Impedance spectroscopy of Sb_2Se_3 photovoltaics consisting of $(Sb_4Se_6)_n$ nanoribbons under light illumination

*Jaemin Park, Thomas P. Shalvey, Thomas Moehl, Kyoohee Woo, Jonathan D. Major, S. David Tilley, Wooseok Yang**

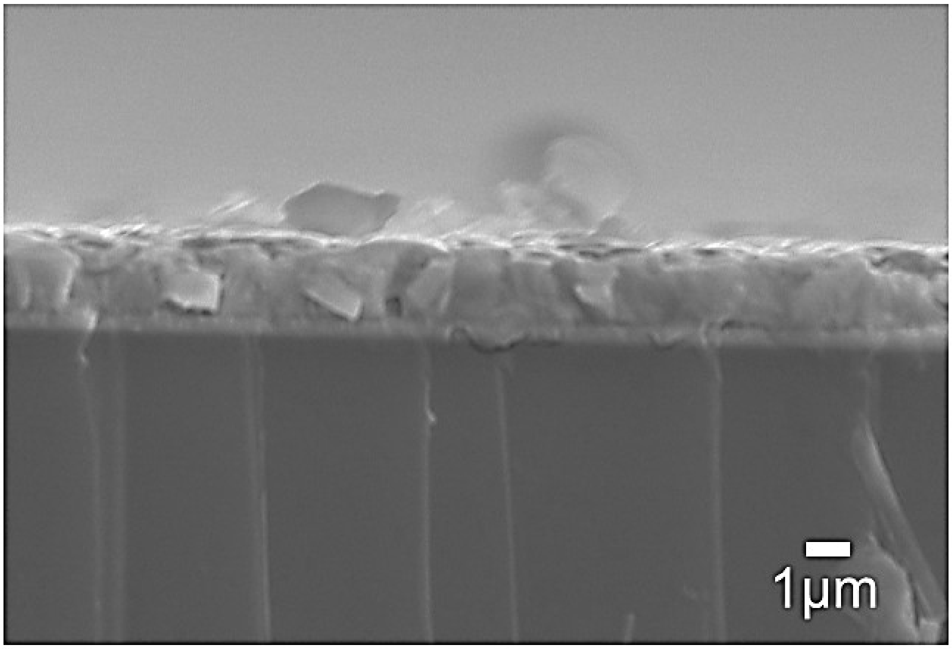

Figure S1. Cross-section SEM image of the w-seed Sb_2Se_3 film on TiO_2/FTO superstrate.

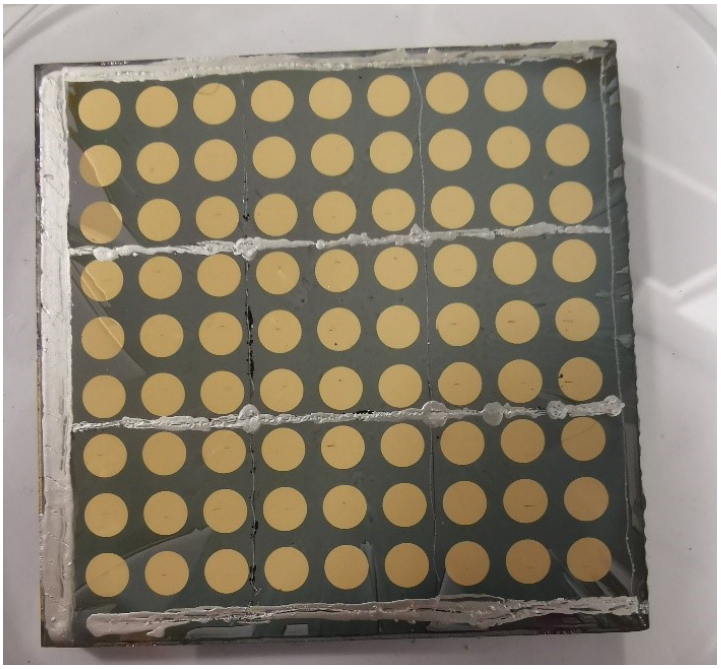

Figure S2. 81 individual Sb_2Se_3 PV devices on a 5x5 cm^2 FTO glass.

