electronic supplementary information (ESI)

$InCl_3$-modified SnO_2 as Electron Transport Layer for Cd-free Antimony Selenide solar cells

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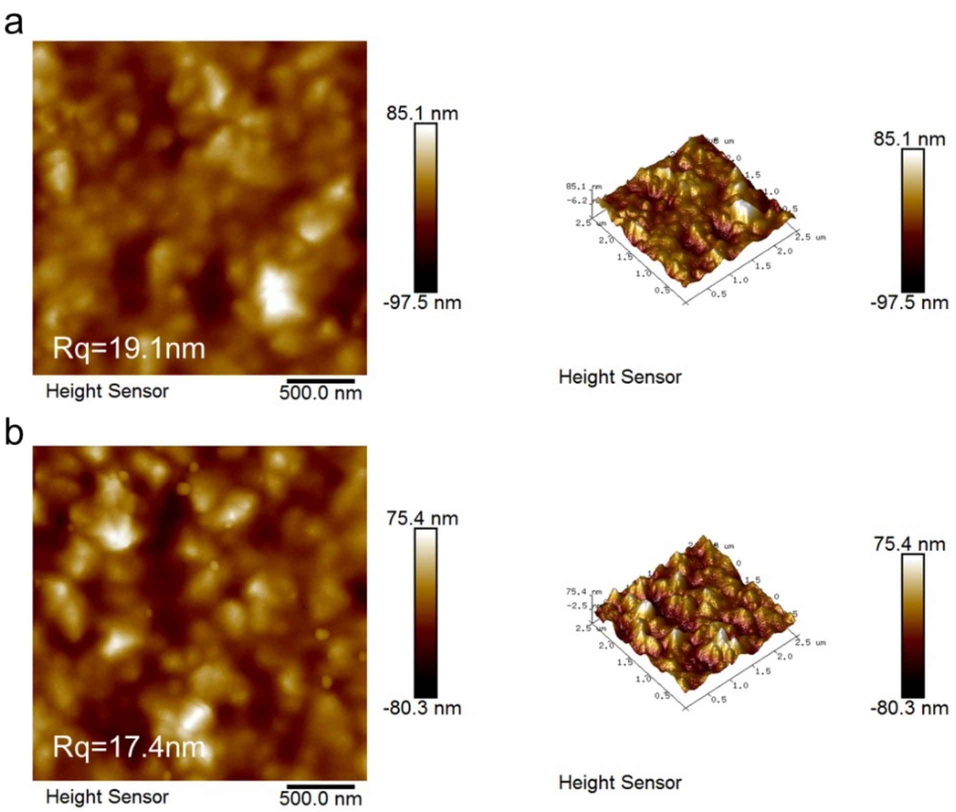

Figure S1. 2D and 3D AFM images of (a) SnO_2 and (b) SnO_2:$InCl_3$.

