

Supporting Information

Dual nanocomposite carrier transport layers enhance the efficiency of planar perovskite photovoltaics

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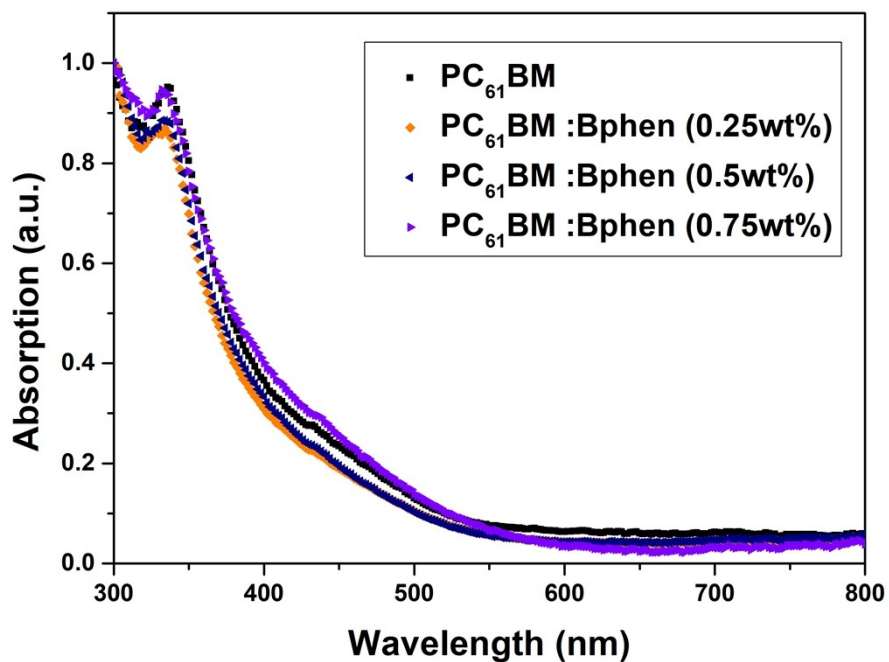


Fig. S1 UV-vis absorption spectra of PC₆₁BM incorporating Bphen at various contents (0, 0.25, 0.375, 0.5 wt%).

