

Supporting information

Semi-transparent perovskite solar cells: Unveiling the trade-off between transparency and efficiency

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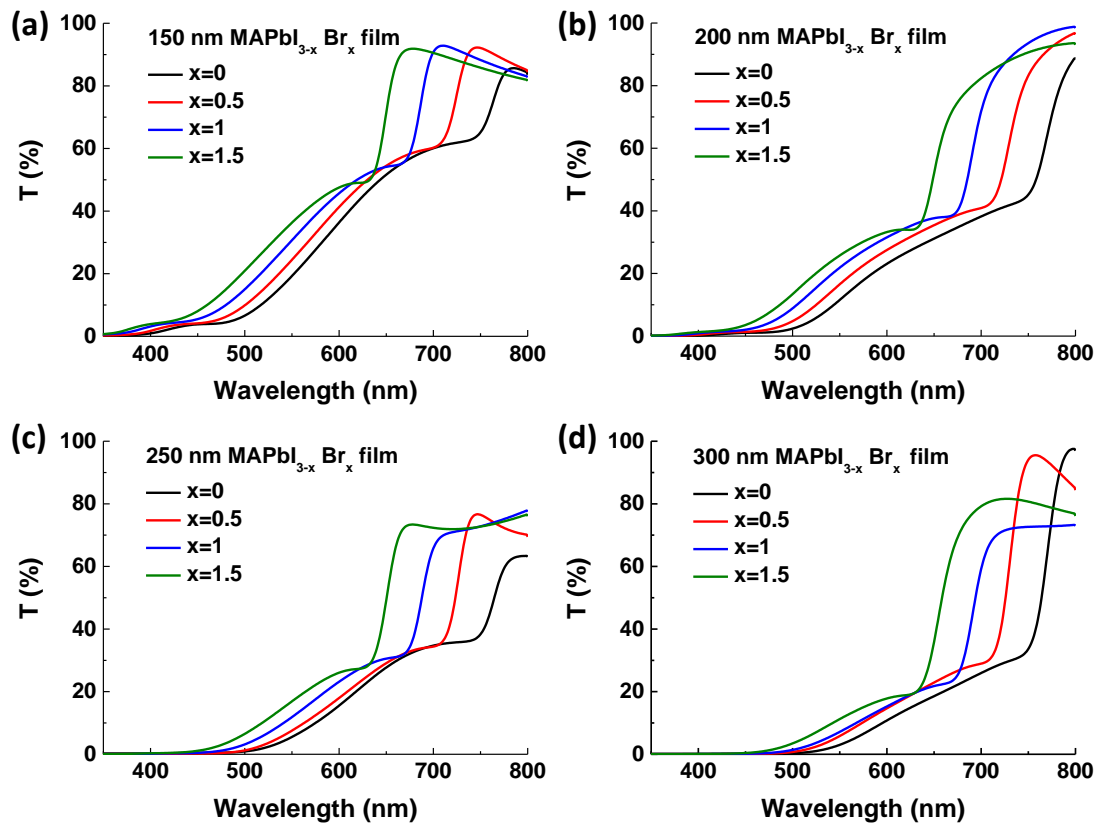


Figure S1. The transmittance spectra of MAPbI_{3-x}Br_x (x=0, 0.5, 1 and 1.5) films with different thicknesses, (a) 150 nm, (b) 200 nm, (c) 250 nm and (d) 300 nm.

