Supporting Information for

Humidity controlled crystallization of thin $CH_3NH_3PbI_3$ films for high performance perovskite solar cell

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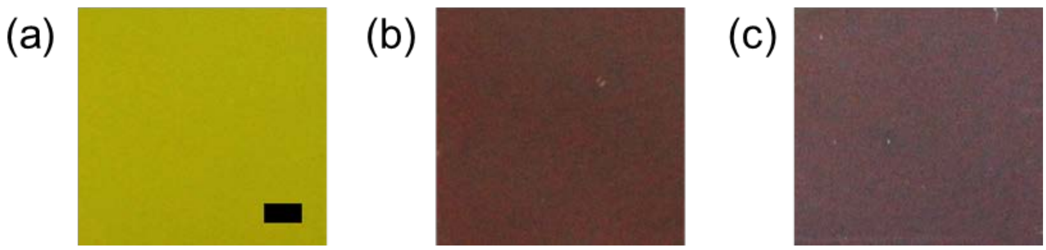

Figure S1 Visible colors of (a) PbI_2 film, (b) $CH_3NH_3PbI_3$ film after MAI spin-coating on PbI_2 in 40% humidity, (c) followed by thermal annealing at 100 °C for 45 min in 40% humidity condition. The magnitude of the scale bar is 2 mm.

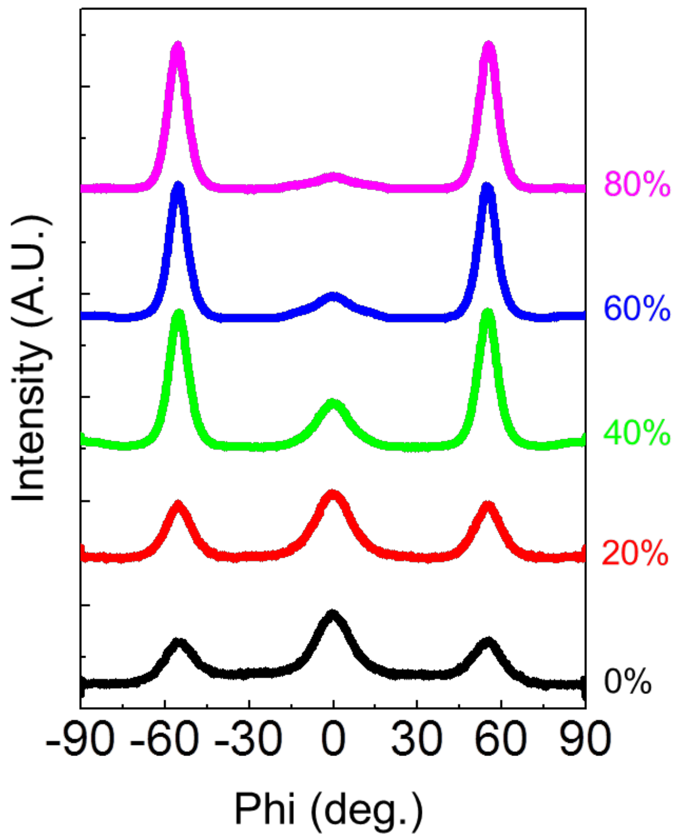

Figure S2 Azimuthal plots at q=1.0 nm^{-1} for the perovskite films fabricated at different humidity condition. The data was extracted from the GIWAXS patterns in Fig. 3b.