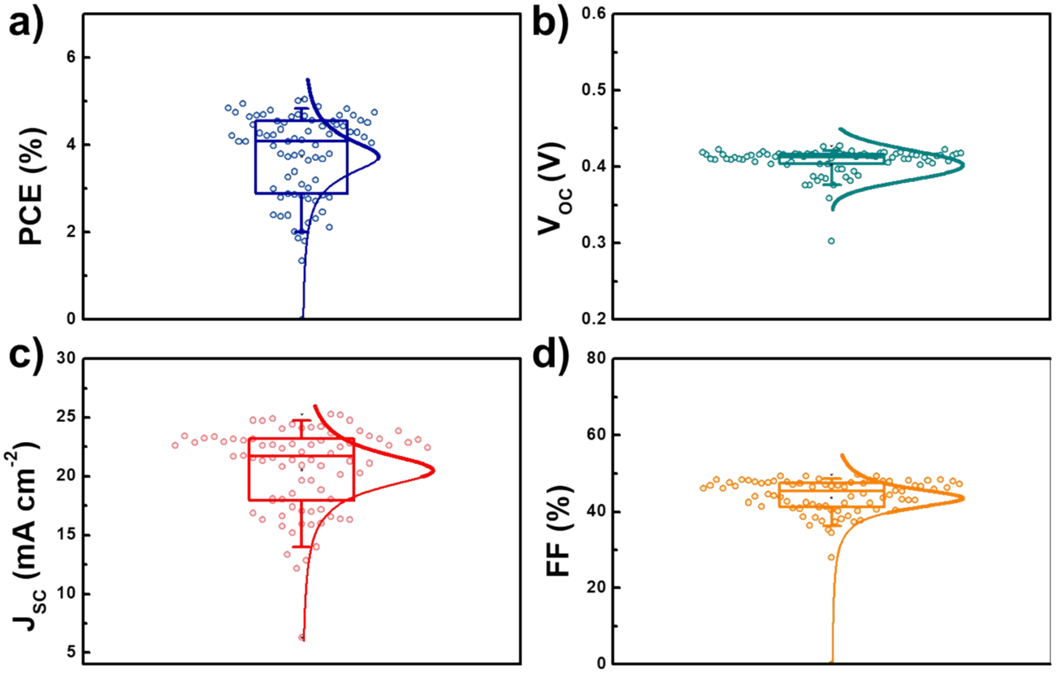

Figure S3. Device performance statistics of the a) PCE, b) V_{OC}, c) J_{SC}, and d) FF with 81 cells of w-seed Sb_2Se_3 PVs. The horizontal middle lines represent the median, the box edges represent the standard deviations.

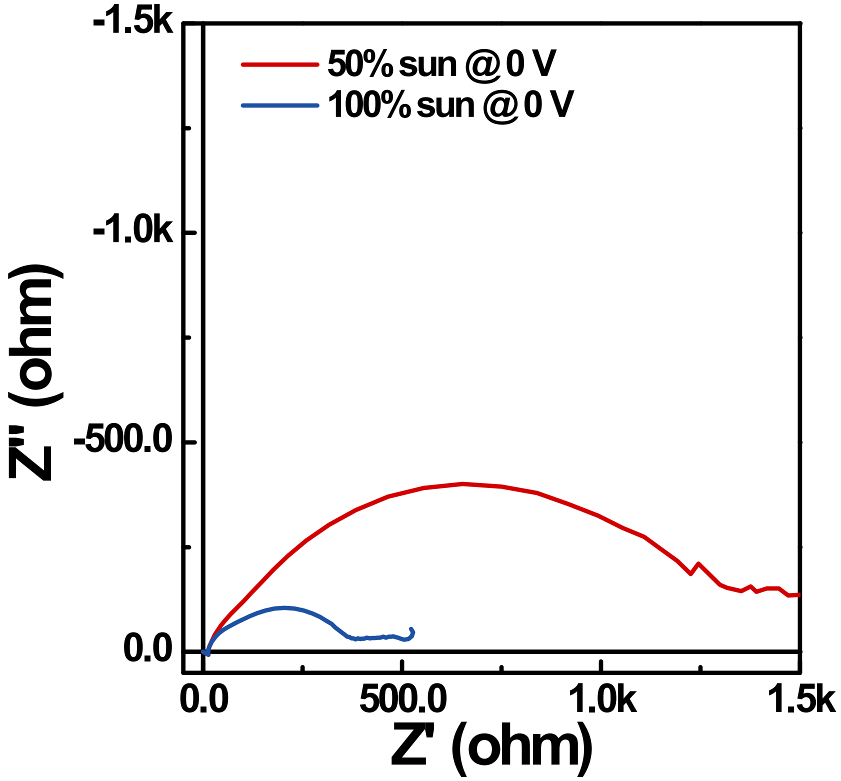

Figure S4. Nyquist plots of the w-seed Sb_2Se_3 PV at 0 V under 50 and 100% light intensities.