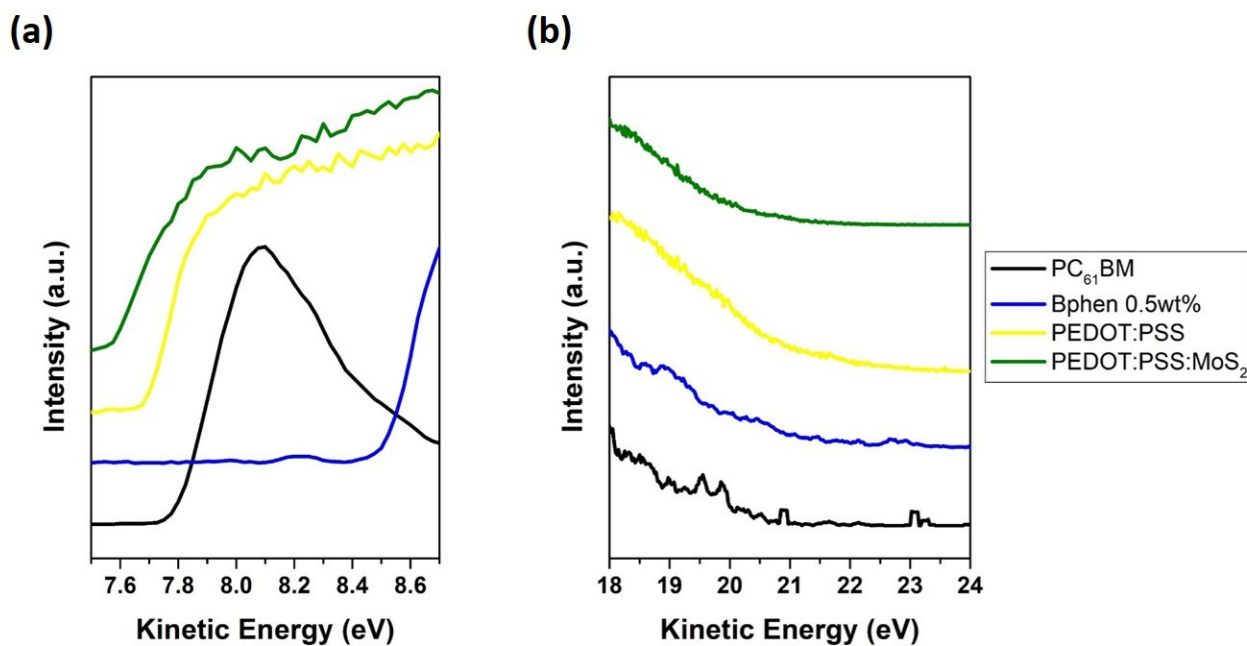


Fig. S2 UPS spectra of PC₆₁BM, PC₆₁BM:Bphen(0.5wt%), PEDOT:PSS and PEDOT:PSS:MoS₂(0.1 wt%) in (a) cutoff energy regions and (b) onset energy regions.

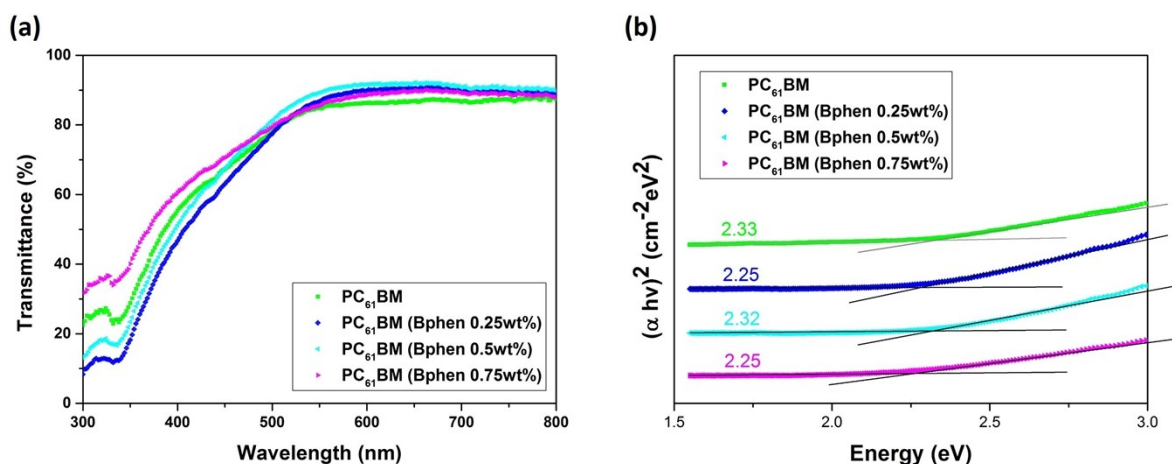
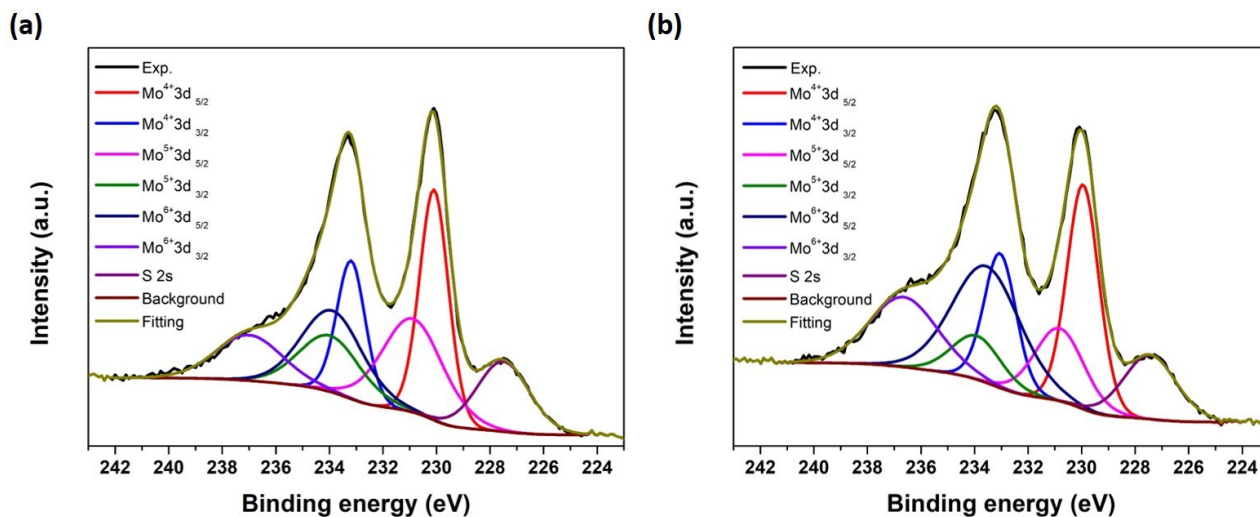


Fig. S3 (a) UV-Vis transmission spectra of films processed using PC₆₁BM incorporating Bphen at various contents (0, 0.25, 0.375, 0.5 wt%). (b) Energy gap in PC₆₁BM incorporating Bphen at various contents (0, 0.25, 0.375, 0.5 wt%) by calculating through a Tauc plot.



