Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.

Supporting Information

Ultrathin, lightweight, and flexible perovskite solar cells with an excellent power-per-weight performance

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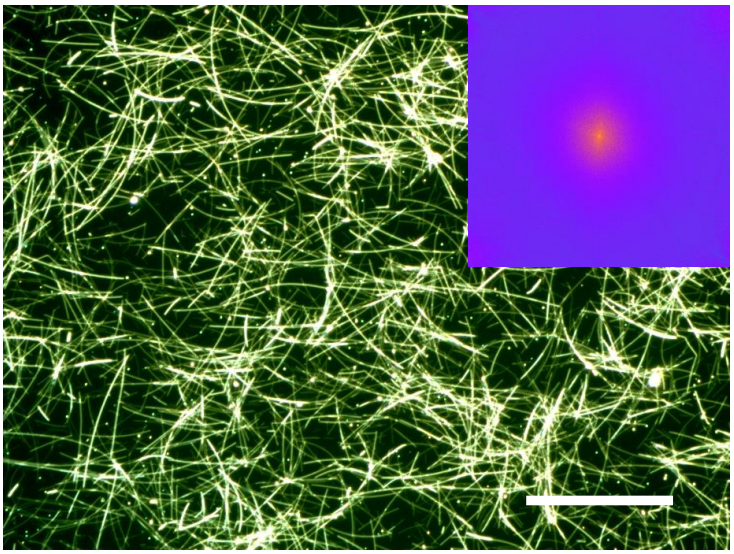


Fig. S1. Dark-field optical micrograph of a random AgNW network. The fast Fourier transform (FFT) image of the optical micrograph (inset) shows a blurred circular pattern, reflecting the randomness of the corresponding surface geometric structure. The scale bar indicates 40μm.

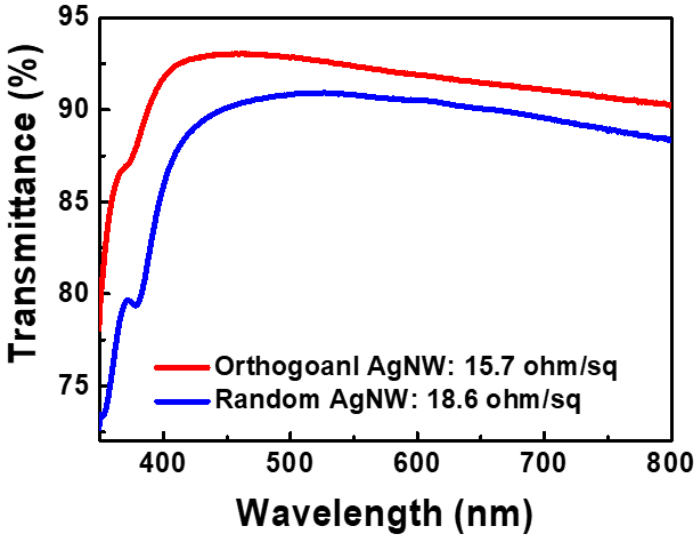


Fig. S2. The optical transmittance of orthogonal AgNW and random AgNW electrodes deposited onto glass substrates. Samples were scanned over the visible wavelength range (350–800 nm). The corresponding sheet resistances of the electrodes are given in the figure. The glass substrate was used as a reference.

