Supporting Information

High-Performance Flexible Perovskite Solar Cells by Using a Combination of Ultrasonic Spray-Coating and Low Thermal Budget Photonic Curing

Sanjib Das,[†] Bin Yang,[‡] Gong Gu,[†] Pooran C. Joshi,[§] Ilia N. Ivanov,[‡] Christopher M. Rouleau,[‡] Tolga Aytug,[⊥] David B. Geohegan,[‡] and Kai Xiao[*,‡]

[†]Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, TN 37996, USA.

[‡]Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA.

[§]Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA.

[⊥]Chemical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA.

[*]E-mail: xiaok@ornl.gov

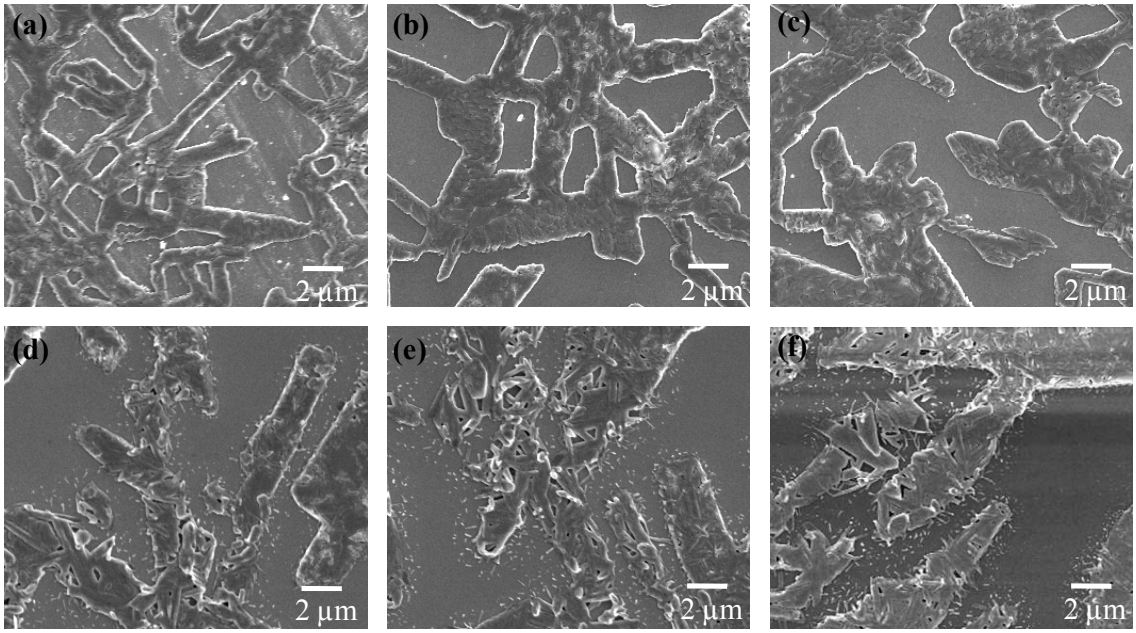

Figure S1. SEM images of a perovskite films spray-coated using DMSO on TiO_2/ITO/glass substrates at substrate temperature of (a) 60 °C (b) 75 °C, (c) 90 °C, (d) 105 °C, (e) 120 °C, and (f) 130 °C.

Table S1. Comparison of device performance based on perovskite films spray-coated using DMF and DMSO at a substrate temperature of 75 °C.

Solvent	J_{SC} [mA/cm^2]	V_{OC} [V]	FF [%]	PCE$^*_{avg}$ [%]
DMF	13.8 ± 0.5	0.98 ± 0.02	60.8 ± 3.3	8.2 ± 0.3
DMSO	8.7 ± 1.6	0.80 ± 0.06	60.6 ± 3.2	4.2 ± 0.5

*Average is based on 8 devices, measured under AM 1.5G illumination conditions.