XPS area ratio (%)	Mo ⁴⁺	Mo ⁵⁺	Mo ⁶⁺	S 2s
MoS ₂	33.7	29.2	25.5	11.6
MoS ₂ UV treatment	34.5	17.3	38.1	10.1

Fig. S4 XPS narrow-scan spectra (Mo 3d) of perovskite films prepared (a) with and (b) without UV-ozone treatment; (c) XPS area ratios of chemical states of Mo species.

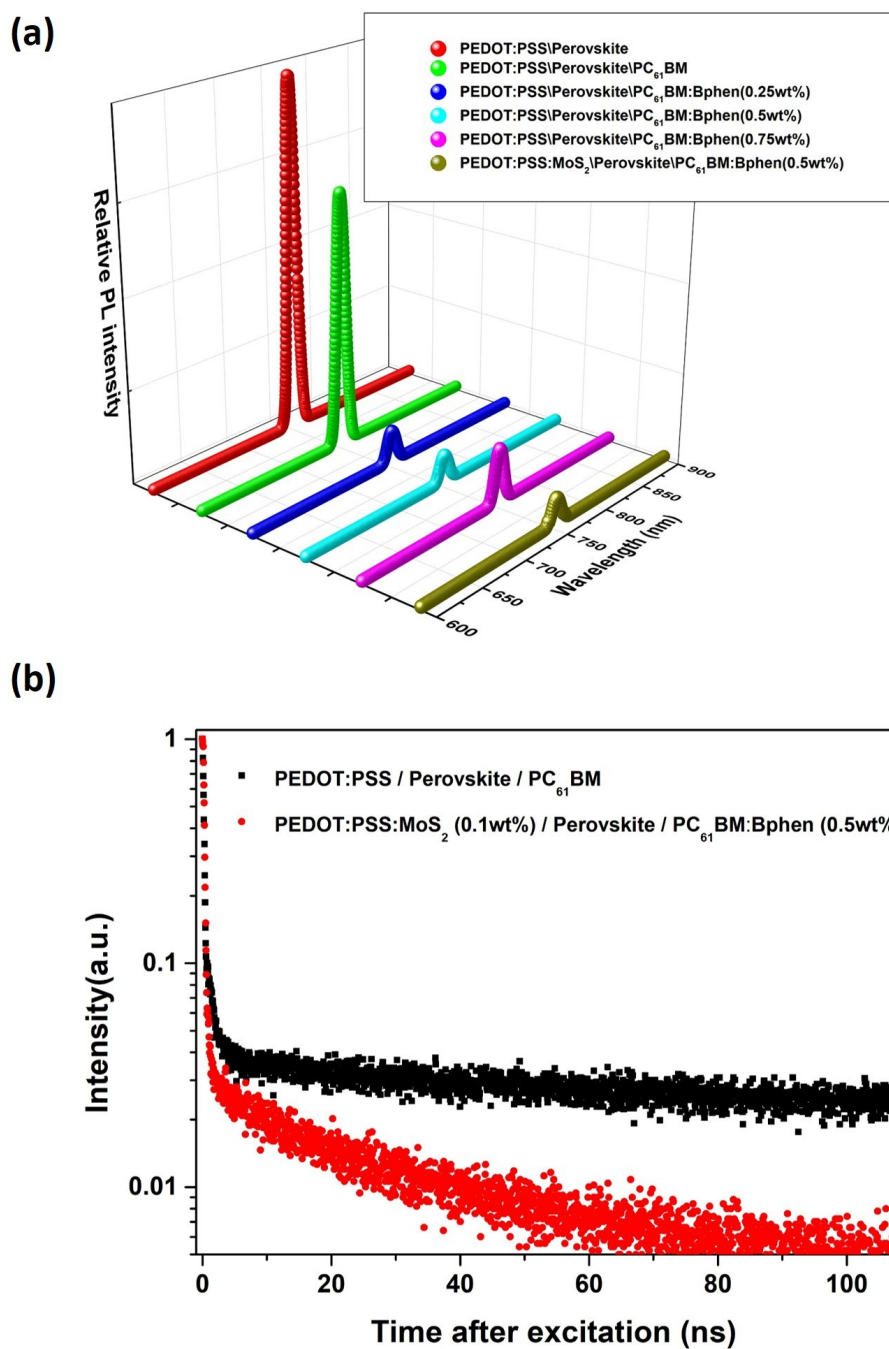


Fig. S5 (a) steady state PL spectra of films processed using PEDOT:PSS/perovskite, PEDOT:PSS/perovskite/ PC_{61}BM