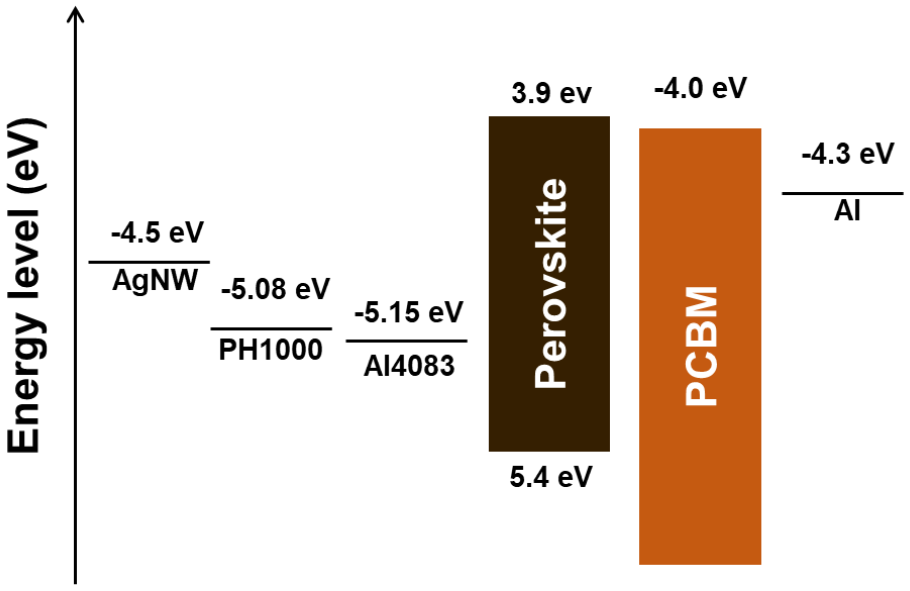


Fig. S3. The energy band diagram for the PSC with an orthogonal AgNW electrode.

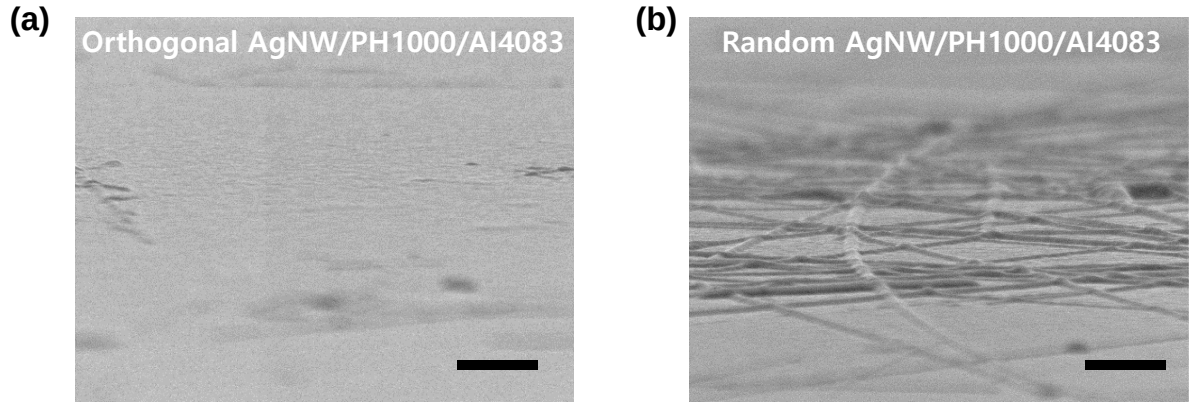


Fig. S4. Tilted SEM images of the surface of PEDOT:PSS coated onto (a) a PH1000/orthogonal AgNW electrode and (b) a PH1000/random AgNW electrode. Scale bars indicate 500 nm.

