Supporting Information

Thin film solar cells with 19% efficiency by thermal evaporation of CdSe and CdTe

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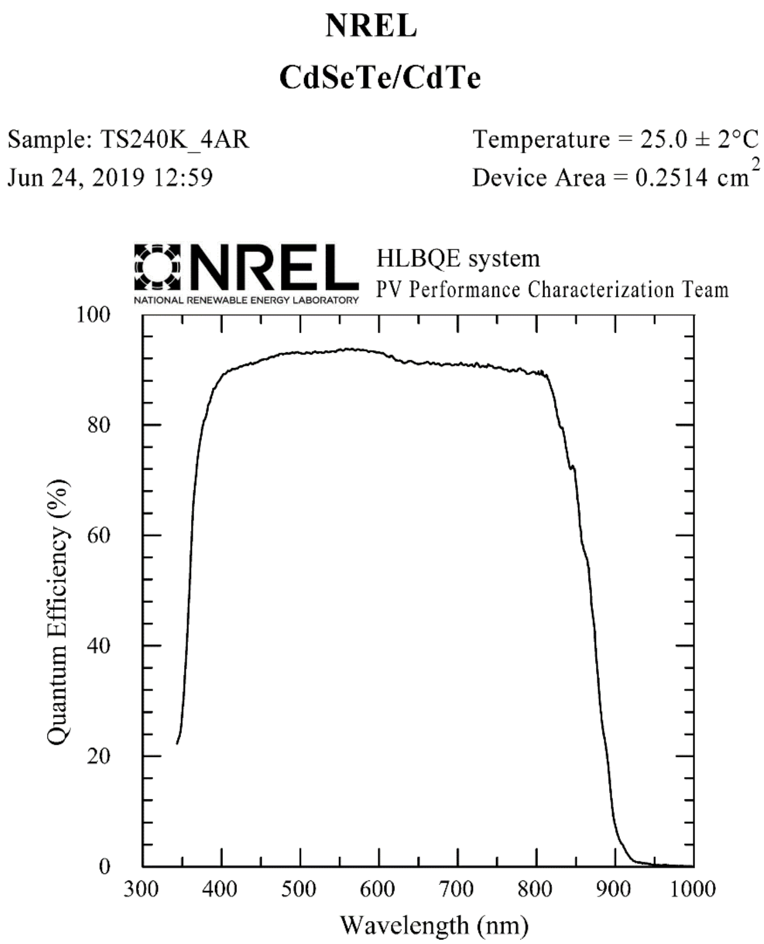

Figure S1. External quantum efficiency measurement data taken by the NREL PV Device Performance Testing Center at zero voltage bias and 2.50 mA light bias into 0.25 cm^2.

NREL

CdSeTe/CdTe Cell

Device ID: TS240K_4AR
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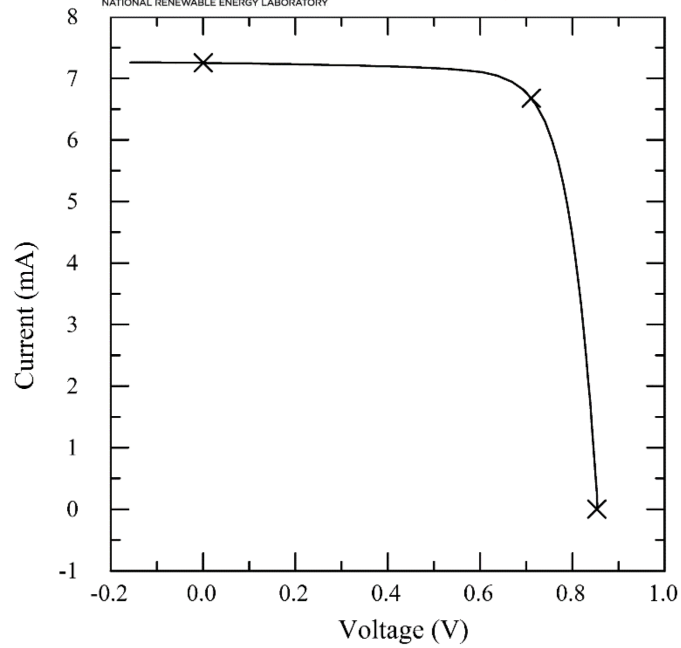
Spectrum: ASTM G173 global

Device Temperature: 26.4 ± 1.6 °C
Device Area: 0.2514 cm^2 ± 0.3 %
Irradiance: 1000.0 W/m^2

NREL NATIONAL RENEWABLE ENERGY LABORATORY
X25 IV System
PV Performance Characterization Team



V_{oc} = 0.8530 ± 0.0050 V
I_{sc} = 7.251 ± 0.044 mA
J_{sc} = 28.85 ± 0.20 mA/cm^2
Fill Factor = 76.73 ± 0.46 %

I_{max} = 6.678 ± 0.041 mA
V_{max} = 0.710741 ± 0.000100 V
P_{max} = 4.746 ± 0.029 mW
Efficiency = 18.88 ± 0.13 %

Figure S2. J-V plot of a cell from CM150 (150-nm CdSe thickness) measured by NREL's PV Device Performance Testing Center.

