# Impedance analysis of perovskite solar cells: a case study

Lidia Contreras-Bernal[a,¶], Susana Ramos-Terrón[a,¶], Antonio Riquelme[a], Pablo Boix[c], Jesús Idígoras[a,]*, Iván Mora-Seró[b,]*, Juan A. Anta[a,]*

[a] Área de Química Física, Universidad Pablo de Olavide, Seville, Spain.
[b] Institute of Advanced Materials (INAM), Universitat Jaume I, E-12006 Castelló, Spain
[c] Instituto de Ciencia Molecular, Universidad de Valencia, C/J. Beltrán 2, Paterna, Spain

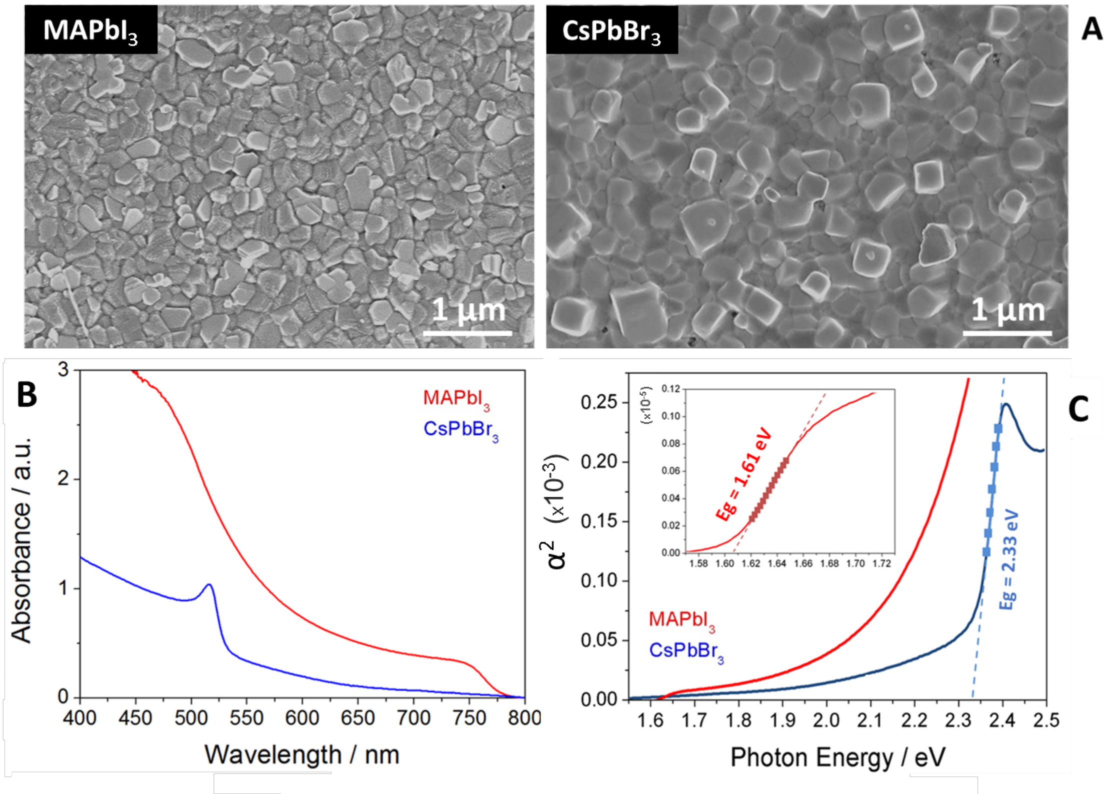


**Figure S1**. Morphological, and optical characterization of $MAPbI_3$ and $CsPbBr_3$ films and solar cells: (A) Plane-view scanning electron microscope images (SEM), (B) UV-Vis spectra (C) Tauc plot