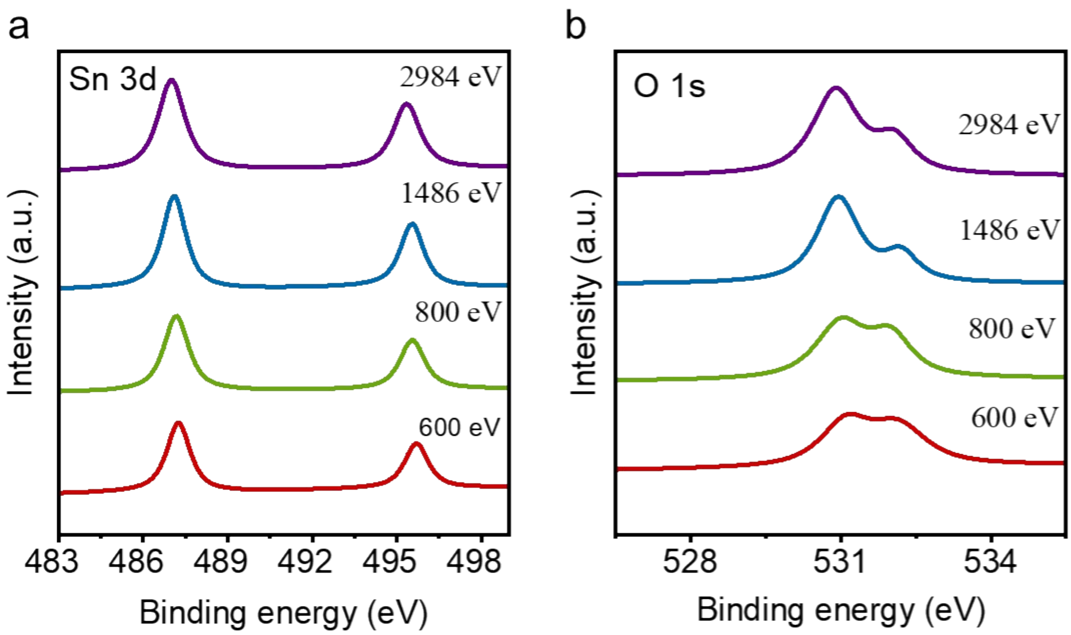

Figure S2. (a) Sn 3d and (b) O 1s SRPES spectra of SnO_2:$InCl_3$ with different photon energies.

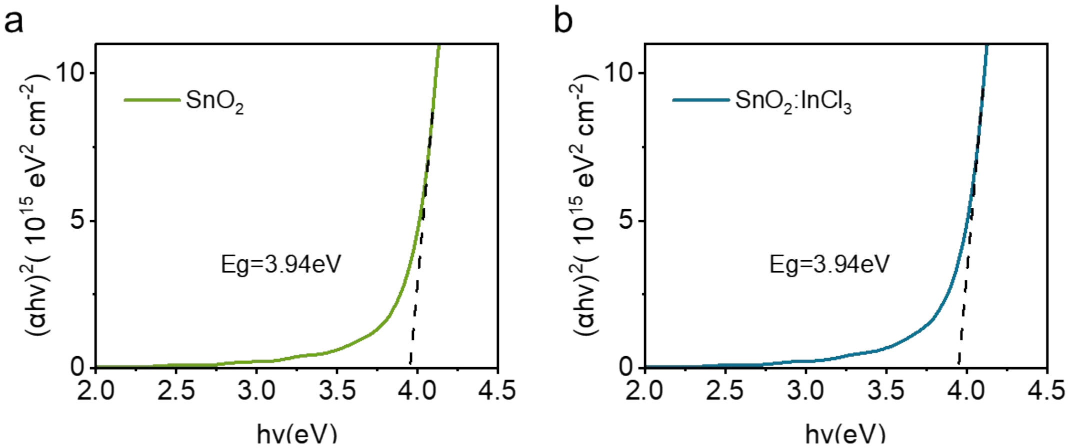

Figure S3. Tauc plot of (a) SnO_2 and (b) SnO_2:$InCl_3$ on top of the FTO substrate.

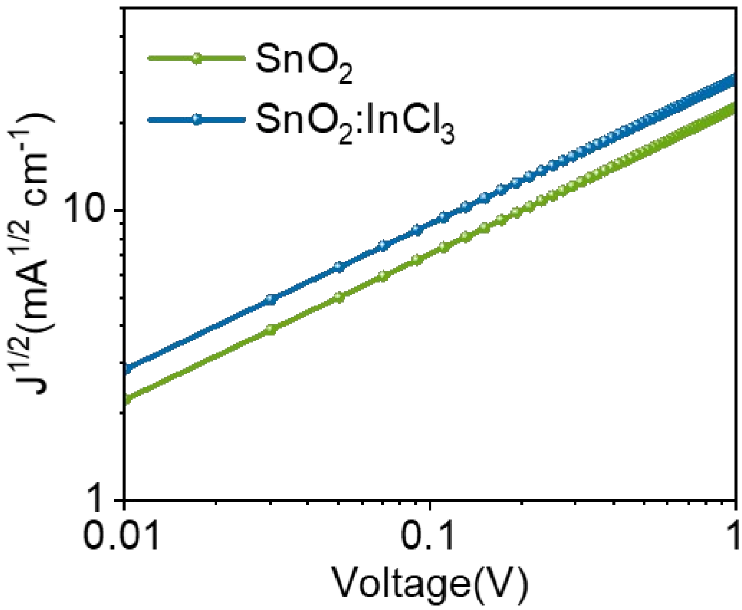

Figure S4. SCLC curves of SnO_2 and SnO_2:$InCl_3$.

