Supporting Information

Cu_2O-CuSCN Nanocomposite as a Hole-Transport Material of Perovskite Solar Cells for the Enhanced Carrier Transport and Suppressed Interfacial Degradation

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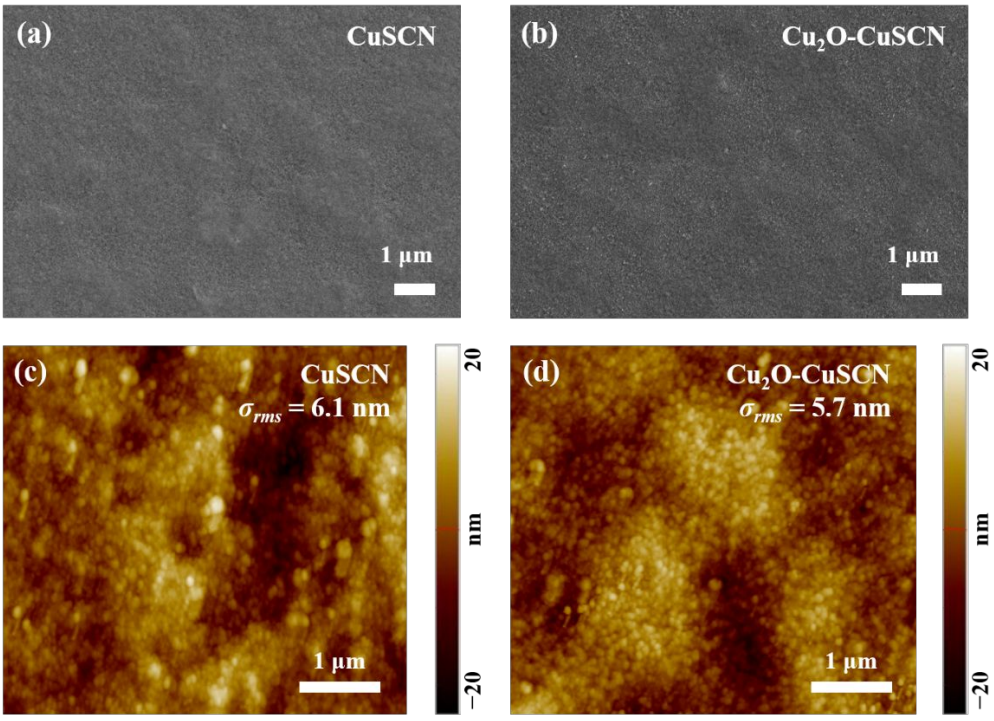

Figure S1. Surface morphologies and roughnesses of different HTLs. (a) SEM image of each HTL depostied on CsFAMA. (b) Topography of each HTL as obtained by AFM.

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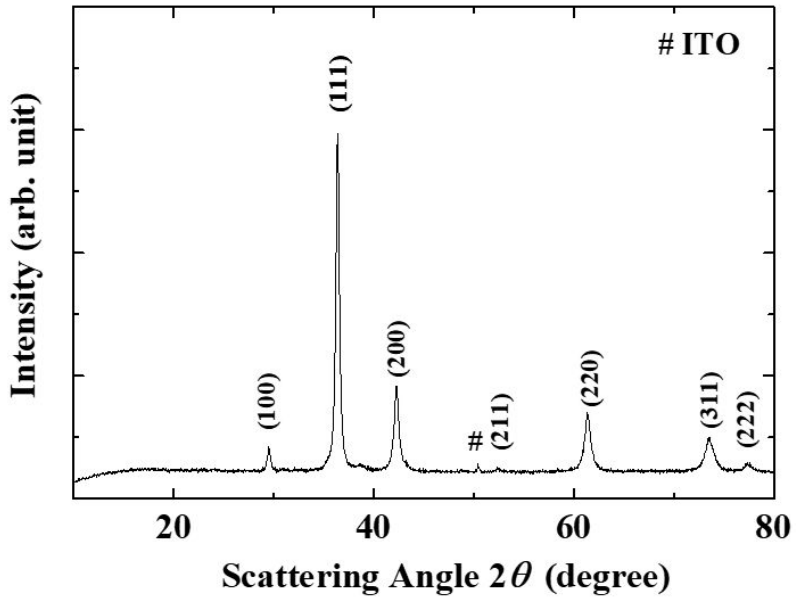

Figure S2. X-ray diffraction pattern of the Cu_2O nanoparticles.

