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

Supplementary Information

Effect of $CH_3NH_3PbI_3$ Thickness on Device Efficiency in Planar Heterojunction Perovskite Solar Cells

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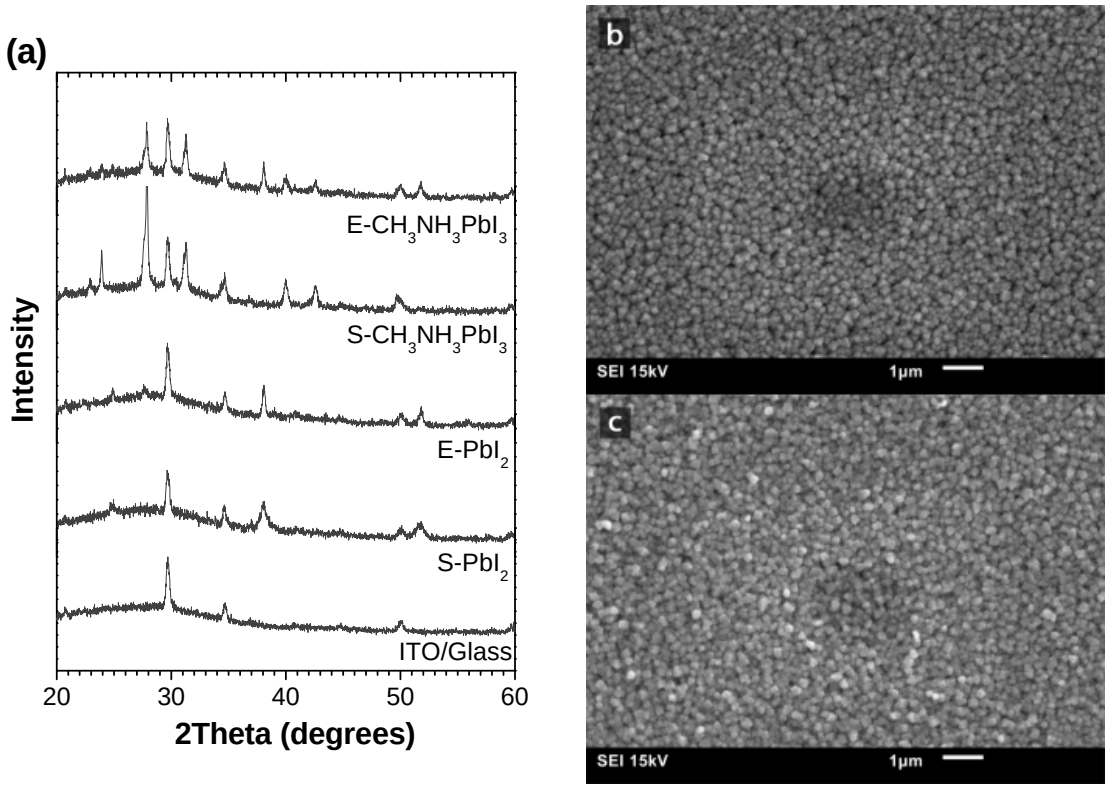

Figure S1. (a) Powder X-ray diffraction patterns of PbI_2 films deposited by spin coating (S-PbI_2) and thermal evaporation (E-PbI_2), and the corresponding $CH_3NH_3PbI_3$ films after dipping in methylammonium iodide solution. All films were deposited on ITO/glass substrates. (b) SEM micrograph of a perovskite film produced from a spin coated PbI_2 film; (c) SEM micrograph of a perovskite film produced from an evaporated PbI_2 film.