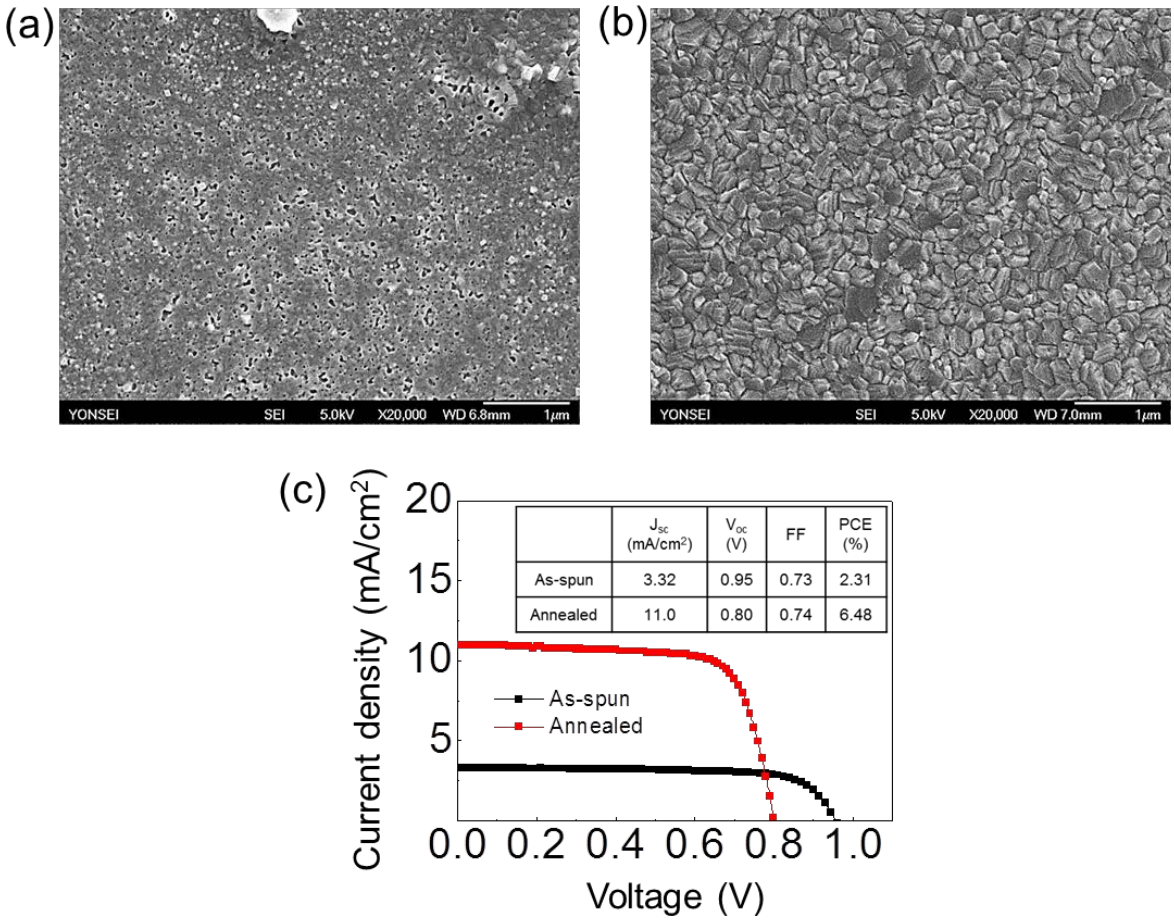

Figure S3 (a) SEM image of a $CH_3NH_3PbI_3$ film spin-coated with MAI in 0% humidity condition and (b) followed by thermal annealing at 100 ºC for 45 min in 0% humidity. (c) *J-V* characteristic of a solar cell with the film.

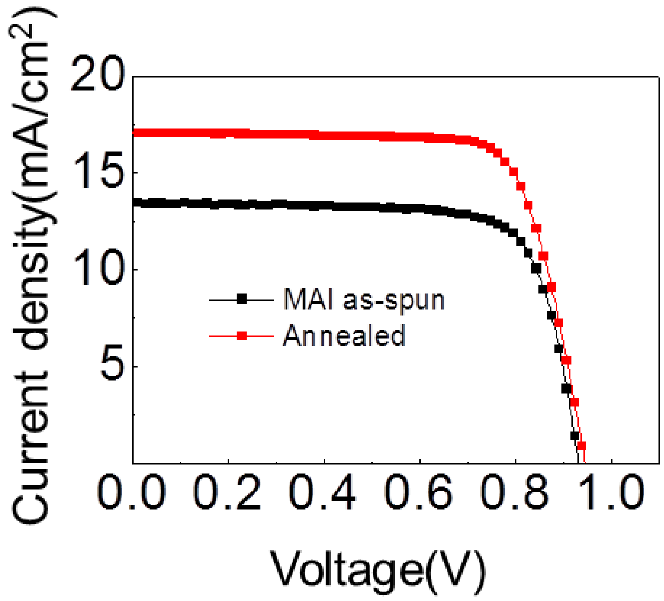

Figure S4 J-V characteristics of $CH_3NH_3PbI_3$ solar cells of MAI as-spun with different humidity conditions followed by thermal annealing in 40% humidity.