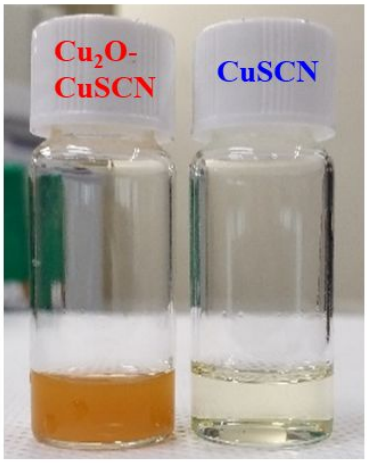

Figure S3. Optical images of the Cu_2O-CuSCN and CuSCN solutions in diethyl sulfide.

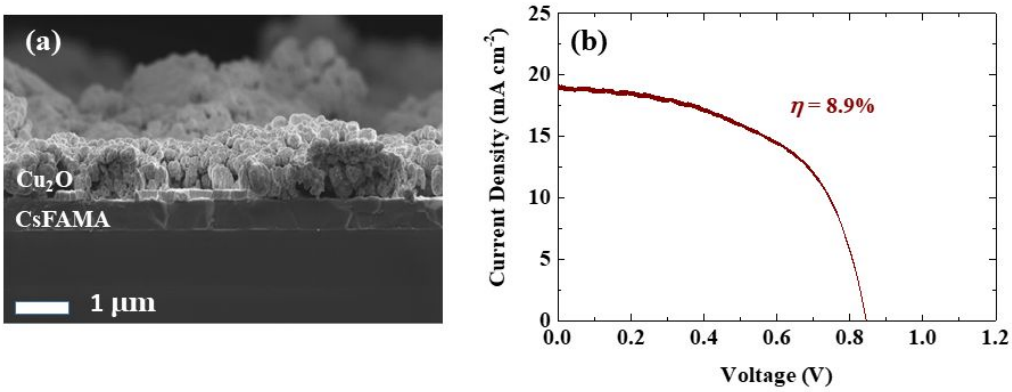

Figure S4. The film morphology and solar-cell performance with only Cu_2O as an HTL. (a) Cross-sectional SEM image of the pure Cu_2O film deposited on $Cs_{0.05}(FA_{0.85}MA_{0.15})_{0.95}Pb(I_{0.85}Br_{0.15})_3$ (CsFAMA) film. (b) A *J-V* curve of the solar cell utilizing only Cu_2O as an HTL. The device parameters are: V_{OC} = 0.846 V, J_{SC} = 18.9 mA/cm^2, *FF* = 0.55, and η = 8.9%.