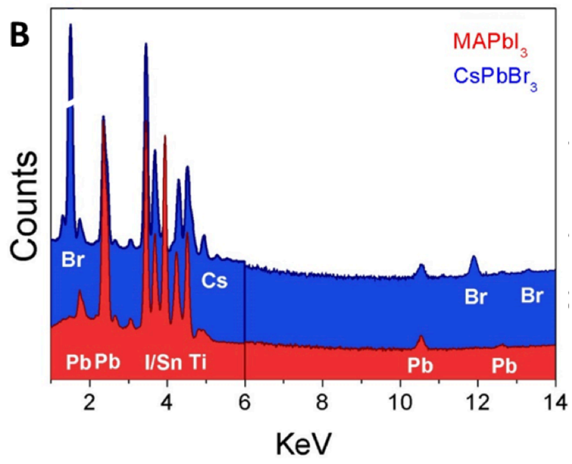


**Figure S2.** EDX map of $MAPbI_3$ and $CsPbBr_3$ films.

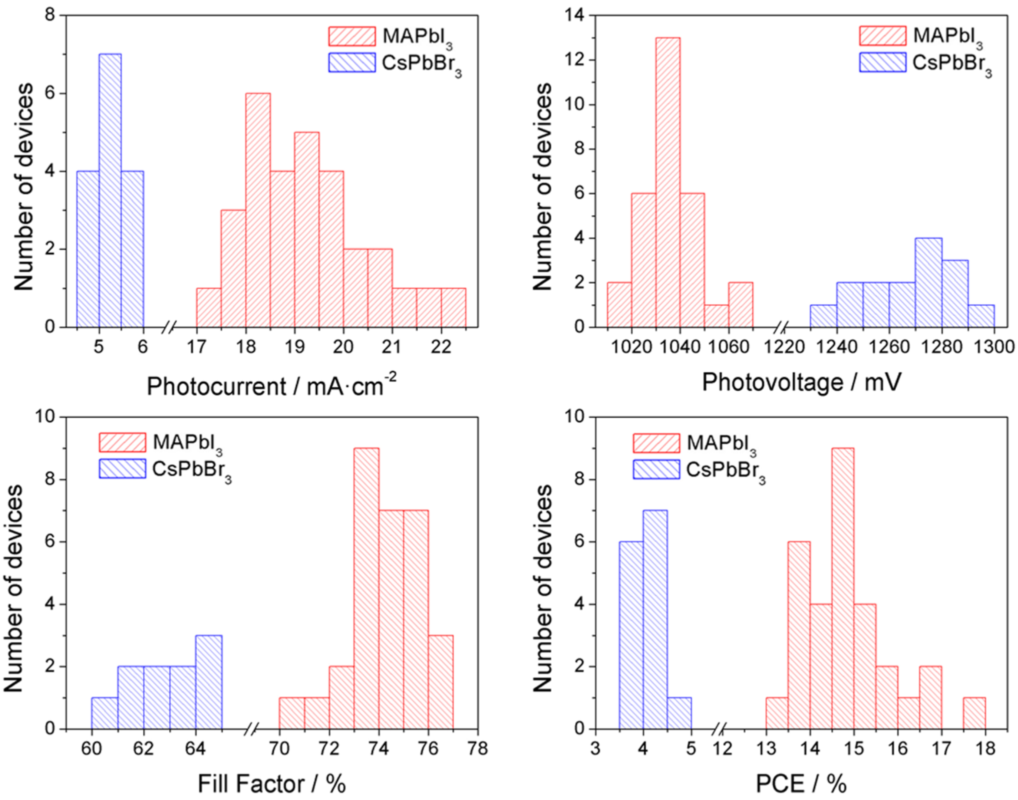


**Figure S3.** Statistical data of photovoltaic parameters for $MAPbI_3$ and $CsPbBr_3$ solar cell devices.

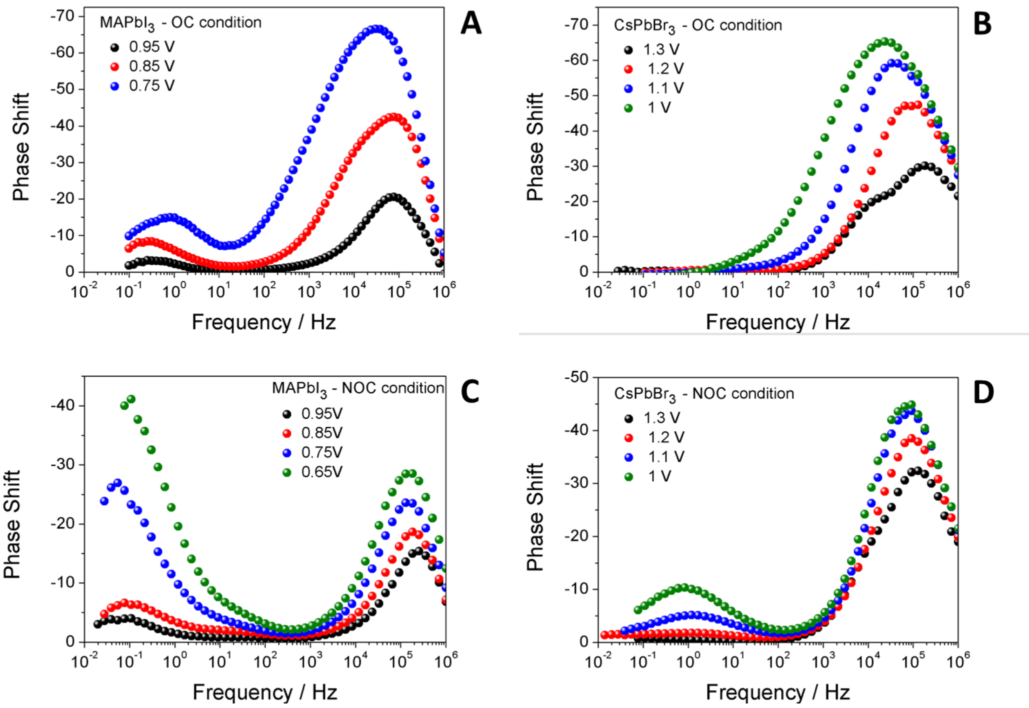


**Figure S4.** Impedance Bode plots of MAPI and $CsPbBr_3$ solar cells at OC and NOC conditions

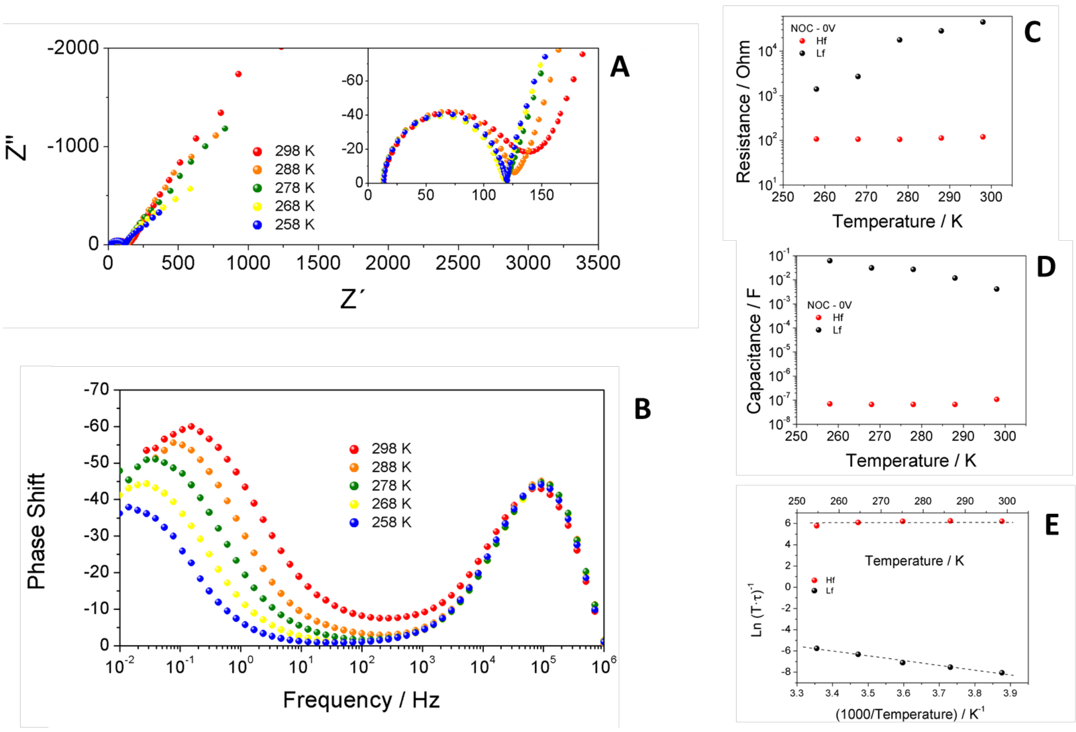


**Figure S5. (A)** Impedance spectra and **(B)** frequency plot for $MAPbI_3$ based devices at SC conditions and different temperatures. **(C)** and **(D)** resistances and capacitances at SC circuit as a function of temperature. **(E)** Arrhenius plot of the low and high frequency time constants. An activation energy of 36.9 kJ/mol can be extracted from the low frequency data.

