Supporting Information

Enhancing Electron Transport through Metal Oxide Adjustments in Perovskite Solar Cells and Their Suitability for X-ray Detection

Xin Li[1,2,3#], Sikandar Aftab [4,5#], Hailiang Liu[6#], Dhanasekaran Vikraman[7], Sajjad Hussain[8], Abdullah A. Al-Kahtani[9], Ganesh Koyyada[10], Jungwon Kang[6], Erdi Akman[11]

[1]State Key Laboratory of Pulsed Power Laser Technology, National University of Defense Technology, Hefei 230037, Anhui, China
[2]Anhui Laboratory of Advanced Laser Technology, Hefei 230037, Anhui, China
[3]Nanhu laser laboratory, Changsha 410015, Hunan, China
[4]Department of Semiconductor Systems Engineering and Clean Energy, Sejong University, Seoul 05006, Republic of Korea
[5]Department of Artificial Intelligence and Robotics, Sejong University, Seoul 05006, Republic of Korea
[6] Department of Electronics and Electrical Engineering, Dankook University, Yongin 16890, Korea
[7] Division of Electronics and Electrical Engineering, Dongguk University-Seoul, Seoul 04620, Korea
[8] Department of Nanotechnology and Advanced Materials Engineering, Sejong University, Seoul, South Korea
[9]Chemistry Department, Collage of Science, King Saud University, P. O. Box 2455, Riyadh, 11451 Saudi Arabia
[10]School of Chemical Engineering, Yeungnam University, Gyeongsan 38541, Republic of Korea.
[11]Scientific and Technological Research & Application Center, Karamanoglu Mehmetbey University, Karaman, 70100, Turkey

# These authors are contributed equally
*Email# aftab@sejong.ac.kr

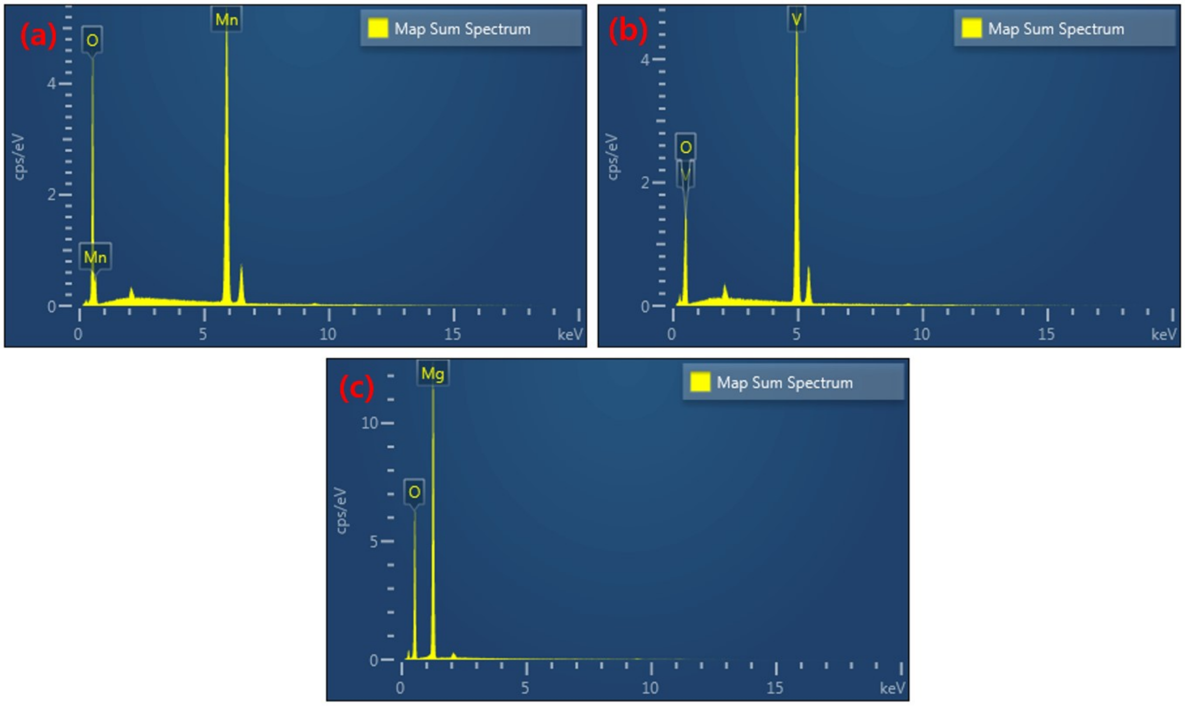


Figure S1. EDX mappings of (a) MnO_2, (b) V_2O_2, and (c) MgO.

