Supplementary Information

Higher Efficiency Perovskite Solar Cells Using Additives of LiI, LiTFSI and BMImI in the PbI_2 Precursor

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Figure S1 shows the J-V characteristics of perovskite solar cells made from pristine and perovskite films doped with different concentrations (6, 9, 12, 15 mg/ml) of BMImI in the PbI_2 precursor. Table S1 shows photovoltaic parameters including short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and efficiency (η) obtained from the fabricated solar cells. It was observed that by increasing concentration of BMImI additive in perovskite films, there was enhancement in J_{sc}, V_{oc} and η up to 12 mg/ml compared to solar cells made from pristine perovskite films, beyond 12mg/ml, these parameters start to decrease. An optimum efficiency (η) of 18.00% was observed for the 12 mg/ml BMImI doped perovskite based device, which is significantly improved as compared to the efficiency of 11.30% obtained from device made from pristine perovskite films.

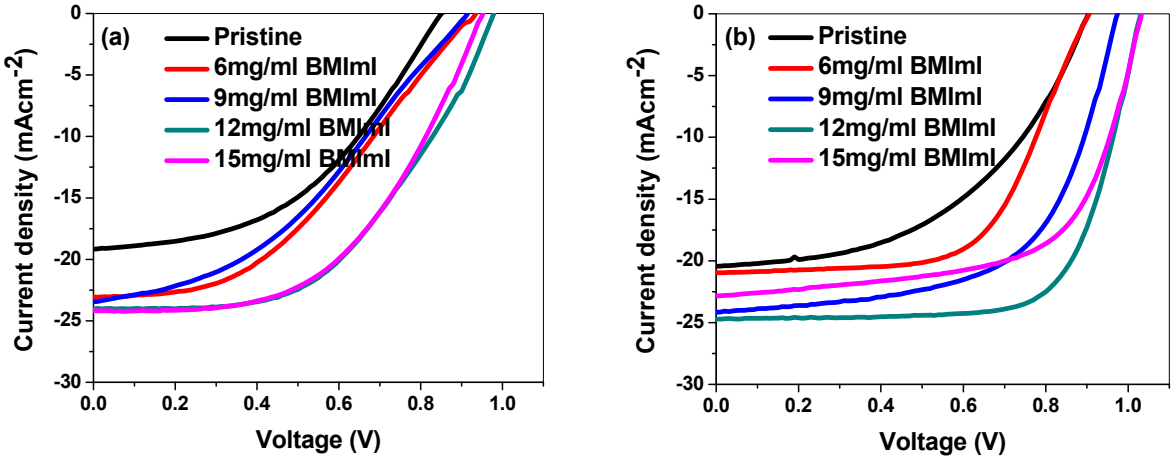

Figure S1. (a) Forward and (b) reverse current density-voltage (J-V) characteristics of perovskite solar cells made from pristine and different concentration (6, 9, 12, 15 mg/ml) of BMImI doped perovskite films.

Table S1. Photovoltaic parameters of fabricated perovskite solar cells made from pristine and different concentration (6, 9, 12, 15 mg/ml) of BMImI doped perovskite films.

BMImI	Bias	Jsc ($mAcm^{-2}$)	Voc (V)	FF	η (%)
------	Forward	19.15	0.86	0.46	7.58
	Reverse	20.45	0.91	0.48	8.93
6mg/ml	Forward	23.05	0.94	0.40	8.67
	Reverse	20.95	0.91	0.61	11.63
9mg/ml	Forward	23.44	0.92	0.39	8.41
	Reverse	24.16	0.98	0.60	14.21
12mg/ml	Forward	24.03	0.98	0.51	12.1
	Reverse	24.70	1.04	0.7	18.00
15mg/ml	Forward	24.16	0.96	0.52	12.06
	Reverse	22.83	1.04	0.63	14.96

Figure S2 shows the J-V characteristics of perovskite solar cells made from pristine and perovskite films doped with different concentrations (6, 9, 12, 15 mg/ml) of LiI in the PbI_2 precursor. Table S2 shows photovoltaic parameters including short circuit current density (J_{sc}),

open circuit voltage (V_{oc}), fill factor (FF) and efficiency (η) obtained from the fabricated solar cells. It was observed that by increasing concentration of LiI additive in perovskite films, there was enhancement in J_{sc}, V_{oc} and η up to 12 mg/ml compared to solar cells made from pristine perovskite films, beyond 12mg/ml, these parameters start to decrease. An optimum efficiency (η) of 17.01% was observed for the 12 mg/ml LiI doped perovskite based device, which is significantly improved as compared to the efficiency of 11.30% obtained from device made from pristine perovskite films.