incorporating Bphen at various contents (0, 0.25, 0.5, 0.75 wt%) and PEDOT:PSS MoS_2 (0.1wt%)/Perovskite/ PC_{61}BM :Bphen (0.5wt%). (b) time-resolved photoluminescence (TRPL) spectra of PEDOT:PSS/perovskite/ PC_{61}BM and PEDOT:PSS MoS_2 (0.1wt%)/Perovskite/ PC_{61}BM :Bphen (0.5wt%).

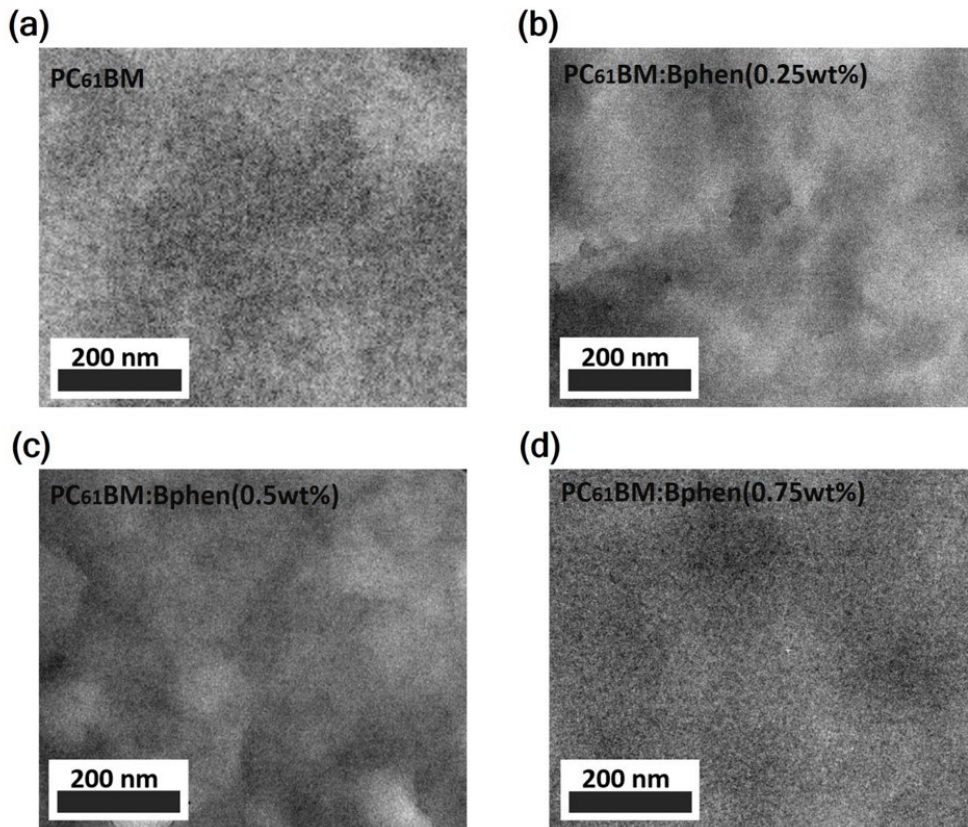


Fig. S6 TEM images of PC₆₁BM films incorporating Bphen at various contents (0.25, 0.5, 0.75 wt%).

