Supporting information

Open Atmosphere Processed Stable Perovskite Solar Cells Using Molecular Engineered, Dopant-Free, Highly Hydrophobic Polymeric Hole Transporting Materials: Influence of Thiophene and Alkyl Chain on Power Conversion Efficiency

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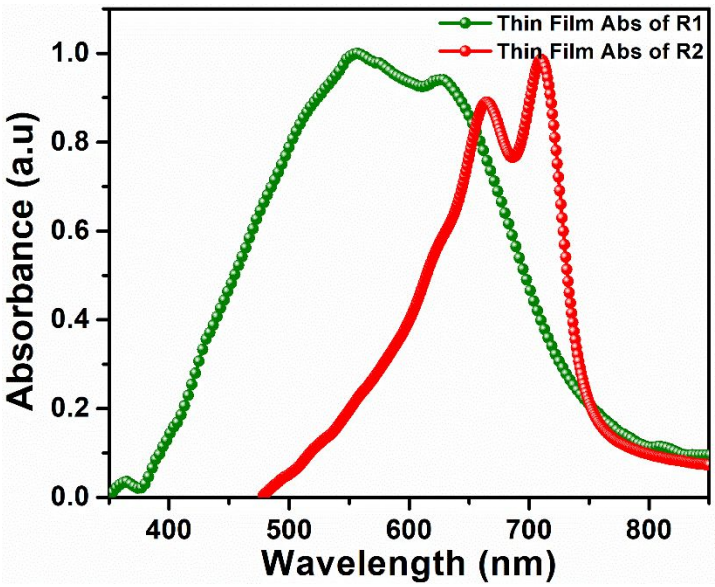

Figure S1. Thin film absorption of R1 and R2 Polymer.

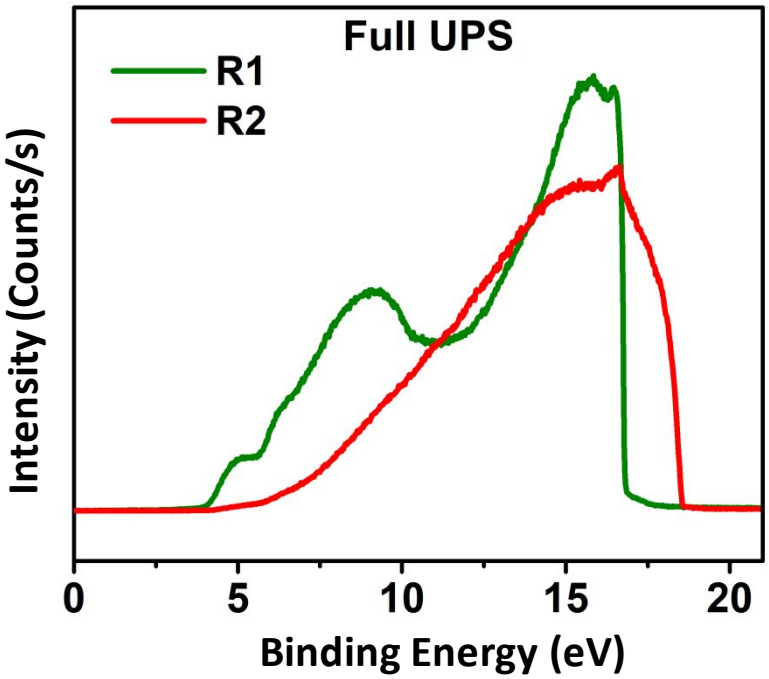

Figure S2. The full UPS spectra of polymer.

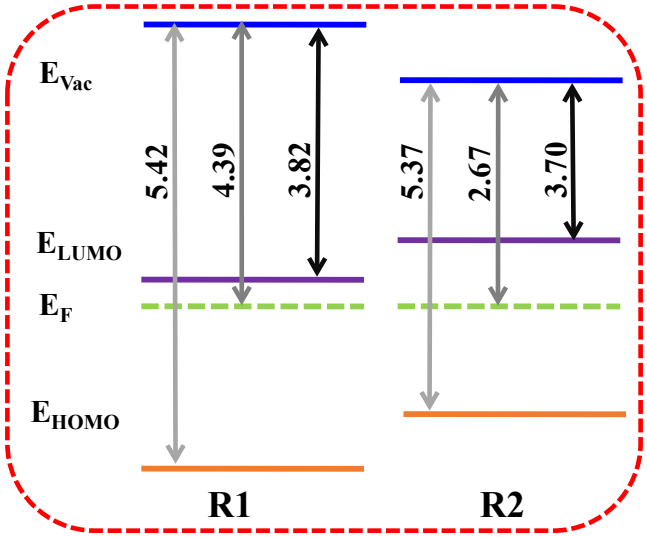

Figure S3. Energy level of different polymer.

