Supporting Information

'*Bio-inspired'* Carbon Hole Extraction Layer Derived from Aloe Vera Plant for Cost Effective Fully Printable Mesoscopic Perovskite Solar Cells

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Fig. S-1 Thermogravimetric analysis (TGA) curves of as synthesized (black solid line) and annealed (red solid line) at 1000 °C AV-C powder sample.

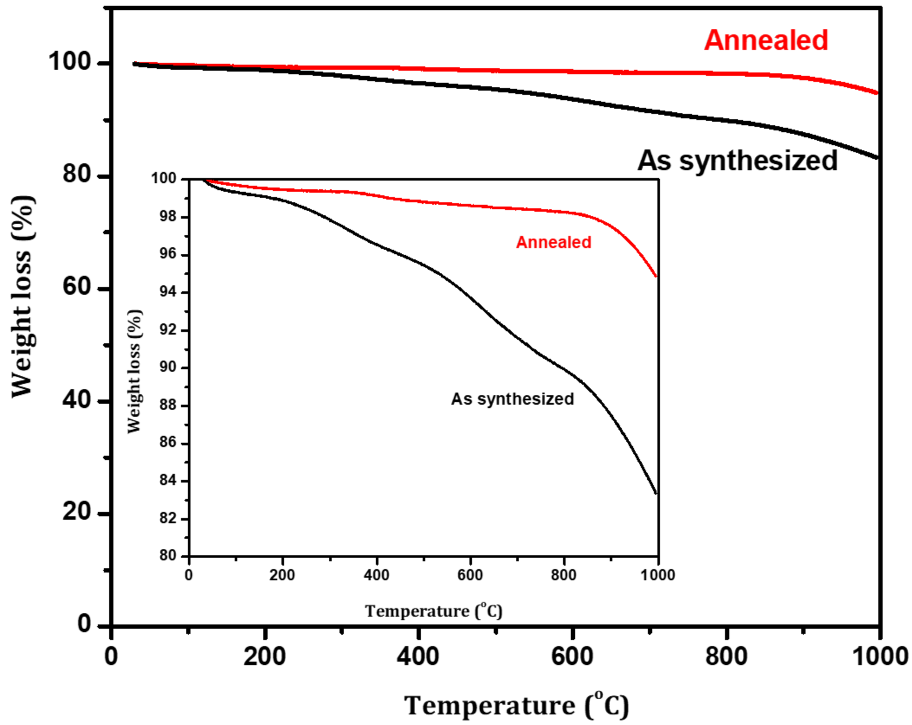


Fig. S-2 Surface morphology of screen-printed commercial colloidal carbon and bio-inspired AV-C after 12 hours' ball milling (a) top-view of screen printed commercial colloidal carbon (b) top-view screen printed AV-C and (c-e) TEM and HRTEM images of AV-C after ball milling for 12 hours at different magnification.