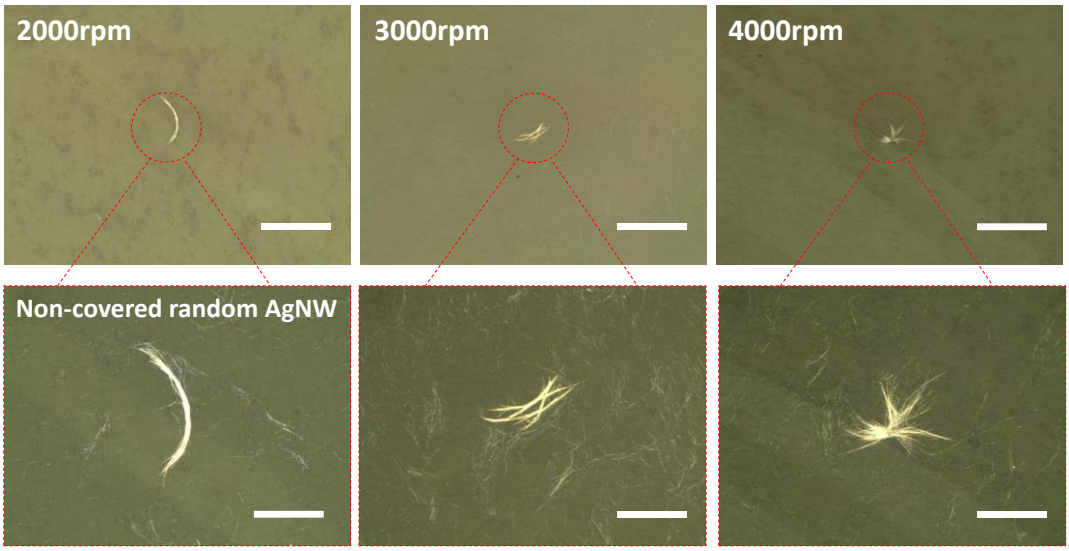


Fig. S5. Optical microscope images of the surface morphologies of AI4083 coated on PH100 0/random AgNW electrodes with different thickness of PH1000, controlled by the speed of sp in-coating. The scale bars are (Upper) 100μm and (Bottom) 40μm, respectively.

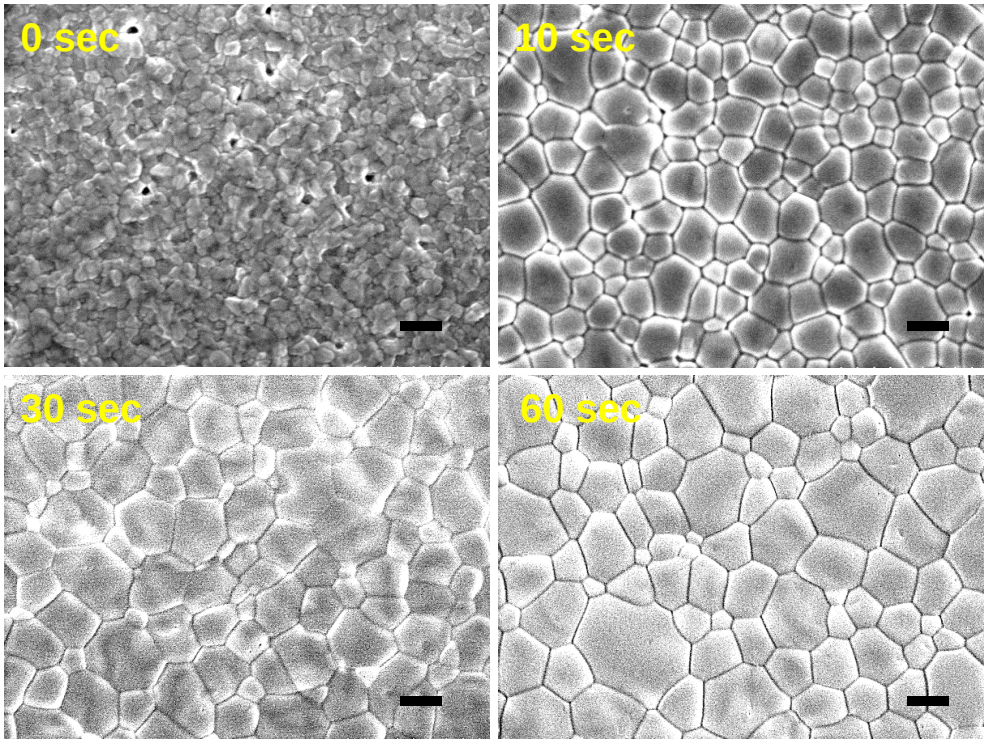
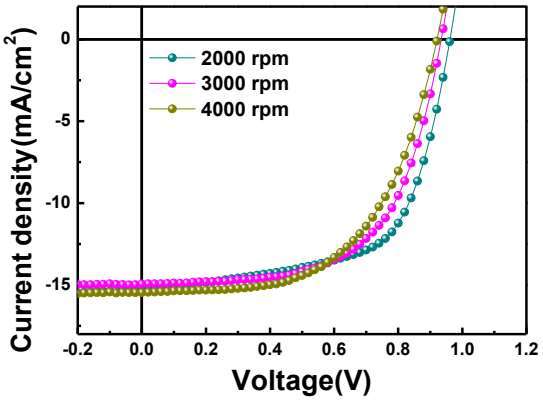
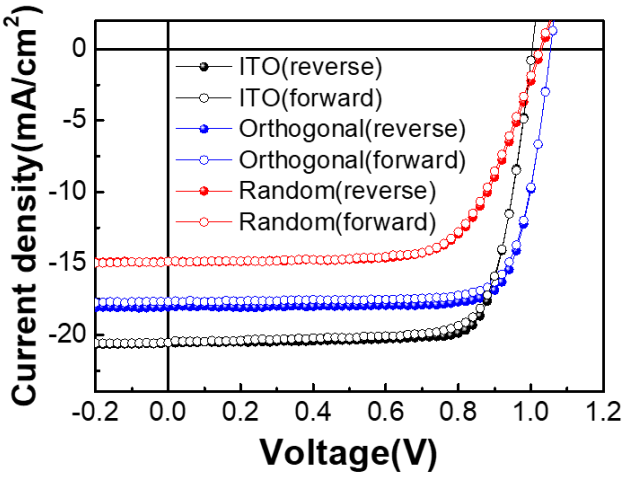


