

Supplementary data

Enhanced Efficiency and Stability of Scalable Spray-coated Perovskite Solar Cells with Ionic liquid Additives

Shun-Hsiang Yang,^{a†} Chia-Hao Tsai,^{b†} Xiao-Feng Wang,^c Tai-Chou Lee,^a and Cheng-Liang Liu^{*b}

^a *Department of Chemical and Materials Engineering, National Central University, Taoyuan 32001, Taiwan. Email: liucl@ntu.edu.tw*

^b *Department of Materials Science and Engineering, National Taiwan University, Taipei 10617, Taiwan*

^c *Key Laboratory of Physics and Technology for Advanced Batteries (Ministry of Education) College of Physics, Jilin University, Changchun 130012, China*

† The authors contributed to this work equally.

S.1 Instrumentation

X-ray diffraction (XRD) analyzes were performed on a Bruker D8 Advance diffractometer (CuK α , $\lambda = 1.54 \text{ \AA}$). Field-emission scanning electron microscopy (FESEM) images were obtained using a JSM-7600F instrument (JEOL). UV–Vis absorption spectra of all samples were recorded on A JASCO V-670 spectrophotometer. Steady-state photoluminescence (PL) and time-resolved photoluminescence (TRPL) spectrometers were measured using a Horiba Jobin Yvon FluoroLog-3 fluorimeter. The valance band levels for the perovskite have been conducted using a Riken Keiki AC-2 photoelectron spectroscopy in the air (PESA) spectrometer.

Table. S1. PL lifetime obtained from fitted TRPL decay and the average lifetime of the perovskite film with and without BMIMBF₄ additive. The molar concentration of BMIMBF₄ is 0.30 mol% (champion device).

	τ_1 (ns)	τ_2 (ns)	τ_{avg} (ns)
w/o BMIMBF ₄	5.79	37.80	8.39
w/ BMIMBF ₄	6.99	44.13	18.39

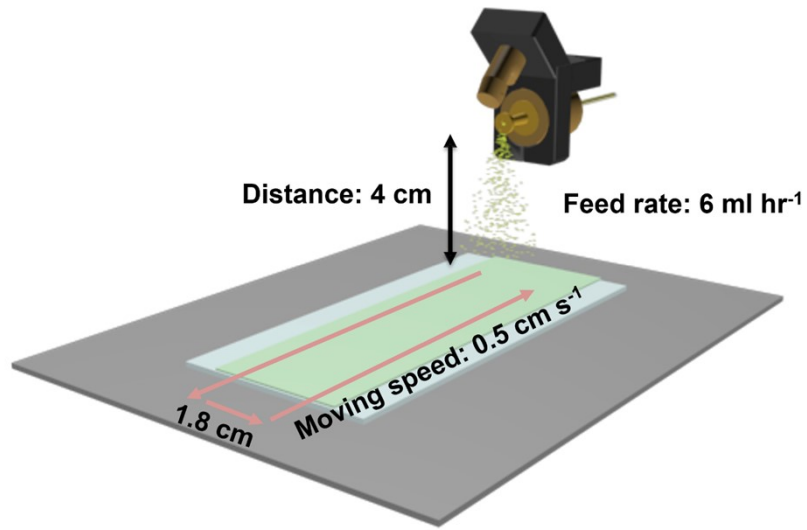


Fig. S1 Schematic illustration of large area coating of perovskite film.