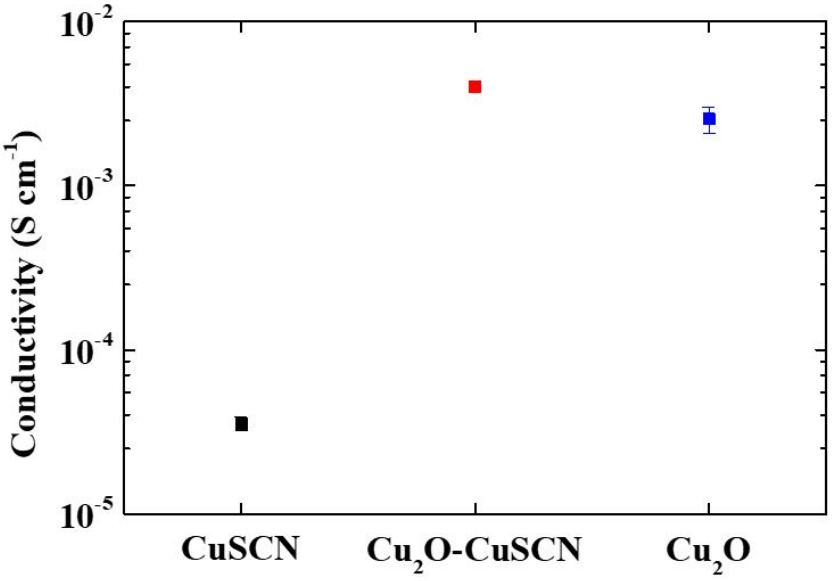

Figure S5. Electrical properties of various HTLs. In-plane conductivity is measured by four-point probe for CuSCN, Cu_2O-CuSCN nanocomposite, and Cu_2O films deposited on glass substrates.

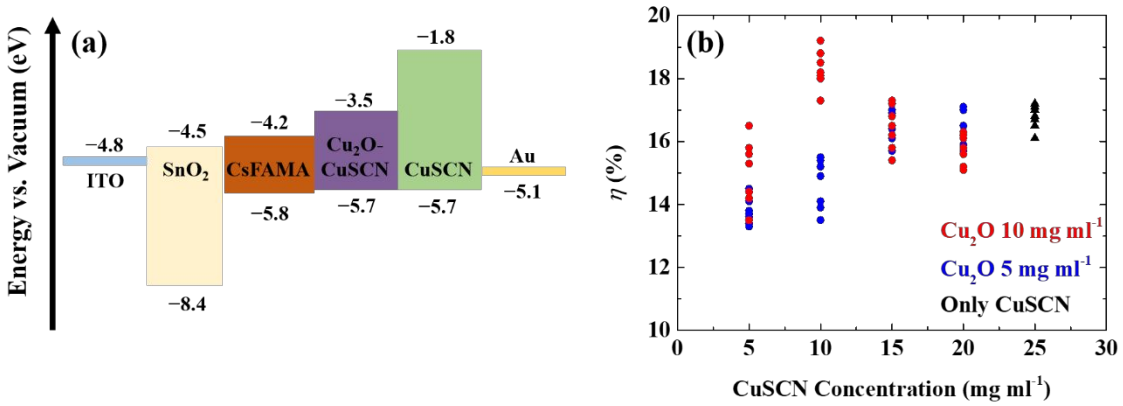

Figure S6. The energy level diagram and optimization processes of nanocomposite-based solar cells. (a) A schematic illustration of band structure of a solar cell. (b) Comparison of the solar-cell efficiencies at various Cu_2O and CuSCN concentrations. The optimum condition is 10 mg/ml for both Cu_2O and CuSCN.

