**Supplementary Information**

**Enhancing performance of low-temperature processed CsPbI2Br all-inorganic perovskite solar cells using polyethylene oxide-modified TiO2**

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**Table S1.** Photovoltaic parameters of PEO-PSCs based on different PEO concentrations. *V*oc, *J*sc, and FF represent open circuit voltage, short-circuit current density, and fill factor, respectively

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| PEO concentration / (mg·mL−1) | *V*oc / V | *J*sc / (mA·cm−2) | FF | PCE / % |
| 0 | 1.104 | 13.23 | 0.625 | 9.13 |
| 0.06 | 1.101 | 13.44 | 0.642 | 9.51 |
| 0.12 | 1.172 | 13.80 | 0.660 | 10.68 |
| 0.18 | 1.213 | 13.73 | 0.675 | 11.24 |
| 0.24 | 1.170 | 13.66 | 0.658 | 10.51 |

**Table S2.** Photovoltaic parameter statistics of reported carbon-based CsPbI2Br PSCs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Device architecture | *V*oc / V | *J*sc / (mA·cm−2) | FF | PCE / % | Ref. |
| FTO/TiO2/PEO/CsPbI2Br/Carbon | 1.213  | 13.79  | 0.675  | 11.24  | This work |
| FTO/c-TiO2/CsPbI2Br/Carbon | 1.150  | 13.54  | 0.642  | 10.00  | [1] |
| FTO/TiO2/CsPbI2Br/P3HT-MWCNT/Carbon | 1.210  | 13.35  | 0.620  | 10.01  | [2] |
| FTO/TiO2/CsCl/CsPbI2Br/Carbon | 1.150  | 14.39  | 0.691  | 11.45  | [3] |
| FTO/TiO2-TiCl*x*/CsPbI2Br/Carbon | 1.280  | 14.21  | 0.794  | 14.46  | [4] |
| FTO/TiO2/BMIMPF6/CsPbI2Br/Carbon | 1.220  | 14.33  | 0.753  | 13.19  | [5] |
| FTO/TiO2/CsPbI2Br/CuPc/Carbon  | 1.220  | 14.33  | 0.750  | 13.16  | [7] |
| FTO/TiO2/CsPbI2Br/Cs2SnI6 NCs/Carbon | 1.267  | 14.51  | 0.798  | 14.67  | [8] |
| FTO/TiO2/CsPbI2Br/BN-DHI/Carbon | 1.280  | 14.12  | 0.781  | 14.14  | [9] |
| FTO/TiO2@Sb2S3-MPA/CsPbI2Br/Carbon | 1.290  | 14.50  | 0.775  | 14.59  | [10] |
| FTO/TiO2-Mxene/CsPbI2Br/Carbon (Reported the best PCE) | 1.289  | 14.96  | 0.803  | 15.48  | [11]  |