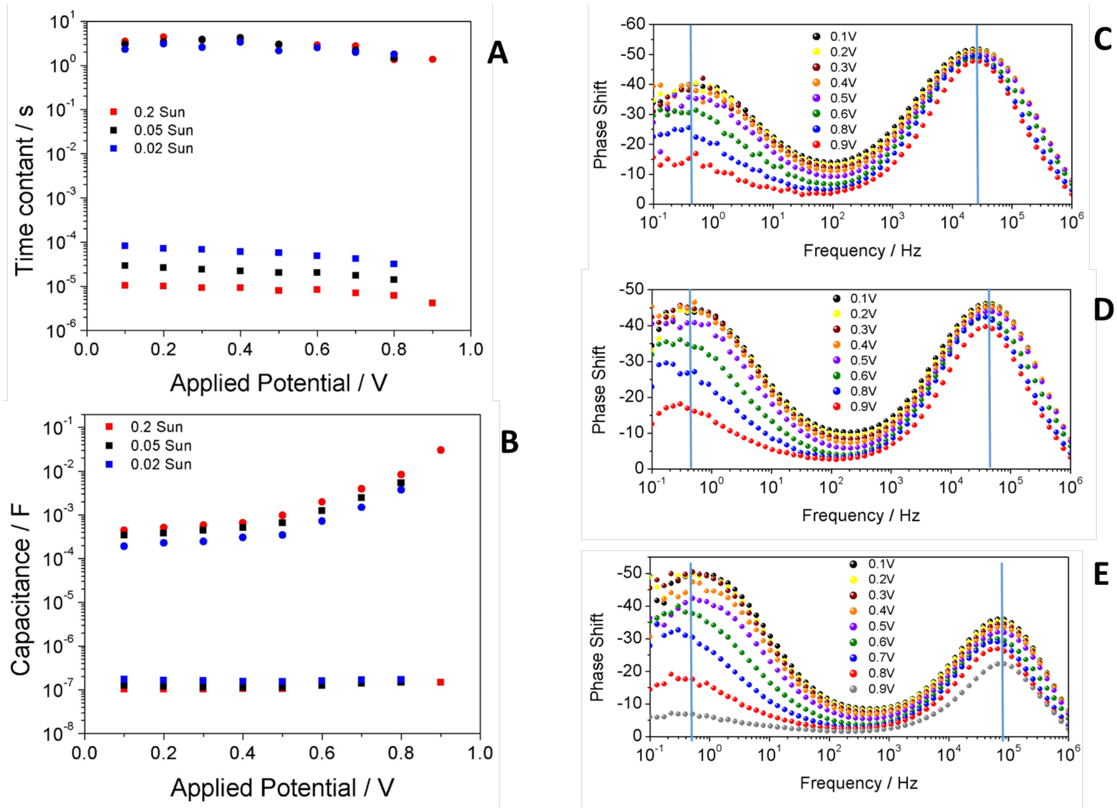


**Figure S6.** Effect of illumination on the impedance response of $MAPbI_3$ based devices at NOC conditions. In Panels **(A)** and **(B)** the voltage dependence of both the high and low frequency time constants and capacitances is shown. Frequency Bode plots at 0.02, 0.05 and 0.2 suns are shown in panels **(C)**, **(D)** and **(E)** respectively. Vertical lines mark the position of the frequency peaks.

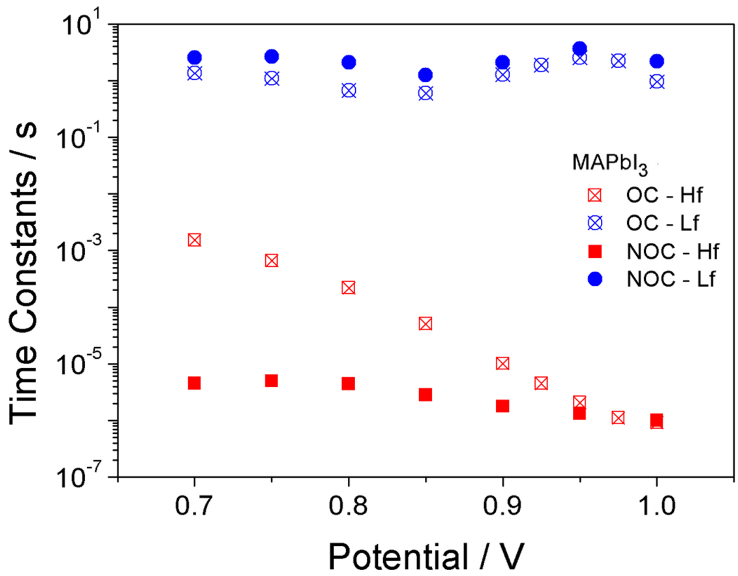


**Figure S7.** High and low frequency time constants as extracted from fittings for $MAPbI_3$ based devices at OC and NOC conditions