Brief details of the Auger electron spectroscopy (AES) procedures and data analysis

AES analyses were performed on a Physical Electronics 670 AES system using a 5-kV, 20-nA primary beam defocused to a 50-μm diameter. Sputter cycles were performed using a 3-kV monoatomic argon beam rastered over a 3 mm × 3 mm area. Due to the much larger size of the sputter crater, the depth resolution of the AES measurements was not affected by the laterally non-uniform sputtering that occurs near the sputter crater edges. AES sensitivity factors for cadmium, selenium, and tellurium were calculated as described previously[1] using an ungraded CdSeTe standard film of known composition that had been determined using X-ray fluorescence. Under these conditions for smooth films, our AES setup has demonstrated a depth resolution of better than 10 nm. For example, Fig. S3(a) indicates depth profiles from step-graded combinatorial samples[2] having 50-nm thick layers. In contrast to smooth films, for the CdSeTe films that are the focus of this paper, the depth resolution is significantly worse due to the starting surface roughness and its propagation through the film during sputter profiling. To gauge the effects of how the propagation of initial surface roughness affects depth resolution of buried selenium-rich layers in CdSeTe alloys, in select cases we compared depth profiles taken from the air-side and transparent-conducting-oxide (TCO) side of the same samples. TCO-side samples were prepared by a liquid-nitrogen delamination technique described earlier[3]. The sample preparation method cleanly separates CdSeTe layers from the underlying TCO. By starting a depth profile from the TCO side where the selenium concentration is highest, the effects of air-side roughness and its propagation through microns of absorber are eliminated. The comparison of two selenium profiles is shown in Fig. S3(b), in which the time axis was reversed and shifted for data from the TCO side for direct comparison with those of the air side. Although the selenium profile from the TCO side is somewhat sharper and has slightly higher maximum concentration than the profile taken from the air side, the two profiles are remarkably similar. Thus, we conclude that the depth resolution even from the air side profiles is sufficient to resolve the relatively broad selenium profiles in the films. For this reason and due to the significant extra effort required for TCO-side profiles, subsequent profiling was done from the air side only.

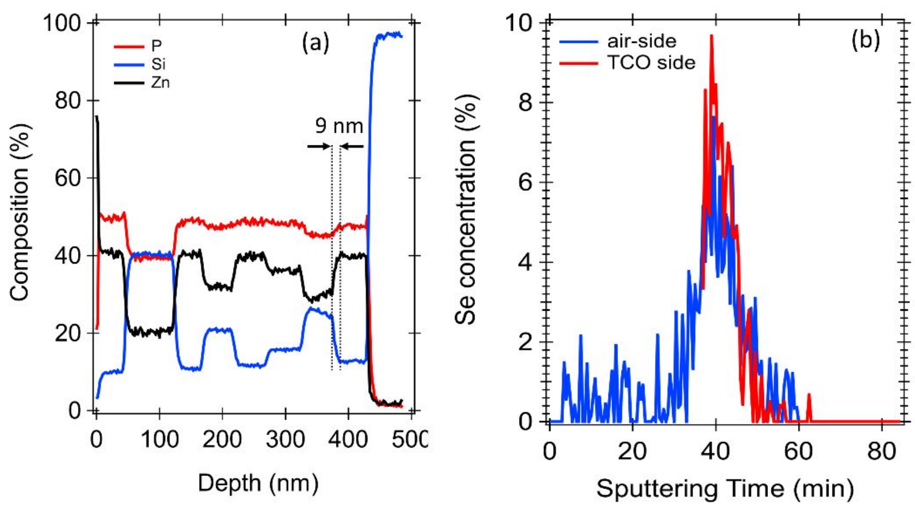


Figure S3. (a) AES depth profiles from a step graded combinatorial sample. (b) Comparison of two selenium profiles taken from air-side and TCO-side after breaking a CdSeTe/CdTe solar cell at the buffer/absorber interface.

References

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3. Perkins, C. L.; McGott, D. L.; Reese, M. O.; Metzger, W. K., SnO2-Catalyzed Oxidation in High-Efficiency CdTe Solar Cells. *ACS Applied Materials & Interfaces* **2019,** *11* (13), 13003-13010.