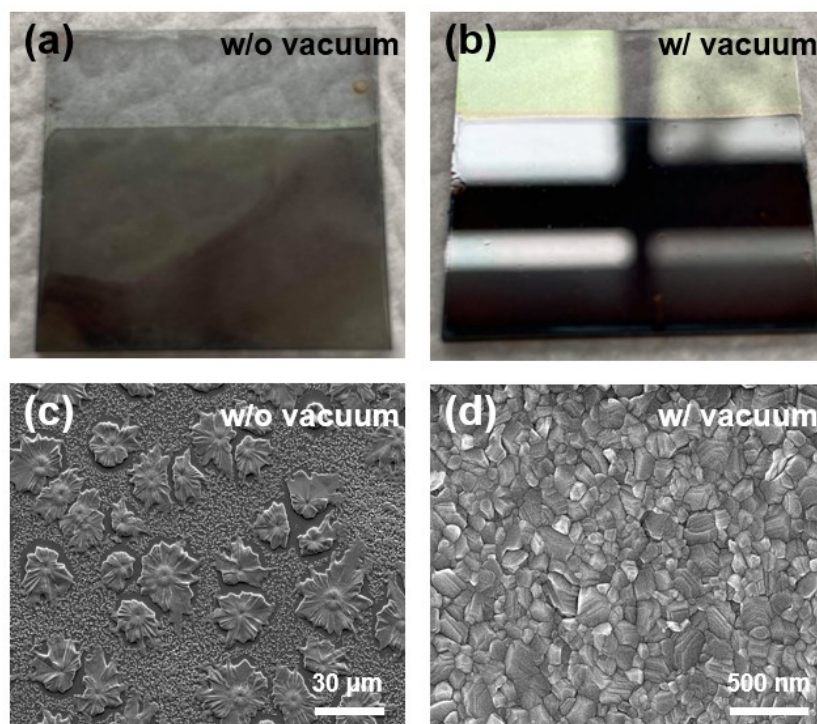


Fig. S2 (a, b) Photographs and (c, d) plane SEM images of perovskite film without (a, c) and with (b, d) vacuum extraction.

