Supplementary Information for

Suppressing non-radiative recombination for efficient and stable perovskite solar cells

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Supplementary Table 1 | Photovoltaic parameters of single-junction perovskite solar cells. *Certified PCE.

Year	Polarity	Device configuration	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)	Ref.
2012	*n-i-p*	Ag/Spiro-OMeTAD/$MAPbI_2Cl$/$cTiO_2$/FTO	0.98	17.8	63.0	10.9	1
2013	*n-i-p*	Au/Spiro-OMeTAD/$MAPbI_3$/$mTiO_2$/FTO	1.00	21.3	66.0	14.1*	2
2013	*n-i-p*	Ag/Spiro-OMeTAD/$MAPbI_{3-x}Cl_x$/$cTiO_2$/FTO	1.07	21.5	68.0	15.4	3
2014	*n-i-p*	Ag/Spiro-OMeTAD/$MAPbI_3$/ZnO/ITO	1.03	20.4	74.9	15.7	4
2014	*n-i-p*	Au/PTAA/$MAPb(I_{1-x}Br_x)_3$/$mTiO_2$/FTO	1.11	19.6	74.2	16.2*	5
2014	*n-i-p*	Au/Spiro-OMeTAD/$MAPbI_{3-x}Cl_x$/Y-TiO_2/PEIE/ITO	1.13	22.7	75.0	19.3	6
2015	*p-i-n*	Ag/Ti(Nb)O_x/PCBM/$MAPbI_3$/NiMgLiO/FTO	1.09	20.9	66.8	15.0*	7
2015	*n-i-p*	Au/PTAA/$MAPbI_3$/Zn_2SnO_4/ITO	1.06	21.6	66.8	15.3	8
2015	*n-i-p*	Au/Spiro-OMeTAD/$MAPbI_3$/SnO_2/FTO	1.11	23.3	67.0	17.2	9
2015	*n-i-p*	Au/PTAA/$FAPbI_3$/$mTiO_2$/FTO	1.06	24.7	77.0	20.1*	10
2016	*p-i-n*	Ag/Ti(Nb)O_x/PCBM/$FA_{0.85}MA_{0.15}Pb(I_{0.85}Br_{0.15})_3$/$NiO_x$/	1.08	21.9	78.4	18.2*	11

		FTO					
2016	*n-i-p*	Au/Spiro-OMeTAD/$(FAPbI_3)_{0.97}(MAPbBr_3)_{0.03}/SnO_2$/ITO	1.07	24.3	76.6	19.9*	12
2016	*n-i-p*	Au/Spiro-OMeTAD/$RbCsMAFAPbI_3/mTiO_2/cTiO_2$/FTO	1.18	22.6	81.0	21.6	13
2017	*n-i-p*	Au/Spiro-OMeTAD/$MA_{0.33}FA_{0.67}Pb(Br_{0.17}I_{0.83})_3/Nb_2O_5$/ITO	1.06	24.7	71.1	18.6	14

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Year	Polarity	Device configuration	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)	Ref.
2017	*n-i-p*	Au/Spiro-OMeTAD/$(FAPbI_3)_{1-x}(MAPbBr_3)_x$/$SnO_2$/ITO	1.12	24.0	78.0	20.9*	15
2017	*n-i-p*	Au/PDCBT/Ta-WO_x/$FA_{0.83}MA_{0.17}Pb_{1.1}Br_{0.5}I_{2.8}$/$C_{60}$-SAM/ITO	1.17	22.7	80.0	21.2	16
2017	*n-i-p*	Au/PTAA/$MAPbI_3$/(La)$BaSnO_3$/FTO	1.12	23.4	81.3	21.3	17
2017	*n-i-p*	Au/PTAA/$FAPbI_3$/mTiO_2/cTiO_2/FTO	1.10	25.0	80.3	22.1*	18
2018	*n-i-p*	Au/Spiro-OMeTAD/$MAPbI_3$/ZnO/ITO	1.13	22.9	77.1	19.9	19
2018	*p-i-n*	Ag/PCBM/ZrAcac/CsMAFAPbI_3/NiO_x/ITO	1.12	23.2	80.3	20.9	20
2018	*n-i-p*	Au/DM/$(FAPbI_3)_{0.95}(MAPbBr_3)_{0.05}$/m$TiO_2$/c$TiO_2$/FTO	1.13	24.9	80.5	22.6*	21
2019	*p-i-n*	Cu/BCP/MeO-2PACz/$Cs_{0.05}(MA_{0.17}FA_{0.83})_{0.95}Pb(I_{0.83}Br_{0.17})_3$/SAM/ITO	1.16	21.8	80.9	20.4*	22
2019	*n-i-p*	Au/P3HT/$(FAPbI_3)_{0.95}(MAPbBr_3)_{0.05}$/m$TiO_2$/c$TiO_2$/FTO	1.14	24.9	79.6	22.7*	23
2019	*n-i-p*	Au/Spiro-OMeTAD/PEAI/$FA_{1-x}MA_xPbI_3$/SnO_2/ITO	1.18	25.2	78.4	23.3*	24
2020	*n-i-p*	Au/Spiro-OMeTAD/$Cs_{0.05}(MA_{0.15}FA_{0.85})_{0.95}Pb(I_{0.85}Br_{0.15})_3$/$Zn_2Sn$	1.14	23.6	79.0	21.3	25

