Electronic Supplementary Information

Pinhole-free TiO\(_2/Ag(O)/ZnO\) Configuration for Flexible Perovskite Solar Cells with Ultralow Optoelectrical Loss

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Fig. S1. Comparison of the chemical features of Ag and Ag\textsubscript{O}. (a) X-ray photoelectron profiles of Ag 3d core level spectra and (b) Ag MNN Auger spectra measured from ca. 20-nm Ag and Ag\textsubscript{O} layers deposited on Si wafers.
Fig. S2. Comparison of the crystallographic features of Ag and Ag$_{(O)}$. XRD patterns of 2$\theta$ scan measured for ca. 9-nm Ag and Ag$_{(O)}$ TEs sandwiched between ca. 15-nm SiO$_2$ layers.
**Fig. S3.** Cross-sectional FE-SEM images of the pinhole distribution in TAZ (left) and TAOZ (right), which are composed of 20-nm top TiO$_2$ ETLs, either 7.5-nm Ag or Ag$_2$(O)$_3$ TEs, respectively, and 15-nm bottom ZnO layer.
**Fig. S4.** Planar FE-SEM images of 10-nm top TiO$_2$ ETLs in different OMO configurations: TiO$_2$/Ag/TiO$_2$ (TAT), TiO$_2$/Ag/ZnO (TAZ), TiO$_2$/Ag$_{(O)}$/TiO$_2$ (TAOT), and TiO$_2$/Ag$_{(O)}$/ZnO (TAOZ) using 7.5-nm Ag and Ag$_{(O)}$ TEs and 5-nm bottom oxides.
**Fig. S5.** Current leakage distribution through nanoscopic pinholes in 10-nm top TiO$_2$ ETLs. (a) 2D morphological scan images of 10-nm top TiO$_2$ ETLs of TiO$_2$/7.5-nm Ag/5-nm ZnO (TAZ) and TiO$_2$/7.5-nm Ag(O)/5-nm ZnO (TAOZ) determined using tapping-mode AFM. (b) 2D and (c) 3D current scan images of the ETLs determined using conductive-mode AFM.
**Fig. S6.** Optical characteristics of OMOs. (a) Reflection and (b) absorbance spectra of TAT, TAOT, TAZ, and TAOZ using 7.5-nm Ag or Ag$_{O}$ TEs, corresponding to the conditions given in Fig. 5b. The absorbance spectra were determined by the formula absorbance = 100 – (transmittance + reflectance).
Fig. S7. Transmittance spectra of PET and OMOs using 7.5-nm Ag or Ag\(_{(0)}\) TEs, corresponding to the conditions given in Fig. 5b. The transmittance spectra of OMOs include the transmittance loss due to their PET substrates.
Fig. S8. Transmittance spectra of 20-nm TiO$_2$/7.5-nm Ag$_{2}O$/ZnO (TAOZ) with bottom ZnO layers of various thicknesses. The transmittance of the PET substrates was subtracted from the transmittance spectra of the TAOZ configuration.
Fig. S9. Transmittance spectra of 7.5-nm Ag and Ag\(_{(O)}\) layers deposited on PET substrates without oxides. The transmittance of the PET substrates was subtracted from the transmittance spectra of the Ag and Ag\(_{(O)}\) single films.