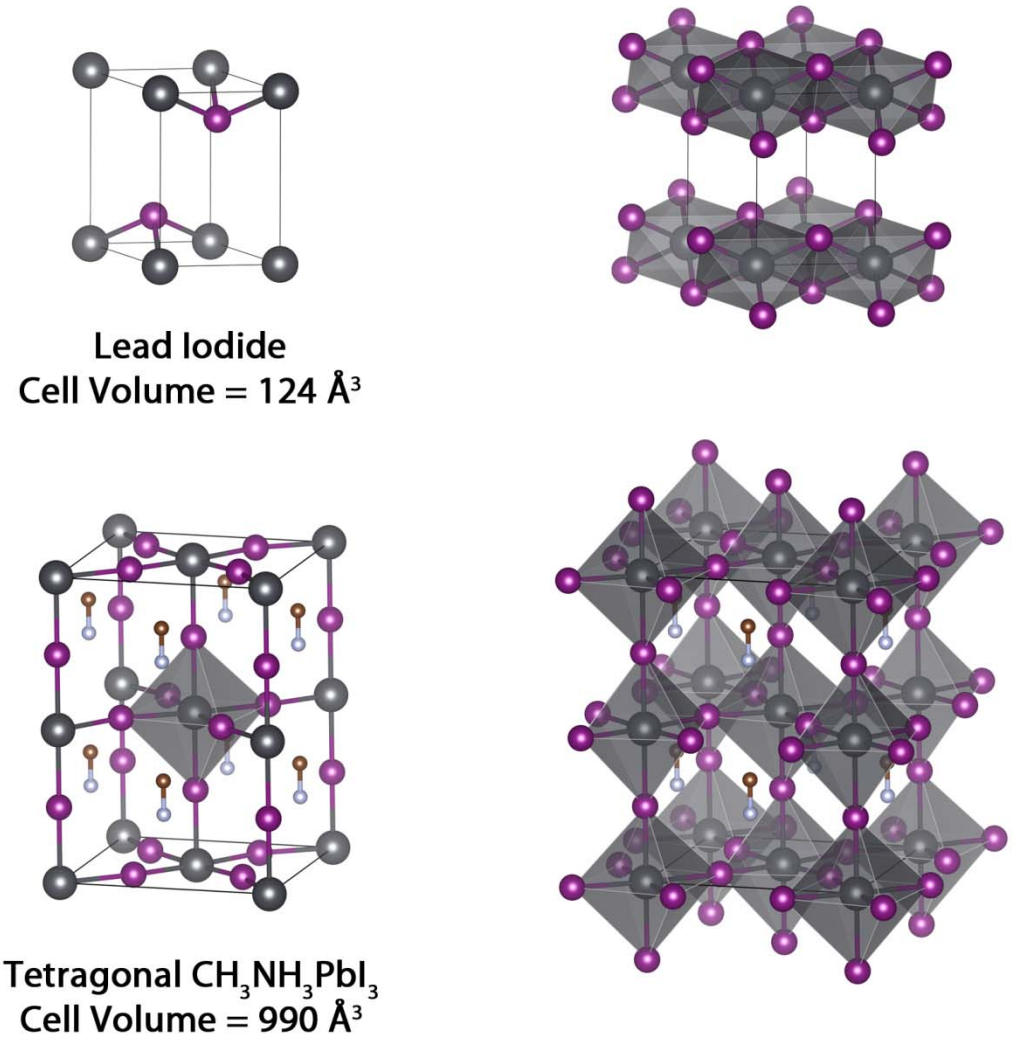

Figure S2. The unit cells and cell volumes of lead iodide and tetragonal $CH_3NH_3PbI_3$: Pb (grey), I (purple), C (brown) and N (pale blue). The unit cell of $CH_3NH_3PbI_3$ contains four $CH_3NH_3PbI_3$ units, and so the volume per $CH_3NH_3PbI_3$ repeat unit is 248 $Å^3$.