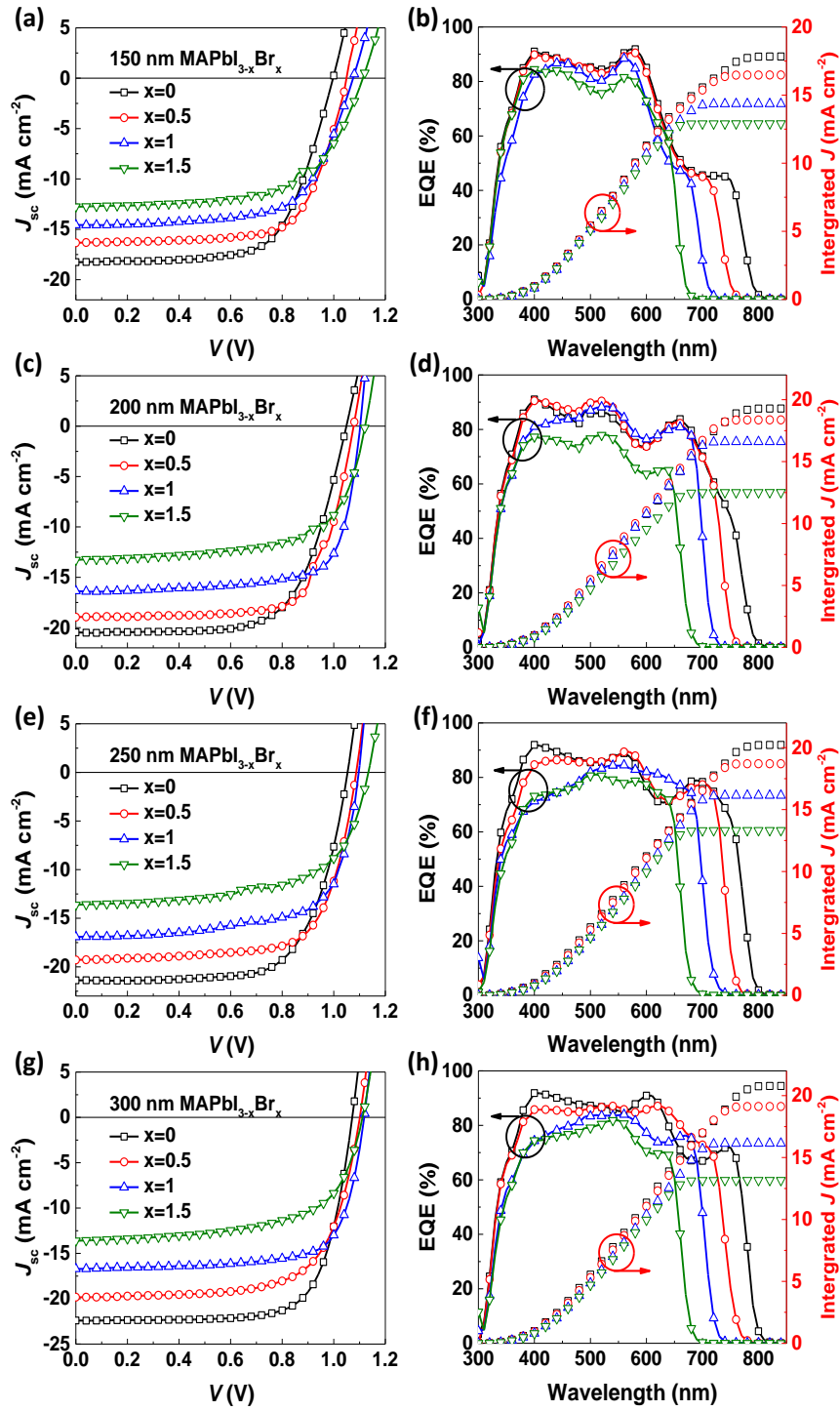


Figure S2. The J - V and EQE curves of opaque Pero-SCs with different thicknesses of $\text{MAPbI}_{3-x}\text{Br}_x$ ($x=0, 0.5, 1$ and 1.5) films, (a),(b) 150 nm, (c), (d) 200 nm, (e),(f) 250 nm and (g),(h) 300 nm.