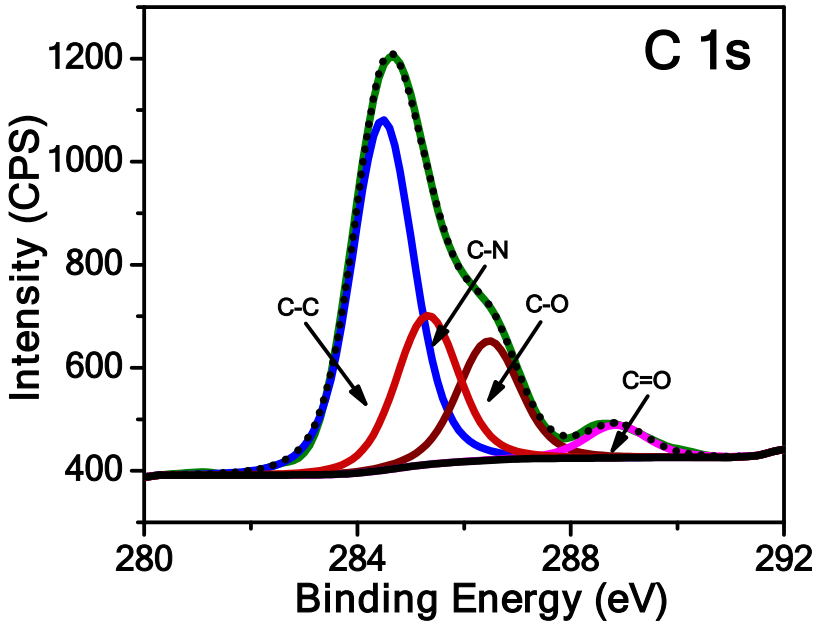

Figure S4. Core-level spectra of C 1s of $CH_3NH_3PbI_3$ perovskite.

Table S1. Impedence paramters of perovskite solar cells with different HTMs.

HTM	C_{rec} (F)	R_{rec}(Ω)	R_{series} (Ω)	τ_{rec} (μs)
HTM free	13.08×10^{-9}	400.5	25.12	5.238
Perovskite/R2	7.309×10^{-9}	998.7	20.1	7.299
Perovskite/R1	6.797×10^{-9}	1369	17.81	9.305

Table S2. Life time decay data of Perovskite and Perovskite/HTM.

	τ_1 (ns)	α_1(%)	τ_2 (ns)	α_2(%)	τ_{ave} (ns)
Perovskite	3.01	73.51	14.51	26.09	10.27
Perovskite/R1	0.46	90.89	1.73	9.11	0.80
Perovskite/R2	0.48	89.98	1.76	10.02	0.85

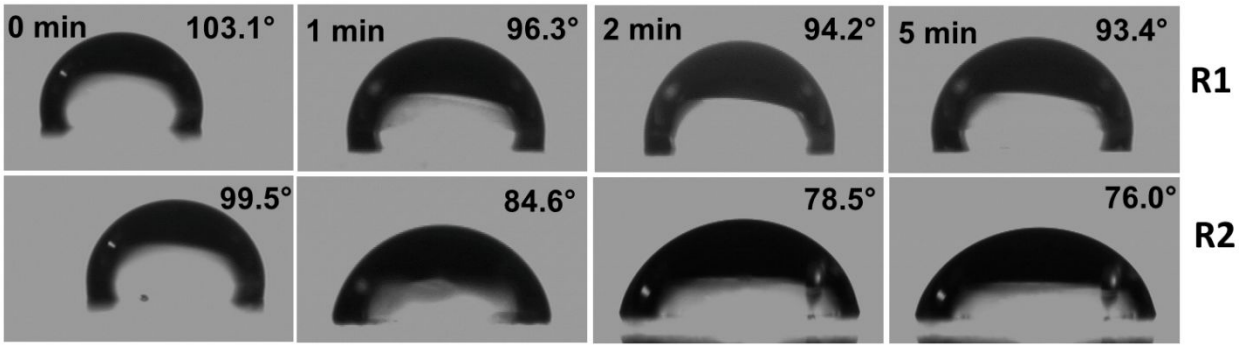

Figure S5. Changing trend of water contact angle in different time scale of 0, 1, 2, and 5 minutes in open atmosphere.