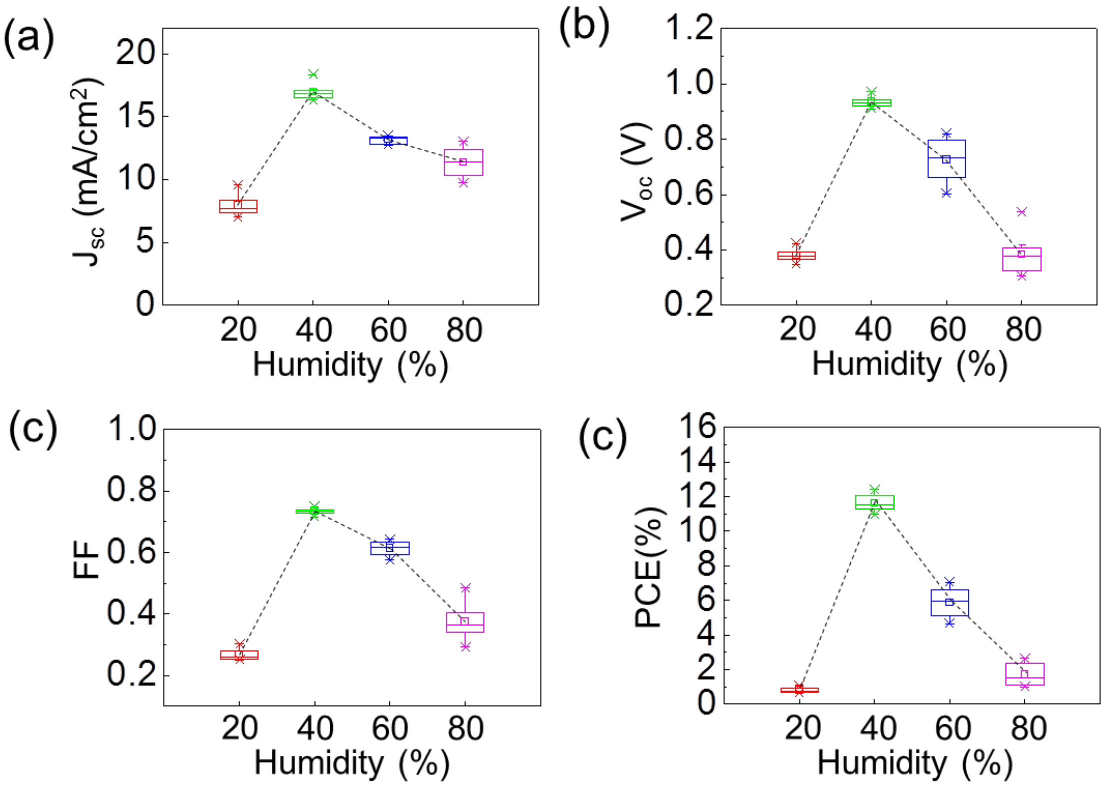

Figure S5 (a) Box-whisker plot to show cell-to-cell variation of photovoltaic parameter of short circuit current density, (b) open circuit voltage, (c) fill factor and (d) power-conversion efficiency of the devices of MAI as-spun in different humidity conditions and followed by thermal annealing in 40% humidity. 10 cells were tested in this study.