Table S1. Photovoltaic parameters of opaque Pero-SCs with different thicknesses of MAPbI_{3-x}Br_x (x=0, 0.5, 1 and 1.5).
150 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 1.00 | 18.25 | 66.4 | 12.08 |
| x=0.5 | 1.05 | 16.33 | 69.4 | 11.90 |
| x=1 | 1.08 | 14.58 | 65.8 | 10.30 |
| x=1.5 | 1.11 | 12.75 | 62.2 | 8.80 |

200 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 1.05 | 20.47 | 67.0 | 14.39 |
| x=0.5 | 1.07 | 18.56 | 71.7 | 14.23 |
| x=1 | 1.10 | 16.36 | 74.3 | 13.30 |
| x=1.5 | 1.12 | 13.23 | 65.2 | 9.71 |

250 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 1.05 | 21.38 | 68.5 | 15.43 |
| x=0.5 | 1.07 | 19.35 | 69.0 | 14.34 |
| x=1 | 1.09 | 16.59 | 70.8 | 12.70 |
| x=1.5 | 1.13 | 13.62 | 62.0 | 9.58 |

300 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 1.07 | 22.40 | 73.0 | 17.53 |
| x=0.5 | 1.10 | 19.83 | 68.1 | 14.88 |
| x=1 | 1.12 | 16.70 | 73.5 | 13.72 |
| x=1.5 | 1.11 | 13.60 | 62.1 | 9.39 |

