Electronic Supplementary Material (ESI) for Sustainable Energy & Fuels.

Blue and Red Wavelength Resolved Impedance Response of Efficient Perovskite Solar Cells

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Experimental Section

Device fabrication

Nippon Sheet Glass 10 Ω/sq was cleaned by sonication in 2% Hellmanex water solution for 30 min. After rinsing with deionised water and ethanol, the substrates were further cleaned with UV ozone treatment for 15 min. Then, a compact thick titanium dioxide layer was deposited by spray pyrolysis of 9 ml ethanol solution containing 0.6 mL titanium diisopropoxide bis(acetylacetonate) solution (75% in 2-propanol, Sigma-Aldrich) and 0.4 mL acetylacetone at 450° C in air. The devices were made of a stacking of FTO/compact TiO_2-layer/perovskite/ spiro-MeOTAD/Au.

For deposition of perovskite film, $(FAPbI_3)_{0.85}(MAPbBr_3)_{0.15}$ precursor solution was prepared by mixing formamidinium iodide (FAI, 1.0 M, Dyesol), PbI_2 (1.10 M, TCI), methylammonium bromide (MABr, 0.20 M, Dyesol) and $PbBr_2$ (0.20 M, TCI) in a mixed solvent of DMF:DMSO = 4:1 (volume ratio). Then, 5 vol% of CsI solution (1.5 M in DMSO) was added into the perovskite solution in order to make a triple cations perovskite. The solution was spincoated at 1000 rpm for 10 s and, continuously at 6000 rpm for 20 s. During the second step, 100 µL of chlorobenzene was dropped on top film 10 second before end of spinning. Afterward, the film was annealed at 100 °C for 60 min.

The HTL solution was prepared by dissolving spiro-OMeTAD (70 mM) in 1 mL chlorobenzene and adding 18 µL solution of bis(trifluoromethylsulfonyl)imide lithium salt (Li- TFSI, Sigma-Aldrich) in acetonitrile (520 mg/1mL) and 33 µL of (4-tert-butylpyridine-Sigma- Aldrich). After annealing, the solution was spin-coated at 4000 rpm for 20 s with ramp rate of 2000 rpm/s. Finally, gold electrode as the back-contact was deposited using thermal evaporation with 80-nm thick. The active area of device was 0.16 cm^2.

Device characterization

The *J-V* characteristics of the devices were measured under 100 mW/cm^2 conditions using a 450 W Xenon lamp (Oriel), as a light sourceThe current–voltage characteristics of the devices were obtained by applying external potential bias to the cell while recording the generated photocurrent using a Autolab (Metrohm) digital source meter. The EIS measurements where done in Autolab equipped with temperature probe station (LASC). For the measurement of solar cell under blue and red wavelength, blue and red led (Luminox) was derived through led driver with the use of Autolab. The specification of the used led was as follows:

LED Color	Blue	Red
Lumens @ 350mA	35 lm	64 lm
Lumens @ 700mA	56 lm	118 lm
Lumens @ 1000mA	77 lm	--------
(1)Wavelength Range	460 to 485nm	620 to 645nm
(2)Beam Angle	9°	9°
(3)Recommended Operating Current	700 mA	350 mA
Maximum Rated Drive Current	1000 mA	700 mA
(4)Typical Forward Voltage	2.95 Vf	2.1 Vf

(4,6)Maximum Forward Voltage	3.51 Vf	2.6 Vf
(5)Thermal Resistance	10.7 C°/W	7.7 C°/W
Max Recommended Junction Temp	150 °C	135 °C
Operating Temperature Range	-40 to 135 °C	-40 to 120 °C
Dimensions L x W x H	25 x 25 x 3.7 mm	25 x 25 x 3.7 mm

The surface morphology of the perovskite absorber layer was explored by a ZEISS Merlin HR-SEM. An electron beam accelerated to 3 kV was used with an in-lens detector.

