

## Supplementary Materials

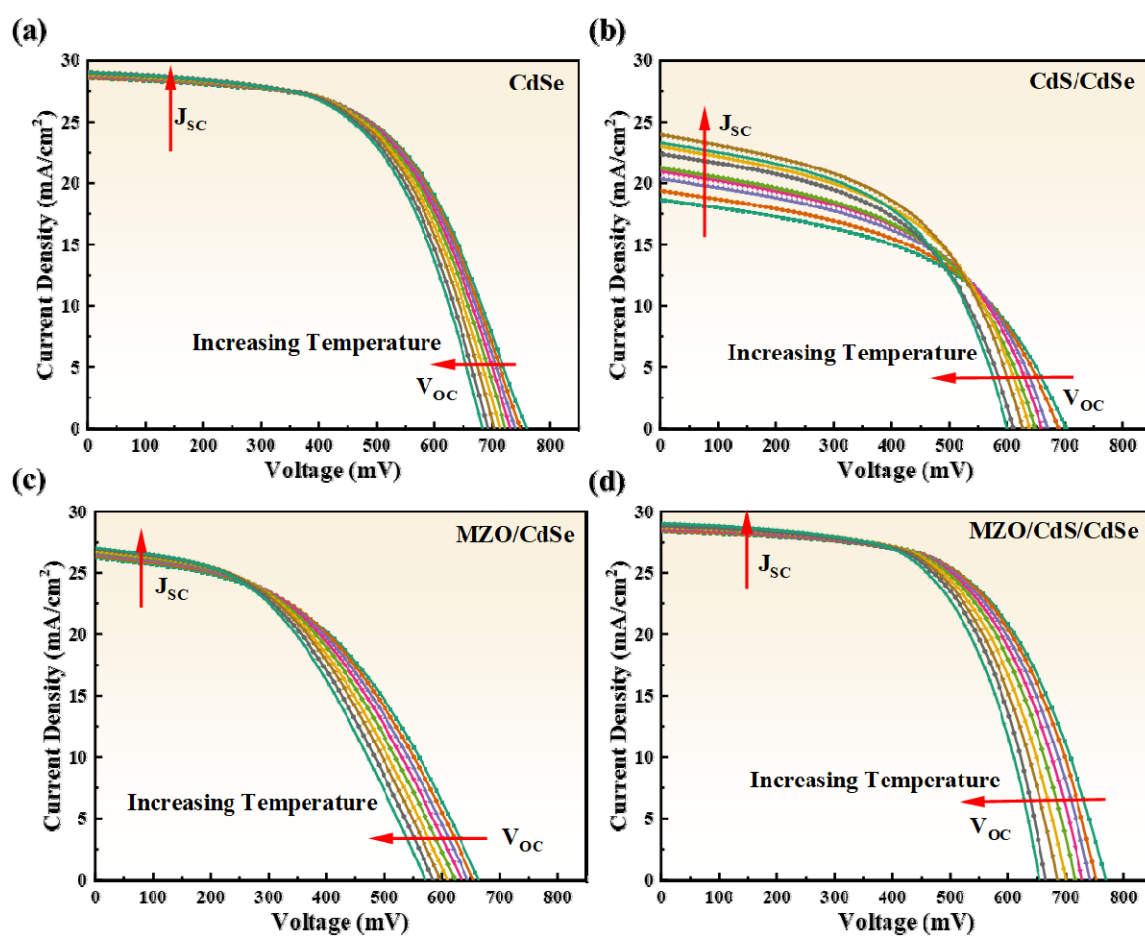
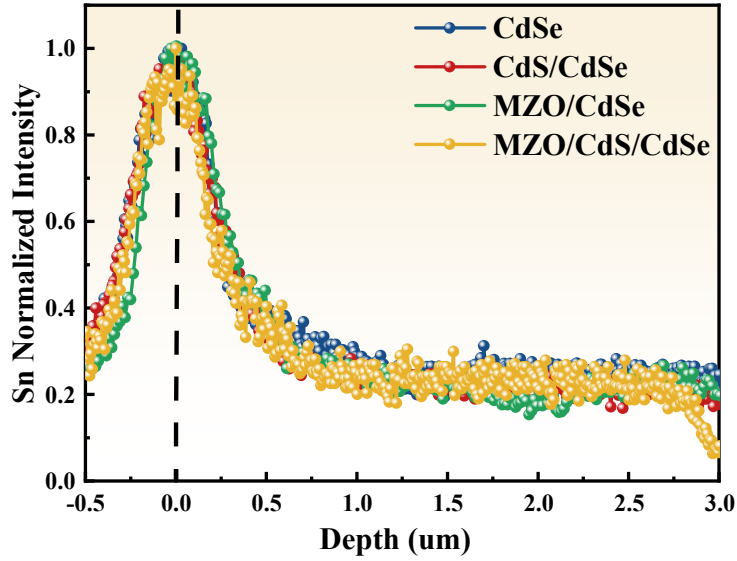