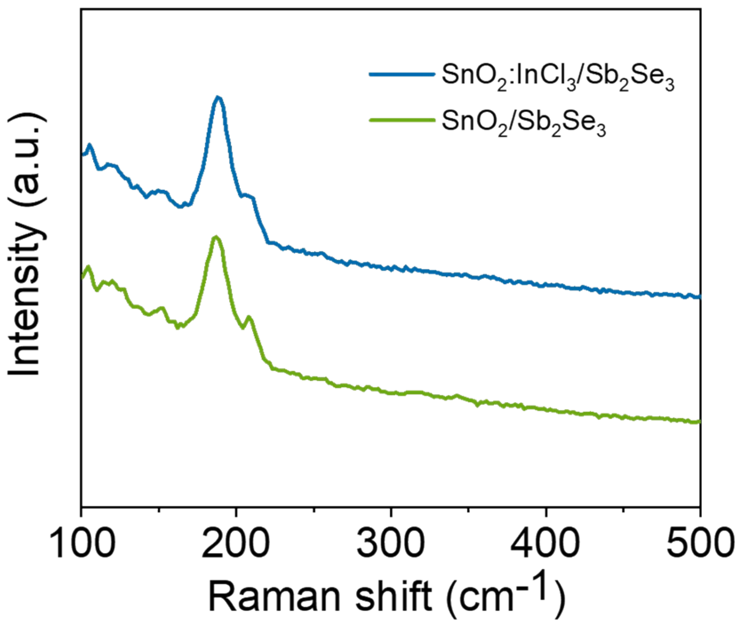

Figure S5. Raman spectra of the Sb_2Se_3 films that deposited on SnO_2 and SnO_2:$InCl_3$.

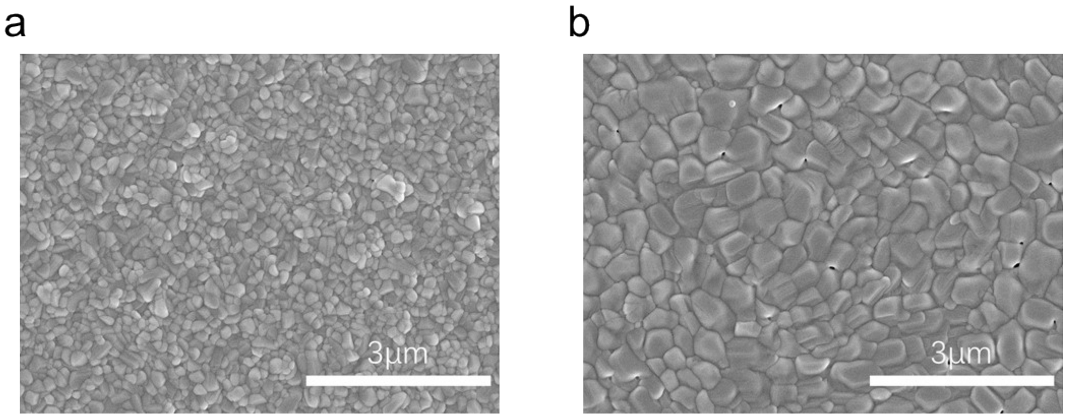

Figure S6. Surface SEM images of Sb_2Se_3 films on (a) SnO_2 and (c) SnO_2:$InCl_3$ at small magnifications.

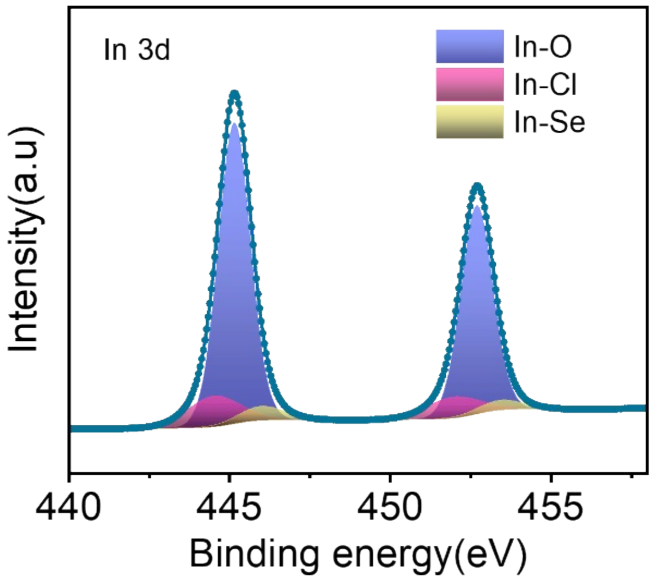

Figure S7. High-resolution XPS spectra of In 3d on SnO_2:$InCl_3$ ETL deposited with 3 nm of Sb_2Se_3 film.

