Supporting Information

High-Efficiency CIGSSe Solar Cells Enabled by Solution-Processed ZnO, TiO_2, and SnO_2 Nanoparticle Window Layers

Chunyi Li,[a] Dongdong Shen,[a, b] Bowen Liu,[a, b] Zhuoer Deng,[a] Yongliang Lai,[a] Xinan Shi[a]* and Daocheng Pan[a, b]*

[a]State Key Laboratory of Featured Metal Materials and Life-cycle Safety for Composite Structures; Guangxi Key Laboratory of Processing for Non-ferrous Metals and Featured Materials; Guangxi Key Laboratory of Advanced Rare Earth Materials; School of Resources, Environment and Materials, Guangxi University, Nanning 530004, China

[b]School of Chemistry and Chemical Engineering, Guangxi University, Nanning 530004, China

E-mail: xashi@gxu.edu.cn and dcpan@gxu.edu.cn

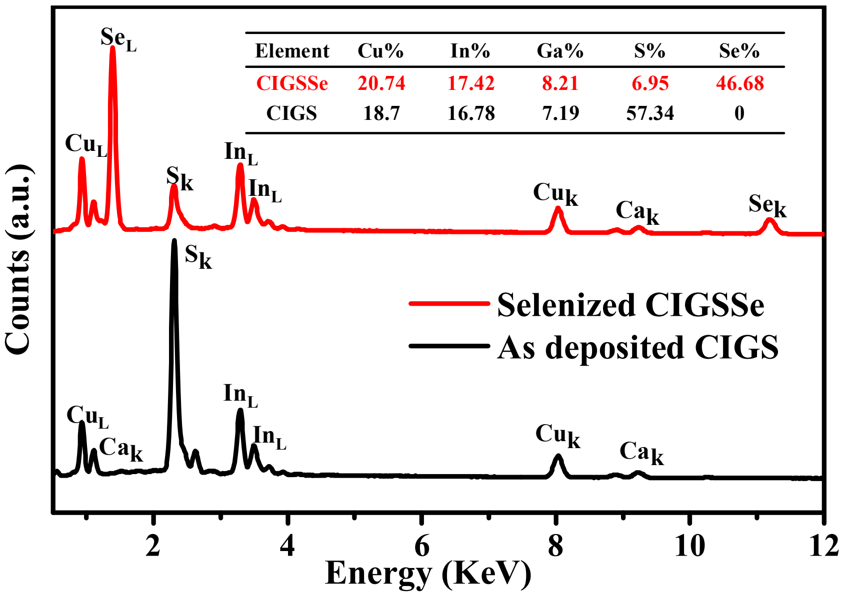

Figure S1 EDS spectra of the as-deposited CIGS precursor film and the selenized CIGSSe thin film.

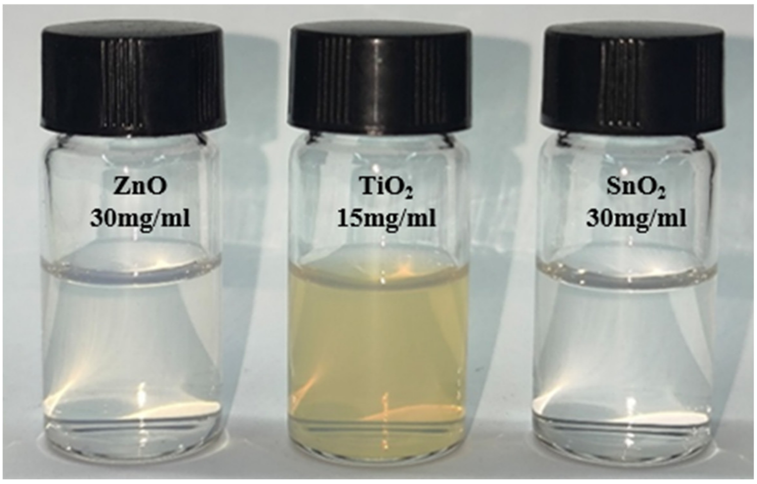

Figure S2 Photograph of ZnO, TiO_2, and SnO_2 nanoparticles dispersed in ethanol.