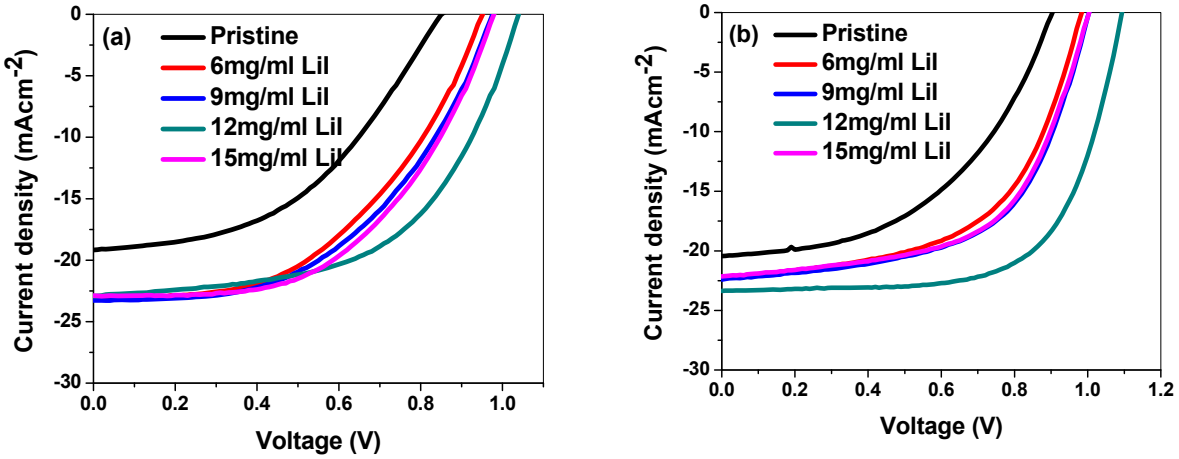

Figure S2. (a) Forward and (b) reverse current density-voltage (J-V) characteristics of perovskite solar cells made from pristine and different concentration (6, 9, 12, 15 mg/ml) of LiI doped perovskite films.

Table S2. Photovoltaic parameters of fabricated perovskite solar cells made from pristine and different concentration (6, 9, 12, 15 mg/ml) of LiI doped perovskite films.

LiI	Bias	Jsc ($mAcm^{-2}$)	Voc (V)	FF	η (%)
------	Forward	19.15	0.86	0.46	7.58
	Reverse	20.45	0.91	0.48	8.93
6mg/ml	Forward	23.2	0.96	0.49	10.91
	Reverse	22.2	0.99	0.56	12.31

9mg/ml	Forward	23.26	0.98	0.5	11.40
	Reverse	22.42	1.01	0.58	13.13
12mg/ml	Forward	22.92	1.00	0.58	13.33
	Reverse	23.36	1.10	0.66	17.01
15mg/ml	Forward	22.15	0.98	0.48	10.42
	Reverse	23.77	1.01	0.58	13.92

Figure S3 shows the J-V characteristics of perovskite solar cells made from pristine and perovskite films doped with different concentrations (6, 9, 12, 15 mg/ml) of LiTFSI in the PbI_2 precursor. Table S3 shows photovoltaic parameters including short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and efficiency (η) obtained from the fabricated solar cells. It was observed that by increasing concentration of LiTFSI additive in perovskite films, there was enhancement in J_{sc}, V_{oc} and η up to 12 mg/ml compared to solar cells made from pristine perovskite films, beyond 12mg/ml, these parameters start to decrease. An optimum efficiency (η) of 15.60% was observed for the 12 mg/ml LiTFSI doped perovskite based device, which is significantly improved as compared to the efficiency of 11.30% obtained from device made from pristine perovskite films.

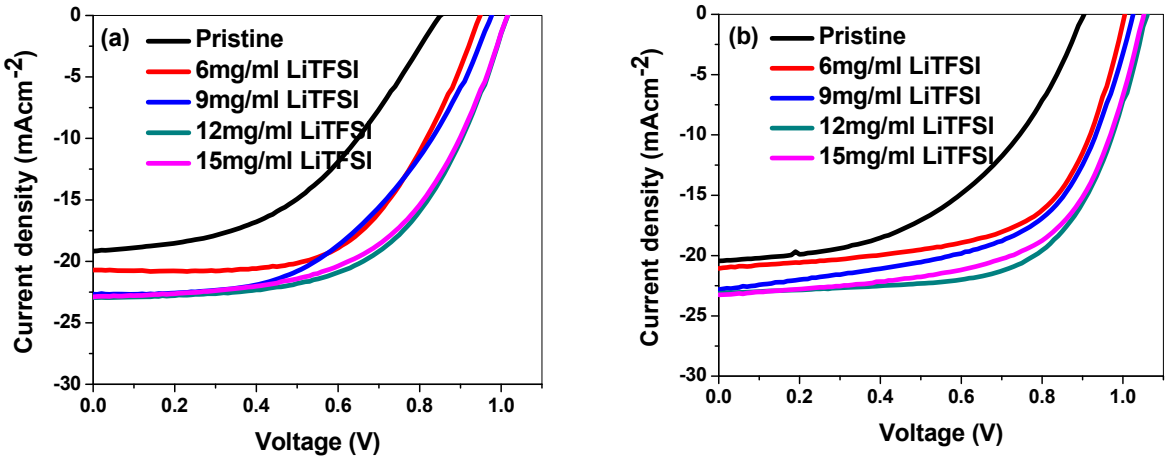

Figure S3. (a) Forward and (b) reverse current density-voltage (J-V) characteristics of perovskite solar cells made from pristine and different concentration (6, 9, 12, 15 mg/ml) of LiTFSI doped perovskite films.

