The first ITO-free CZTSSe solar cell over 10% PCE achieved by a ZnO/AgNWs/ZnO (ZAZ) matrix

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Aims and Highlights

- To achieve a low-cost and 100% rare-metal-free (Indium) window layer in CZTSSe solar cells.
- A ZnO/AgNWs/ZnO (ZAZ) matrix improved the contact between AgNWs and CZTSSe/CdS with reduced silver nanowire dangling.
- A decreased Voc loss and better defect control are demonstrated with ZAZ based solar cells.

Enhanced Silver Nanowire Contact

- The ZAZ structure was fabricated using a layer-by-layer method. Firstly, 30 nm ZnO was deposited on CZTSSe/CdS, followed by a spin-coated AgNW layer, finally a second 30 nm ZnO layer was sputtered on top.

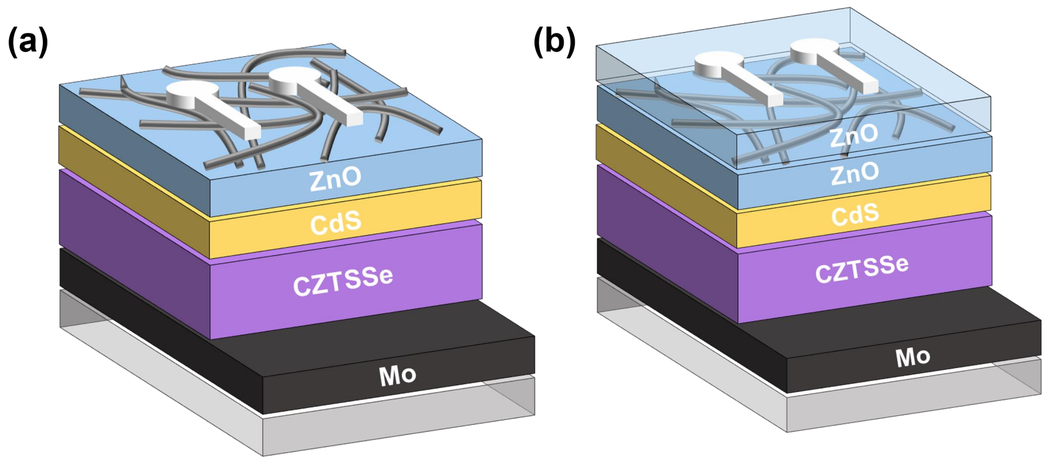


Figure 1: Cell structures with ZA (a) and ZAZ (b) window-layer respectively.