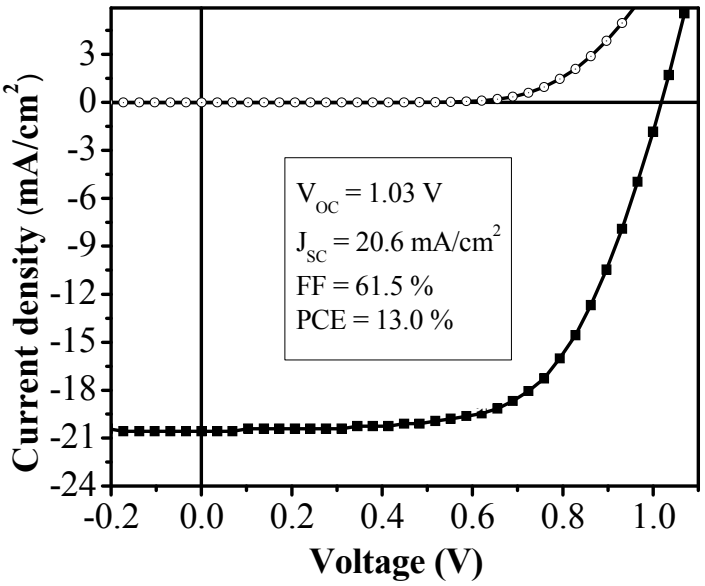

Figure S2. *J-V* curves of the champion device under dark and AM 1.5G (100 mW cm^{-2}) illumination conditions, measured in a nitrogen-filled glovebox.

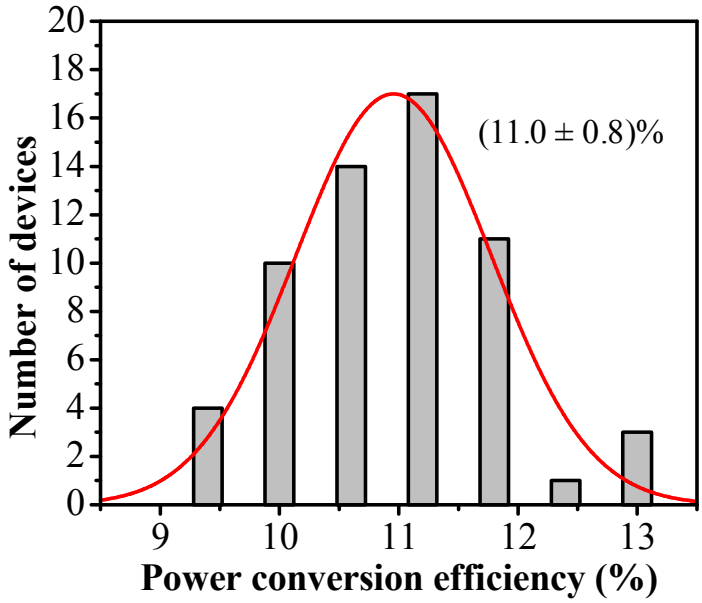

Figure S3. The histogram of PCEs, measured for 60 devices fabricated by spin-coating method, showing an average PCE of (11.0 ± 0.8)%.

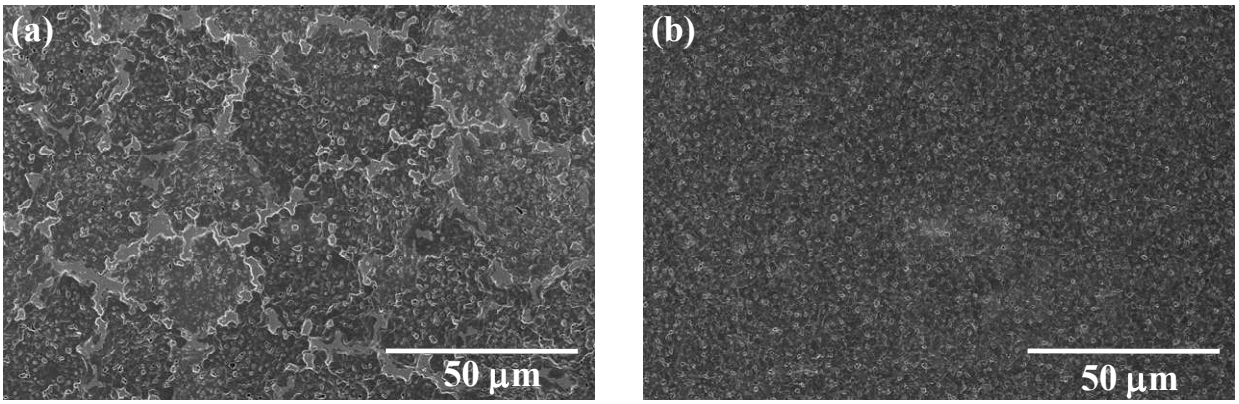

Figure S4. SEM image of a) spray-coated and b) spin-coated $CH_3NH_3PbI_{3-x}Cl_x$ films on TiO_2/ITO/glass substrates under optimized processing conditions, showing film coverage over large area.