Fig. S6. SEM images of the surface of perovskite active layers deposited onto PEDOT:PSS/PH1000/AgNW; the images correspond to different SVA times. Scale bars are 500 nm.



Electrode	PH1000	AI4083	*Jsc (mA/cm^2)*	*Voc (V)*	*FF(%)*	*PCE (%)*
Random AgNW	X	O	-	-	-	-
	2000 rpm		15.15	0.96	63	9.25
	3000 rpm		14.92	0.93	61	8.51
	4000 rpm		15.46	0.92	57	8.11

Fig. S7. *J-V* characteristics of the PSC devices with different thickness of PH1000.



Electrode	Scan direction	*Jsc (mA/cm^2)*	*Voc (V)*	*FF (%)*	*PCE (%)*
ITO	Reverse	20.32±0.366	1.00±0.003	78±0.5	16.00±0.258
	Forward	20.46±0.099	1.00±0.001	76±0.2	15.68±0.072
Orthogonal AgNW	Reverse	18.20±0.301	1.06±0.008	78±1.5	15.06±0.174
	Forward	17.98±0.282	1.05±0.003	78±1.4	14.81±0.285
Random AgNW	Reverse	14.38±0.602	1.03±0.001	67±1.2	9.88±0.555
	Forward	14.27±0.576	1.02±0.012	67±1	9.80±0.519

Fig. S8. *J–V* hysteresis characteristics of a PSC with ITO, orthogonal AgNW and random Ag NW electrodes measured with forward and reverse bias.