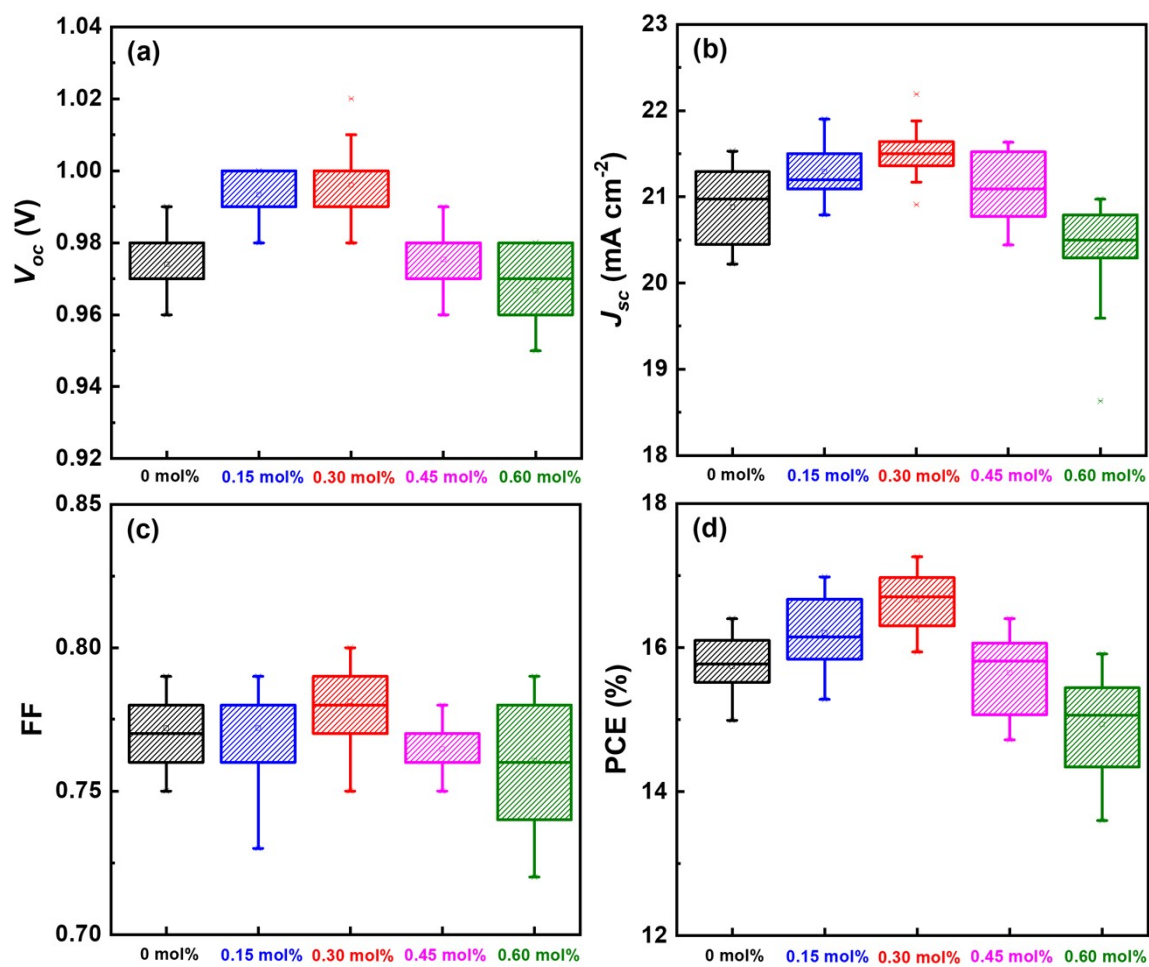


Fig. S3 Statistics of (a) V_{oc} , (b) J_{sc} , (c) FF, and (d) PCE of perovskite solar devices with different molar ratios BMIMBF₄ additive. The statistical data were obtained from 15 cells for each molar ratio.

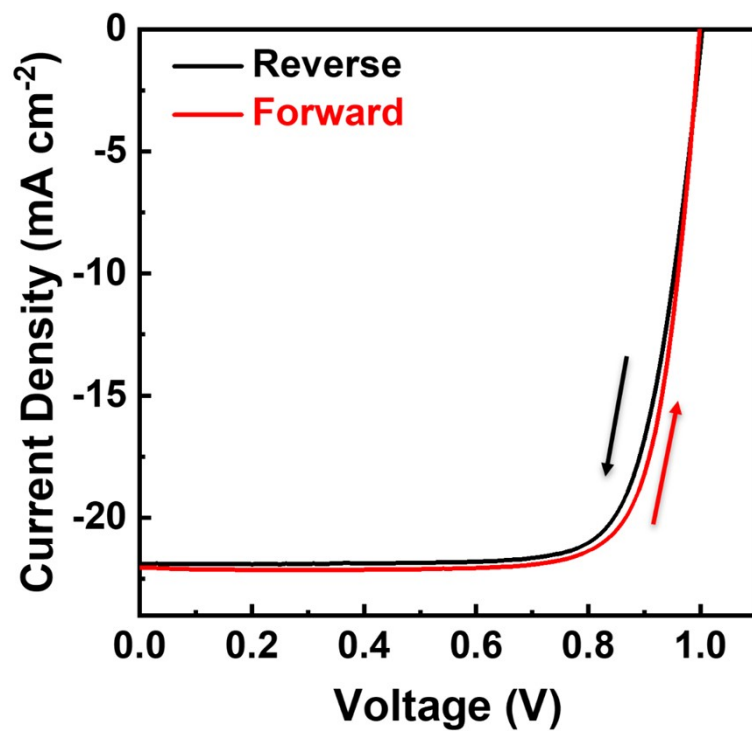


Fig. S4 *J-V* characteristics under AM 1.5G illumination for best-performing perovskite solar cells with 0.30 mol% BMIMBF₄ under forward and reverse scan.

