**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

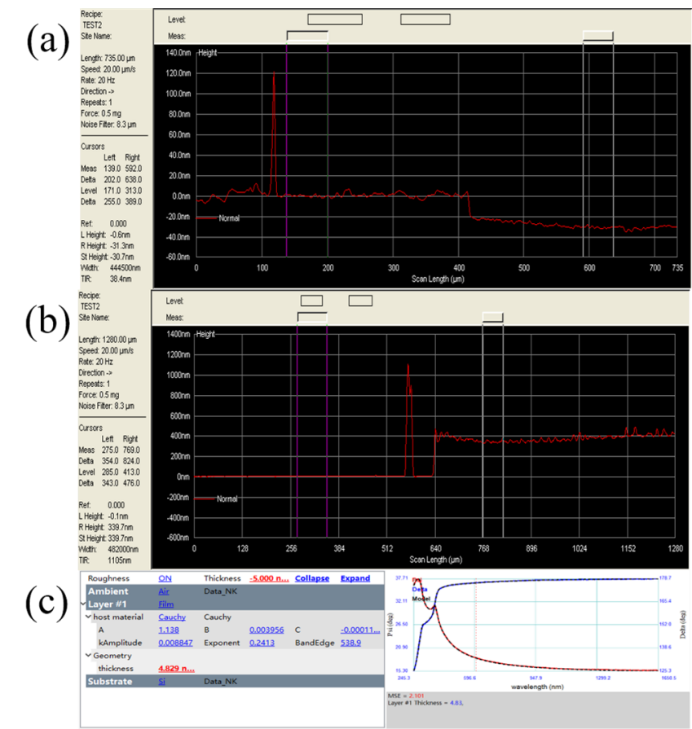
|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| PEO-PSCs | *V*oc / V | *J*sc / (mA·cm−2) | FF | PCE / % |
| 1 | 1.171 | 13.77 | 0.673 | 10.85 |
| 2 | 1.172 | 13.74 | 0.670 | 10.79 |
| 3 | 1.182 | 13.82 | 0.664 | 10.85 |
| 4 | 1.185 | 13.81 | 0.662 | 10.83 |
| 5 | 1.187 | 13.81 | 0.666 | 10.92 |
| 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

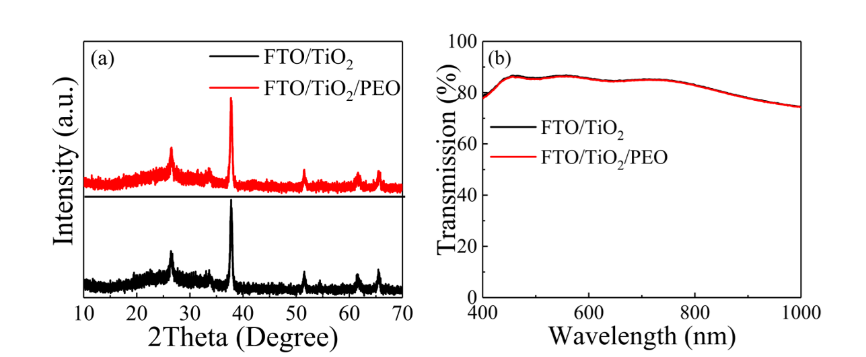
|  |  |  |
| --- | --- | --- |
| Number of devices | HI in Reference-PSC | HI in PEO-PSC |
| 1 | 0.202 | 0.074 |
| 2 | 0.198 | 0.090 |
| 3 | 0.196 | 0.075 |
| 4 | 0.198 | 0.082 |
| 5 | 0.203 | 0.091 |
| 6 | 0.201 | 0.091 |
| 7 | 0.200 | 0.091 |
| 8 | 0.198 | 0.091 |
| 9 | 0.195 | 0.091 |
| 10 | 0.204 | 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.