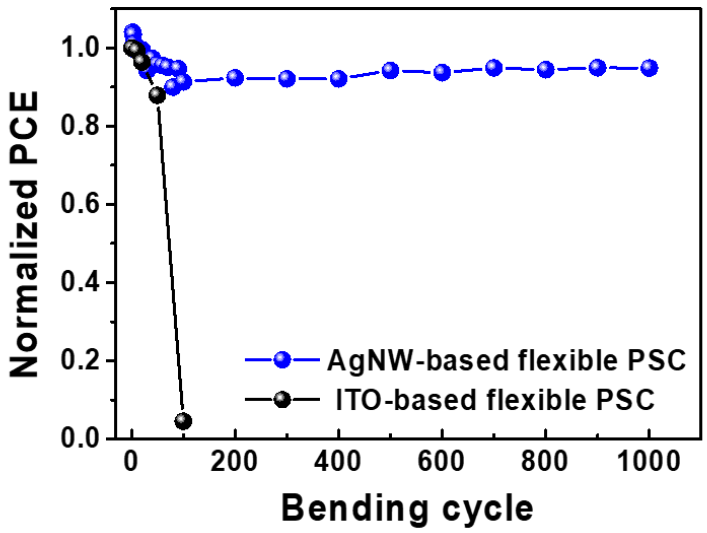


Fig. S9. Variation in normalized device efficiency of PSCs with ITO and orthogonal AgNW electrodes under repeated (1000 times) bending cycles.

Fig. S10. Photograph of an ultralight PSC device on an electronic scale, demonstrating its extremely low weight. The device size is 13 mm x 13mm.

Table S1. Comparison of the device performance of our PSC with orthogonal AgNW arrays and those of other AgNW-based PSC devices.

Device structure	J_{sc} (mA/cm^2)	V_{oc} (V)	*FF*	PCE (%)	Ref.
Glass/AZO/AgNW/a-AZO/ZnO/Perovskite/Sprio-OMeTAD/Au	18.5	1.12	67.4	13.93	Adv. Energy Mater. 2018[1]
Glass/FTO/TiO_2/Perovskite/Spiro-OMeTAD/AgNWs/PDMS	15.24	1.07	68.8	11.12	Adv. Funct. Mater. 2018[2]
ITO/PTAA:F4TCNQ/Perovskite/PCBM/AgNW@Au	18.5	0.99	64.3	11.0	Sol. Energy Mater. Sol. Cells 2017[3]
Au/Spiro-OMeTAD/$CH_3NH_3PbI_3$/mAl2O3/ZnO/ITO/AgNW/ITO	13.17	1.04	61.8	8.44	Nanoscale 2016[4]
AgNW/ZnO:F/TiO_2/Perovskite/Sprio-OMeTAD/Ag	12.2	0.685	39.5	3.29	J. Mater. Chem. A 2015[5]
Glass/orthogonal AgNW/PH1000/PEDOT:PSS/MAPbI3/PCBM/Al	**18.63**	**1.06**	**77**	**15.18**	**This work**
Flexible film/orthogonal AgNW/PH1000/PEDOT:PSS/MAPbI3/PCBM/Al	**17.99**	**1.00**	**72**	**13.05**	**This work**
Ultrathin foil/orthogonal AgNW/PH1000/PEDOT:PSS/MAPbI3/PCBM/Al	**18.88**	**0.95**	**69**	**12.85**	**This work**

Movie S1. An ultralight PSC on a flying bubble, demonstrating its lightweight character.

Notes and references

1. Lee, E.; Ahn, J.; Kwon, H. C.; Ma, S.; Kim, K.; Yun, S.; Moon, J., *Adv. Energy Mater*. 2018, **8,** 1702182.

2. Yunsheng, F.; Zhicong, W.; Jia, L.; Fangyuan, J.; Kui, Z.; Yanli, Z.; Yinhua, Z.; Jun, Z.; Bin, H., *Adv. Funct. Mater.* 2018, **28**, 1705409.

3. Liu, T.; Liu, W.; Zhu, Y.; Wang, S.; Wu, G.; Chen, H., *Sol. Energy Mater. Sol. Cells* 2017, **171**, 43-49.

4. Kim, A.; Lee, H.; Kwon, H.-C.; Jung, H. S.; Park, N.-G.; Jeong, S.; Moon, J., *Nanoscale* 2016, **8**, 6308-6316.

5. Han, J.; Yuan, S.; Liu, L.; Qiu, X.; Gong, H.; Yang, X.; Li, C.; Hao, Y.; Cao, B., *J. Mater. Chem. A* 2015, **3**, 5375-5384.