# Supplementary information

## Efficient Minority Carrier Detrapping mediating the Radiation Hardness of Triple-Cation Perovskite Solar Cells under Proton Irradiation

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# Proton induced external quantum efficiency measurements

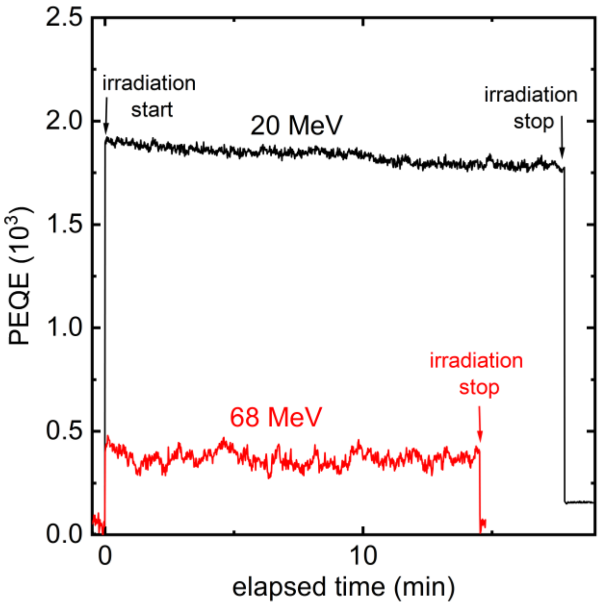


Figure S1: *In-situ measurement of the proton induced current for $Cs_{0.05}MA_{0.17}FA_{0.83}Pb(I_{0.83}Br_{0.17})_3$ based diodes under 20 and 68 MeV proton irradiation. Depicted is the proton induced external quantum efficiency as a function of the* elapsed irradiation time. In both cases the irradiation was stopped once a proton dose of $\Phi = 10^{12}$ p/cm$^2$ is reached.

# Photoluminescence spectra under CW excitation

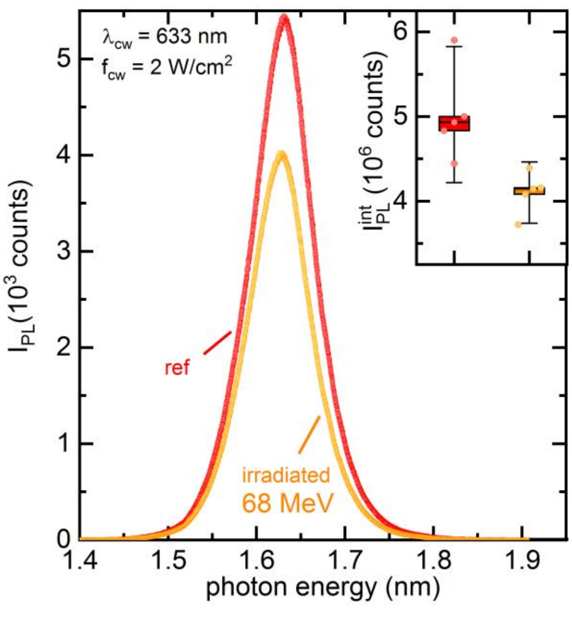


Figure S2: *Photoluminescence spectra of reference and 68 MeV proton irradiated $Cs_{0.05}MA_{0.17}FA_{0.83}Pb(I_{0.83}Br_{0.17})_3$ thin-films on glass* under excitation with a 633 nm CW laser. The inset shows the integrated area for a number of measurements on reference and irradiated specimens. In all cases, the excitation was performed through the quartz substrate.