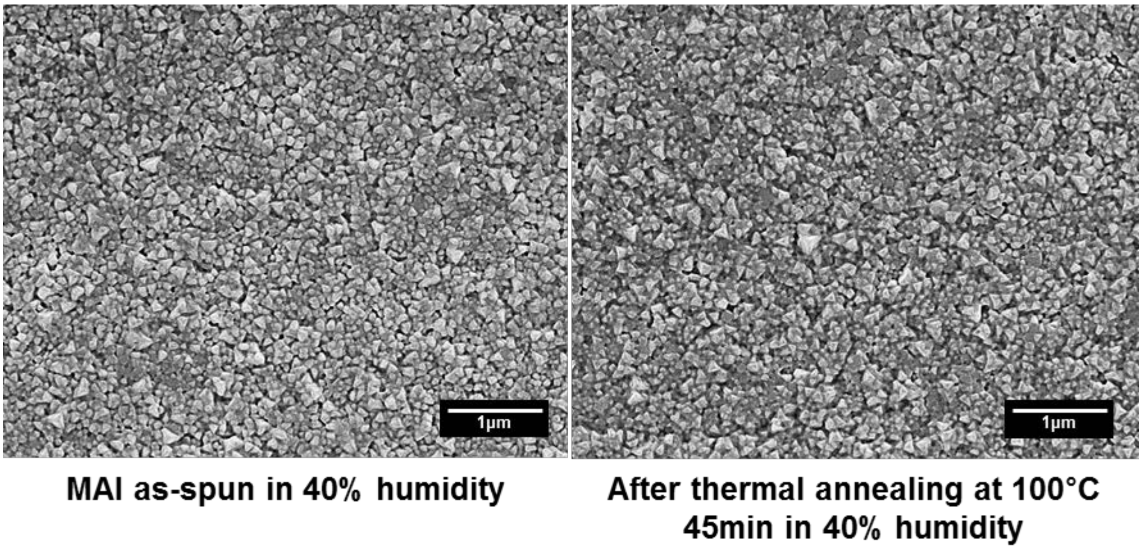

Figure S6 SEM images of surface morphology of $CH_3NH_3PbI_3$ film MAI as-spun (left) and followed by thermal annealing (right) in 40% humidity condition.

