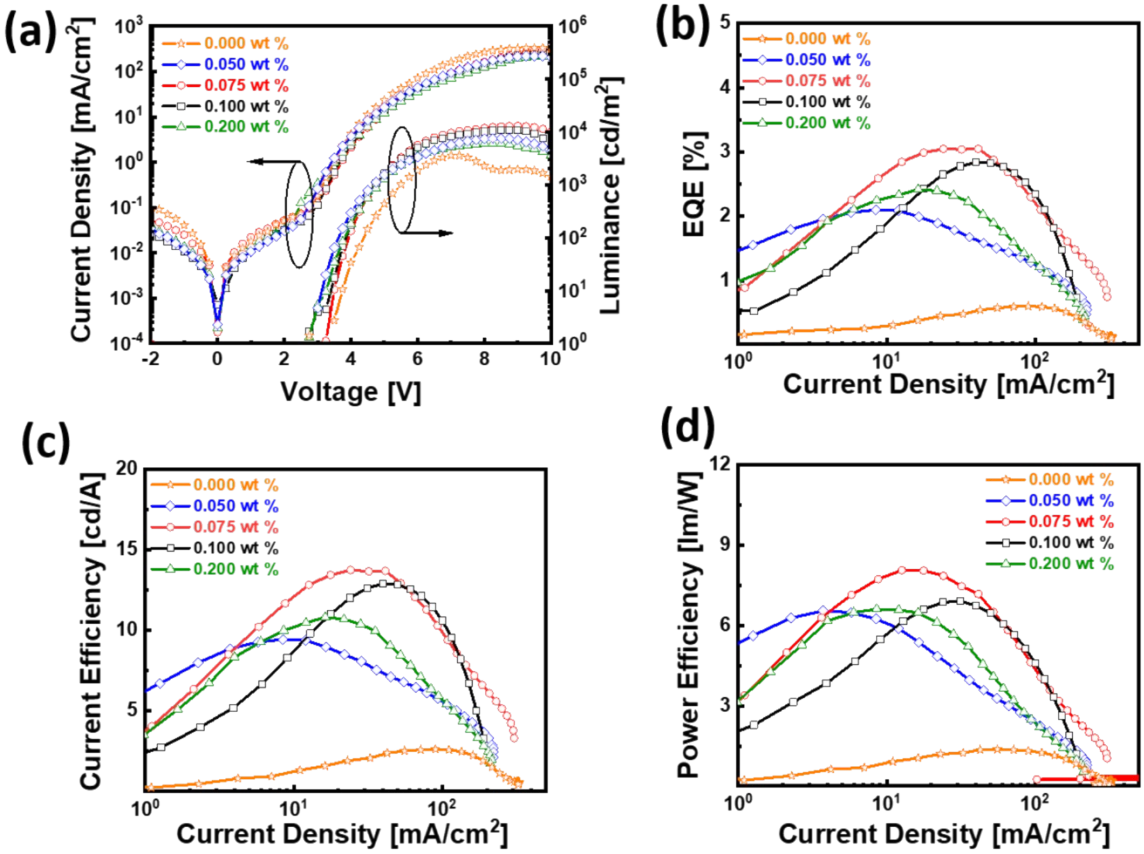


Figure S15. Optimization of TOPO in anti-solvent treatment for forming $MAPbBr_3$ films