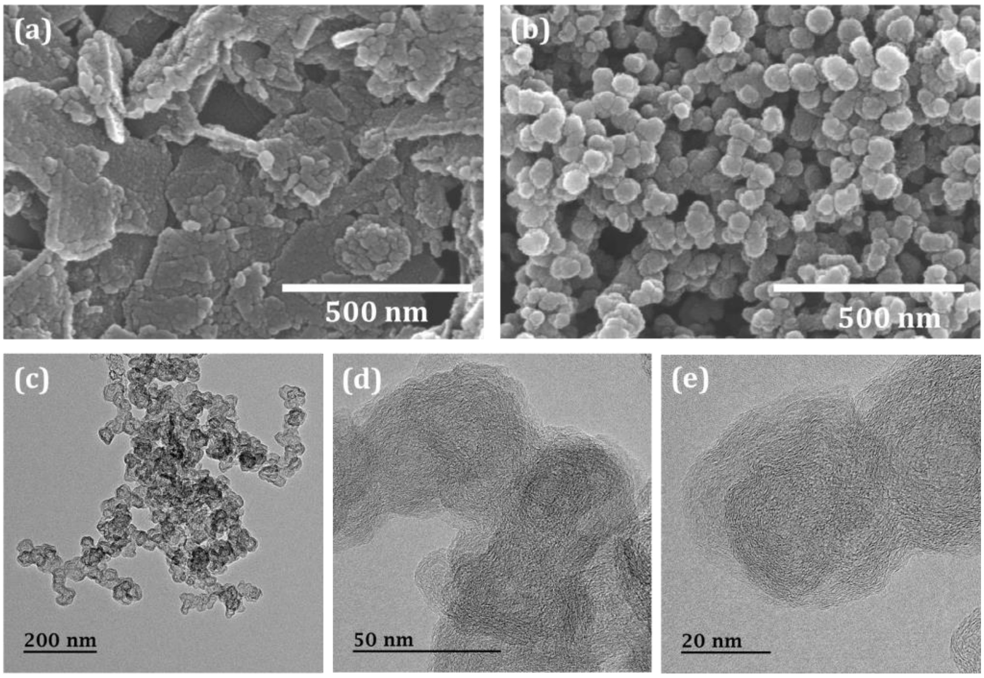
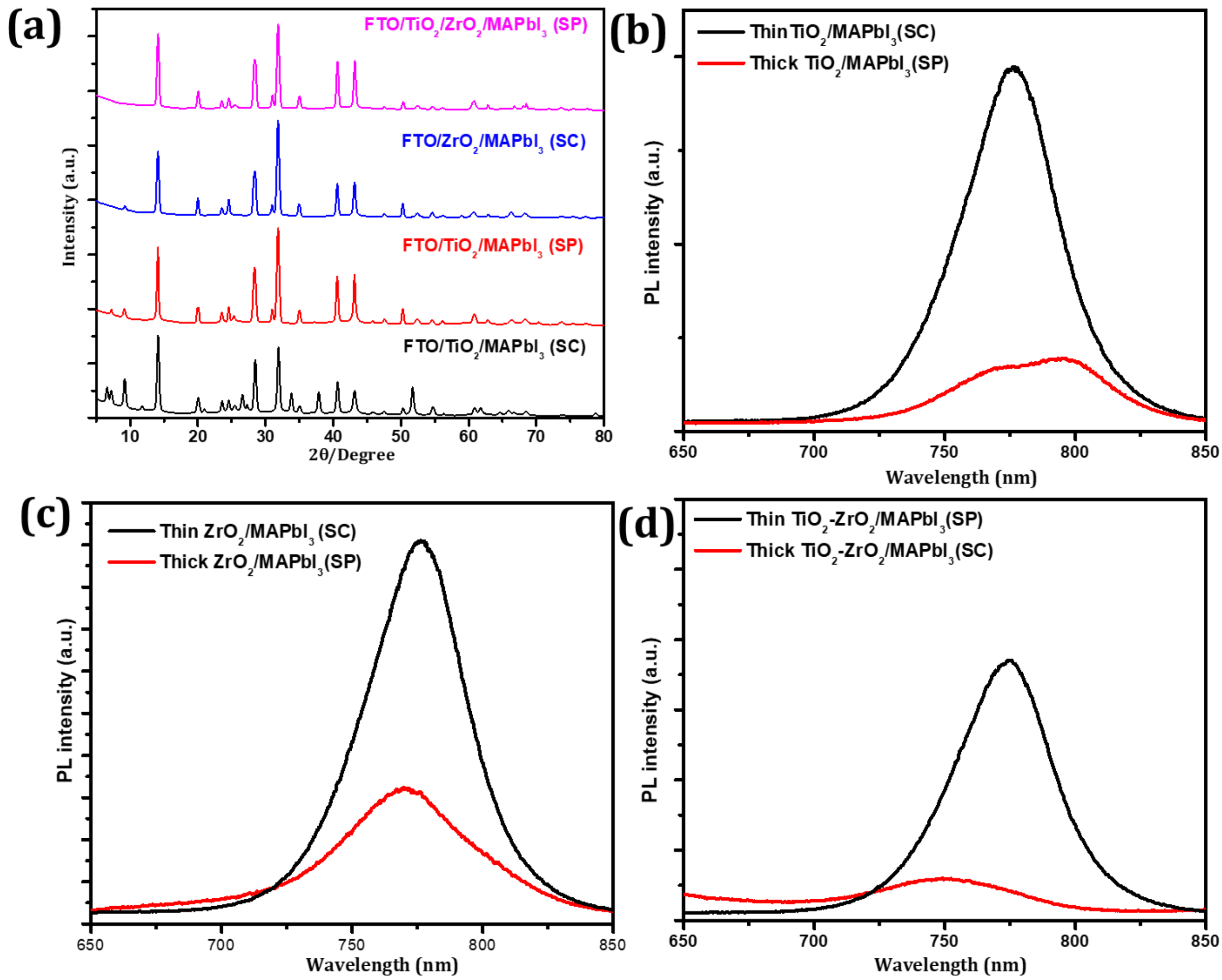