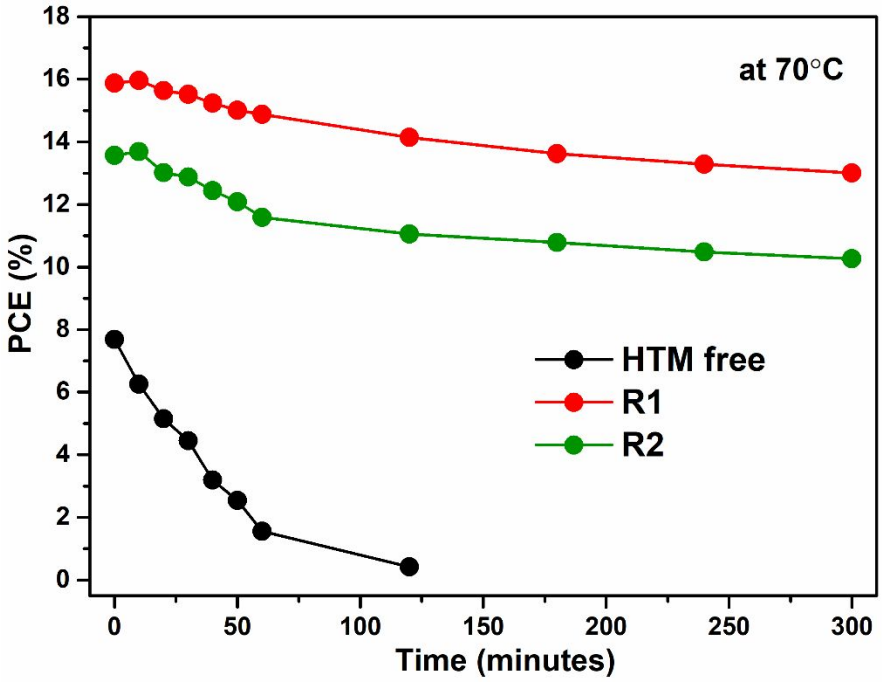

Figure S6. Thermal stability data of the PSCs with and without HTMs at different time interval at 70°C.

Table S3: Efficiency comparison of the perovskite devices fabricated in open atmosphere.

S.No	Device architecture	Dopant	V_{oc}	J_{sc}	FF	Efficiency	Year	Ref
1	FTO/C-TiO_2/mTiO_2/$CH_3NH_3PbI_3$ /spiro-MeOTAD/Au	Yes	0.90	17.54	0.41	6.79	2015	[1]
2	FTO/C-TiO_2/mTiO_2/ $CH_3NH_3PbCl_xI_{3-x}$ /spiro-MeOTAD/Au (GFA)	Yes	0.98	21.49	0.63	13.31	2015	[1]
3	FTO/C-TiO_2/mTiO_2/ $CH_3NH_3PbCl_xI_{3-x}$ /spiro-MeOTAD/Au	Yes	0.67	21.7	0.48	7.0	2015	[2]
4	FTO/C-TiO_2/mTiO_2/$CH_3NH_3PbI_3$ /spiro-MeOTAD/Au	Yes	0.898	14.9	0.599	8.02	2016	[3]
5	FTO/C-TiO_2/mTiO_2/$CH_3NH_3PbI_{3-x}(SCN)_x$/spiro-MeOTAD/Au	Yes	0.963	20.9	0.72	14.52	2016	[3]
6	FTO/C-TiO_2/mTiO_2/$CH_3NH_3PbI_3$ /spiro-MeOTAD/Au	Yes	1.00	24.2	0.51	12.3	2017	[4]
7	FTO/C-TiO_2/mTiO_2/$CH_3NH_3PbI_3$ /P3HT/Au	Yes	0.89	18.55	0.52	8.62	2017	[4]
8	FTO/ZnO/$CH_3NH_3PbI_3$ /spiro-MeOTAD/Au	Yes	1.03	18.78	0.63	12.46	2017	[5]
9	FTO/ZnO/ $CH_3NH_3PbI_3$-IPA95 /spiro-MeOTAD/Au	Yes	1.03	18.14	0.65	12.445	2017	[5]
10	FTO/ZnO/ $CH_3NH_3PbI_3$-Tol/spiro-MeOTAD/Au	Yes	1.00	14.77	0.69	10.33	2017	[5]
11	FTO/ZnO/ $CH_3NH_3PbI_3$-H_2O /spiro-MeOTAD/Au	Yes	0.81	13.69	0.61	6.85	2017	[5]
12	FTO/ZnO/ $CH_3NH_3PbI_3$-IPA100 /spiro-MeOTAD/Au	Yes	1.09	20.30	0.73	16.27	2017	[5]
13	FTO/ZnO/ $CH_3NH_3PbI_3$(DMSO:Pb 1.25) /spiro-MeOTAD/Au (RH: 30%)	Yes	1.05	22.4	0.78	18.7	2017	[6]
14	FTO/ZnO/ $CH_3NH_3PbI_3$(DMSO:Pb 0.75-1.00) /spiro-MeOTAD/Au (RH: 60%)	Yes	1.00	20.5	0.72	14.5	2017	[6]
15	NiO:GO/Perovskite/GO-Li:TiOx	Yes	0.96	17.7	0.61	10.4	2018	[7]
*16	FTO/c-TiO_2/m-TiO_2/$CH_3NH_3PbI_3$ / Au	No	0.79	14.98	0.64	**7.64**		**This Work**
*17	FTO/c-TiO_2/m-TiO_2/$CH_3NH_3PbI_3$ /R1/Au	No	0.98	23.48	0.68	**15.82**		**This Work**
*18	FTO/ c-TiO_2/m-TiO_2/$CH_3NH_3PbI_3$ /R2/Au	No	0.87	23.47	0.64	**13.35**		**This Work**