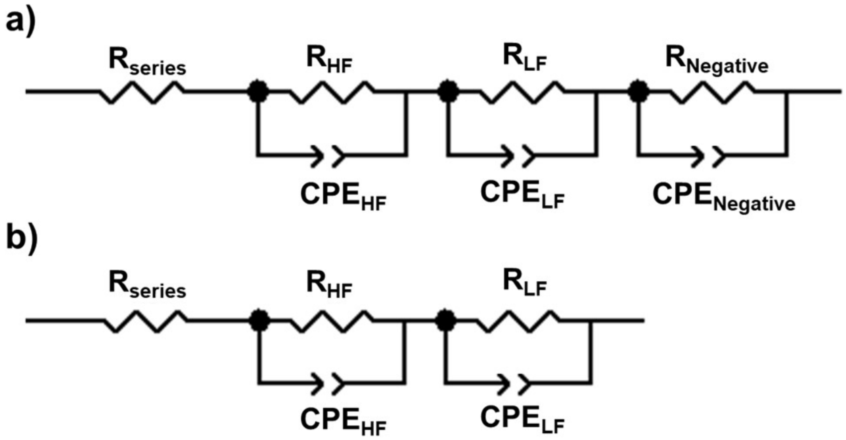

Figure S5. Voight circuit used to fit IS data of a) Figure 2b and b) Figure 2c,d.

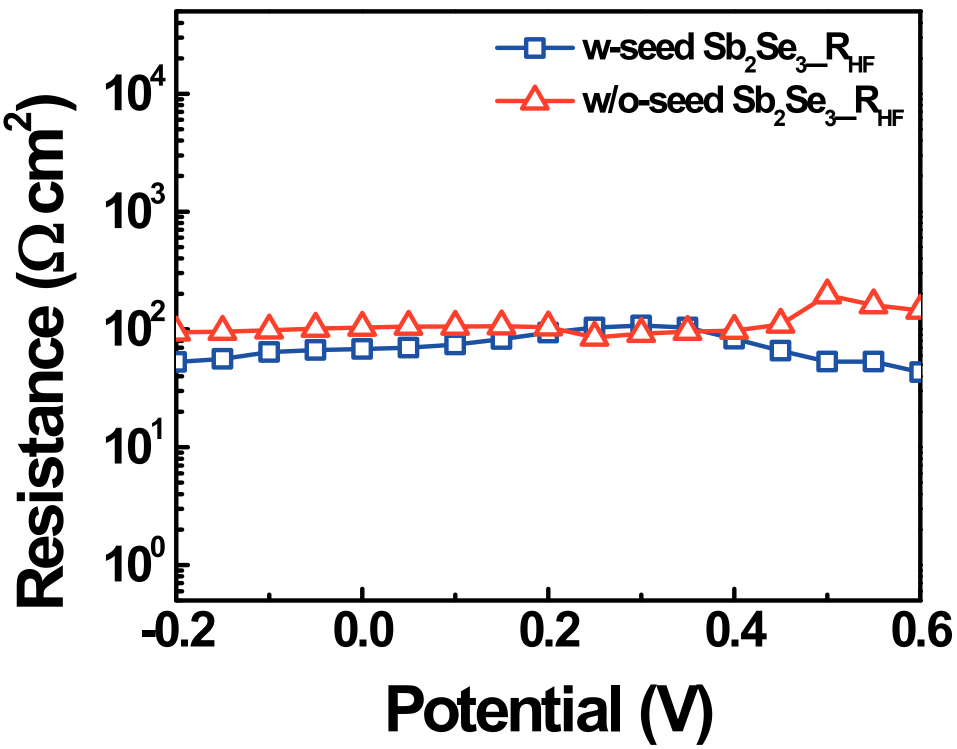

Figure S6. Resistances from the high frequency semi-circle fitted with the Voight circuit in Figure S5.