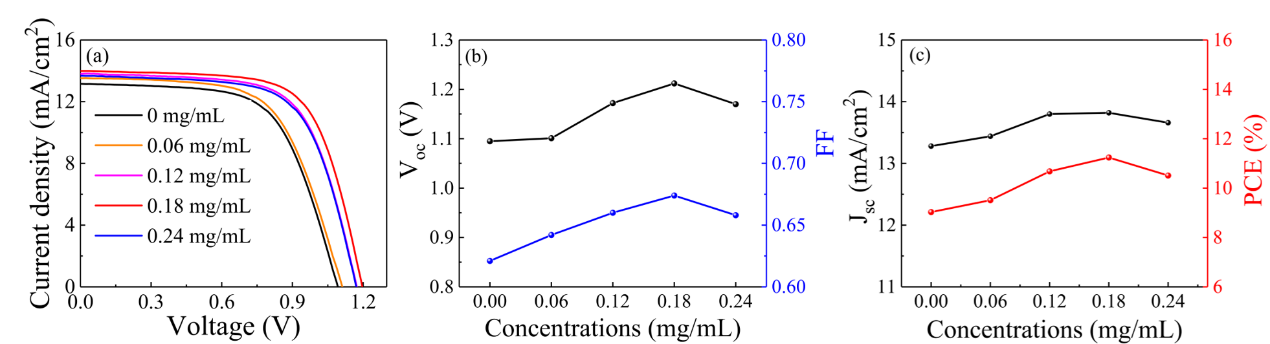
|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Device | *R*s / (Ω·cm2) | *R*tra / (Ω·cm2) | *R*rec / (Ω·cm2) | CPEtra-T / (nF·cm−2) | CPErec-T / (nF·cm−2) | CPEtra-P | CPErec-P |
| Reference-PSC | 2.88 | 15.01 | 72.61 | 757.36 | 138.33 | 0.984 | 0.992 |
| PEO-PSC | 2.73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



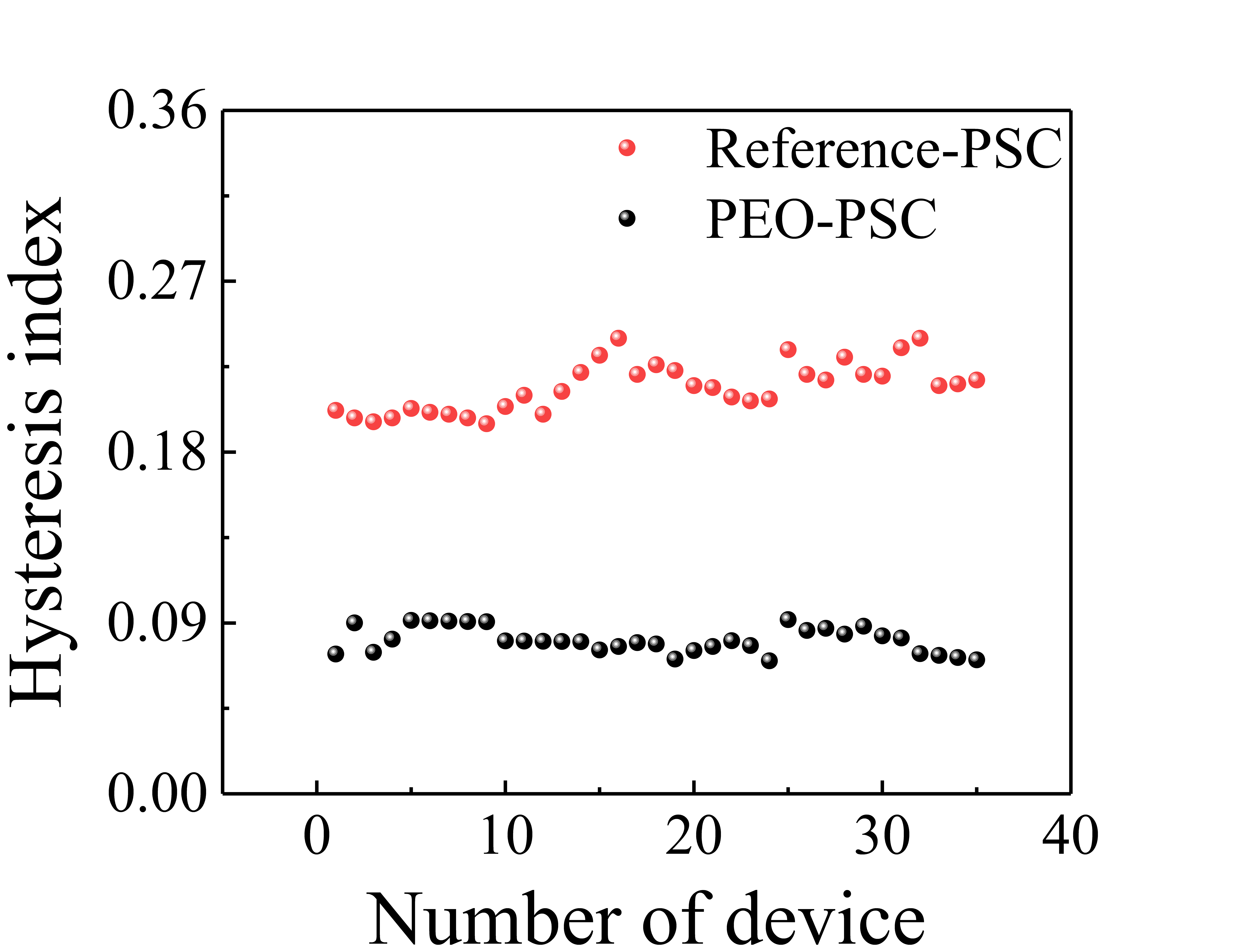
**Fig. S2.** (a) XRD patterns. (b) Transmittance spectra of TiO2 and TiO2/PEO film deposited on FTO substrate (FTO/TiO2/PEO).