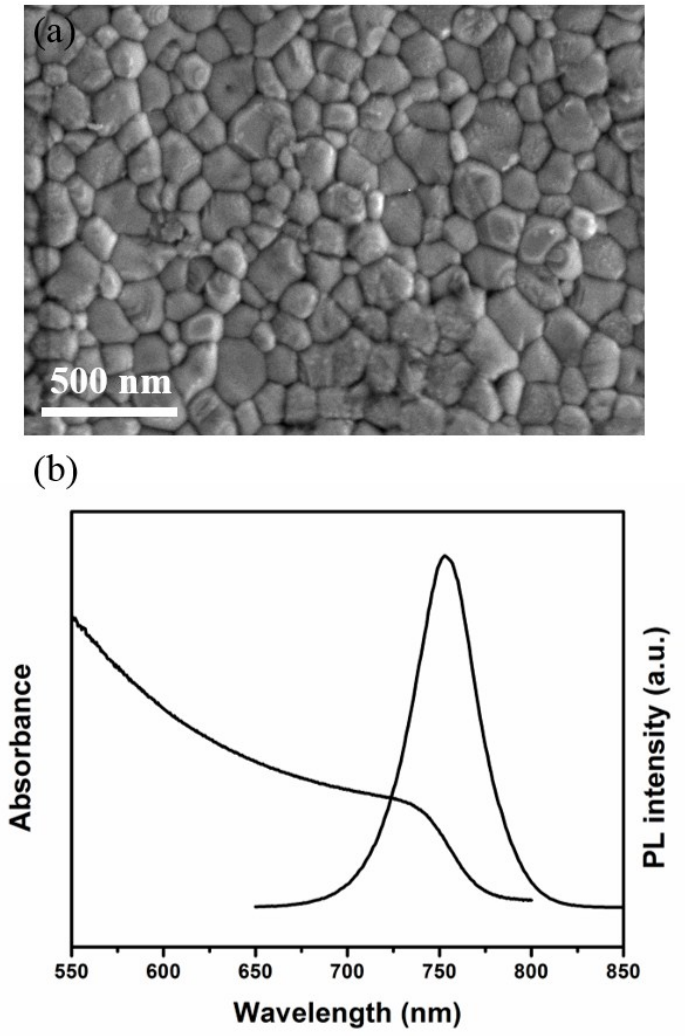

Fig. S1. (a) SEM image and (b) UV-Vis and PL spectra of the obtained triple cation thin film.

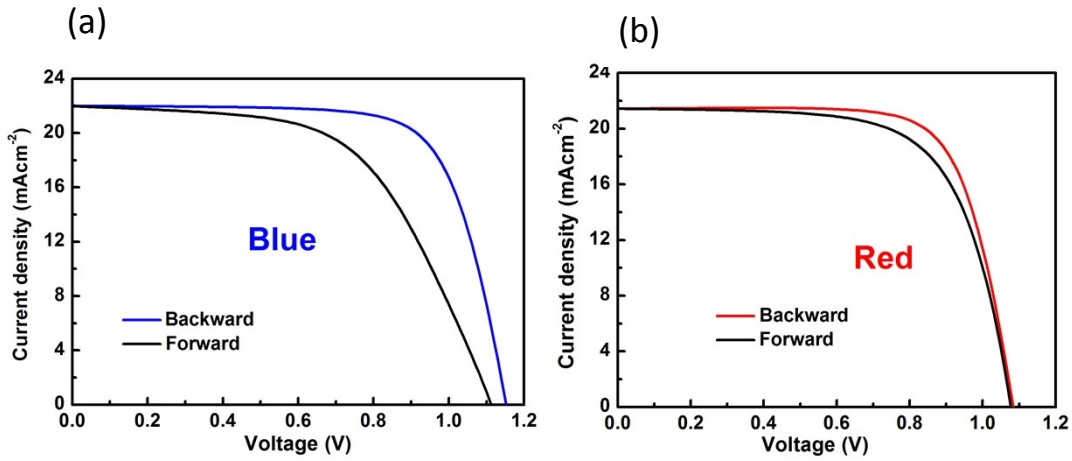

Fig. S2. J-V characterization measured at forward and reverse scan direction (a) blue wavelength and (b) red wavelength.