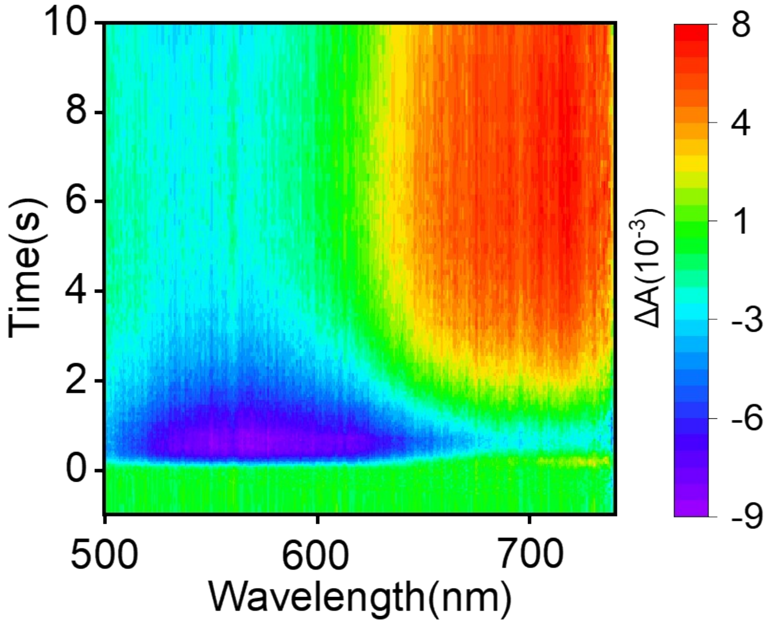

Figure S8. TAS spectrum of SnO_2/Sb_2Se_3.

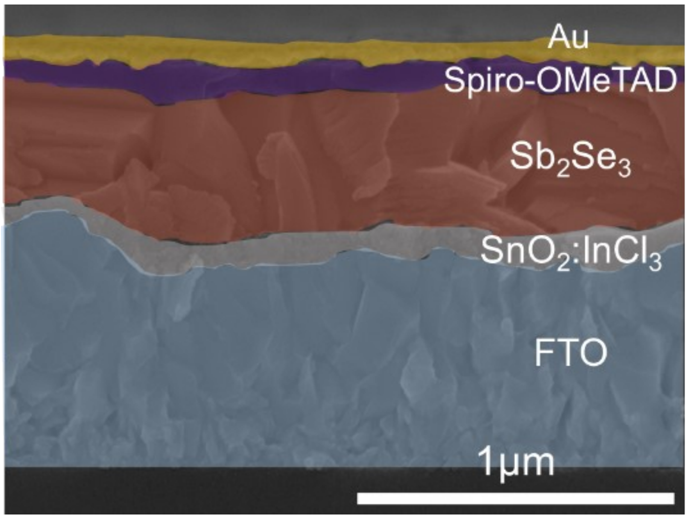

Figure S9. Cross-sectional SEM images of the device with structure of FTO/SnO_2:$InCl_3$/Sb_2Se_3/Spiro-OMeTAD/Au.

Note to the DLTS measurement:

Bulk defect properties of the Sb_2Se_3 were studied by the deep-level transient spectroscopy (DLTS) characterization.

The Arrhenius plots are calculated from DLTS test signals by Equation (1) and (2):

$$ln(\tau_e \upsilon_{th,n} N_C) = \frac{E_C - E_T}{k_B T} - ln(X_n \sigma_n) \quad (1)$$

$$\ln(\tau_e \upsilon_{th,p} N_V) = \frac{E_T - E_V}{k_B T} - \ln(X_n \sigma_p) \quad (2)$$

Where the τ_e is the emission time constant, N_C the conduction band state density, N_V the valence band state density, E_C the conduction band, E_T the trap energy level and E_V the valence band. X_n (X_p), σ_n (σ_p) and $\upsilon_{th,n}$ ($\upsilon_{th,p}$) are the entropy factor, the capture cross section and the thermal velocity for electron (hole), respectively. Trap activation energies (E_a, E_C-E_T or E_T-E_V) and capture cross section (σ) were determined from the Arrhenius plot, and more specifically, from the slope and y-axis intercept of the fitting line, separately. N_T is the trap concentration, which can be calculated by the Equation (3):

$$N_T = 2Ns\frac{\Delta C}{C_R} \quad (3)$$

where N_S is the shallow donor concentration, C_R the capacitance under reverse bias, ΔC the amplitude of transient capacitance.