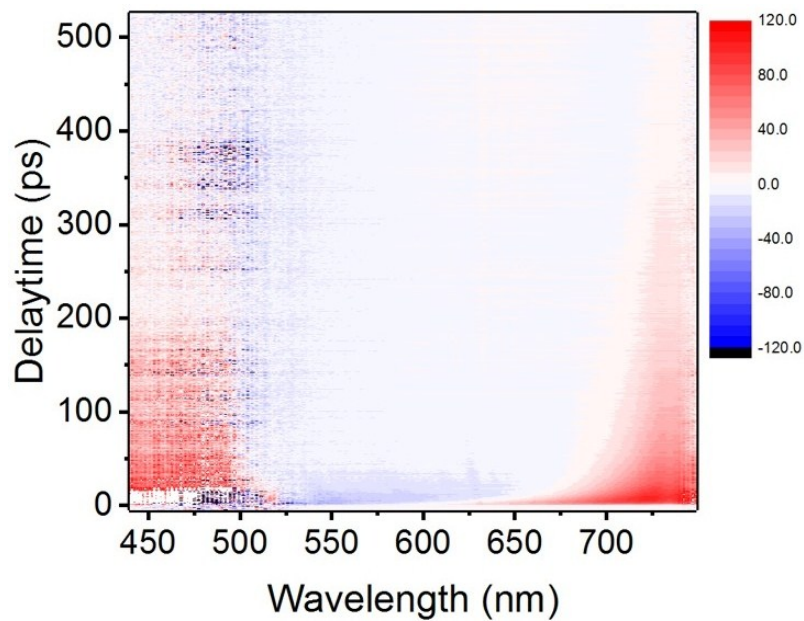


Fig. S7 2-D plots of ultrafast transient absorption difference ΔA on ITO/PEDOT:PSS/CH₃NH₃PbI_{3-x}Cl_x/PC₆₁BM.

Table S2 Fitting parameters of 1-D GISAXS profiles of the PC₆₁BM:x wt% Bphen (x = 0, 0.25, 0.5 and 0.75)

Parameter	PC ₆₁ BM	PC ₆₁ BM: x wt% Bphen		
		x = 0.25	x = 0.5	x = 0.75
Φ: volume fraction	3E-4	9.12E-4	8.2E-3	7.9E-3
R: mean radius (Å)	5.7	5.5	5.1	4.8
Df: fractal dimension	2.39	2.67	2.56	2.55
ξ: correlation length(Å)	472	312	308	304
SLD sphere (Å ⁻²)	4.1E-6	4.1E-6	4.10E-6	4.1E-6
SLD solvent (Å ⁻²)	4.7E-6	4.7E-6	4.70E-6	4.7E-6
bkg (cm ⁻¹ sr ⁻¹).	7E-4	5E-4	5E-4	7E-4
Domain size: Rg (nm)	95	69	66	65

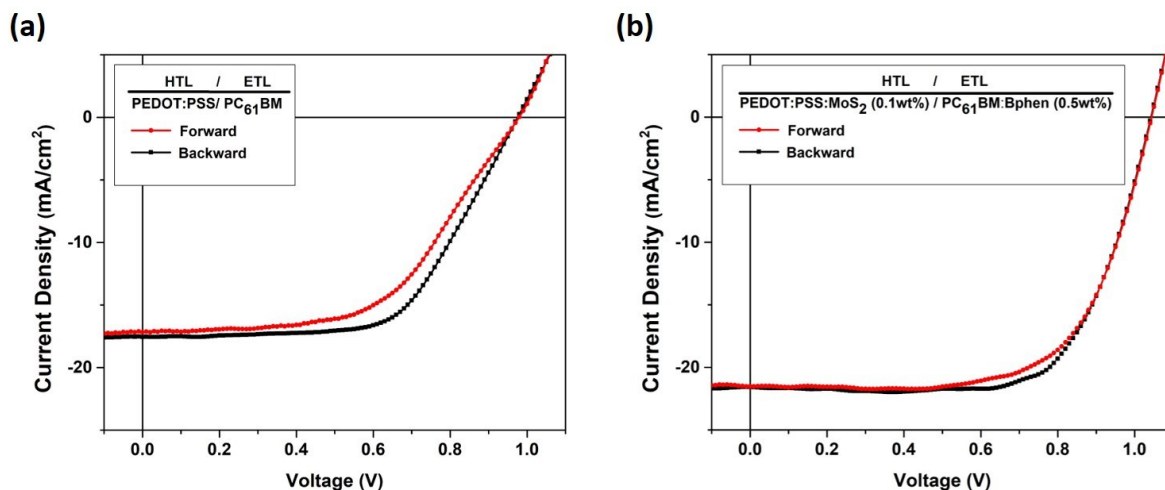


Fig. S8 Current density–voltage (J–V) characteristic curves of the perovskite solar cells at forward scan and backward scan for control device and doubly modified with carrier transport layers device.