Table S2. Device-to-device performance variation in spray-coated devices.

Substrate (S)	Device (D)	J_{SC} [mA/cm^2]	V_{OC} [V]	FF [%]	PCE [%]
S1	D1	19.1	1.00	61.9	11.8
	D2	20.3	0.97	58.0	11.4
	D3	19.1	0.98	63.3	11.8
	D4	18.8	0.97	62.1	11.3
S2	D1	18.2	0.97	62.8	11.1
	D2	20.0	0.95	55.9	10.6
	D3	19.5	1.00	63.3	12.4
	D4	18.5	0.99	62.1	11.4

Table S3. Summary of device parameters, i.e., J_{SC}, V_{OC}, FF, and PCE of the perovskite PVs fabricated using different deposition techniques and substrates with optimized processing conditions.

Deposition Technique	Substrate Type	J_{SC} [mA/cm^2]	V_{OC} [V]	FF [%]	PCE^*_{avg} [%]	PCE_{max} [%]
Spray Coating	Glass	17.4 ± 1.5	0.99 ± 0.04	61.4 ± 2.8	10.6 ± 1.1	13.0
	PET	13.8 ± 2.6	1.00 ± 0.03	43.0 ± 7.6	5.9 ± 1.3	8.1
Spin-coating	Glass	18.4 ± 1.1	0.95 ± 0.03	62.7 ± 2.7	11.0 ± 0.8	13.0

PET	16.7 ± 1.9	1.02 ± 0.04	45.5 ± 6.5	7.7 ± 1.0	8.9

*The average device performances are based on 60 devices each in case of glass substrates, and 18 and 10 devices in case of spray-coated and spin-coated flexible substrates, respectively, measured under AM 1.5G illumination conditions.

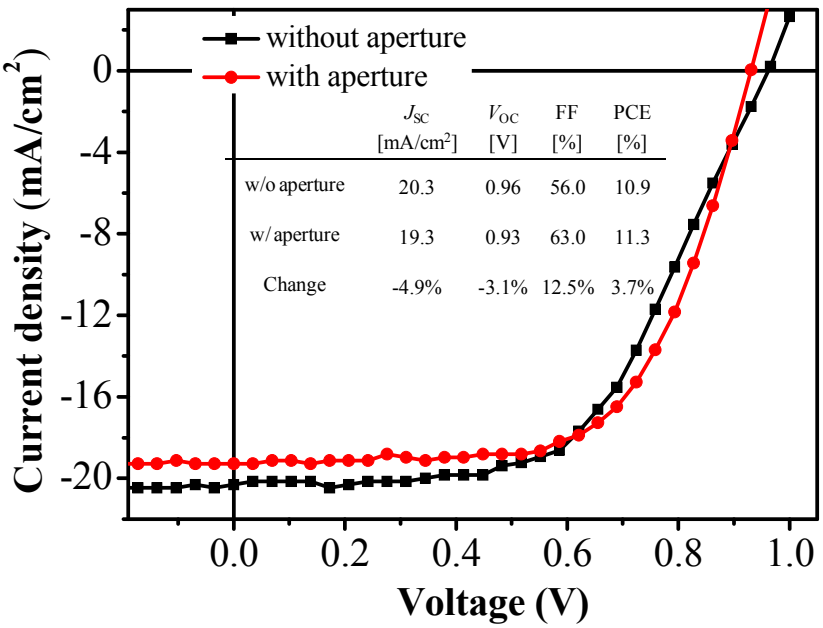

Figure S5. Performance measurement of a cell with 23.7 mm^2 area without and with an aperture of 6.02 mm^2 on an opaque mask.