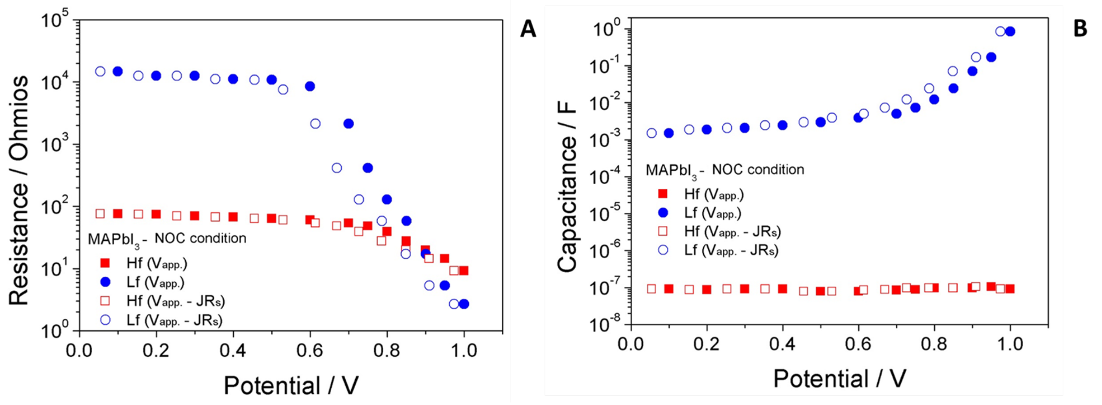


**Figure S8.** Correction for voltage drop due to series resistance in the impedance measurements at NOC conditions for $MAPbI_3$ devices.

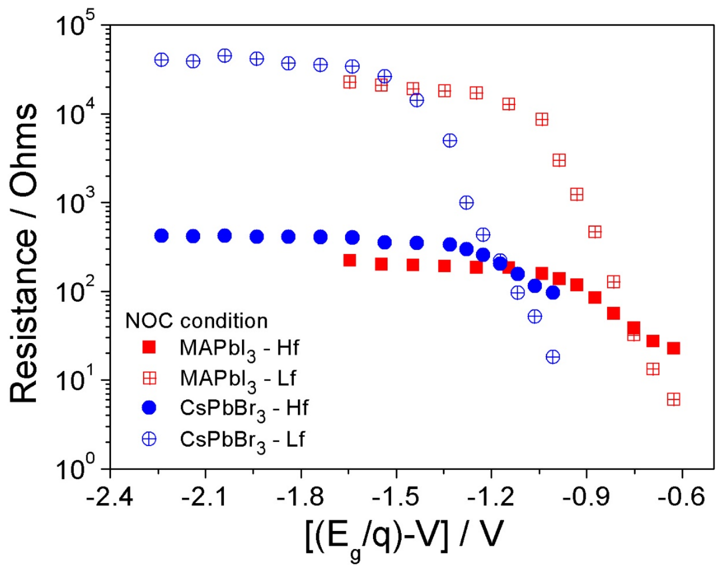


**Figure S9.** Resistances at NOC conditions corrected for the optical band gap of the perovskite.

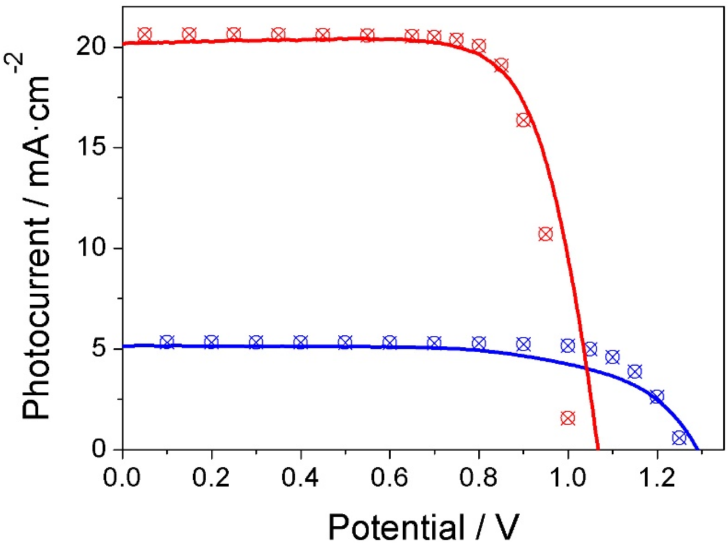


**Figure S10.** Experimental JV curves (symbols) and reconstruction from the impedance data at NOC conditions using Eq. (8) in the main text (lines)