Figure S1: Temperature-dependent J–V curves for devices with different window layer structures.



**Figure S2:** Normalized Sn distribution profiles with different window layer structures.

**Table S1:** Comparison between J-V measured current density ( $J_{\text{measure}}$ ) and EQE-integrated current density ( $J_{\text{integrate}}$ ) for different window layers.

Window layer	$J_{\text{measure}}$	$J_{\text{integrate}}$	$J_{\text{measure}} - J_{\text{integrate}}$
	(mA/cm <sup>2</sup> )	(mA/cm <sup>2</sup> )	(mA/cm <sup>2</sup> )
CdSe	28.50	27.37	1.13
CdS/CdSe	24.53	24.17	0.36
MZO/CdSe	26.88	26.39	0.49
MZO/CdS/CdSe	27.73	26.71	1.02

**Table S2:** Summarized  $V_{\text{OC}}-T$  linear fitting results across the four window layer devices.

Window layer	Intercept	Slop	Pearson's	R-Square
	V	V/K		
CdSe	1.394	-0.0025	-0.9995	0.9991
	( $\pm 0.0090$ )	( $\pm 2.84 \times 10^{-5}$ )		
CdS/CdSe	1.249	-0.0020	-0.9993	0.9986
	( $\pm 0.0091$ )	( $\pm 2.87 \times 10^{-5}$ )		
MZO/CdSe	1.312	-0.0023	-0.9988	0.9975
	( $\pm 0.0137$ )	( $\pm 2.89 \times 10^{-5}$ )		
MZO/CdS/CdSe	1.415	-0.0024	-0.9996	0.9992
	( $\pm 0.0083$ )	( $\pm 2.61 \times 10^{-5}$ )		

Pearson's: The strength of the linear relationship, a value closer to  $\pm 1$  indicates a stronger linear relationship;  
R-Square: The goodness-of-fit of the linear model, a value closer to 1 indicates a better quality of the linear fit.

**Table S3:** EDS line-scan error statistics for various elements in different window layer devices.

Window layer	Element	Wt%	Wt% Sigma
CdSe	Sn	9.38	0.11
	Se	1.77	0.05
	Te	44.41	0.11
	Cd	42.08	0.11
CdS/CdSe	Sn	13.74	0.11
	Se	1.10	0.05
	Te	43.04	0.12
	Cd	41.91	0.12
	S	0.13	0.02
MZO/CdSe	Sn	6.39	0.11
	Se	0.55	0.05
	Te	43.63	0.12
	Cd	41.21	0.12
	Zn	3.83	0.08
MZO/CdS/CdSe	Sn	10.14	0.19
	Se	1.03	0.09
	Te	43.17	0.22
	Cd	39.80	0.21
	Zn	2.78	0.16
	S	0.12	0.04