**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.

**References:**[1] C. Dong, X.X. Han, Y. Zhao, J.J. Li, L. Chang, and W.N. Zhao, A green anti-solvent process for high performance carbon-based CsPbI2Br all-inorganic perovskite solar cell, *Sol*. *RRL*, 2(2018), No. 9, art. No. 1800139.[2] G.Q. Wang, J.Q. Liu, K. Chen, R. Pathak, A. Gurung, and Q.Q. Qiao, High-performance carbon electrode-based CsPbI2Br inorganic perovskite solar cell based on poly(3-hexylthiophene)-carbon nanotubes composite hole-transporting layer, *J*. *Colloid Interface Sci*., 555(2019), p. 180.[3] W.X. Cai, Y.Q. Lv, K.C. Chen, Z.B. Zhang, Y.Z. Jin, and X.F. Zhou, Carbon-based all-inorganic CsPbI2Br perovskite solar cells using TiO2 nanorod arrays: Interface modification and the enhanced photovoltaic performance, *Energy Fuels*, 34(2020), No. 9, p. 11670.[4] W.R. Wang, Y. Lin, G.Z. Zhang, *et al.*, Modification of compact TiO2 layer by TiCl4–TiCl3 mixture treatment and construction of high-efficiency carbon-based CsPbI2Br perovskite solar cells, *J*. *Energy Chem*., 63(2021), p. 442.[5] R. Yin, K.X. Wang, S. Cui, *et al.*, Dual-interface modification with BMIMPF6 for high-efficiency and stable carbon-based CsPbI2Br perovskite solar cells, *ACS Appl*. *Energy Mater*., 4(2021), No. 9, p. 9294.[6] G.Z. Zhang, P.F. Xie, Z.S. Huang, *et al.*, Modification of energy level alignment for boosting carbon-based CsPbI2Br solar cells with 14% certified efficiency, *Adv*. *Funct*. *Mater*., 31(2021), No. 19, art. No. 2011187.[7] Z.G. Tang, L.J. Zhang, Z.H. Su, *et al.*, A study of interfacial electronic structure at the CuPc/CsPbI2Br interface, *Crystals*, 11(2021), No. 5, art. No. 547.[8] G.Z. Zhang, J.X. Zhang, Y.Y. Liao, Z.X. Pan, H.S. Rao, and X.H. Zhong, Cs2SnI6 nanocrystals enhancing hole extraction for efficient carbon-based CsPbI2Br perovskite solar cells, *Chem*. *Eng*. *J*., 440(2022), art. No. 135710.[9] Q.Y. Guo, J.L. Duan, J.S. Zhang, *et al.*, Universal dynamic liquid interface for healing perovskite solar cells, *Adv*. *Mater*., 34(2022), No. 26, art. No. e2202301.[10] Y. Jing, X. Liu, Y. Xu, *et al.*, Amorphous antimony sulfide nanoparticles construct multi-contact electron transport layers for efficient carbon-based all-inorganic CsPbI2Br perovskite solar cells, *Chem*. *Eng*. *J*., 455(2023), art. No. 140871.[11] Y. Xu, F.L. Liu, R.S. Li, *et al.*, Mxene regulates the stress of perovskite and improves interface contact for high-efficiency carbon-based all-inorganic solar cells, *Chem*. *Eng*. *J*., 461(2023), art. No. 141895.