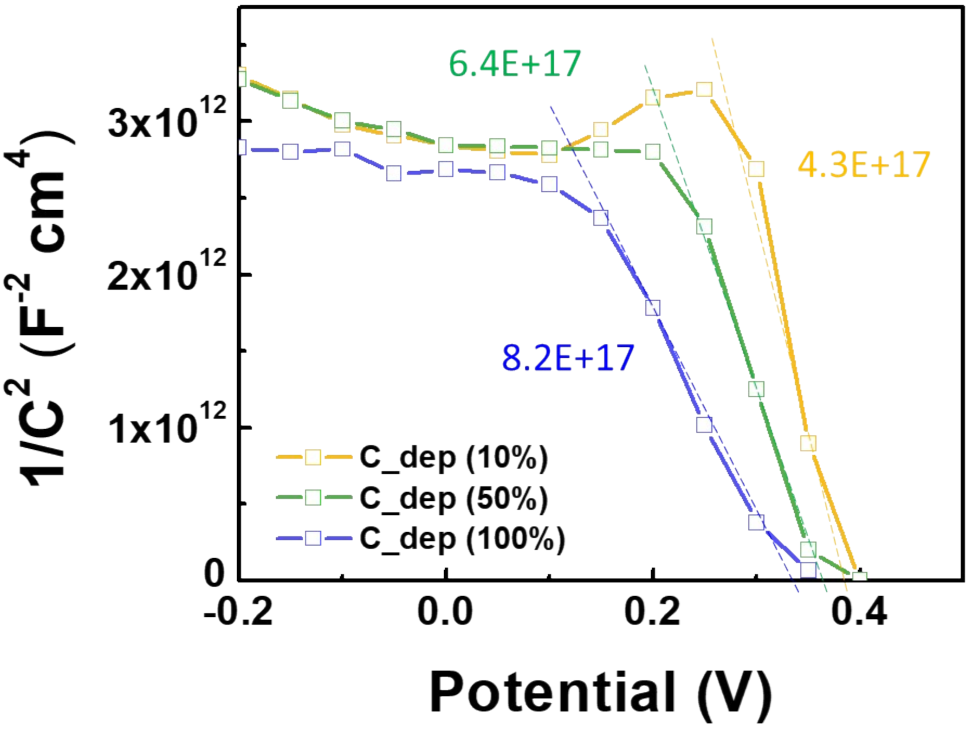

Figure S7. Mott-Schottky plots obtained by C_dep w-seed Sb_2Se_3 PVs under the 10, 50, and 100% light illumination.

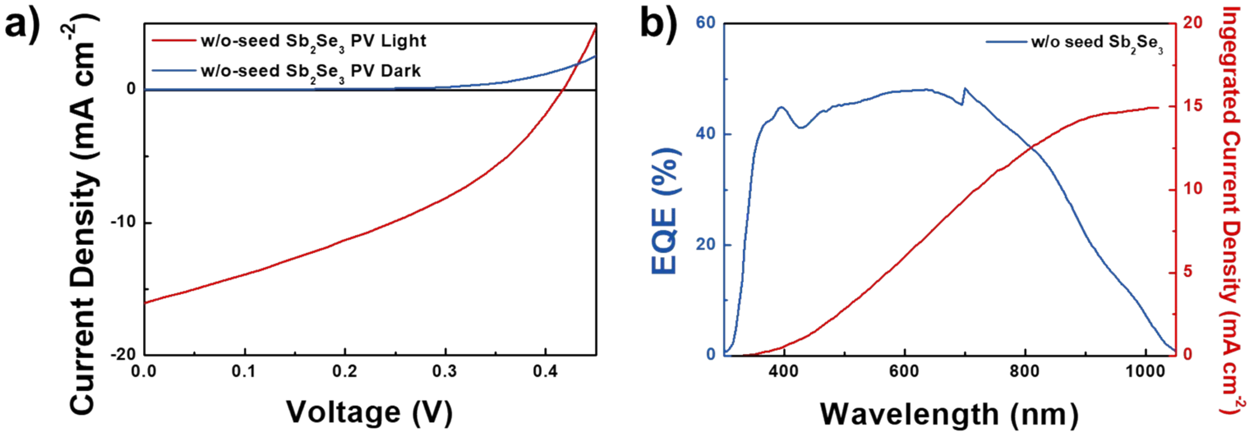

Figure S8. a) J–V characteristics of champion w/o-seed Sb_2Se_3 PV. b) EQE spectra of a w/o-seed Sb_2Se_3 based PV.