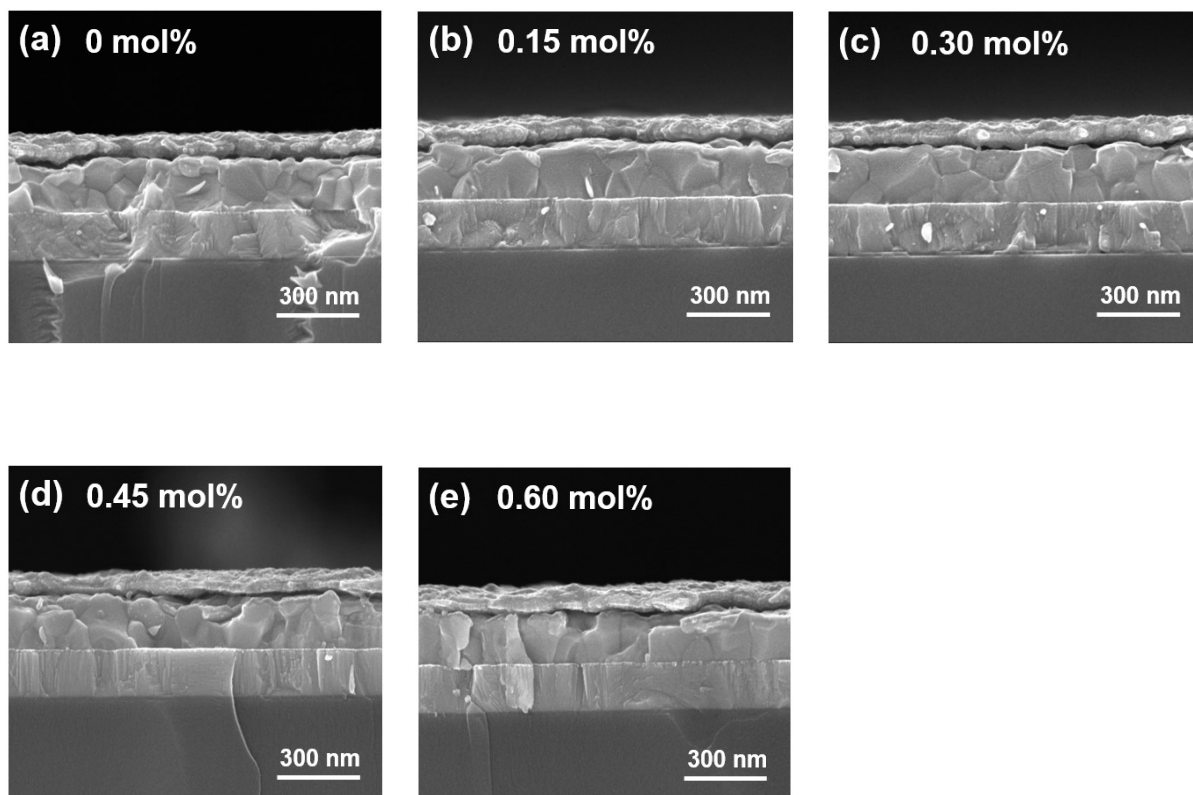


Fig. S5 Cross-section SEM images of of perovskite films (a) without BMIMBF₄, and with (b) 0.15 mol%, (c) 0.30 mol%, (d) 0.45 mol%, and (e) 0.60 mol% BMIMBF₄.

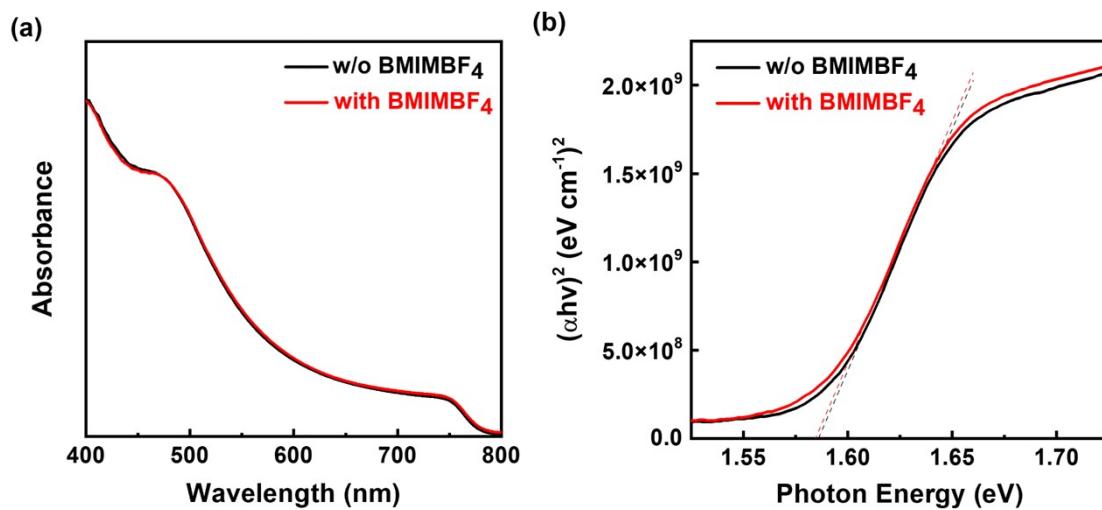


Fig. S6 (a) UV-Vis absorbance and (b) Tauc plot of the perovskite films with and without BMIMBF₄ additive. The molar concentration of BMIMBF₄ is 0.30 mol% (champion device).