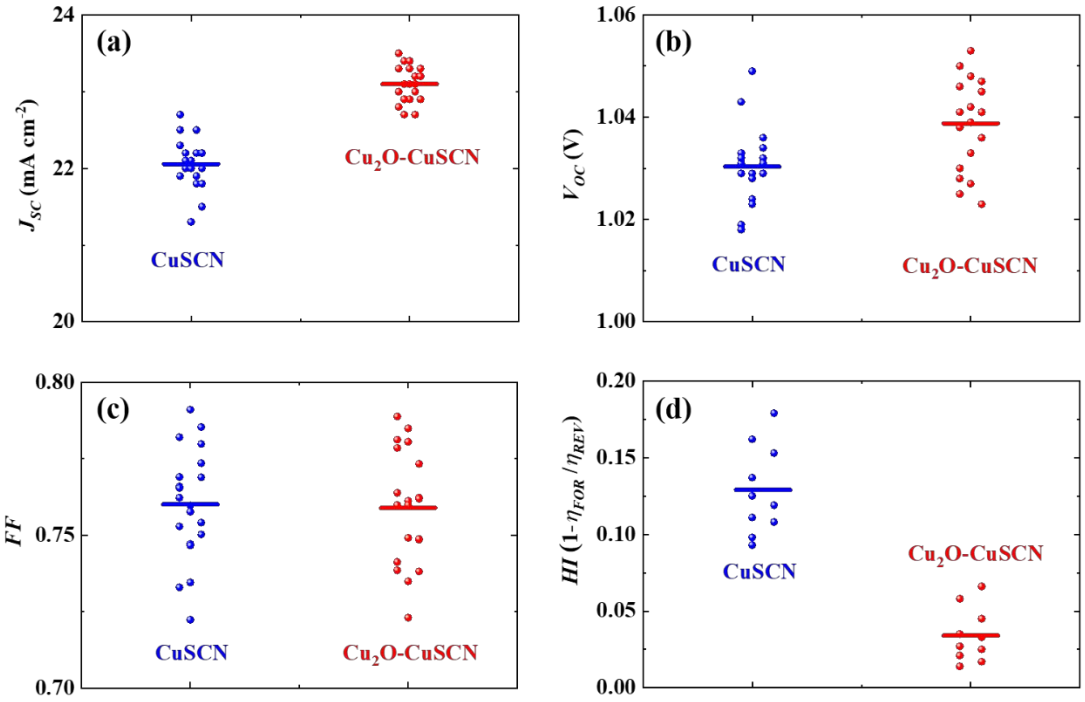

Figure S7. Device performance of solar cells with different HTLs. (a) J_{SC}, (b) V_{OC}, (c) FF, and (d) hysteresis index ($HI = 1 - \eta_{FOR}/\eta_{REV}$) of the solar cells with Cu_2O-CuSCN or CuSCN as an HTL, where lines represent average values.

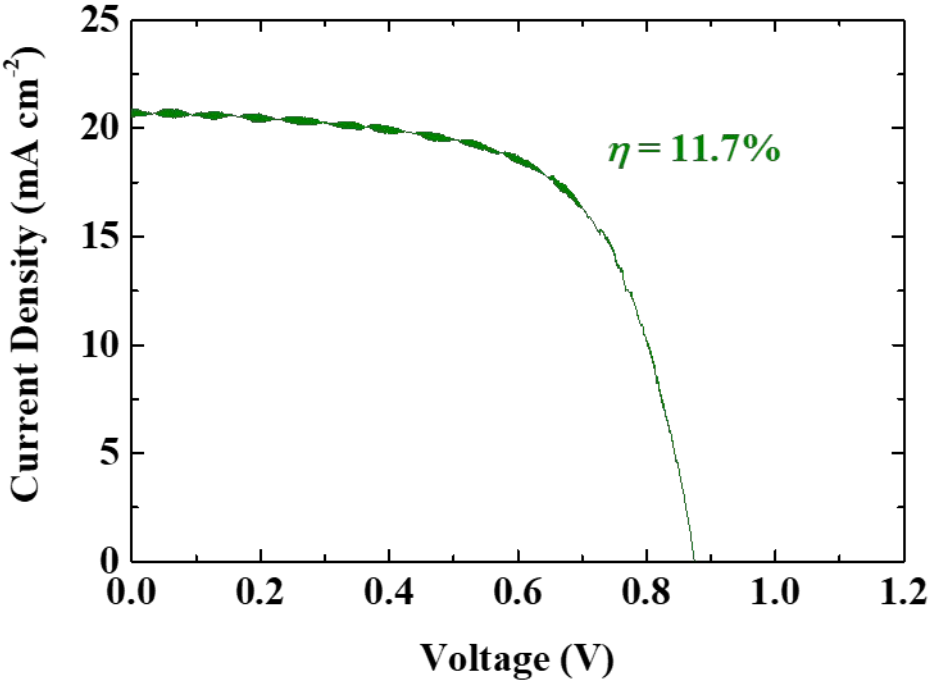

Figure S8. The *J-V* plot of the solar cell with a sequentially-deposited bilayer HTL. The perovskite solar cell was fabricated by the following sequence: 10 mg/ml of Cu_2O-dispersion solution was spin coated on a perovskite film, then 10 mg/ml of CuSCN solution was deposited subsequently. The device parameters are: V_{OC} = 0.875 V, J_{SC} = 20.5 mA/cm^2, FF = 0.652, and η = 11.7%.