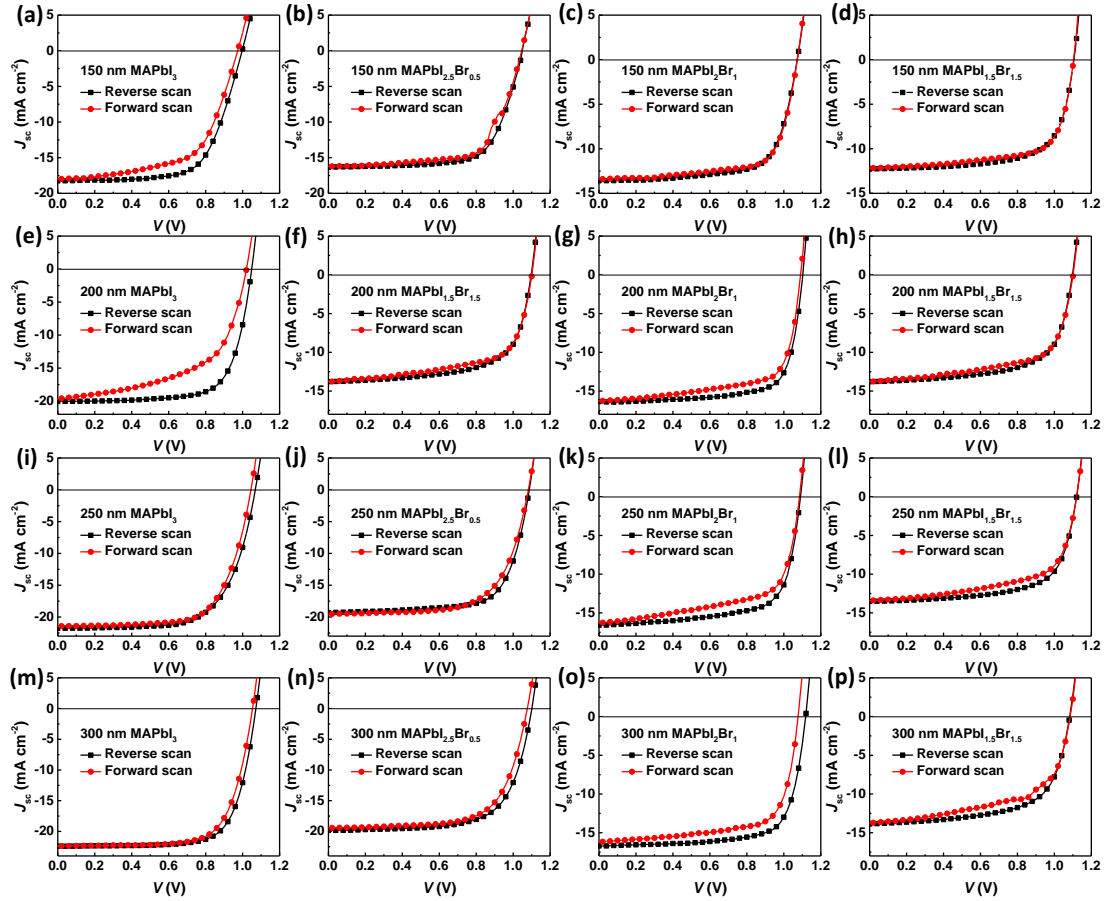


Figure S3. J - V curves of opaque Pero-SCs with different thicknesses of $\text{MAPb}_{3-x}\text{Br}_x$ ($x=0, 0.5, 1$ and 1.5) film using reverse and forward scans under the illumination of AM 1.5G with power of 100 mW cm^{-2} . Scan range $-0.2 - 1.2 \text{ V}$, scan rate 0.02 V s^{-1} , delay time 100 ms .

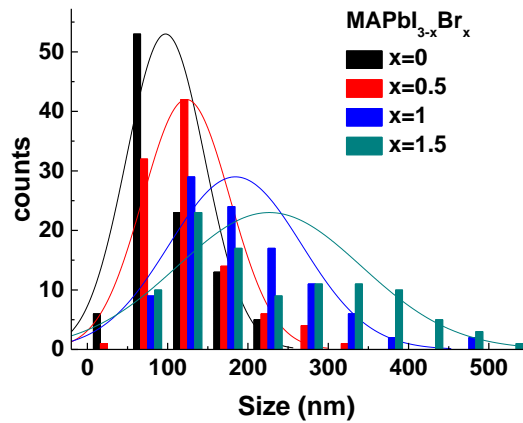


Figure S4. The analysis of grain size in the $\text{MAPb}_{3-x}\text{Br}_x$ ($x=0, 0.5, 1$ and 1.5) films.

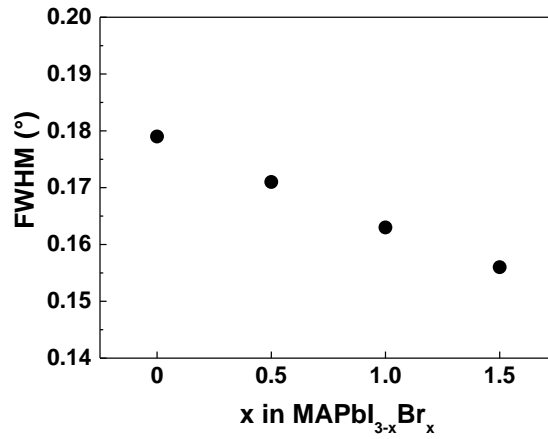


Figure S5. FWHM of the (110) diffraction versus the Br content of MAPbI_{3-x}Br_x films.