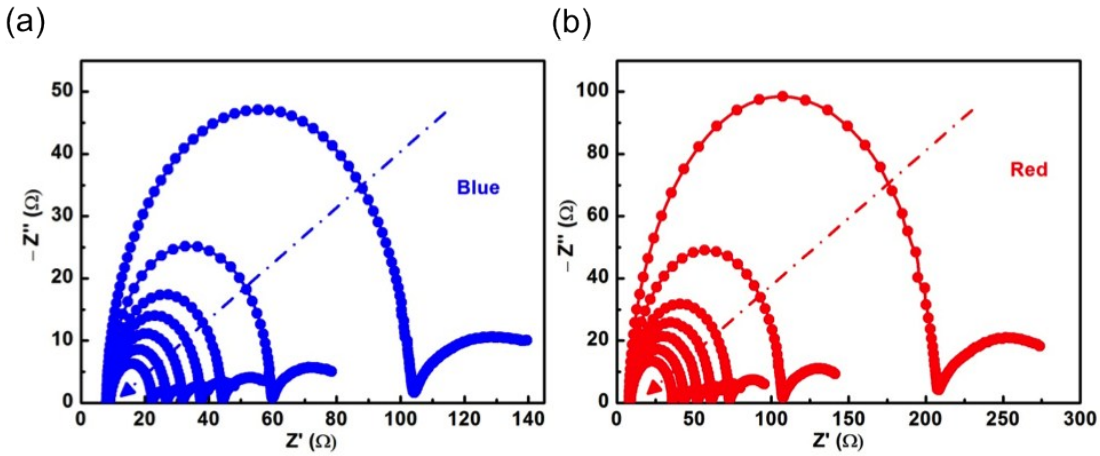

Fig. S3. EIS spectra measured at open circuit voltage under (a) blue wavelength and (b) red wavelength as a function of light intensity, (arrow shows the increase in illumination intensity starting from 50 mW/cm^2 to 100 mW/cm^2 in a step of 10mW/cm^2).

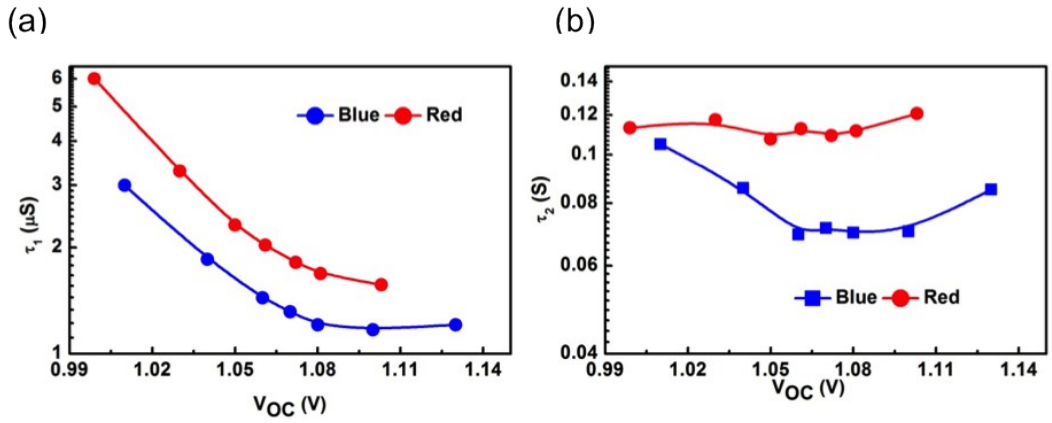

Fig. S4. The time scale associated with the high and low frequency spectra of EIS measured under blue and red wavelength in (a) high frequency time response and (b) low frequency time response.