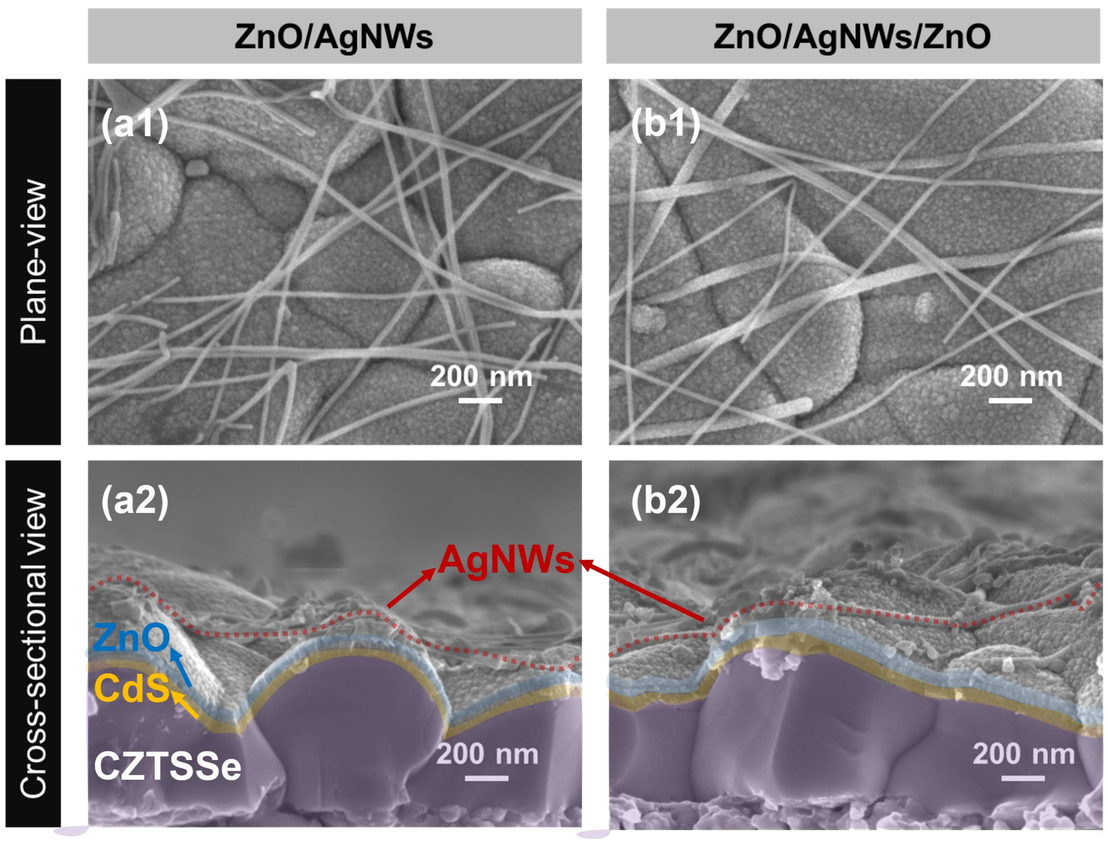
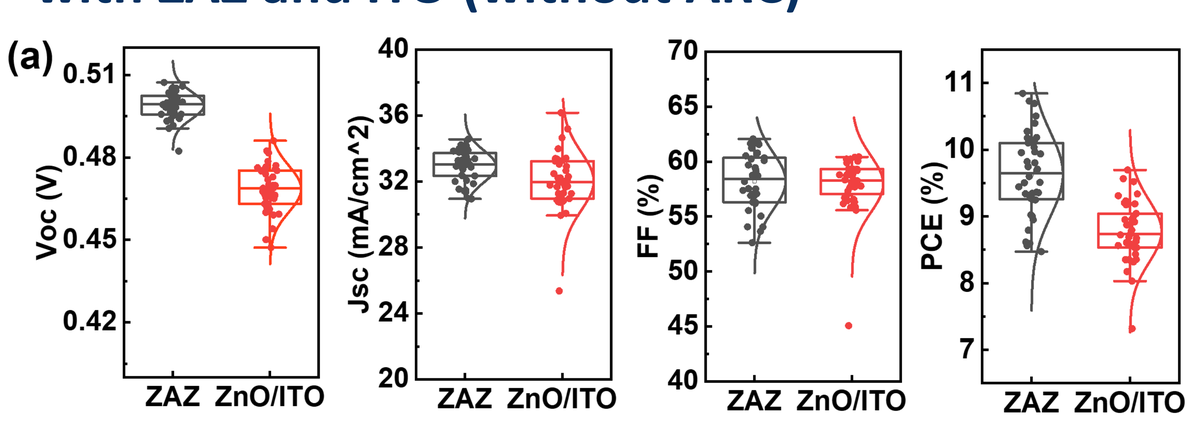


Figure 2. Plane-view SEM images of ZnO/AgNWs (a1) and ZnO/AgNWs/ZnO (b1) window layers in CZTSSe/CdS solar cells, and corresponding cross-sectional SEM images (a2, b2). Red dot line is silver nanowire.