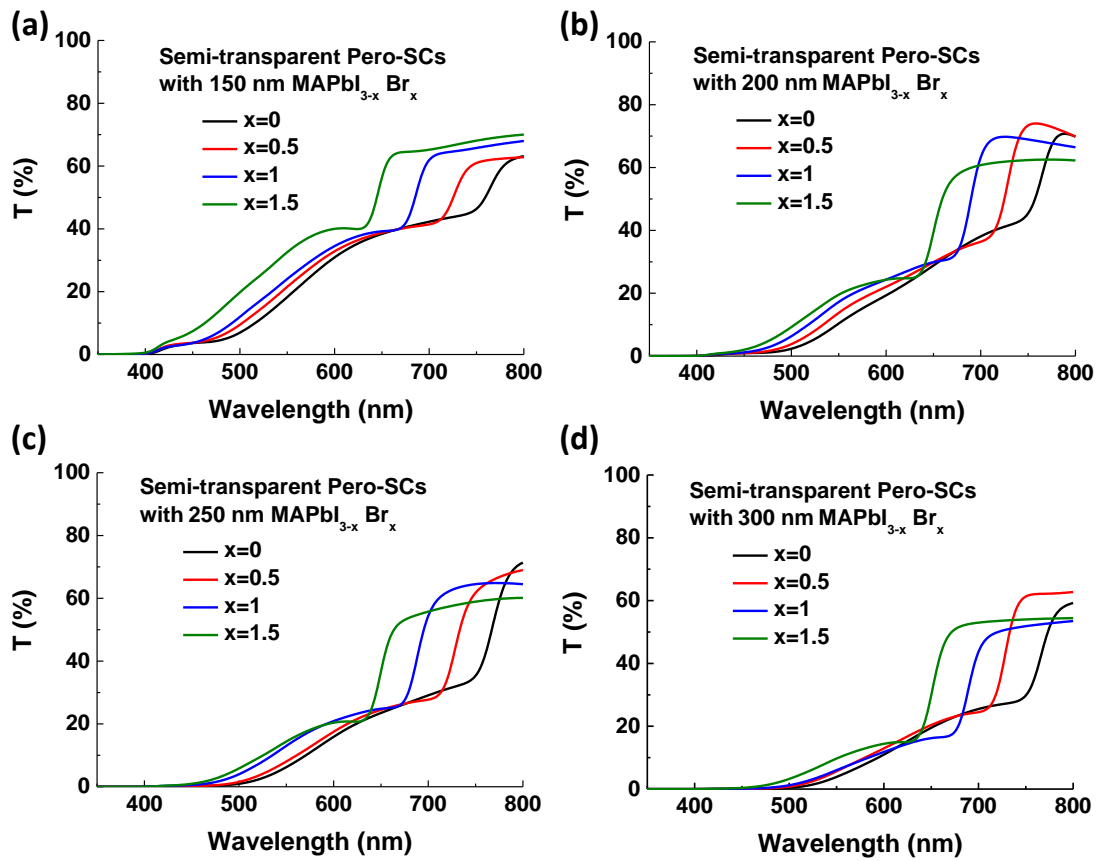


Figure S6. Transparent spectra of semi-transparent Pero-SCs with different thicknesses of MAPbI_{3-x}Br_x (x=0, 0.5, 1 and 1.5) film, (a) 150 nm, (b) 200 nm, (c) 250 nm and (d) 300 nm.

Table S2. Photovoltaic parameters of semi-transparent Pero-SCs with different thicknesses of MAPbI_{3-x}Br_x (x=0, 0.5,1 and 1.5) film.

150 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 1.01 | 15.53 | 69.0 | 10.83 |
| x=0.5 | 1.05 | 13.58 | 68.3 | 9.73 |
| x=1 | 1.07 | 11.93 | 67.1 | 8.66 |
| x=1.5 | 1.11 | 9.77 | 62.3 | 6.84 |

200 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 1.00 | 17.77 | 66.6 | 11.78 |
| x=0.5 | 1.07 | 16.21 | 71.0 | 12.33 |
| x=1 | 1.10 | 14.17 | 70.7 | 11.03 |
| x=1.5 | 1.11 | 11.85 | 69.9 | 9.18 |

250 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 1.00 | 19.53 | 67.6 | 13.24 |
| x=0.5 | 1.08 | 17.12 | 70.7 | 13.10 |
| x=1 | 1.11 | 15.10 | 72.8 | 12.19 |
| x=1.5 | 1.12 | 12.37 | 71.0 | 9.82 |

300 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 1.02 | 20.92 | 66.3 | 14.15 |
| x=0.5 | 1.07 | 17.60 | 71.9 | 13.54 |
| x=1 | 1.11 | 15.62 | 70.2 | 12.26 |
| x=1.5 | 1.13 | 12.79 | 69.7 | 10.03 |

Table S3. Photovoltaic parameters of semi-transparent Pero-SCs with different thicknesses of MAPbI_{3-x}Br_x (x=0, 0.5,1 and 1.5) film measured from Au side.