***Fabrication of all the device were carried out in complete open atmosphere using dopant free pristine polymers.**

The above table represent the efficiency of perovskite solar cell in complete open atmosphere with dopant Spiro-MeOTAD and synthesized dopant free pristine polymer.

Table S4: 20 Device power conversion efficiency data of HTM free device in open atmosphere.

No of Device	*Voc*	*Jsc*	*FF*	Efficiency
1	0.78	13.98	0.65	7.08
2	0.74	13.78	0.64	6.52
3	0.76	13.99	0.65	6.91
4	0.79	14.05	0.66	7.32
5	0.72	14.25	0.64	6.56
6	0.77	13.92	0.65	6.96
7	0.72	13.69	0.66	6.57
8	0.75	14.31	0.63	6.76
9	0.79	14.98	0.64	7.64
10	0.78	14.21	0.63	7.04
11	0.74	14.05	0.61	6.38
12	0.76	13.87	0.59	6.26
13	0.73	13.98	0.58	6.04
14	0.75	13.93	0.59	6.29
15	0.72	13.86	0.62	6.30
16	0.71	13.85	0.62	6.14
17	0.74	13.87	0.59	6.18
18	0.74	14.03	0.64	6.74
19	0.72	14.12	0.63	6.52
20	0.75	14.15	0.65	6.97
Average	0.75	14.04	0.63	6.66

Table S5: 20 Device power conversion efficiency data of dopant free pristine R1 polymer device in open atmosphere.

No of Device	*Voc*	*Jsc*	*FF*	Efficiency
1	0.97	22.14	0.65	14.04
2	0.95	23.35	0.64	14.41
3	0.96	22.10	0.64	13.57
4	0.97	23.19	0.62	14.10
5	0.96	23.45	0.65	14.80
6	0.97	22.93	0.67	14.97
7	0.98	23.48	0.68	15.82
8	0.96	22.67	0.65	14.30
9	0.97	23.48	0.68	15.75
10	0.96	22.84	0.67	14.81
11	0.96	23.54	0.67	15.45
12	0.95	23.15	0.67	15.05
13	0.96	23.78	0.65	15.10
14	0.95	23.52	0.66	14.98
15	0.97	23.49	0.68	15.74
16	0.96	23.94	0.67	15.60
17	0.98	23.48	0.67	15.67
18	0.98	23.25	0.69	15.75
19	0.98	23.49	0.67	15.61
20	0.98	23.24	0.69	15.81
Average	0.97	23.22	0.66	15.07

Table S6: 20 Device power conversion efficiency data of dopant free pristine R2 polymer device in open atmosphere.

No of Device	*Voc*	*Jsc*	*FF*	Efficiency
1	0.89	21.98	0.62	12.38
2	0.87	23.58	0.62	12.97
3	0.85	23.28	0.61	12.23
4	0.84	22.27	0.64	12.14
5	0.86	23.68	0.64	13.33
6	0.85	23.78	0.62	12.78
7	0.86	22.98	0.63	12.65
8	0.87	23.48	0.65	13.41
9	0.86	23.65	0.64	13.31
10	0.87	22.48	0.61	12.13
11	0.86	23.45	0.62	12.81
12	0.87	23.47	0.64	13.35
13	0.86	23.78	0.63	13.16
14	0.89	23.49	0.62	13.23
15	0.87	23.81	0.63	13.26
16	0.86	23.78	0.62	12.99
17	0.86	23.58	0.62	12.81
18	0.86	23.25	0.65	13.25
19	0.86	23.48	0.62	12.79
20	0.84	22.98	0.63	12.34
Average	0.86	23.31	0.63	12.87

Reference

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