## Spectra used to mimic AM0 and AM1.5G conditions

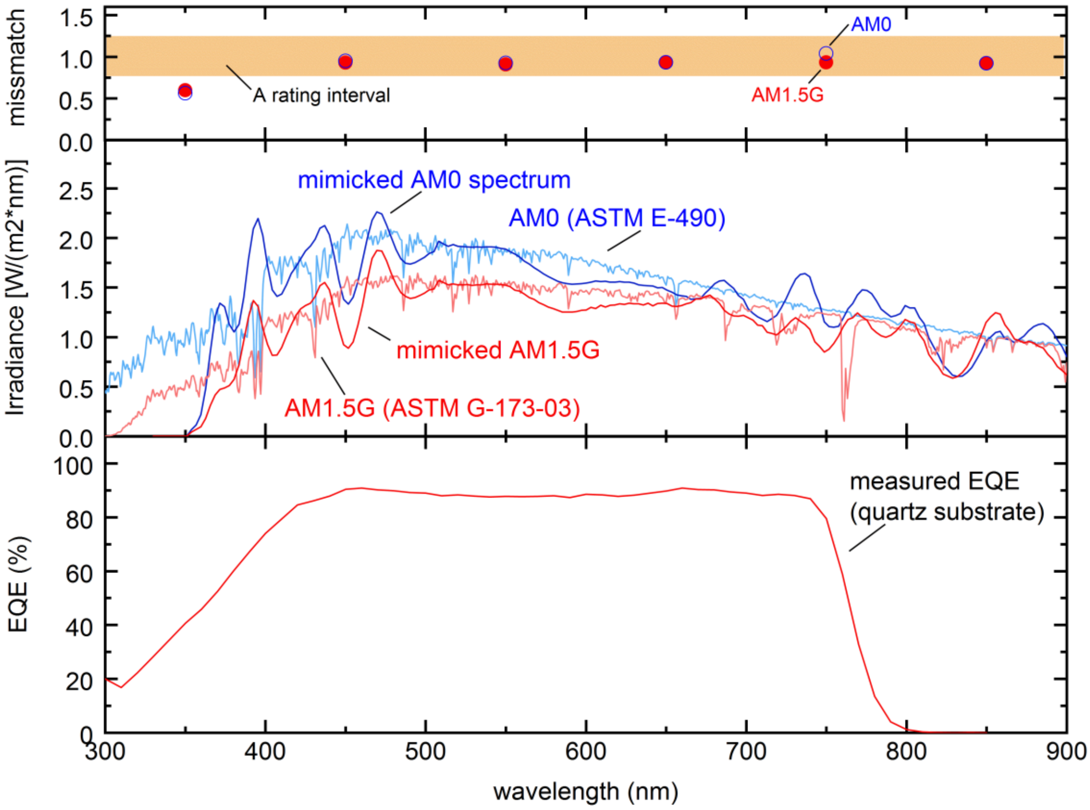


*Figure S3: Mimicked AM0 and AM1.5G spectra, compared to the standard AM0 and AM1,5G spectra[1]. The top panel depicts the spectral mismatch in 100 nm intervals. The bottom panel depicts measured EQE spectra prior to irradiation.*

*Table S1: Overview of proton irradiation tests of hybrid perovskites published in literature. Some of the efficiencies were estimated based on the remaining factor and the initial efficiency. Consequently those values may be imprecise.*

| Publication | Device architecture | Initial efficiency | End efficiency | proton energy | accumulated fluence |
|---|---|---|---|---|---|
| Y. Miyazawa, et al. (2015). *IEEE PVSC*[2] | Glass/ITO/$TiO_2$/ $CH_3NH_3PbI_3$/$P_3HT$/Au | ≈3 % | ≈2.8 % | 150 keV | $10^{14}$ p/cm$^2$ |
| F. Lang et al. (2016). Advanced Materials, 28(39), 8726–8731.[3] | Glass/ITO/PEDOT:PSS/ $CH_3NH_3PbI_3$/PCBM/BCP/ Ag | 12.1 % | 6 % | 68 MeV | $10^{13}$ p/cm$^2$ |
| Y. Miyazawa, et al. (2018). IScience, 2, 148–155.[4] | Glass/ITO/$TiO_2$/ $CH_3NH_3PbI_3$/P3HT/Au | 4.8 % | ≈5.3 % | 50 keV | $10^{14}$ p/cm$^2$ |
| Y. Miyazawa, et al. (2018). IScience, 2, 148–155.[4] | Glass/ITO/$TiO_2$/ FAMAPb$(IBr)_3$/P3HT/Au | 4.4 % | ≈3.5 % | 50 keV | $10^{14}$ p/cm$^2$ |
| This manuscript | glass/ITO/PTAA/ $Cs_{0.05}MA_{0.17}Fa_{0.83}Pb$ $(I_{0.83}Br_{0.17})_3$/$C_{60}$/BCP/Cu | 18.8% | 17.8% | 20MeV 68 MeV | $10^{12}$ p/cm$^2$ |

# References


[1] American Society for Testing and Materials (ASTM) Terrestrial Reference Spectra for Photovoltaic Performance Evaluation, "Reference Solar Spectral Irradiance Air Mass 1.5 ASTM G173," can be found under http://rredc.nrel.gov/solar/spectra/am1.5/, **2017**.

[2] Y. Miyazawa, M. Ikegami, T. Miyasaka, T. Ohshima, M. Imaizumi, K. Hirose, in *2015 IEEE 42nd Photovolt. Spec. Conf.*, IEEE, **2015**, p. 1.

[3] F. Lang, N. H. Nickel, J. Bundesmann, S. Seidel, A. Denker, S. Albrecht, V. V. Brus, J. Rappich, B. Rech, G. Landi, H. C. Neitzert, *Adv. Mater.* **2016**, *28*, 8726.

[4] Y. Miyazawa, M. Ikegami, H.-W. Chen, T. Ohshima, M. Imaizumi, K. Hirose, T. Miyasaka, *iScience* **2018**, *2*, 148.