150 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 0.98 | 9.09 | 69.0 | 5.89 |
| x=0.5 | 1.01 | 8.12 | 66.9 | 5.50 |
| x=1 | 1.04 | 7.11 | 66.6 | 4.94 |
| x=1.5 | 1.05 | 5.36 | 58.9 | 3.41 |

200 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 0.98 | 10.82 | 70.9 | 7.56 |
| x=0.5 | 1.04 | 9.75 | 72.9 | 7.38 |
| x=1 | 1.05 | 8.15 | 71.9 | 6.15 |
| x=1.5 | 1.06 | 6.88 | 70.7 | 5.17 |

250 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 0.98 | 11.56 | 71.5 | 8.10 |
| x=0.5 | 1.04 | 10.02 | 72.3 | 7.59 |
| x=1 | 1.07 | 9.13 | 73.7 | 7.20 |
| x=1.5 | 1.06 | 7.26 | 71.9 | 5.56 |

300 nm thickness of perovskite layer

| MAPbI _{3-x} Br _x | V _{oc} (V) | J _{sc} (mA cm ⁻²) | FF (%) | PCE (%) |
|--------------------------------------|---------------------|--|--------|---------|
| x=0 | 0.96 | 13.42 | 72.7 | 9.31 |
| x=0.5 | 1.04 | 10.99 | 71.2 | 8.29 |
| x=1 | 1.07 | 9.67 | 73.7 | 7.64 |
| x=1.5 | 1.08 | 7.81 | 69.6 | 5.88 |

Table S4. Summary of semi-transparent Pero-SCs reported in the literature.

| Active materials | configuration | Active thickness (nm) | Wavelength (nm) | AVT (%) | PCE (%) | Ref. |
|--|--|-----------------------|-----------------|---------|---------|------|
| CH ₃ NH ₃ PbI ₃ island | Glass/FTO/ TiO ₂ / CH ₃ NH ₃ PbI ₃ island /spiro-OMeTAD/Au | ----- | 370-740 | 30 | 3.5 | [1] |
| CH ₃ NH ₃ PbI ₃ island | Glass/FTO/TiO ₂ / CH ₃ NH ₃ PbI ₃ island /Octadecyl-trichlorosilane/spiro-OMeTAD/Au | ----- | ----- | 38 | 6.1 | [2] |
| CH ₃ NH ₃ PbI ₃ island | Glass/Compact TiO ₂ / CH ₃ NH ₃ PbI ₃ island/Spiro-OMeTAD/Au | ----- | 370-740 | 34 | 6.4 | [3] |
| NH ₂ CH=NH ₂ PbI ₃ island | Glass/Compact TiO ₂ /NH ₂ CH=NH ₂ PbI ₃ island/Spiro-OMeTAD/Au | ----- | 370-740 | 28 | 5.2 | [3] |
| CH ₃ NH ₃ PbI ₃ island | FTO/TiO ₂ /PS interlayer/ CH ₃ NH ₃ PbI ₃ island/PTAA/PEDOT:PSS | ----- | ----- | 20.9 | 6.17 | [4] |
| CH ₃ NH ₃ PbI ₃ grid | FTO glass/ compact TiO ₂ /mesoporous TiO ₂ /grid of CH ₃ NH ₃ PbI ₃ /Au | ----- | 400-800 | 19 | 4.98 | [5] |
| CH ₃ NH ₃ PbI ₃ | Glass/ITO/PEDOT:PSS/CH ₃ NH ₃ PbI ₃ /PCBM/Au/LiF | 40 | 400-800 | 35 | 3.4 | [6] |
| | | 100 | | 29 | 6.4 | |
| | | 180 | | 22 | 7.3 | |
| | | 280 | | 10 | 7.73 | |
| CH ₃ NH ₃ PbI ₃ | Glass/CuSCN/CH ₃ NH ₃ PbI ₃ /PCBM/Ag | 180 | ----- | 25 | 10 | [7] |
| | | 240 | | 13 | 10.7 | |
| CH ₃ NH ₃ PbI _{3-x} Cl _x | ITO glass/PEDOT:PSS/CH ₃ NH ₃ PbI _{3-x} Cl _x /PC ₆₀ BM/ZnO/Ag NW | 150 | ----- | 28.4 | 8.49 | [8] |
| | | 70 | | 37 | 7.81 | |
| CH ₃ NH ₃ PbI _{3-x} Cl _x | ITO glass/PEDOT:PSS/CH ₃ NH ₃ PbI _{3-x} Cl _x /PC ₆₀ BM/ZnO/Ag NW | 100 | 370-740 | 29 | 9.55 | [9] |
| | | 129 | | 23 | 10.81 | |
| | | 339 | | 14 | 14 | |
| CH ₃ NH ₃ PbI ₃ | ITO Glass/PEDOT:PSS/CH ₃ NH ₃ PbI ₃ /ALD ZnO/Ag NW/ALD Al ₂ O ₃ -coated PET | 220 | 380-750 | 25.5 | 10.8 | [10] |
| | | 54 | | 31 | 5.3 | |
| CH ₃ NH ₃ PbI ₃ | Glass/FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /Spiro-OMeTAD/MoO ₃ /Au/MoO ₃ | 107 | 370-740 | 19 | 8.8 | [11] |
| | | 141 | | 16 | 10.1 | |
| | | 280 | | 7 | 13.6 | |
| CH ₃ NH ₃ PbI ₃ | Glass/FTO/TiO ₂ /CH ₃ NH ₃ PbI ₃ /HTL with PEDOT/ITO glass | 5000 rpm | ----- | 17.3 | 12.55 | [12] |
| | | 4500 rpm | | 15.3 | 13.25 | |
| | | 4000 rpm | | 12.5 | 14.35 | |
| | | 3500 rpm | | 9.6 | 14.5 | |