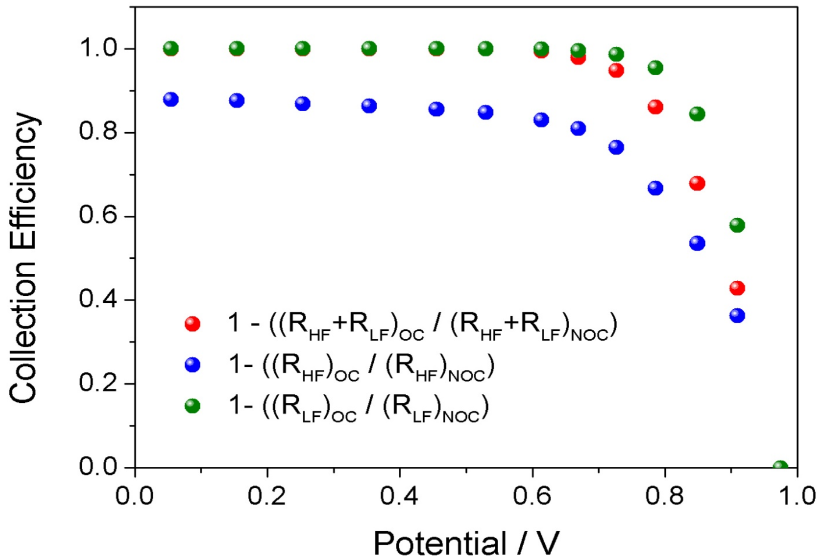


**Figure S11.** Charge collection efficiency of $MAPbI_3$ solar cells as predicted by Eq. (9) using impedance data at OC and NOC conditions for several choices of $R_{rec}$.

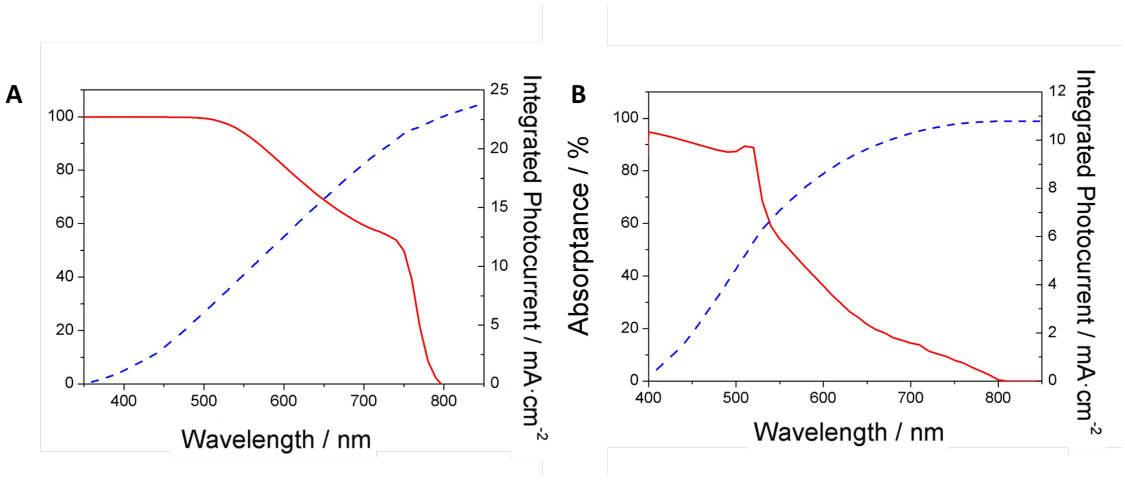


**Figure S12.** Absorptance and integrated photocurrent for $MAPbI_3$ (A) and $CsPbBr_3$ (B). Total integrated photocurrent amounts to 24.9 and 10.8 mA/$cm^2$, respectively.