		O_4/FTO					
2020	*p-i-n*	Ag/BCP/PCBM/CsMAFAPbI_3/F2HCNQ/NiO_x/ITO	1.14	23.4	82.8	22.1	26
2020	*n-i-p*	Au/Spiro-OMeTAD/MAxFA_{1-x}Pb($I_{1-x}$$Br_x$$)_3$/ZnO-KCl/ITO	1.17	24.0	80.0	22.6	27
2020	*n-i-p*	Au/Spiro-OMeTAD/(FAPb$I_3$$)_{1-x}$(MC$)_x$/mTi$O_2$/cTi$O_2$/FTO	1.16	26.2	80.1	24.4 *	28
2020	*n-i-p*	Au/Spiro-*m*F/FAPbI_3/mTiO_2/cTiO_2/FTO	1.18	26.2	79.6	24.6 *	29

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Year	Polarity	Device configuration	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)	Ref.
2021	*n-i-p*	Ag/TPBI/VO_x/Spiro-TTB/$Cs_{0.05}MA_{0.15}FA_{0.8}Pb(I_{0.85}Br_{0.15})_3$/$Nb_2O_5$/$C_{60}$-SAM/ITO	1.15	24.0	76.8	21.3	30
2021	*p-i-n*	Ag/BCP/C_{60}/$Cs_{0.18}FA_{0.82}PbI_3$/2PACz/ITO	1.16	23.5	83.2	22.7	31
2021	*n-i-p*	Au/Spiro-OMeTAD/OAI/$FAPbI_3$/mTiO_2/cTiO_2/FTO	1.17	26.2	81.8	25.2*	32
2021	*n-i-p*	Au/Spiro-OMeTAD/$FAMAPb(I,Cl)_3$/SnO_2/FTO	1.18	25.1	84.8	25.2*	33
2021	*n-i-p*	Au/Spiro-OMeTAD/MeO-PEAI/$FAMAPb(I,Cl)_3$/SnO_2/FTO	1.19	25.7	83.2	25.5*	34
2022	*p-i-n*	Ag/BCP/C_{60}/$FcTc_2$/$Cs_{0.05}(MA_{0.02}FA_{0.98})_{0.95}Pb(I_{0.98}Br_{0.02})_3$/PTAA/ITO	1.18	25.6	80.6	24.3*	35
2022	*n-i-p*	Au/MoO_3/Spiro-OMeTAD/$Cs_{0.15}FA_{0.85}Pb(I_{0.95}Br_{0.017}Cl_{0.033})_3$/$SnO_2$/FTO	1.18	25.3	84.6	24.5*	36
2022	*n-i-p*	Au/Spiro-OMeTAD-TFSI/$FAPbI_3$/SnO_2/ITO	1.16	26.5	81.4	25.0*	37
2023	*p-i-n*	Ag/BCP/PCBM/$FcTc_2$/$Cs_{0.05}FA_{0.95}PbI_3$/Al_2O_3/PTAA/NiO_x/ITO	1.17	25.7	81.6	24.6*	38
2023	*p-i-n*	Ag/BCP/C_{60}/$Cs_{0.05}(MA_{0.05}FA_{0.95})_{0.95}Pb(I_{0.95}Br_{0.05})_3$/MPA-CPA/ITO	1.21	24.8	84.7	25.4*	39

2023	*p-i-n*	Ag/BCP/C_{60}/CF3-PEAMAI/perovskite/MeO-4PADBC/NiO_x/ITO	1.19	25.4	84.6	25.6*	40
2023	*n-i-p*	Au/Spiro-OMeTAD/$FAPbI_3$/SnO_2/ITO	1.18	25.6	85.1	25.7*	41
2024	*p-i-n*	Ag/C_{60}/SnO_2/perovskite/SAMs/FTO	1.174	26.13	85.2	26.1*	42

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Year	Polarity	Device configuration	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)	Ref.
2024	*n-i-p*	Au/Spiro-OMeTAD/$FAPbI_3$/SnO_2/ITO	1.175	26.47	84.94	26.41	43

Supplementary Table 2 | Photovoltaic parameters of perovskite-silicon tandem solar cells. Heterojunction solar cell (HJT).