| | | | | | | |
|--|---|--------------|---------|----------|------------|------|
| | | 3000 rpm | | 7.8 | 15.1 | |
| | | 2500 rpm | | 6.3 | 15.8 | |
| CH ₃ NH ₃ PbI ₃ | Glass/FTO/ZnO/PCBM/CH ₃ NH ₃ PbI ₃ / Spiro-OMeTAD/MoO ₃ /In ₂ O ₃ :H | ---- | ---- | ---- | 14.5 | [13] |
| CH ₃ NH ₃ PbI _{3-x} Cl _x | Glass/Au/PEDOT: PSS/CH ₃ NH ₃ PbI _{3-x} Cl _x / PCBM/DMD | 240 | 500-800 | 15.9 | 8.67 | [14] |
| CH ₃ NH ₃ PbI _{3-x} Cl _x | TO/PEDOT:PSS/ CH ₃ NH ₃ PbI _{3-x} Cl _x : PVP/CYTOP/PCBM/PEIE/Ag | 90 | 400-800 | 34 | 5.36 | [15] |
| CH ₃ NH ₃ PbI ₃ | glass/ITO/PEDOT:PSS/CH ₃ NH ₃ PbI ₃ /P CBM/C ₆₀ /Al | 150 110 | 400-800 | 29 34 | 9.4 8.2 | [16] |
| CH ₃ NH ₃ PbI _{3-x} Cl _x | Glass/FTO/compact TiO ₂ /SiO ₂ HC/ CH ₃ NH ₃ PbI _{3-x} Cl _x /Spiro-OMETAD/Ag | ---- | 380-780 | 28 | 9.5 | [17] |
| CH ₃ NH ₃ PbI ₃ | FTO/TiO ₂ /PCBM/ CH ₃ NH ₃ PbI ₃ /Sprio- OMeTAD/PEDOT:PSS | 100 | ---- | 23 | 8.23 | [18] |
| CH ₃ NH ₃ PbI ₃ | Glass/ITO/PEDOT:PSS/CH ₃ NH ₃ PbI ₃ /P CBM/Au | 150 ----- | 370-740 | 18 3 | 9.1 12 | [19] |

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