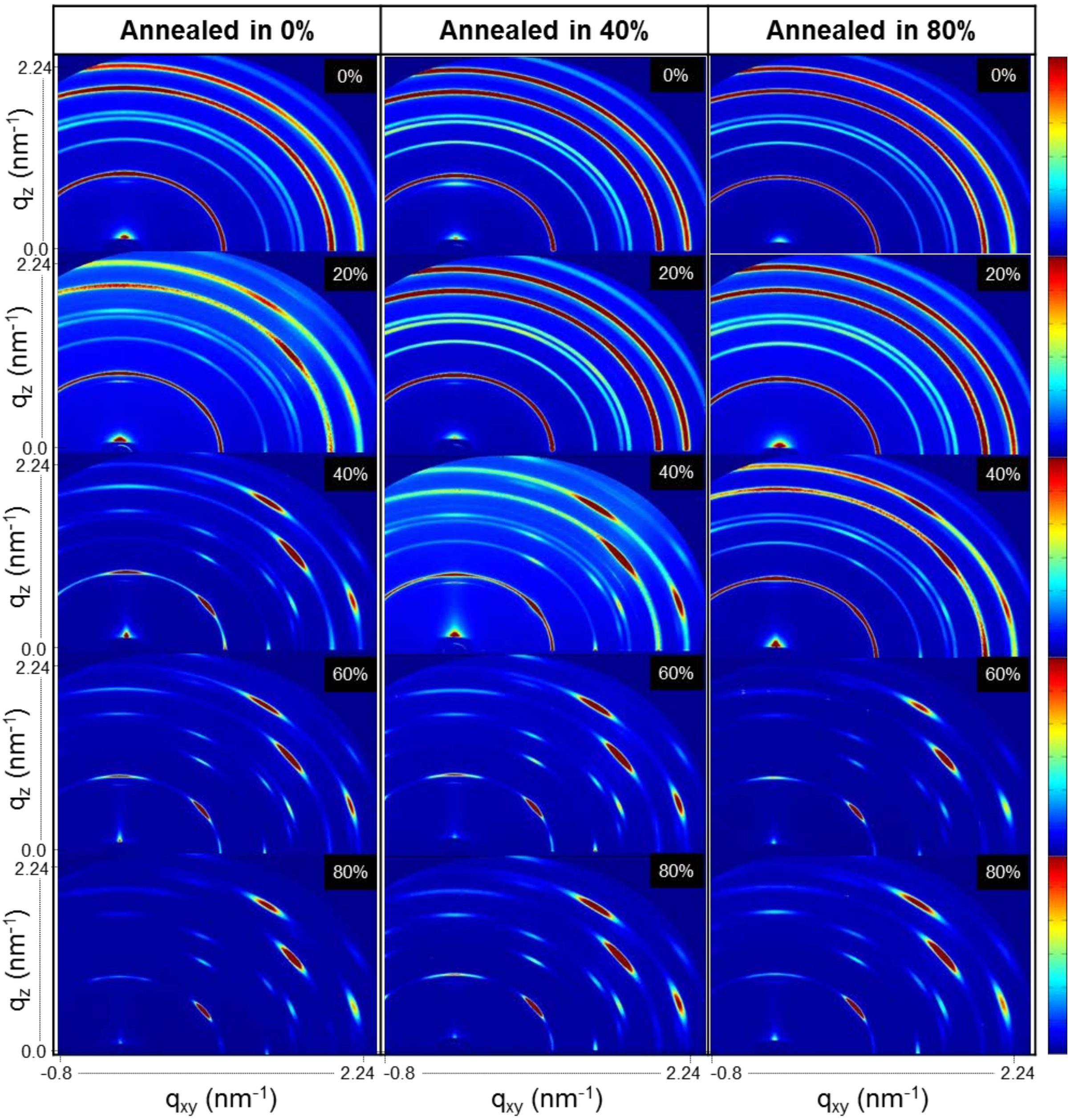

Figure S7 GIWAXS patterns of $CH_3NH_3PbI_3$ films spin-coated with MAI in various humidity conditions followed by thermal annealing at 100 °C for 45 min in controlled 0%, 40%, and 80% humidity condition. 1st row (left): thermal annealing in 0% humidity condition. 2nd row (middle): thermal annealing in 40% humidity condition. 3rd row (right): thermal annealing in 80% humidity condition. The % number in the black box right upper in each image means the degree of humidity in which the perovskite film is spin-coated with MAI.

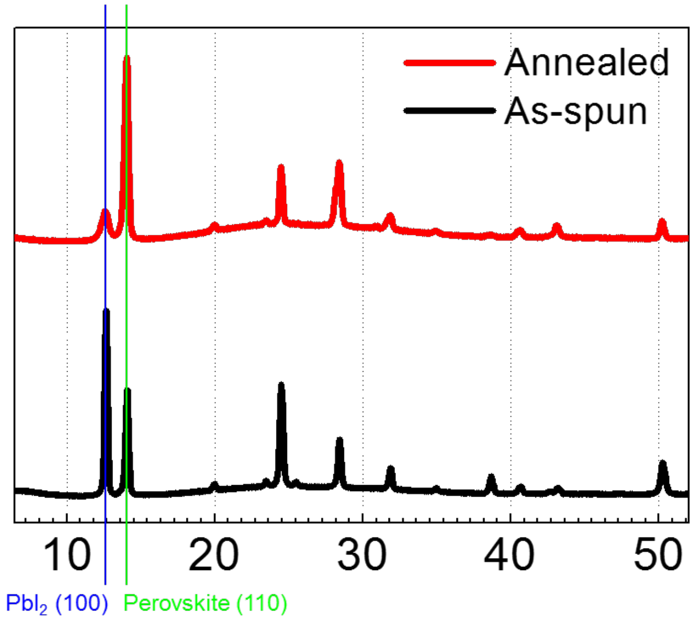

Figure S8 HR-XRD patterns of MAI as-spun on PbI_2 film at 40% humidity (black), followed by thermal annealing at 100 ºC for 45 min at 40% humidity.