Year	Polarity	Perovskite top cell; Silicon bottom cell	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)	Ref.
2016	*n-i-p*	SnO_2/$(FAPbI_3)_x(MAPbBr_3)_{1-x}$/Spiro-OMeTAD/$MoO_3$/ITO/Ag/LiF; HJT	1.79	14.0	79.5	19.9	44
2016	*n-i-p*	PEIE/PCBM/$(FAPbI_3)_x(MAPbBr_3)_{1-x}$/Spiro-OMeTAD/$MoO_3$/ITO/Au; HJT	1.72	16.4	73.1	20.5	45
2017	*p-i-n*	NiO_x/$Cs_{0.17}FA_{0.83}Pb(I_{0.17}Br_{0.83})_3$/PCBM/$SnO_2$/ZTO/ITO/Ag/LiF; HJT	1.65	18.1	79.0	23.6	46
2018	*p-i-n*	PTAA/$FA_{0.75}Cs_{0.25}Pb(I_{0.8}Br_{0.2})_3$/$C_{60}$/$SnO_2$/ITO/Ag/$MgF_x$; HJT	1.77	18.4	77.0	25.0	47
2018	*p-i-n*	Spiro-TTB/$Cs_xFA_{1-x}Pb(I,Br)_3$/LiF/C_{60}/SnO_x/IZO/Ag/MgF_x; HJT	1.79	19.5	73.1	25.2	48
2018	*p-i-n*	PTAA/$Cs_{0.05}(MA_{0.17}FA_{0.83})Pb_{1.1}(I_{0.83}Br_{0.17})_3$/$C_{60}$/$SnO_2$/IZO/LM foil; HJT	1.76	18.5	78.5	25.5	49
2019	*p-i-n*	Spiro-TTB/$Cs_xFA_{1-x}Pb(I,Br)_3$/LiF/C_{60}/SnO_x/IZO/Ag/MgF_x; HJT	1.74	19.5	74.7	25.1	50
2019	*p-i-n*	PTAA/$Cs_{0.15}(FA_{0.83}MA_{0.17})_{0.85}Pb(I_{0.8}Br_{0.2})_3$/ICBA/$C_{60}$/$SnO_x$/IZO/Cu/$MgF_x$; HJT	1.80	17.8	79.4	25.4	51
2020	*p-i-n*	PTAA/$Cs_{0.1}MA_{0.9}Pb(I_{0.9}Br$	1.82	19.2	74.4	26.0	52

		$_{0.1})_3$/C_{60}/SnO_2/ITO/Ag/PDMS; HJT					
2020	*p-i-n*	Spiro-OMeTAD/$(Cs_{0.06}FA_{0.78}MA_{0.16})Pb(I_{0.83}Br_{0.17})_3$/m$TiO_2$/graphene/c$TiO_2$/FTO; HJT	1.80	18.8	77.5	26.3	53

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Year	Polarity	Perovskite top cell; Silicon bottom cell	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)	Ref.
2020	*p-i-n*	NiO_x/PolyTPD/PFNBr/$FA_{0.78}Cs_{0.22}Pb(I_{0.85}Br_{0.15})_3$/LiF/$C_{60}$/ SnO_x/ITO/ Ag/AR foil; HJT	1.89	19.1	75.3	27.0	54
2020	*p-i-n*	Me-4PACz/$Cs_{0.05}(FA_{0.77}MA_{0.23})_{0.95}Pb(I_{0.77}Br_{0.23})_3$/LiF/$C_{60}$/$SnO_x$/ IZO/Ag/LiF; HJT	1.90	19.3	79.5	29.2	55
2021	*p-i-n*	2PACz/$Cs_{0.05}FA_{0.8}MA_{0.15}Pb(I_{0.75}Br_{0.25})_3$/LiF/$C_{60}$/$SnO_x$/IZO/Ag/$MgF_x$; HJT	1.87	19.6	78.6	28.2	56
2022	*p-i-n*	PTAA/LiF/$Cs_{0.1}FA_{0.2}MA_{0.7}Pb(I_{0.85}Br_{0.15})_3$/$C_{60}$/$SnO_2$/ITO/Ag/PDMS; HJT	1.92	19.0	78.5	28.6	57
2022	*p-i-n*	NiO_x/2PACz/$Cs_xFA_yMA_{1-x-y}Pb(I,Br)_3$/LiF/$C_{60}$/$SnO_x$/IZO/Ag/LiF; HJT	1.79	20.1	80.0	28.8	58
2022	*p-i-n*	2PACz/$Cs_{0.05}FA_{0.8}MA_{0.15}Pb(I_{0.755}Br_{0.255})_3$/$MgF_x$/$C_{60}$/$SnO_2$/IZO; HJT	1.91	19.8	77.6	29.3	59
2022	*p-i-n*	Me-4PACz/$Cs_{0.05}(FA_{0.79}MA_{0.21})_{0.95}Pb(I_{0.79}Br_{0.21})_3$/LiF/$C_{60}$/$SnO_x$/ IZO/Ag/LiF; HJT	1.92	19.5	79.4	29.8	60
2023	*p-i-n*	Me-4PACz/$Cs_{0.05}(FA_{0.77}MA_{0.23})_{0.95}Pb(I_{0.77}Br_{0.23})_3$/LiF/$C_{60}$/$SnO_2$/ IZO/Ag/LiF; HJT	1.98	20.2	81.2	32.5	61

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