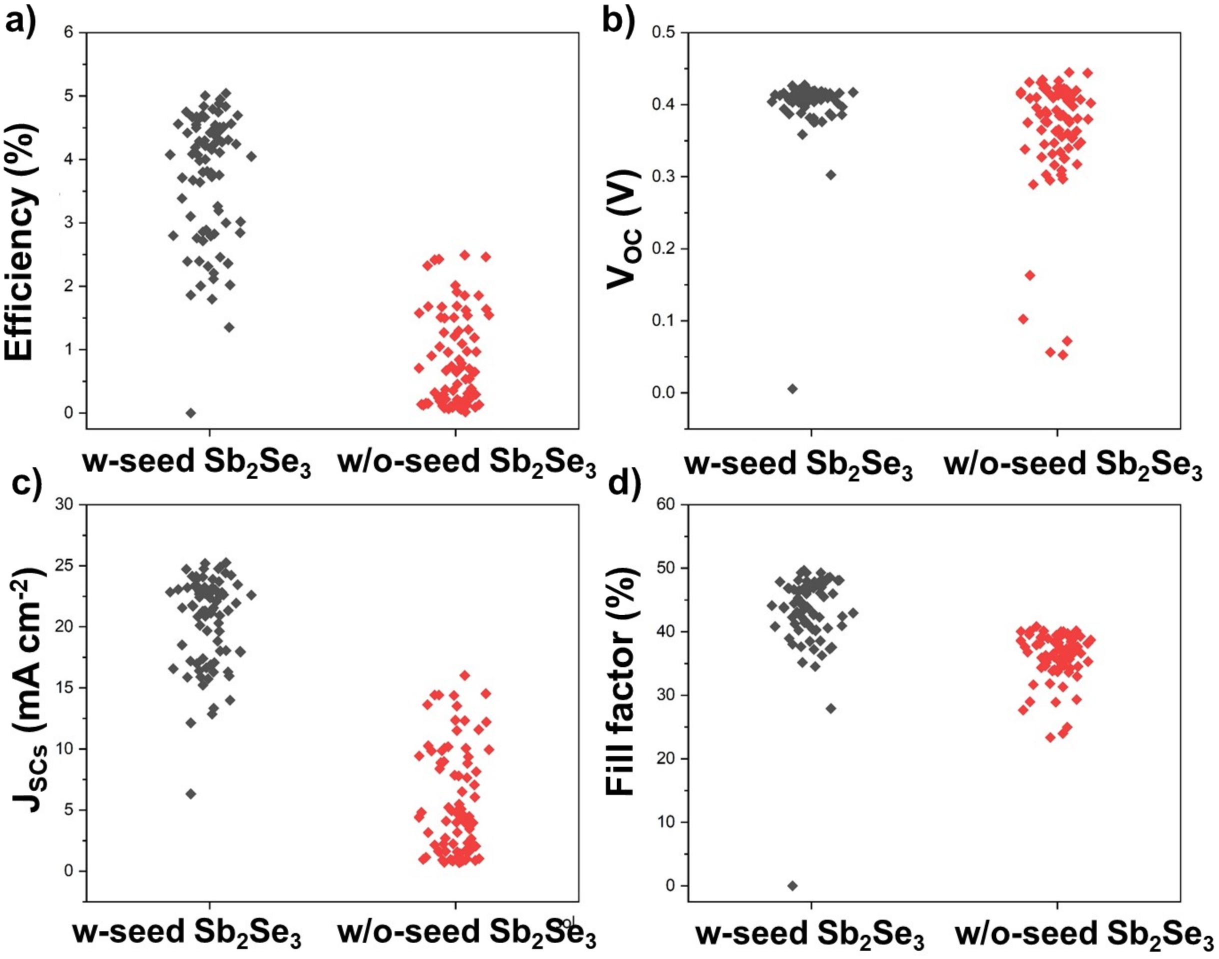

Figure S9. Device performance statistics comparison between w-seed Sb_2Se_3 and w/o-seed Sb_2Se_3 of the a) PCE, b) V_{OC}, c) J_{SC}, and d) FF with 81 cells.