Table S3. Photovoltaic parameters of fabricated perovskite solar cells made from pristine and different concentration (6, 9, 12, 15 mg/ml) of LiTFSI doped perovskite films.

LiTFSI	Bias	Jsc ($mAcm^{-2}$)	Voc (V)	FF	η (%)
------	Forward	19.15	0.86	0.46	7.58
	Reverse	20.45	0.91	0.48	8.93
6mg/ml	Forward	20.71	0.95	0.58	11.41
	Reverse	21.06	1.01	0.61	12.98
9mg/ml	Forward	22.67	0.98	0.51	11.33
	Reverse	22.82	1.03	0.58	13.63
12mg/ml	Forward	22.94	1.02	0.58	13.57
	Reverse	23.14	1.07	0.63	15.60
15mg/ml	Forward	22.89	1.02	0.56	13.07
	Reverse	23.26	1.06	0.61	15.04

The previous results confirmed that the optimum concentration for these mentioned dopants is 12mg/ml, beyond this concentration, performance decrease gradually. This may be when adding 12mg/ml dopant, the precursor PbI_2 solution become fully saturated and any further solute added to the solution doesn't dissolve resulting in rough contaminated film which may hinder charge transport in the film and across the interface at the perovskite/charge transport layer.

Figure S4 shows the J-V characteristics of perovskite solar cells made from 12mg/ml BMImI doped perovskite solar cells compared to perovskite devices doped with mixture of LiI, LiTFSI, and BMImI. Table S4 shows photovoltaic parameters including short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and efficiency (η) obtained from the fabricated solar cells. Results show that the best device performance (18.53%) could be obtained when doping the PbI_2 precursor solution with 12mg/ml BMImI only.

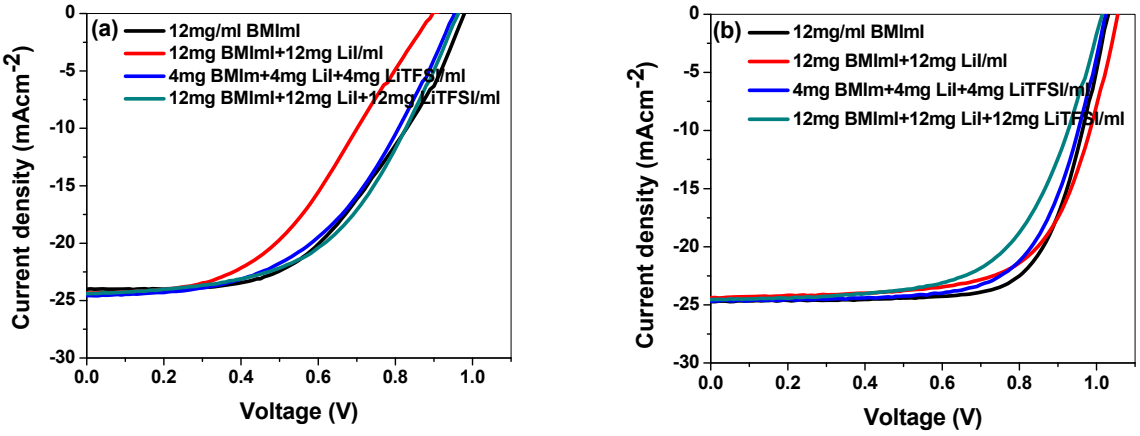

Figure S4. (a) Forward and (b) reverse current density-voltage (J-V) characteristics of perovskite solar cells made from perovskite doped with 12mg BMImI/ml, 12mgBMImI+12mgLiI/ml, 4mgBMImI+4mgLiI+4mgLiTFSI/ml, and 12mgBMImI+12mgLiI+ 12mgLiTFSI/ml.

Table S4. Photovoltaic parameters of fabricated perovskite solar cells made from PbI_2 precursor solutions doped with 12mg BMImI/ml, 12mgBMImI+12mgLiI/ml, 4mgBMImI+4mgLiI+ 4mgLiTFSI/ml, and 12mgBMImI+12mgLiI+12mgLiTFSI/ml.

Additive	Scan	Jsc ($mAcm^{-2}$)	Voc (V)	FF	η (%)
12mg/ml BMImI	Forward	24.03	0.98	0.51	12.10
	Reverse	24.70	1.04	0.7	18
12mg BMImI+ 12mg LiI/ml	Forward	24.35	0.91	0.45	9.89
	Reverse	24.41	1.06	0.66	17.18
4mg BMImI+ 4mg LiI+ 4mg LiTFSI/ml	Forward	24.57	0.95	0.5	11.71
	Reverse	24.69	1.03	0.67	17.02
12mg BMImI+ 12mg/ml LiI+ 12mgLiTFSI/ml	Forward	24.40	0.96	0.53	12.37
	Reverse	24.55	1.02	0.62	15.47