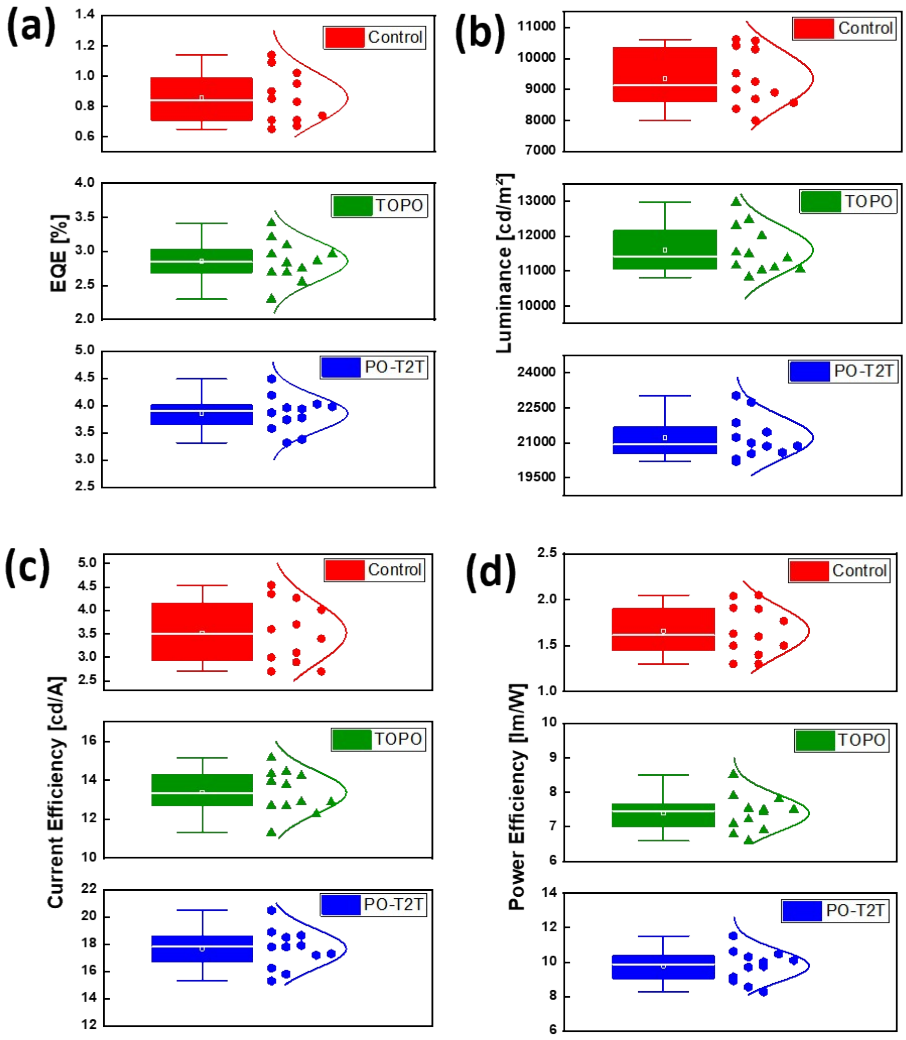


***Figure S16**: Histograms for (a) EQE (b) Luminance (c) Current Efficiency and (d) Power Efficiency of 12 Pe-LED devices.*

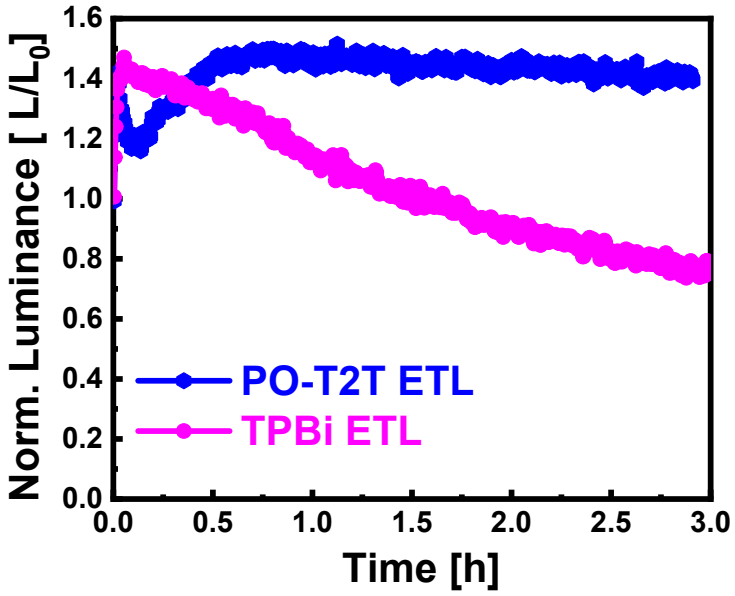


Figure S17. Comparison of Pe-LED lifetime with TPBi ETL conventionally used and PO-T2T ETL used in this work. The $MAPbBr_3$ films had PO-T2T as additive in antisolvent in both cases.

***Table S4**: A literature survey of device performance of 3D Bulk $MAPbBr_3$ Perovskite-based LEDs.*

Serial Number	*Composition of Perovskite*	*EQE [%]*	*Current Efficiency* $[mA/cm^2]$	*EL Stability*	*Reference Number*
1.	*$MAPbBr_3$ [3D, Bulk]*	8.53	*42.9*	-	*[Ref]*[1]
2.	*$MAPbBr_3$ [3D, Bulk]*	*2.96*	*14.31*	-	*[Ref]*[2]
3.	*$MAPbBr_3$ [3D, Bulk]*	*0.78*	*3.7*	-	*[Ref]*[3]
4.	*$MAPbBr_3$ [3D, Bulk]*	-	*0.05*	-	*[Ref]*[4]
5.	*$MAPbBr_3$ [3D, Bulk]*	-	*9.45*	L_{50}~ *0.31 hr @ 100 cd/m²*	*[Ref]*[5]
6.	*$MAPbBr_3$ [3D, Bulk]*	*2.36*	*8.76*	$L_{50} \sim 120\ s$	*[Ref]*[6]
7.	*$MAPbBr_3$ [3D, Bulk]*	*0.8*	-	-	*[Ref]*[7]
8.	*$MAPbBr_3$ [3D, Bulk]*	*0.07*	-	L_{50}~*340 s*	*[Ref]*[8]
9.	*$MAPbBr_3$ [3D, Bulk]*		*13.23*	L_{40}~*38 min*	*[Ref]*[9]
10.	*$MAPbBr_3$ [3D, Bulk]*	*1.03*	-	$L_{50} <$ *100 s*	*[Ref]*[10]
11.	*$MAPbBr_3$ [3D, Bulk]*	*0.71*	-	L_{50}~*55 min @50 mA/cm²*	*[Ref]*[11]
12.	*$MAPbBr_3$ [3D, Bulk]*	*6.18*	-	L_{70}~ *14000 s*	*[Ref]*[12]
13.	*$MAPbBr_3$ [3D, Bulk]*	*0.38*	*1.72*	-	*[Ref]*[13]
14.	*$MAPbBr_3$ [3D, Bulk]*	*0.023*	*0.10*	-	*[Ref]*[14]
15.	*$MAPbBr_3$ [3D, Bulk]*	-	*8.22*	-	*[Ref]*[15]
16.	*$MAPbBr_3$ [3D, Bulk]*	*4.4*	*20.4*	L_{50}*> 3 h@*	*Our work*

				100 cd/m²	

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