Fig. S-3 (a) XRD spectra $MAPbI_3$ deposited on different substrate. Note: SP: screen printed TiO_2 or ZrO_2; SC: spin coated TiO_2 or ZrO_2 and (b) normalized PL spectra of $MAPbI_3$ perovskite deposited on thin (black solid line) and thick (red solid line) TiO_2 mesoporous oxide (c) normalized PL spectra of $MAPbI_3$ perovskite deposited on thin (black solid line) and thick (red solid line) ZrO_2 (d) normalied PL spectra of $MAPbI_3$ perovskite deposited on thin (red solid line) and thick (black solid line) TiO_2-ZrO_2 bilayers. *All PL spectra were recorded with excitation from perovskite side.*



Discussion Supplementary Fig. S-3: The structural properties of $MAPbI_3$ perovskite deposited on different oxide layer was analyzed by XRD measurements. In order to avoid the peak from AV-C we have recorded the XRD spectra only for perovskite layer deposited/infiltrated onto either mp-TiO_2, ZrO_2 or both oxide samples. The infiltrated or spin coated sample was further annealed at 50 °C for 1h and used for measurements. The XRD spectrum of mp-TiO_2/perovskite exhibits the strong peak at $2\theta=14.1°$ which can be assigned (110) of $MAPbI_3$ crystal. All samples show strong peak at 14.1° which clearly exhibited formation of highly crystalline $MAPbI_3$ layer. Figure S-3b shows the PL spectra of $MAPbI_3$ deposited on thin and thick mp-TiO_2 which clearly shows double around 750-830 nm. Similar observation has been observed for ZrO_2/ $MAPbI_3$ sample however there is no doublet form may be due to front illumination. In case of TiO_2/ZrO_2/ $MAPbI_3$ sample the intensity of screen printed sample reduced drastically which clearly revealed the proper infiltration of $MAPbI_3$ solution and formation of crystalline $MAPbI_3$ crystal.

Fig. S-4 (a) XRD spectra $MAPbI_3$ and $MAPbI_{3-x}Cl_3$ deposited on FTO substrate.

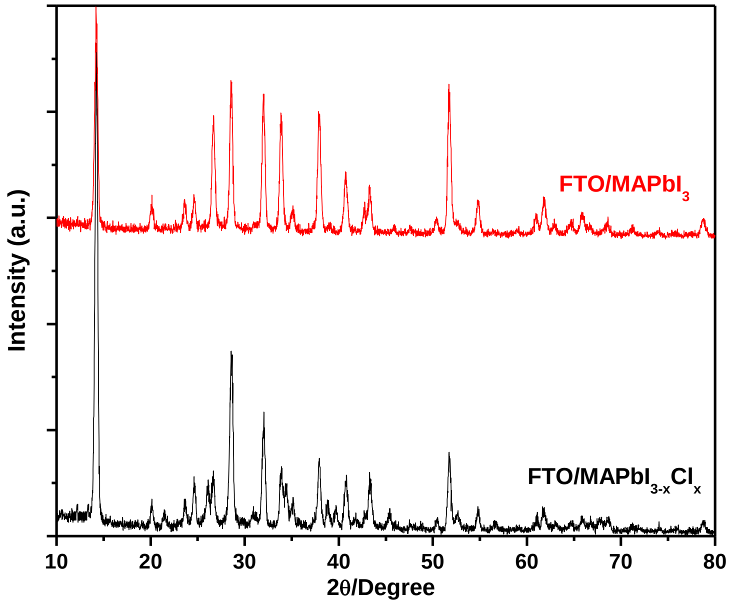
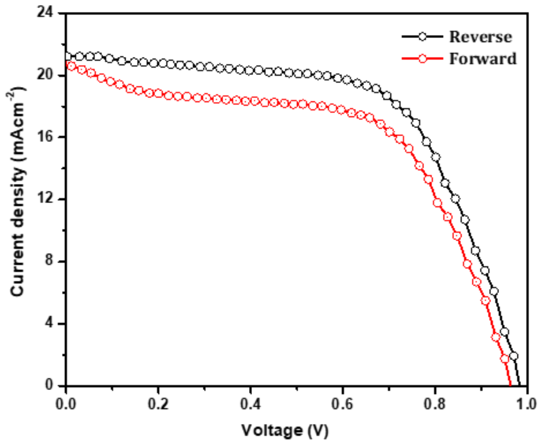