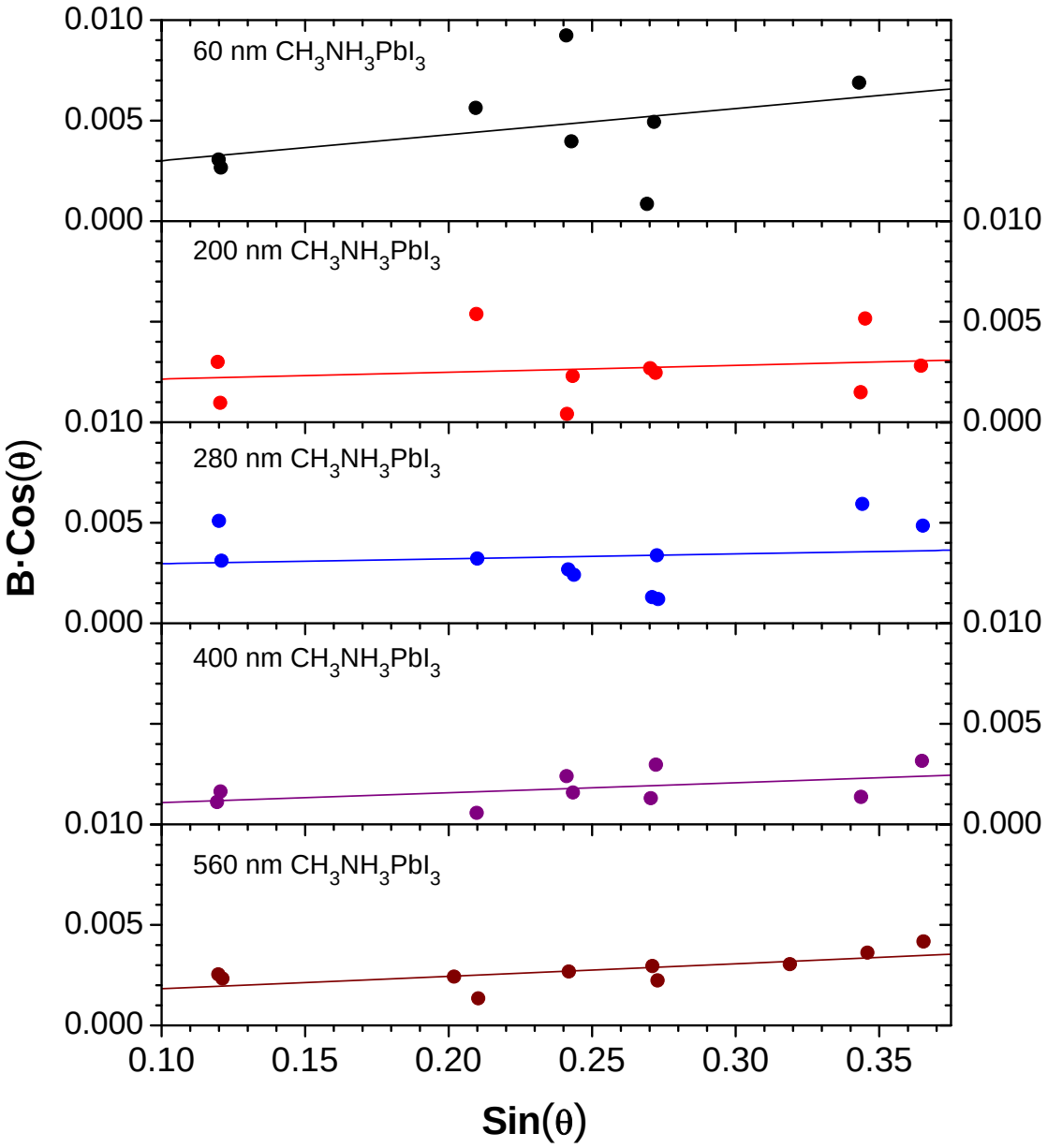

Figure S3. Williamson-Hall plots for $CH_3NH_3PbI_3$ films of various thicknesses. Contributions from instrumental broadening were not subtracted from the data; however, the FWHM of a polycrystalline Si standard indicated the degree of instrumental broadening to be < 0.05° (2θ).