**Table S3.** Summary of photovoltaic parameters for Reference-PSCs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Reference-PSCs | *V*oc / V | *J*sc / (mA·cm−2) | FF | PCE / % |
| 1 | 1.064  | 13.15  | 0.604  | 8.45  |
| 2 | 1.073  | 13.15  | 0.617  | 8.70  |
| 3 | 1.066  | 13.17  | 0.625  | 8.77  |
| 4 | 1.064  | 13.21  | 0.610  | 8.57  |
| 5 | 1.069  | 13.14  | 0.608  | 8.54  |
| 6 | 1.082  | 13.15  | 0.607  | 8.64  |
| 7 | 1.084  | 13.23  | 0.620  | 8.89  |
| 8 | 1.091  | 13.26  | 0.618  | 8.94  |
| 9 | 1.092  | 13.28  | 0.616  | 8.93  |
| 10 | 1.099  | 13.21  | 0.614  | 8.91  |
| 11 | 1.076  | 13.13  | 0.605  | 8.55  |
| 12 | 1.075  | 13.14  | 0.603  | 8.52  |
| 13 | 1.085  | 13.18  | 0.602  | 8.61  |
| 14 | 1.089  | 13.31  | 0.611  | 8.86  |
| 15 | 1.092  | 13.23  | 0.609  | 8.80  |
| 16 | 1.093  | 13.20  | 0.611  | 8.82  |
| 17 | 1.094  | 13.33  | 0.613  | 8.94  |
| 18 | 1.092  | 13.21  | 0.615  | 8.87  |
| 19 | 1.088  | 13.09  | 0.607  | 8.64  |
| 20 | 1.089  | 13.13  | 0.605  | 8.65  |
| 21 | 1.089  | 13.14  | 0.595  | 8.51  |
| 22 | 1.099  | 13.18  | 0.597  | 8.65  |
| 23 | 1.093  | 13.17  | 0.599  | 8.62  |
| 24 | 1.089  | 13.09  | 0.619  | 8.82  |
| 25 | 1.094  | 13.19  | 0.608  | 8.77  |
| 26 | 1.096  | 13.19  | 0.612  | 8.85  |
| 27 | 1.099  | 13.09  | 0.613  | 8.82  |
| 28 | 1.101  | 13.09  | 0.606  | 8.73  |
| 29 | 1.104  | 13.19  | 0.607  | 8.84  |
| 30 | 1.109  | 13.19  | 0.590  | 8.63  |
| 31 | 1.089  | 13.17  | 0.591  | 8.48  |
| 32 | 1.098  | 13.18  | 0.594  | 8.60  |
| 33 | 1.087  | 13.18  | 0.596  | 8.54  |
| 34 | 1.089  | 13.16  | 0.603  | 8.64  |
| 35 | 1.095  | 13.18  | 0.601  | 8.67  |
| Average | 1.088  | 13.18  | 0.607  | 8.70 |

**Table S4.** Summary of photovoltaic parameters for PEO-PSCs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| PEO-PSCs | *V*oc / V | *J*sc / (mA·cm−2) | FF | PCE / % |
| 1 | 1.171 | 13.77 | 0.673 | 10.85 |
| 2 | 1.172 | 13.74 | 0.670 | 10.79 |
| 3 | 1.182 | 13.82 | 0.664 | 10.85 |
| 4 | 1.185 | 13.81 | 0.662 | 10.83 |
| 5 | 1.187 | 13.81 | 0.666 | 10.92 |
| 6 | 1.196 | 13.85 | 0.659 | 10.92 |
| 7 | 1.211 | 13.82 | 0.663 | 11.10 |
| 8 | 1.213 | 13.73 | 0.675 | 11.24 |
| 9 | 1.190 | 13.84 | 0.658 | 10.84 |
| 10 | 1.186 | 13.82 | 0.664 | 10.88 |
| 11 | 1.179 | 13.80 | 0.665 | 10.82 |
| 12 | 1.176 | 13.82 | 0.667 | 10.84 |
| 13 | 1.182 | 13.85 | 0.665 | 10.89 |
| 14 | 1.184 | 13.82 | 0.668 | 10.93 |
| 15 | 1.186 | 13.82 | 0.655 | 10.74 |
| 16 | 1.183 | 13.85 | 0.667 | 10.93 |
| 17 | 1.181 | 13.81 | 0.668 | 10.89 |
| 18 | 1.191 | 13.85 | 0.661 | 10.90 |
| 19 | 1.193 | 13.79 | 0.660 | 10.86 |
| 20 | 1.189 | 13.81 | 0.663 | 10.89 |
| 21 | 1.188 | 13.81 | 0.671 | 11.01 |
| 22 | 1.180 | 13.81 | 0.666 | 10.85 |
| 23 | 1.182 | 13.80 | 0.658 | 10.73 |
| 24 | 1.185 | 13.78 | 0.670 | 10.94 |
| 25 | 1.190 | 13.77 | 0.675 | 11.06 |
| 26 | 1.189 | 13.75 | 0.674 | 11.02 |
| 27 | 1.189 | 13.75 | 0.672 | 10.99 |
| 28 | 1.177 | 13.76 | 0.659 | 10.67 |
| 29 | 1.189 | 13.84 | 0.667 | 10.98 |
| 30 | 1.186 | 13.88 | 0.665 | 10.95 |
| 31 | 1.185 | 13.79 | 0.663 | 10.83 |
| 32 | 1.188 | 13.85 | 0.661 | 10.88 |
| 33 | 1.187 | 13.85 | 0.659 | 10.83 |
| 34 | 1.184 | 13.81 | 0.657 | 10.74 |
| 35 | 1.187 | 13.82 | 0.655 | 10.74 |
| Average | 1.186 | 13.81 | 0.665 | 10.89 |