Fig. S-5 Hysteresis analysis of fully printable AV-C based PSC



Scan	F	R
V_{OC} (V)	0.961	0.985
J_{SC} ($mAcm^{-2}$)	20.85	21.22
FF	57 %	61 %
Eff. (%)	11.42	12.75

Fig. S-6 EDS-line mapping of FTO/Bl-TiO_2/(mp-TiO_2/ZrO_2)+$MAPbI_3$/carbon PSC (a) artificially colored cross sectional SEM graph of device (b, c) line profile of all elements (d) EDS line scanning profile of each element across the device from bottom-to-top (e) respective EDS spectrum

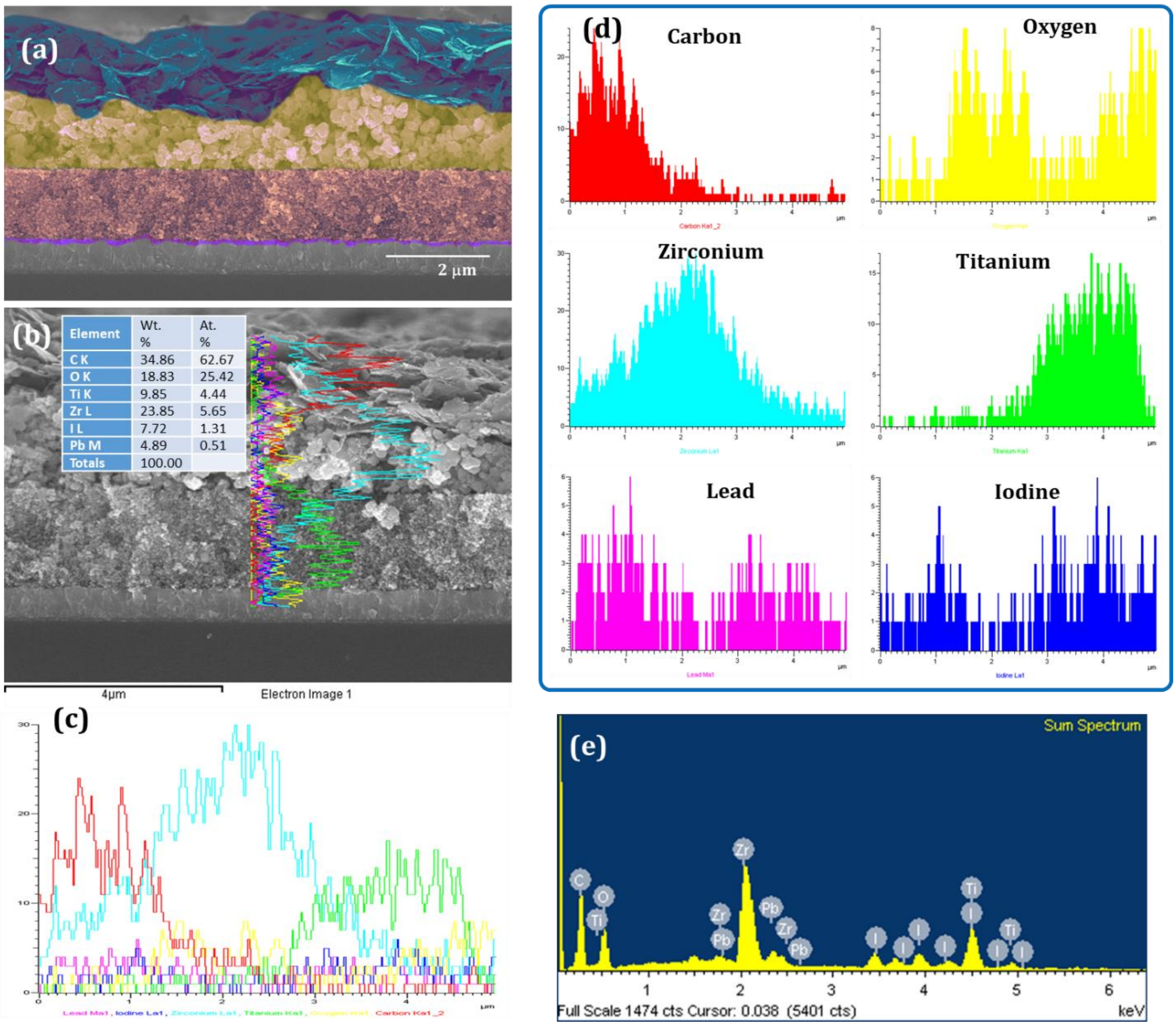


Fig. S-7 EDS-line mapping of FTO/Bl-TiO_2/(mp-TiO_2/ZrO_2) + $MAPbI_3$/AV-C (a) artificially colored cross sectional SEM graph of device (b, c) line profile of all elements (d) EDS line scanning profile of each element across the device from bottom-to-top (e) respective EDS spectrum

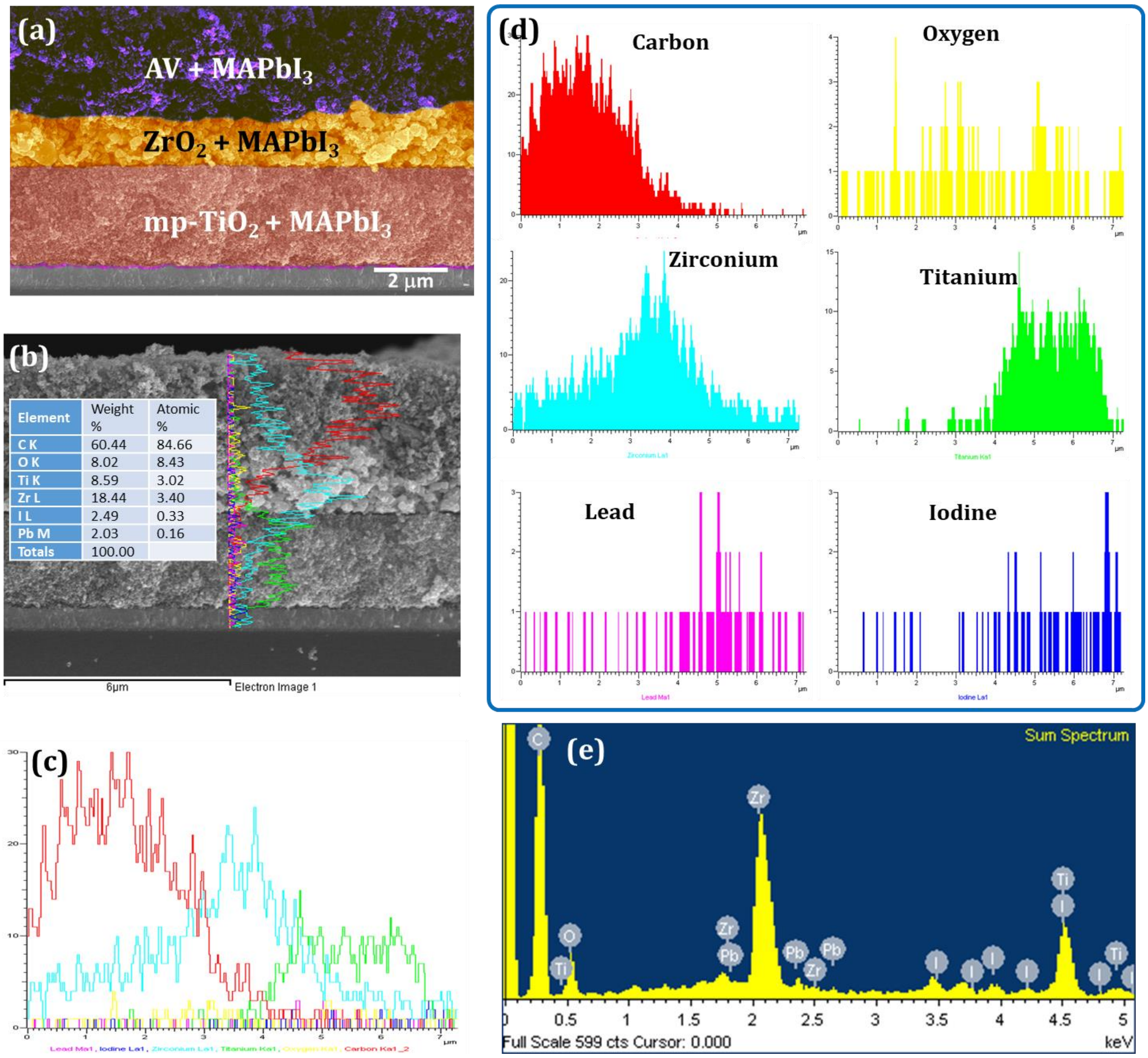
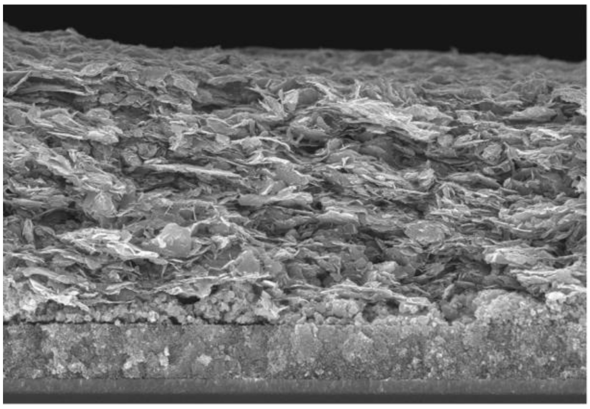