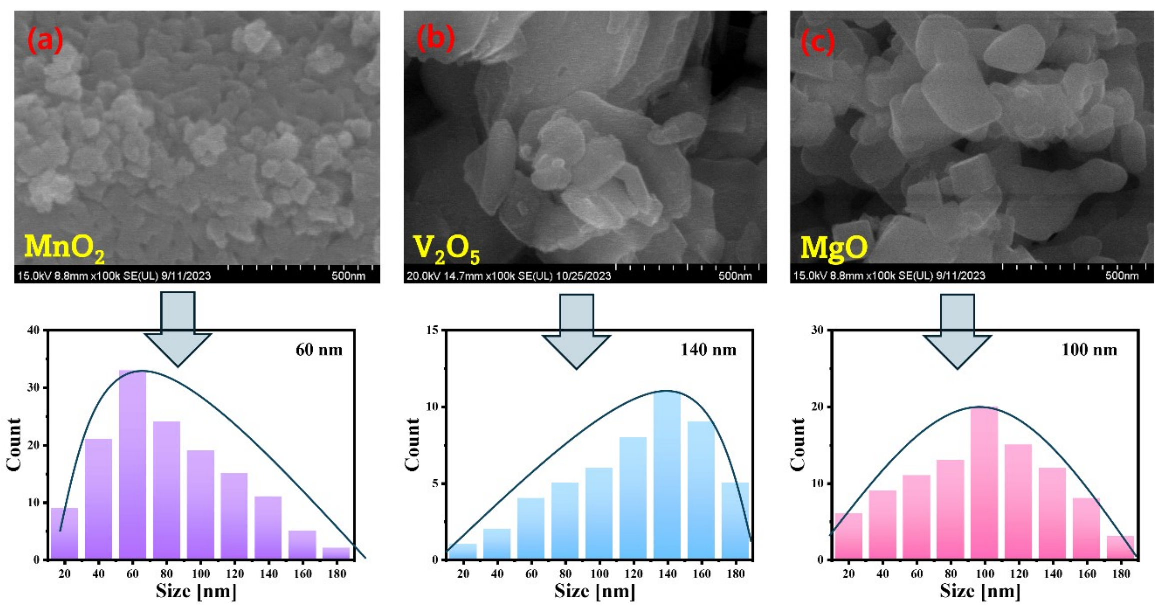


Figure S2. (a-c) SEM images with corresponding profile graphs.

Characterization

The external quantum efficiency (EQE) of the solar cell was measured by using a computer-controlled xenon arc lamp (66477-150XV-R1) coupled with a monochromator (CS130B-1-FH). Current density-voltage (J-V) measurements of photovoltaic devices were evaluated using an electrometer (Keithley 6571B) and a solar simulator (San Ei Elec. XES 40S2-CE) using an AM 1.5G-filtered xenon (Xe) lamp exposure with an intensity of 100 mW/cm^2. The built-in detector combined with CsI (Tl) scintillators (Hamamatsu J13113) converts incident X-ray photons into visible photons and the produced charge carriers during exposure were measured with the electrometer. J-V characteristics of the scintillator-coupled detectors were received using an X-ray generator (AJEX 2000H). The distance between the X-ray source and the scintillator-coupled detector was approximately 30 cm, and the exposure X-ray dose was measured using an ionization chamber (Capintec CII50) at the same distance. For all the experiments, The operating conditions of X-ray generator were fixed at 1.57 sec, 80 kVp and 63 mAÂus for X-ray exposure time, tube voltage and tube current, respectively. All measurements were performed using a constant dose rate of 3.34 mGy and an X-ray source applied bias voltage of -0.6 V. To tune the charge-carrier collection, a bias voltage of -0.2 to -1.0 V, and a dose rate of 1.19 to 5.56 mGy was applied to the detector. The CCD and sensitivity of the detectors were computed from the measured charge amount during X-ray exposure based on the measured charge. Use the following formula to calculate the sensitivity related to X-ray photon to charge conversion efficiency.

$$Sensitivity\ ({}^{mA}/_{Gy \cdot cm^2}) = \frac{Charges\ during\ the\ X-ray\ ON[mA] -\ Charges\ during\ the\ X-ray\ OFF\ [mA]}{Absorbed\ dose\ [Gy] \cdot Detection\ Area\ [cm^2]}$$

The dose absorbed by the exposure was measured using an ionization chamber.