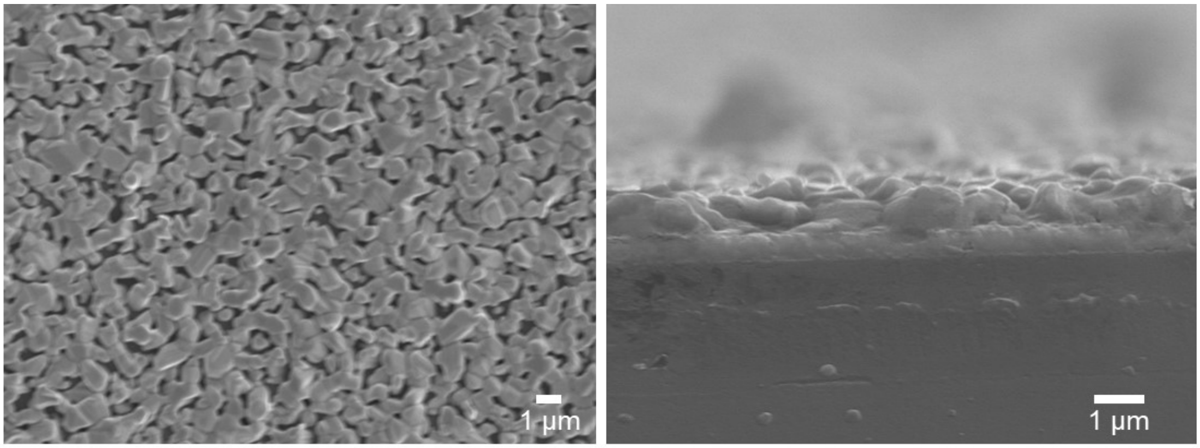

Figure S10. a) Top and b) cross-section SEM images of the w/o-seed Sb_2Se_3 film on TiO_2/FTO superstrate.

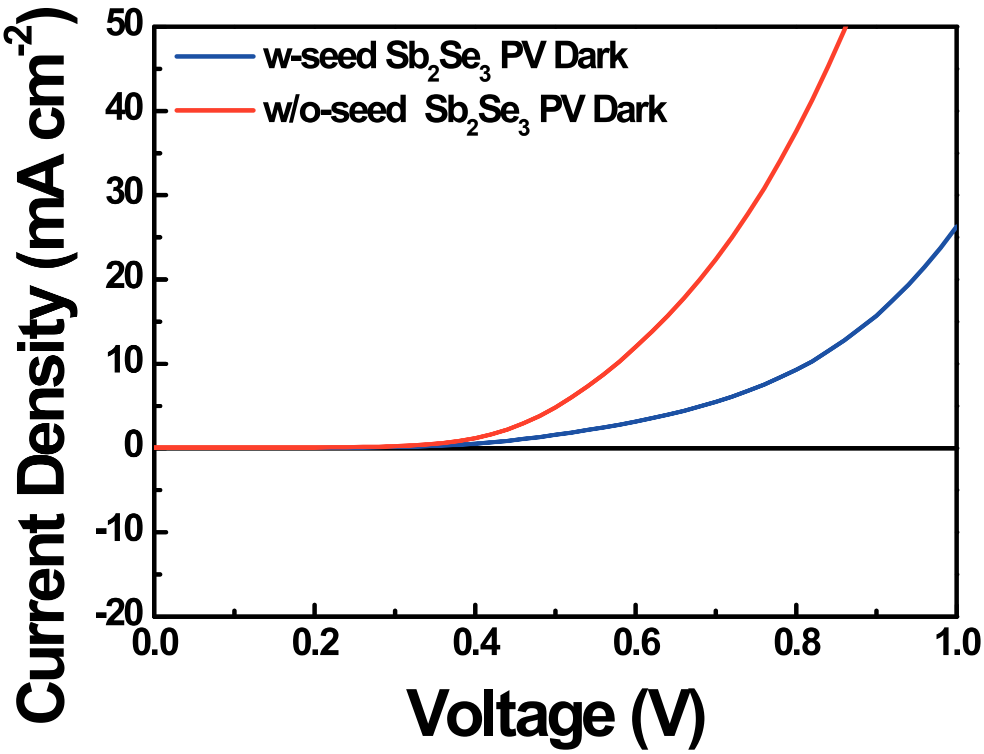

Figure S11. J-V curves of both Sb_2Se_3 PVs under dark conditions.

Supplementary Note 1.

Doping density can be calculated from the equation S1, where ε is the dielectric constant of the semiconductor, ε_o is the permittivity of free space, A is the area, e is the elementary charge, N_d is the density of dopants, V is the applied potential, V_{fb} is the flat band potential, k_B is the Boltzmann constant, and T is the absolute temperature. Here, one-side junction is assumed due to the higher doping concentration of TiO_2.

$$\frac{1}{C^2} = \frac{2}{\varepsilon\varepsilon_o A e N_d}(V - V_{fb} - \frac{k_B T}{e}). \qquad S1)$$