Fig. S-8 J-V characteristics of commercial carbon based fully printable PSC. Inset shows the photovoltaic parameters extracted from the J-V curve.



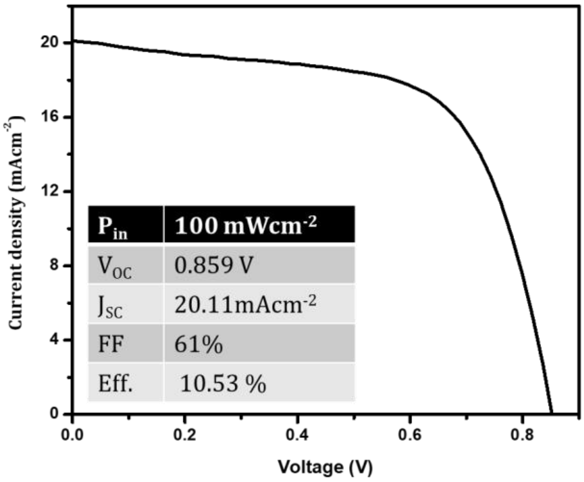
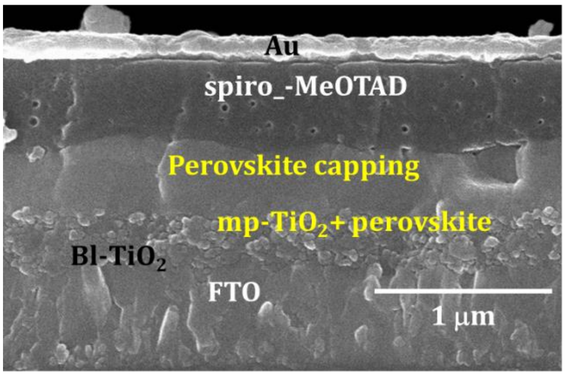


Fig. S-9 Cross-sectional SEM image of conventional spiro-MeOTAD based PSC.