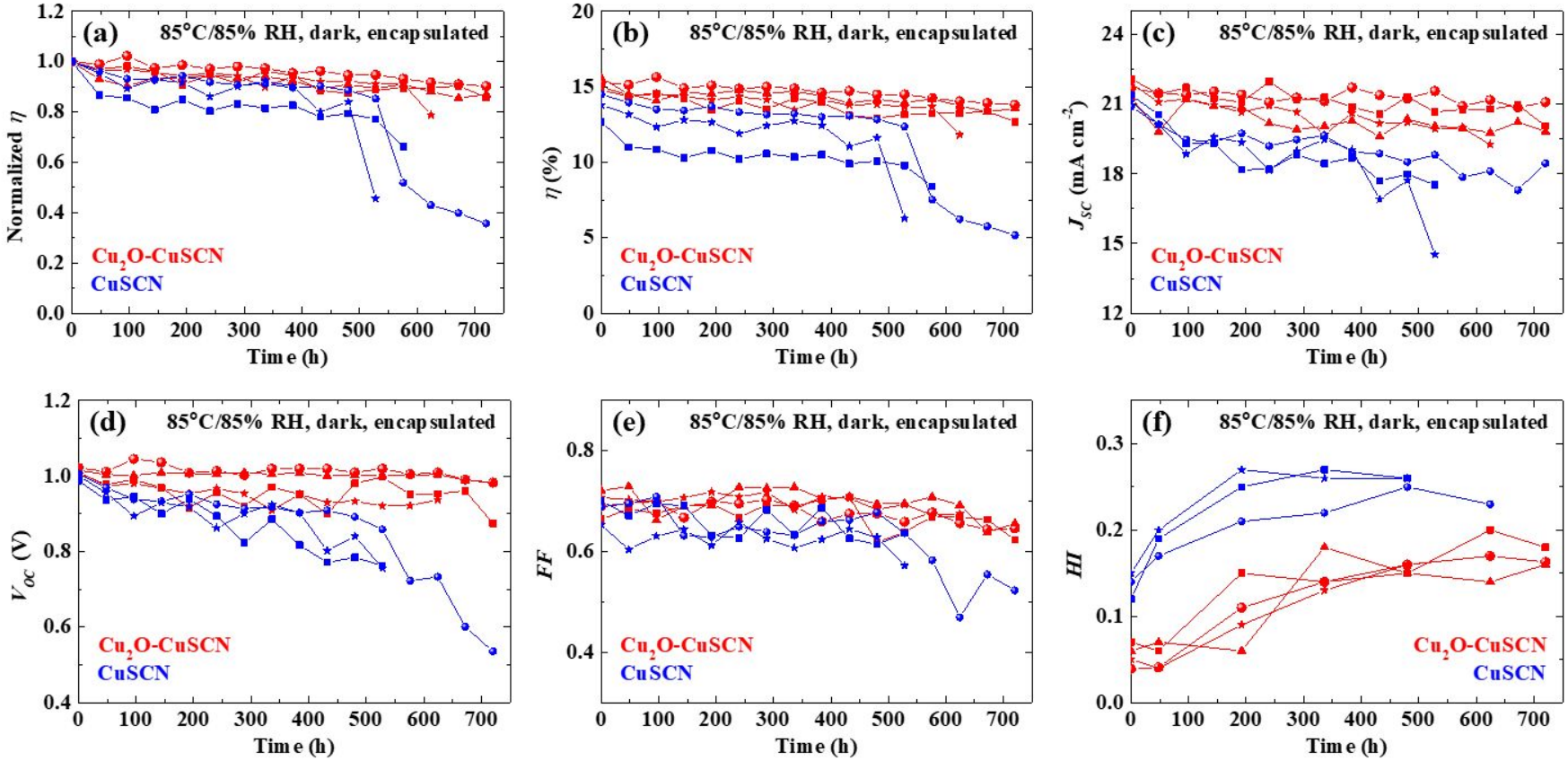

Figure S9. Long-term stability for several devices with different HTLs. (a) Normalized η, (b) η, (c) J_{SC}, (d) V_{OC}, (e) *FF*, and (h) *HI* of the solar cells stored under 85°C/85% RH with encapsulation in dark condition.