Field-emission scanning electron microscopy (FE-SEM, Hitachi S-4700) was used to analyze the compositional properties of metal oxides (MnO_2, V_2O_5 and MgO) and cross-section of the fabricated device. UV-vis optical spectroscopy (Optizen 2120UV) was used to measure the absorption spectra of $FA_{0.5}MA_{0.5}PbI_3$:PCBM doped with 2 wt% metal oxides (MnO_2, V_2O_5 and MgO). The topoology and roughness of the PCBM layer doped with 2 wt% metal oxides

(MnO_2, V_2O_5 and MgO) were investigated by using atomic force microscopy (AFM, Veeco Dimension 3100).

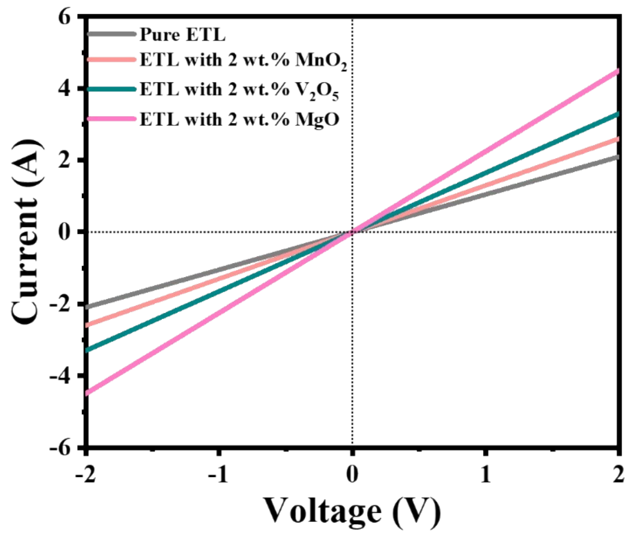
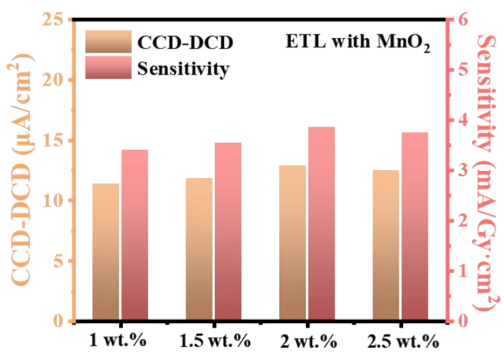
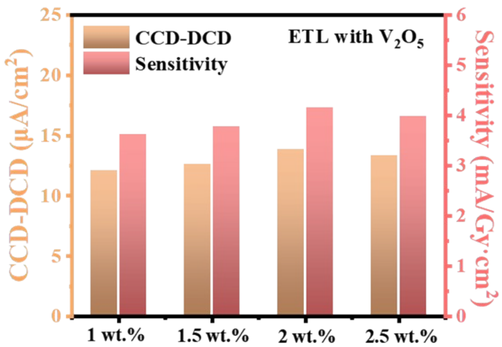


Figure S3. I-V curves of ITO/PCBM/Ag and ITO/Metal oxide:PCBM/Ag devices.



Device	CCD-DDC [μA/cm^2]	Sensitivity [mA/Gy·cm^2]
1 wt%	11.39	3.41
1.5 wt%	11.86	3.55
2 wt%	12.89	3.86
2.5 wt%	12.49	3.74

Figure S4. CCD-DCD and sensitivity for different concentrations (1, 1.5, 2 and 2.5 wt.%) of MnO_2 blended PCBM ETL.



Device	CCD-DDC [μA/cm²]	Sensitivity [mA/Gy·cm²]
1 wt%	12.09	3.62
1.5 wt%	12.63	3.78
2 wt%	13.86	4.15
2.5 wt%	13.33	3.99

Figure S5. CCD-DCD and sensitivity for different concentrations (1, 1.5, 2 and 2.5 wt.%) of V_2O_5 blended PCBM ETL.