**Table S5.** Summary of HI values for Reference- and PEO-PSCs

|  |  |  |
| --- | --- | --- |
| Number of devices | HI in Reference-PSC | HI in PEO-PSC |
| 1 | 0.202 | 0.074 |
| 2 | 0.198 | 0.090 |
| 3 | 0.196 | 0.075 |
| 4 | 0.198 | 0.082 |
| 5 | 0.203 | 0.091 |
| 6 | 0.201 | 0.091 |
| 7 | 0.200 | 0.091 |
| 8 | 0.198 | 0.091 |
| 9 | 0.195 | 0.091 |
| 10 | 0.204 | 0.081 |
| 11 | 0.210 | 0.081 |
| 12 | 0.200 | 0.080 |
| 13 | 0.212 | 0.080 |
| 14 | 0.222 | 0.080 |
| 15 | 0.231 | 0.076 |
| 16 | 0.240 | 0.078 |
| 17 | 0.221 | 0.080 |
| 18 | 0.226 | 0.079 |
| 19 | 0.223 | 0.071 |
| 20 | 0.215 | 0.076 |
| 21 | 0.214 | 0.078 |
| 22 | 0.209 | 0.081 |
| 23 | 0.207 | 0.078 |
| 24 | 0.208 | 0.070 |
| 25 | 0.234 | 0.092 |
| 26 | 0.221 | 0.086 |
| 27 | 0.218 | 0.087 |
| 28 | 0.230 | 0.084 |
| 29 | 0.221 | 0.088 |
| 30 | 0.220 | 0.083 |
| 31 | 0.235 | 0.082 |
| 32 | 0.240 | 0.074 |
| 33 | 0.215 | 0.073 |
| 34 | 0.216 | 0.072 |
| 35 | 0.218 | 0.071 |
| Average | 0.214 | 0.081 |

**Table S6.** Fitting data obtained from Nyquist plots of Reference- and PEO-PSC. The CPE-T and CPE-P correspond to capacitor and dispersion index, respectively.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Device | *R*s / (Ω·cm2) | *R*tra / (Ω·cm2) | *R*rec / (Ω·cm2) | CPEtra-T / (nF·cm−2) | CPErec-T / (nF·cm−2) | CPEtra-P | CPErec-P |
| Reference-PSC | 2.88 | 15.01 | 72.61 | 757.36 | 138.33 | 0.984 | 0.992 |
| PEO-PSC | 2.73 | 9.45 | 109.24 | 1189.89 | 149.56 | 0.989 | 0.981 |



**Fig. S1.** Thickness of (a) TiO2, (b) TiO2/CsPbI2Br, and (c) PEO layer.



**Fig. S2.** (a) XRD patterns. (b) Transmittance spectra of TiO2 and TiO2/PEO film deposited on FTO substrate (FTO/TiO2/PEO).



**Fig. S3.** (a)*J*–*V* curves of PEO-PSCs with different PEO concentrations. (b, c) *V*oc, FF, *J*sc, and PCE as a function of PEO concentrations.



**Fig. S4**. Photovoltaic parameter distributions of Reference- and PEO-PSCs for 35 samples each batch: (a) *V*oc, (b) *J*sc, (c) FF, (d) PCE.



**Fig. S5**. Hysteresis indexes of Reference- and PEO-PSCs for 35 samples each batch.

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