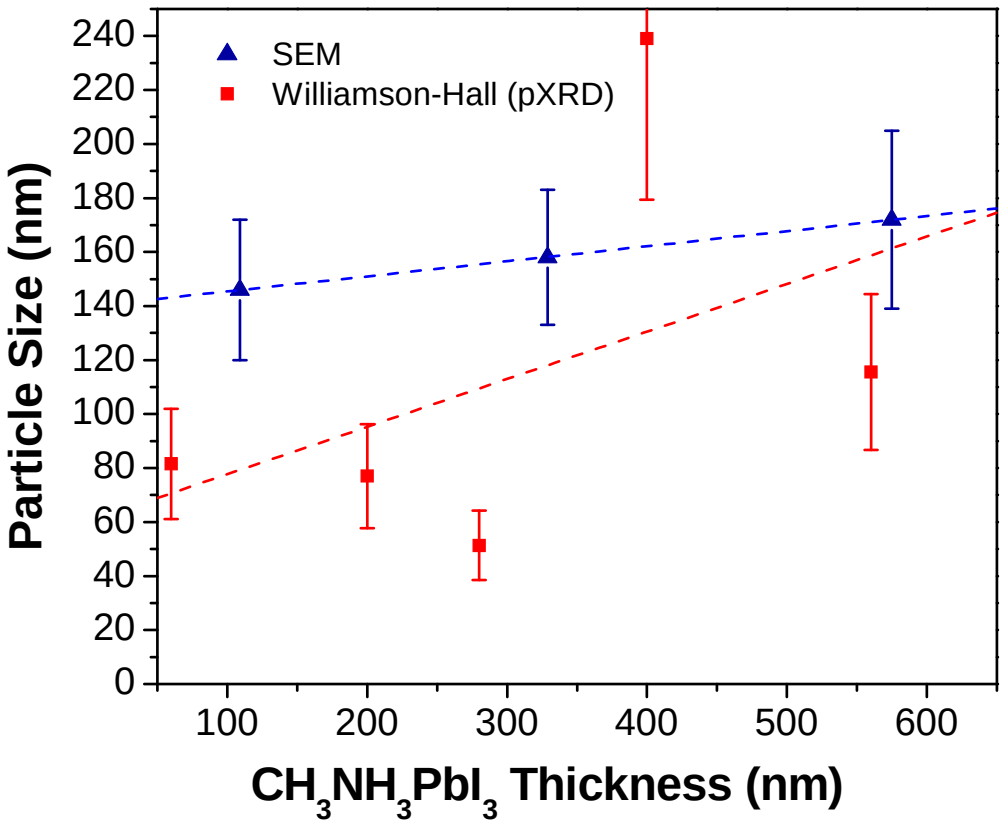

Figure S4. Particle size as measured by SEM (blue triangles) and minimum grain size as determined by a Williamson-Hall analysis of powder X-ray diffraction data (red squares) as a function of perovskite layer thickness. The linear fits are a guide to the eye.

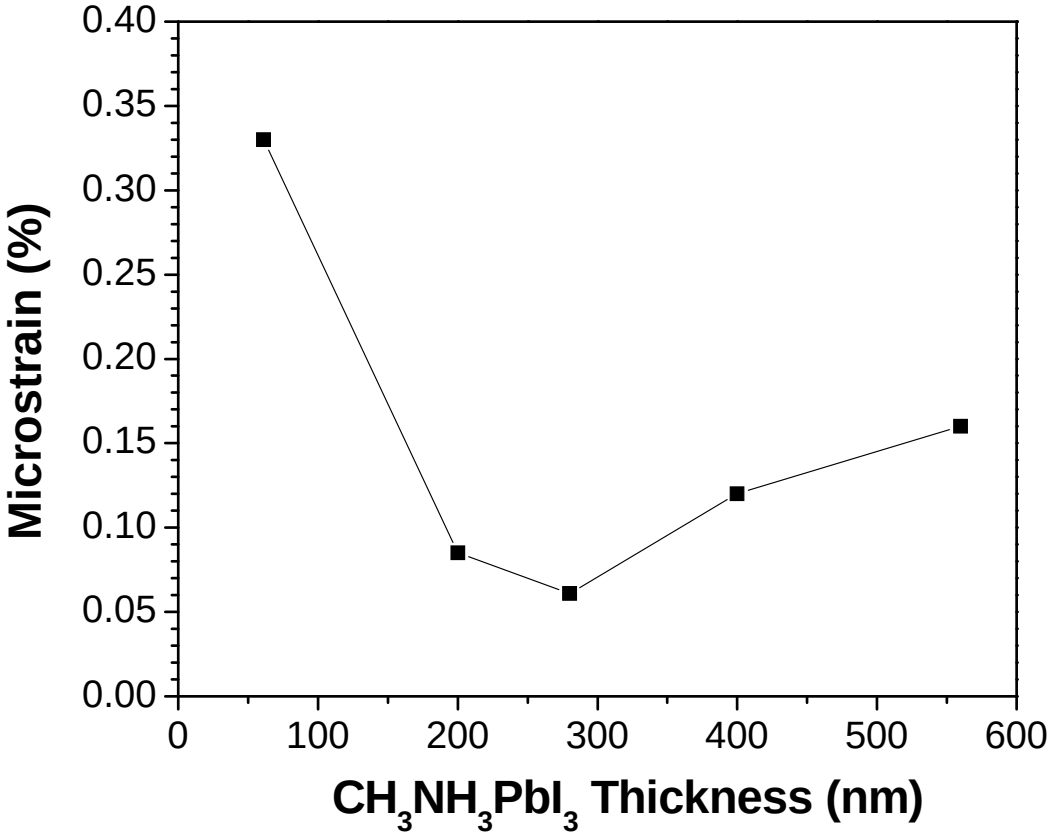

Figure S5. Microstrain (as calculated by a Williamson-Hall analysis of powder X-ray diffraction data) as a function of perovskite layer thickness.