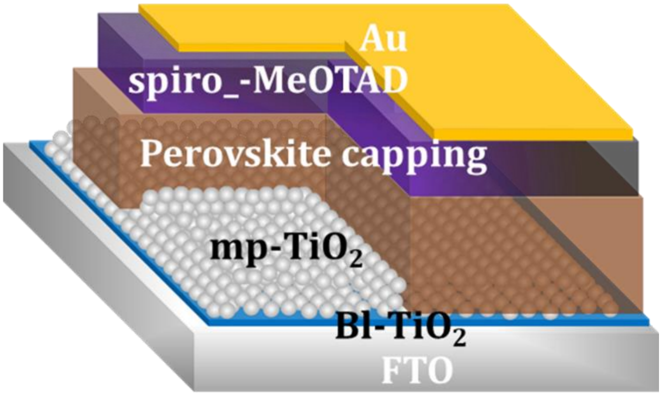


Fig. S-10 Solid state impedance spectroscopy (ssIS) (a) Nyquist plot of the AV-C and commercial colloidal carbon based PSCs recorded under illumination at 0.8 V bias. The inset shows the equivalent circuit used for the analysis.

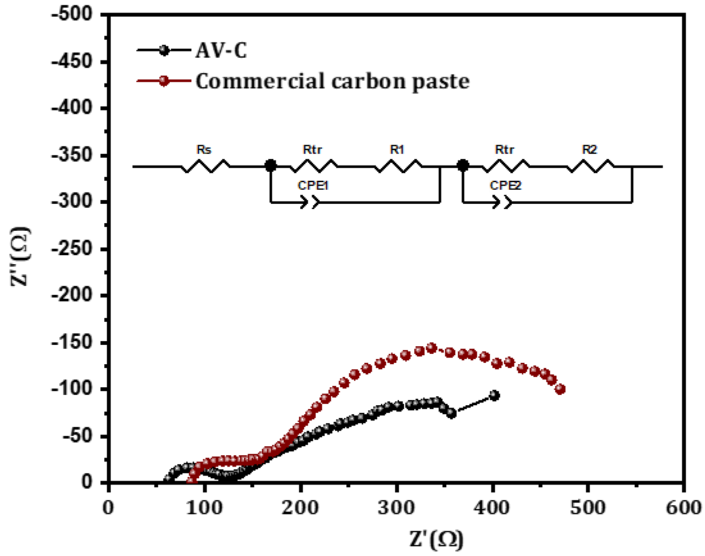


Fig. S-11 Optical images of homemade humidity chamber (A) 37% humidity (B) 98% Humidity.

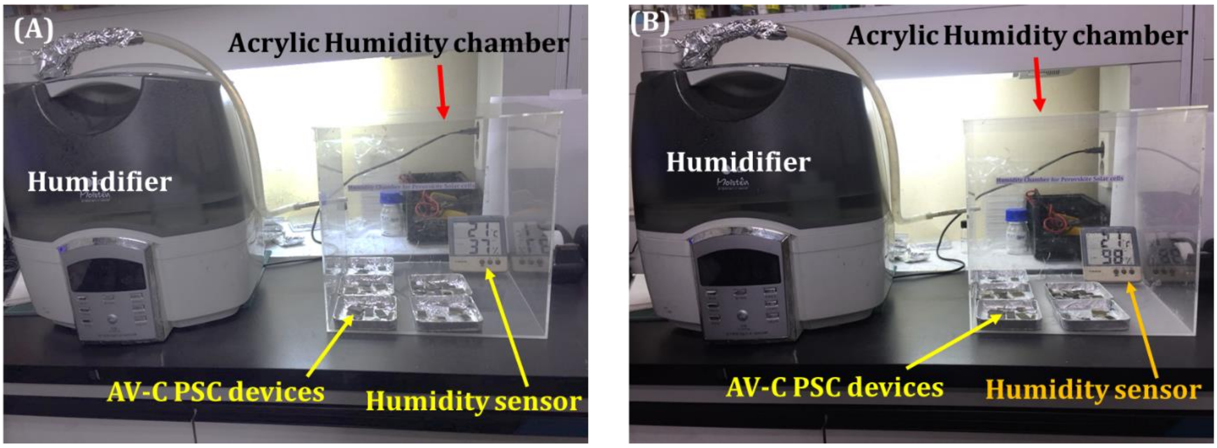


Fig. S-12 Ambient air-stability of spiro-MeOTAD and AV-C based PSCs stored under ambient condition with 65 % RH. Commercial carbon based device stability has been given for comparison.