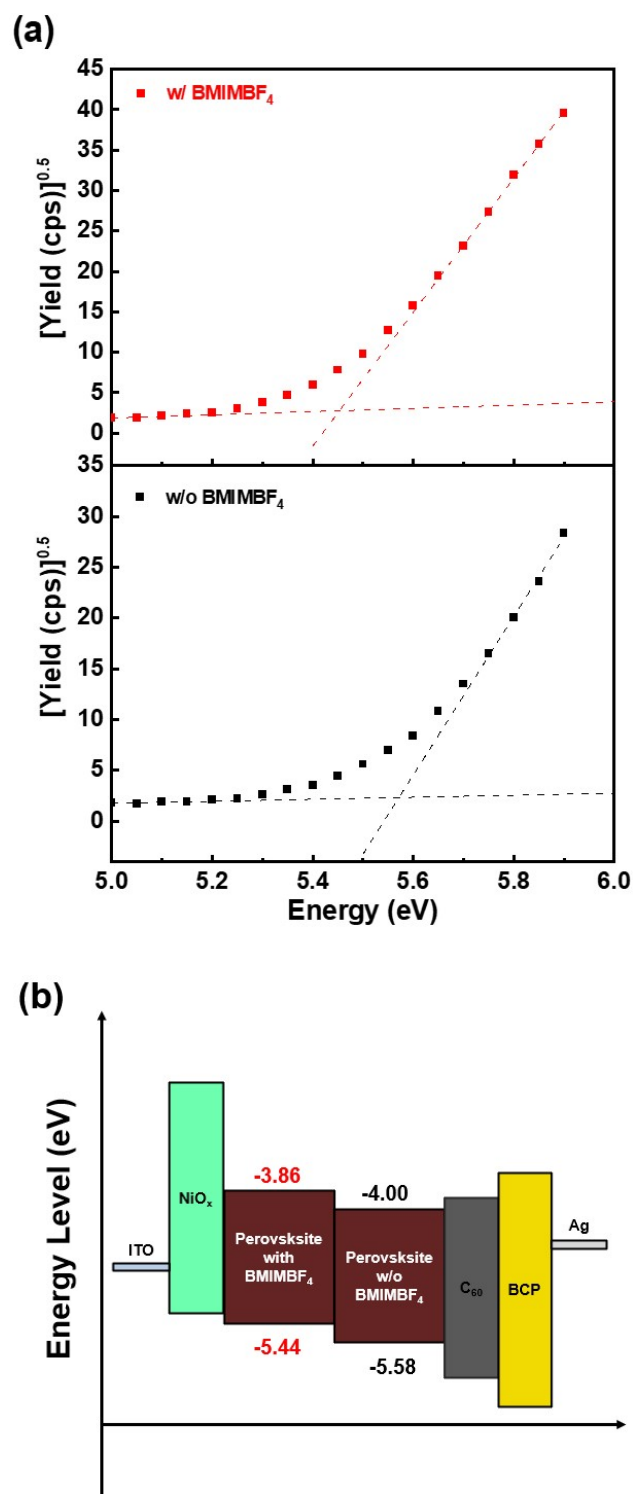


Fig. S7 (a) PESA of the perovskite films with and without BMIMBF₄ additive. The molar concentration of BMIMBF₄ is 0.30 mol% (champion device). (b) Schematic energy level diagram of the perovskite solar cells with and without BMIMBF₄ additive.

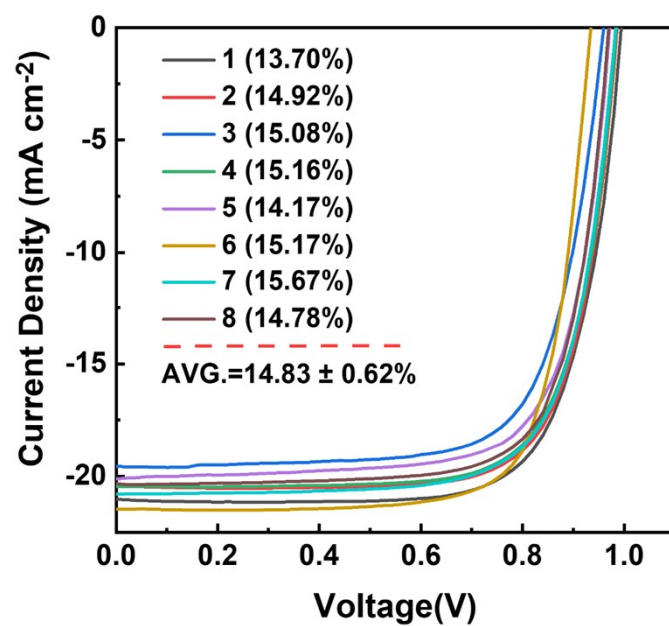


Fig. S8 *J-V* characteristics associated with the complete device produced from the 8 samples shown in **Fig. 9a**.