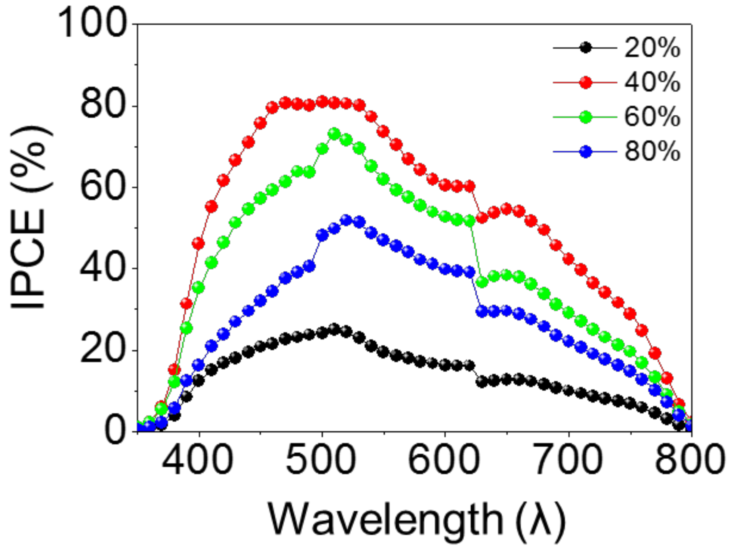

Figure S9 Incident photon-to-current efficiency (IPCE) results of the perovskite solar cells fabricated in different humidity conditions.

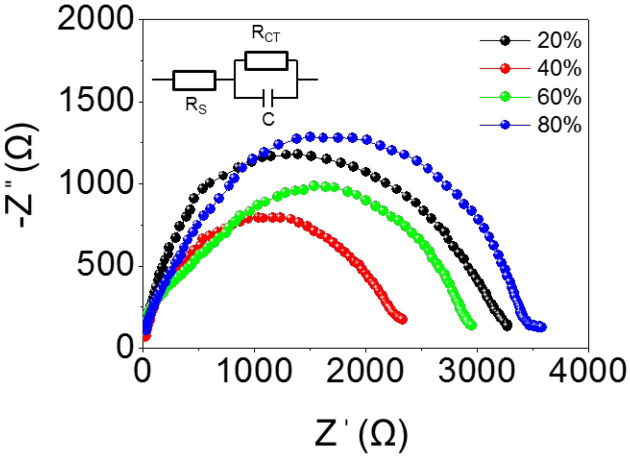

Figure S10 Nyquist plots at $V \sim V_{oc}$ for perovskite solar cells fabricated in different humidity conditions.