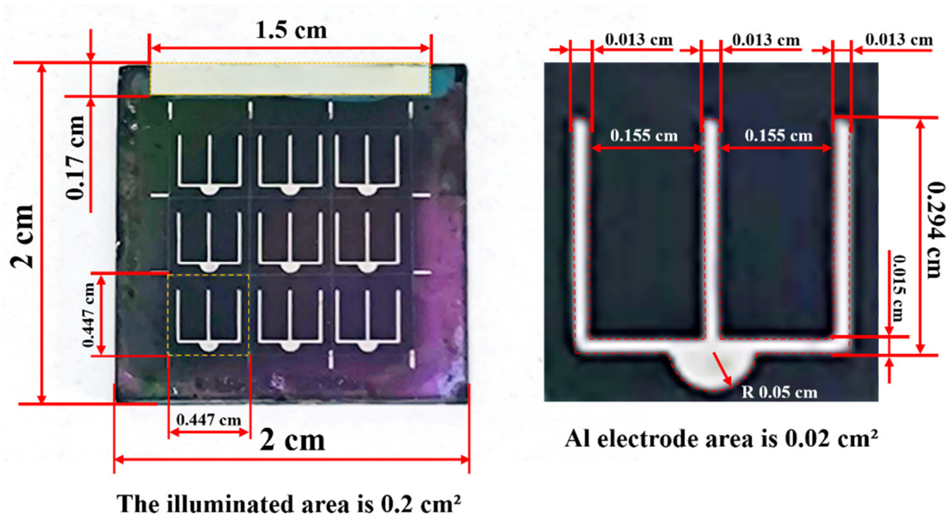

Figure S3 Schematic diagram of a small-area CIGSSe thin-film solar cell.

Table S1 Effects of selenization conditions on the performance of sputtered *i*-ZnO-based CIGSSe thin film solar cells.

T (℃)	Time (min)	J_{SC} (mA/cm^2)	V_{OC} (V)	FF (%)	PCE (%)
520	15	30.77	0.49	43.53	6.58
530	15	28.46	0.54	56.72	8.6
540	15	23.29	0.52	43.58	5.32
550	15	23.75	0.39	30.00	2.76
530	10	25.56	0.52	49.71	6.56
530	15	28.46	0.54	56.72	8.73
530	20	28.27	0.54	42.41	6.44
530	25	26.52	0.46	35.57	4.38

Table S2 Influences of annealing temperature of metal oxide nanoparticles on the performance of CIGSSe solar cell devices.

Window layer	T (°C)	Time (min)	J_{SC} (mA/cm^2)	V_{OC} (V)	FF (%)	PCE (%)
ZnO	100	15	31.14	0.56	52.25	9.15
	115	15	32.34	0.56	56.16	10.22
	130	15	29.41	0.55	54.51	8.80
	145	15	28.01	0.37	31.52	3.26
TiO_2	140	15	30.93	0.55	53.25	9.13
	150	15	31.47	0.56	58.60	10.25
	160	15	24.72	0.51	55.54	7.06
	170	15	20.20	0.55	43.24	4.78
SnO_2	100	15	30.84	0.55	50.93	8.70
	115	15	33.16	0.59	56.86	11.08
	130	15	31.57	0.55	53.34	9.26
	145	15	27.30	0.57	43.96	6.89

Table S3 Impacts of annealing time of metal oxide nanoparticles on the performance of CIGSSe solar cell devices.

Window layer	T (℃)	Time (min)	J_{SC} (mA/cm^2)	V_{OC} (V)	FF (%)	PCE (%)
ZnO	115	10	34.07	0.54	50.86	9.43
	115	15	32.34	0.56	56.16	10.22
	115	20	27.31	0.57	46.61	7.31
	115	25	21.30	0.52	41.61	4.56
TiO_2	150	10	30.42	0.56	53.95	9.22
	150	15	31.47	0.56	58.60	10.25
	150	20	25.69	0.56	59.73	8.58
	150	25	23.20	0.54	38.92	4.86
SnO_2	115	10	30.71	0.57	56.58	9.89
	115	15	33.16	0.59	56.86	11.08
	115	20	29.49	0.55	54.11	8.79
	115	25	21.16	0.50	47.47	5.00

Equation S1[1,2]

$$E_U = \left(\frac{d(\ln EQE)}{d(h\nu)}\right)^{-1}$$

h is the Planck constant, with a value of approximately 4.136×10^{-15} eV·s.

v is the photon frequency, with the unit of Hz (s^{-1}).

Equation S2[3]

$$W = \frac{K_s \mathcal{E}_0 A}{C}$$

K_s: dielectric constant of the semiconductor.

ε_0: vacuum permittivity, 8.85419×10^{-14} F/cm.

A: cell area (cm^2).

C: measured junction capacitance (F).

Equation S3[4]

$$N_{CV} = \frac{2}{qK_s\mathcal{E}_0A^2[\frac{d(1/C^2)}{dV}]}$$

C: measured junction capacitance (F).

V: applied DC bias (V).

q: electron charge, 1.602×10^{-19} C.

K_s: dielectric constant of the semiconductor.

ε_0: vacuum permittivity, 8.85419×10^{-14} F/cm.

A: cell area (cm^2).

Equation S4[3]

$$N_{DLCP} = \frac{C_0^3}{2qK_s\mathcal{E}_0A^2C_1}$$

V: applied DC bias (V).

q: electron charge, 1.602×10^{-19} C.

K_s: dielectric constant of the semiconductor.

ε_0: vacuum permittivity, 8.85419×10^{-14} F/cm.

A: cell area (cm^2).

C_0: zero-order capacitance coefficient; junction capacitance at $\delta V\rightarrow0$, equivalent to the conventional C-V capacitance.

C_1: first-order capacitance coefficient; linear coefficient of capacitance change with respect to δV.

References

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