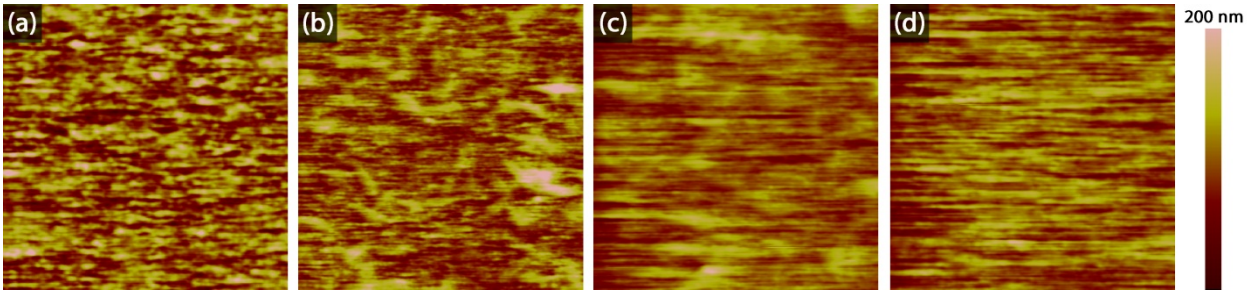

Figure S6. Height mode AFM images of $CH_3NH_3PbI_3$ films of various thicknesses on ITO/ZnO substrates: (a) 200 nm, (b) 280 nm, (c) 400 nm, and (d) 560 nm. All images were of a 15 μm × 15 μm area. The samples had root-mean-squared surface roughnesses (R_{rms}) of: (a) 33, (b) 29, (c) 23, and (d) 49 nm, respectively.

Table S1. Average series (R_s) and shunt (R_{sh}) resistances for perovskite solar cells.

$CH_3NH_3PbI_3$ Thickness (nm)	R_s ($\Omega \cdot cm^2$)	R_{sh} ($k\Omega \cdot cm^2$)
110	170	0.22
210	13	3.0
330	8.0	4.0
410	12	0.42
490	41	0.24
580	110	1.2

Table S2. Tabulated fit parameters for the EIS data.

$CH_3NH_3PbI_3$ Thickness (nm)	R_s (Ω)	R_{co} (Ω)	C_{co} (F)	R_{rec} (Ω)	CPE_μ-T (F)	CPE_μ-P
110	64	5	1×10^{-7}	1	2×10^{-3}	0.57
330	52	31	6×10^{-3}	116	9×10^{-8}	0.84
580	39	1250	2×10^{-7}	1323	9×10^{-7}	0.67

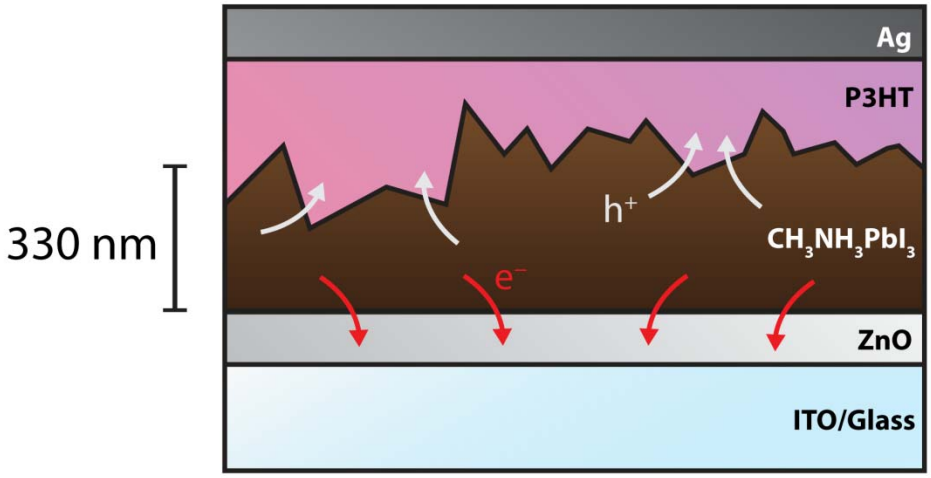

Figure S7. Schematic of the ITO/ZnO/$CH_3NH_3PbI_3$/P3HT/Ag devices tested in this work, showing the effect of the roughened $CH_3NH_3PbI_3$/P3HT interface on the hole-extraction efficiency.