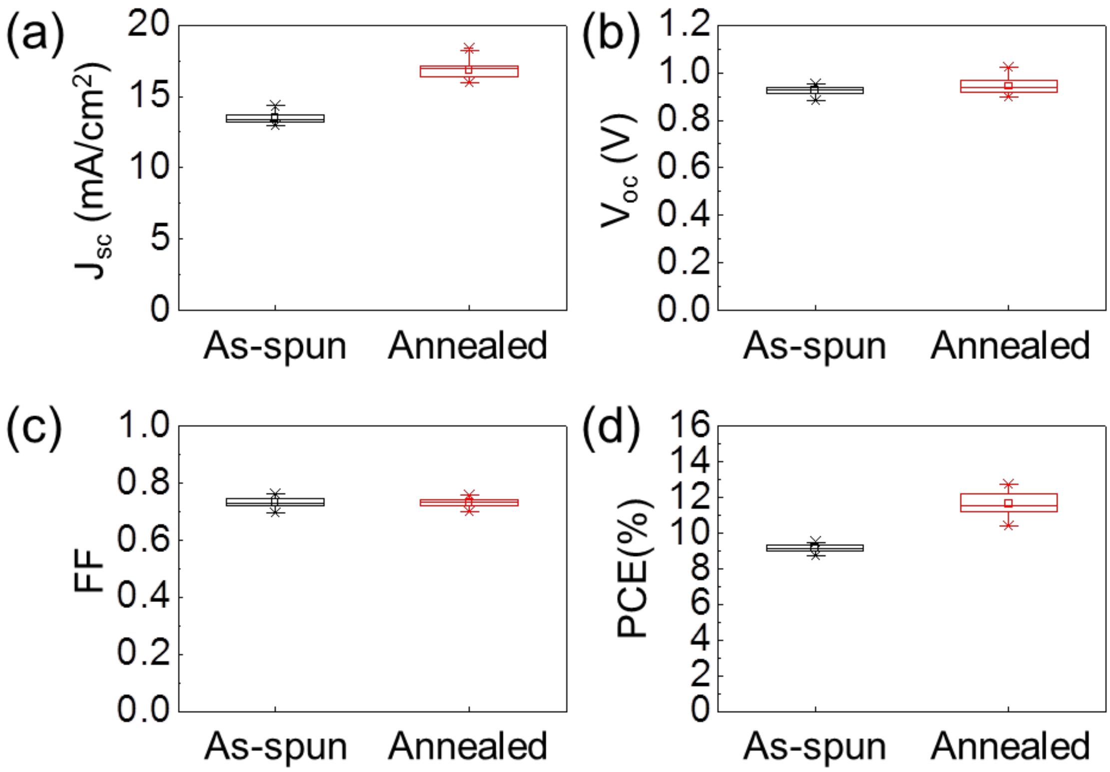

Figure S11 (a) Cell-to-cell variation of photovoltaic parameter of short circuit current density and (b) open-circuit voltage, (c) fill factor, (d) power conversion efficiency of the devices of MAI as-spun and subsequently thermally annealed in 40% humidity. 20 cells were tested in this experiment.

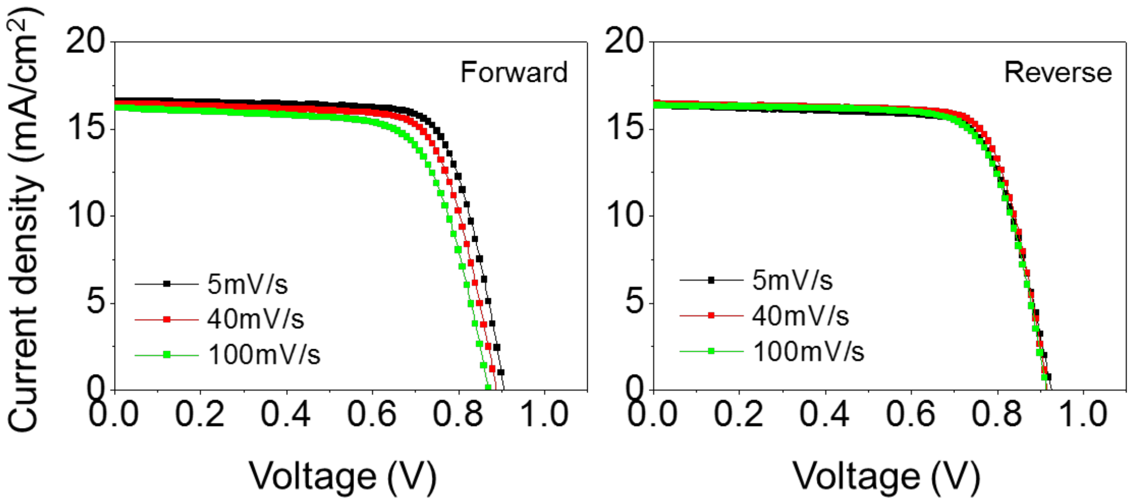

Figure S12 J-V curves of the device fabricated in 40% humidity with different scan rates of forward and reverse scan direction.