Photovoltaic performance of CZTSSe solar cells with ZAZ and ITO (without ARC)



(b)

Device	Voc (V)	Jsc (mA/cm²)	FF (%)	PCE (%)	A	J_0 (mA/cm²)	Rs (ohm cm²)	G_{SH} (mS/cm²)
ZnO/AgNWs/ZnO	0.504	34.6	62.8	10.8	1.49	3.37×10^{-5}	1.83	0.036
ZnO/ITO	0.470	35.2	60.0	9.70	1.82	8.90×10^{-4}	1.52	0.282

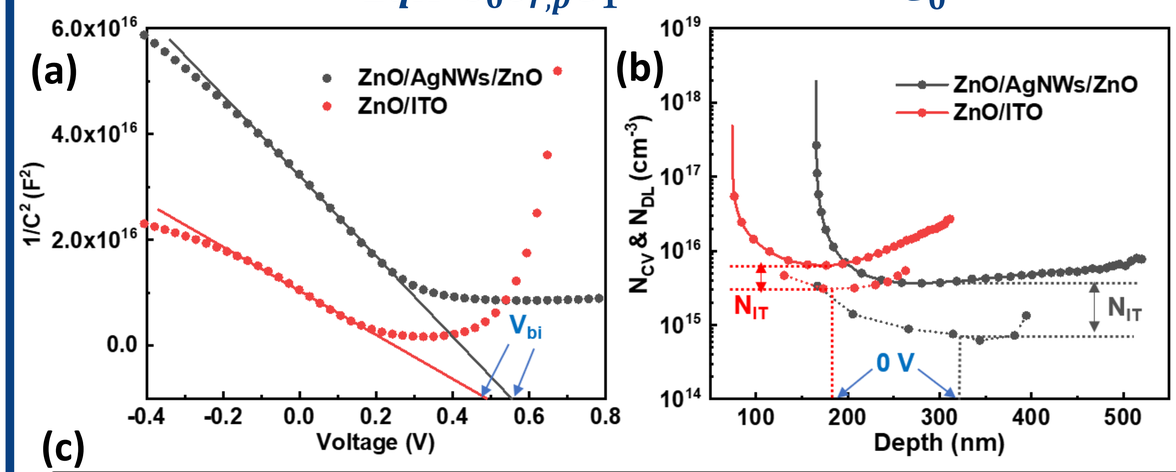
Figure 3. Statistical data of Voc, Jsc, FF, and efficiency of the devices (PCE) fabricated with ZAZ and ZnO/ITO window layers. (b) The photovoltaic and diode parameters of two champion cells.

Defect Characteristics

- The capacitance–voltage (C-V) and driver-level capacitance curve (DLCP) measurements were carried out for two devices. N_{CV} contains interface and bulk defects and free carriers, whereas N_{DLCP} is sensitive to free carriers and the bulk states.[1]

$$N_{CV} = \frac{-\varepsilon_{r,n} N_D}{\left(\frac{d\left(\left(\frac{1}{C^2}\right)\right)}{dV}\right) qA^2\varepsilon_0\varepsilon_{r,n}\varepsilon_{r,p}N_D + 2\varepsilon_{r,p}}$$

$$N_{DLCP} = -\frac{C_0^3}{2qA^2\varepsilon_0\varepsilon_{r,p}C_1} \qquad \chi = -\frac{\varepsilon_0\varepsilon_{r,p}A}{C_0}$$



(c)

Device	V_{bi} (V)	N_{CV} (cm⁻³)	N_{DL} (cm⁻³)	Depletion width (nm)	Interface state response
ZAZ	0.55	3.87×10^{15}	8.83×10^{14}	322	2.99×10^{15}
ZnO/ITO	0.49	6.42×10^{15}	3.09×10^{15}	184	3.33×10^{15}

Figure 4. (a) 1/C2-V plots, and (b) CV-DLCP curves of two devices. The dashed line in figure (b) indicates the depletion width at 0 V bias. (c) CV-DLCP results.

Conclusion and future work

- A 10.8% PCE for an ITO-free, ZnO-AgNW CZTSSe solar cell has been achieved without an anti-reflection coating (ARC).
- Surprisingly, the enhanced performance comes from the reduced Voc loss (higher Vbi) and bulk defects.
- This suggests that the ZAZ window structure offers a pathway to high performance kesterite solar cells.

For Further Information
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Citations
1. G. Liang, et al. Adv. Sci. 2022, 9, e2105142.
2. Ji, Yixiong, et al. "Self-depleted CuSCN as back contact for high performance CZTSSe solar cells" (Adv Funct Mater.)

Acknowledgements
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