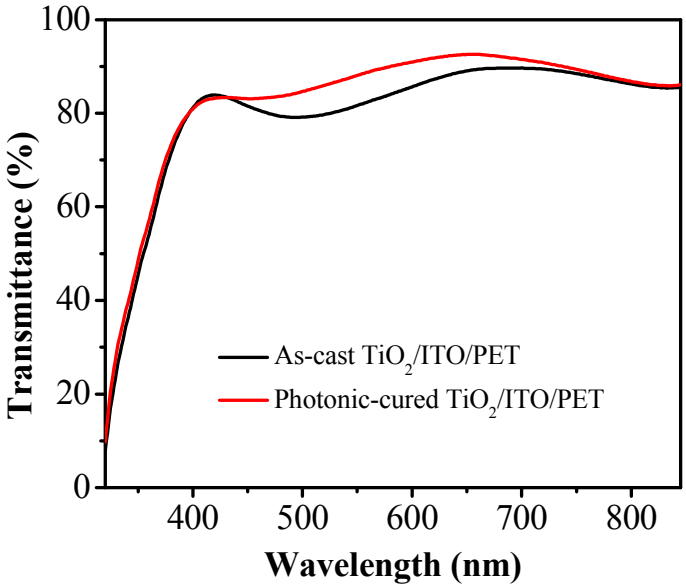

Figure S6. Effect of photonic curing on transmittance of TiO_2/ITO/PET substrates.

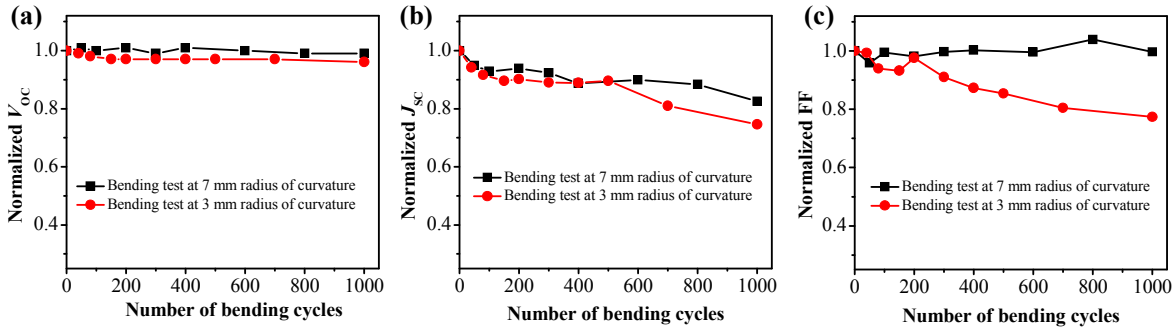

Figure S7. Effect of mechanical stress on different device performance parameters: a) V_{OC}, b) J_{SC}, and c) FF.

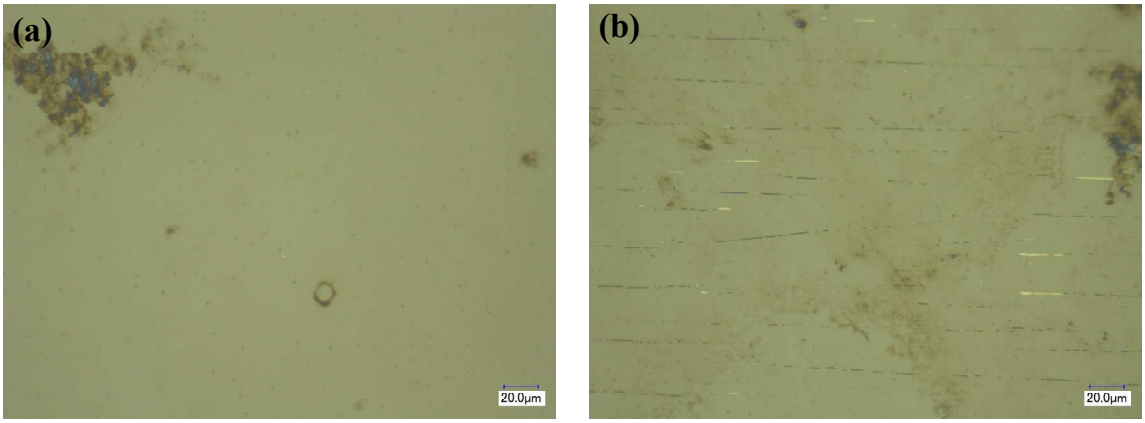

Figure S8. Optical microscope images of ITO morphology on PET substrates a) before any bending and b) after 300 bending cycles using a metal cylinder with 3 mm radius.