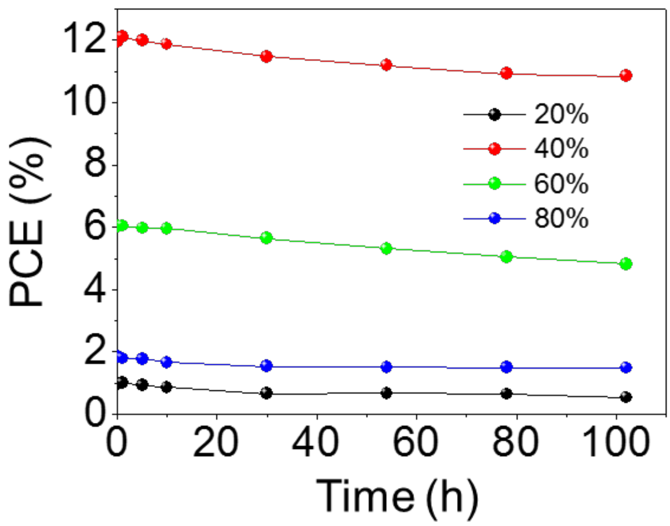

Figure S13 Stability of perovskite solar cells fabricated in different humidity.

Humidity	Process	J_{sc}(mA/cm^2)	V_{oc}(V)	FF	PCE (%)[a)]
20%	MAI as-spun	5.48	0.35	0.22	0.41
	T.A. in 40%	9.57	0.38	0.30	1.10
40%	MAI as-spun	14.29	0.90	0.72	9.37
	T.A. in 40%	17.10	1.02	0.73	12.73
60%	MAI as-spun	13.08	0.53	0.57	3.97
	T.A. in 40%	13.34	0.82	0.64	7.04
80%	MAI as-spun	9.45	0.30	0.31	0.88
	T.A. in 40%	13.01	0.42	0.48	2.65

Table S1 Photovoltaic parameters of the devices of $CH_3NH_3PbI_3$ film (upper row in each humidity category) spin-coated with MAI in 20%, 40%, 60% and 80% humidity conditions and subsequently thermally annealed in 40% humidity condition (bottom row in each humidity category). T.A. in 40% means 'Thermal annealing in 40% humidity condition'.

[a)] Device data was obtained from the devices operating with maximum power conversion efficiency.

Title	Average Efficiency	Best Efficiency	Reference
Impact of Film Stoichiometry on the Ionization Energy and Electronic Structure of $CH_3NH_3PbI_3$ Perovskites	Not shown	9.59 %	*Adv. Mater.* **2016**, *28*, 553
Improved Crystallization of Perovskite Films by Optimized Solvent Annealing for High Efficiency Solar Cell	12.04±1.27 %	13.59 %	*ACS Appl. Mater. Interfaces*, **2015**, *7*, 24008
Non-Thermal Annealing Fabrication of Efficient Planar Perovskite Solar Cells with Inclusion of NH_4Cl	~ 9.2 %	9.32 %	*Chem. Mater.* **2015**, *27*, 1448
A Facile, Solvent Vapor–Fumigation-Induced, Self-Repair Recrystallization of $CH_3NH_3PbI_3$ films for High-Performance Perovskite Solar Cells	10.25±0.9 %	11.15 %	*Nanoscale*, **2015**, *7*, 5427
Efficient Perovskite Hybrid Solar Cells Through a Homogeneous High-Quality Organolead Iodide Layer	11.5±1.5 %	11.49 %	*Small*, **2015**, *11*, 3369
The Importance of Moisture in Hybrid Lead Halide Perovskite Thin Film Fabrication	~12.5 %	~13.3 %	*ACS Nano*, **2015**, *9*, 9380
Moisture Assisted Perovskite Film Growth for High Performance Solar Cells	15.6%	17.1%	*Appl. Phys. Lett.* **2014**, *105*, 183902
Influence of Air Annealing on High Efficiency Planar Structure Perovskite Solar Cells	11.2±0.8 %	12.5 %	*Chem. Mater.* **2015**, *27*, 1597
Effect of Relative Humidity on Crystal Growth, Device Performance and Hysteresis in Planar Heterojunction Perovskite Solar Cells	9±2 %	12.2 %	*Nanoscale*, **2016**, *8*, 6300
Our Result	~12 %	12.73 %	-

Table S2 Comparison of power conversion efficiency with other papers.