

Polycrystalline CdSeTe Solar Cells with Implied Open-Circuit Voltage of 965 mV

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Cadmium telluride solar cells—which now frequently incorporate selenium (CdSeTe) to improve absorber lifetime—compete with silicon technologies in today’s market despite operating at a much smaller fraction of their limiting efficiency. Consequently, there are many remaining opportunities for significant improvements in CdSeTe cell efficiency, and such improvements are likely to translate to large market impacts. The open-circuit voltage (V_{oc}) of CdSeTe is particularly poor, with bandgap-voltage offsets of $W_{oc} > 0.55$ V for commercial cells. Low bulk lifetime, low absorber doping density (the cells operate in low injection), high surface recombination velocity, and imperfectly selective contacts (particularly the rear hole contact) are commonly cited reasons for the poor V_{oc} . While these all undoubtedly contribute, one of the largest impediments to performance advances has been a lack of device characterization tools that disentangle the contribution of each, and thus indicate which is most detrimental in a given cell. In this contribution, we introduce a method to measure the implied voltage (iV), or quasi-Fermi-level splitting, as a function of excess carrier density, which yields both iV_{oc} and implied fill factor (iFF). With this technique, we demonstrate $iV_{oc} = 0.965$ V (corresponding to $iW_{oc} = 0.46$ V) in polycrystalline CdSeTe cells and chart a path to extracting this full chemical potential as a voltage at the cell electrodes. Innovations that enabled such high iV_{oc} include selenium incorporation, an alumina (Al_2O_3) rear passivation layer, a p-type amorphous silicon (a-Si:H(p)) rear hole-selective layer, and an indium tin oxide/silver (ITO/Ag) rear electrode and reflector.

The method to determine implied current density-voltage (J - V) curves, depicted in Figure 1a, is based on injection-dependent external radiative efficiency; we call the method Suns-ERE. Briefly, a Lambertian reflector placed in the sample location is used to determine the incident photon flux from a relatively low-intensity chopped laser that reaches an InGaAs detector. The reflector is then replaced with a sample, which may be a solar cell in any state of completion, provided that it has an absorber, and the detector now measures the photoluminescence photon flux from the sample. The ratio of the fluxes is the ERE , and, if the absorptivity of the absorber is known (and thus the radiative-recombination-limited voltage, V_{rad}), it may be used to calculate an implied voltage according to [1]:

$$iV = V_{rad} - \left| \frac{k_B T}{q} \ln(ERE) \right|$$

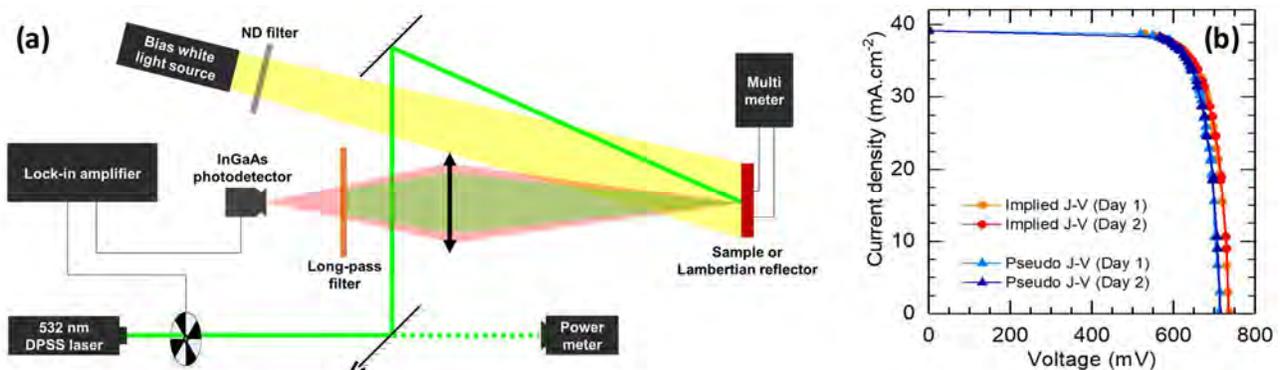


Figure 1. (a) Suns-ERE experimental setup and (b) implied and pseudo J - V curves measured on a silicon heterojunction reference solar cell on two days, demonstrating repeatability.

By varying the intensity of a white bias light source via neutral density filters, iV may be measured as a function of excess carrier density or equivalent current density; the result is shown in Figure 1b for a silicon heterojunction solar cell. A silicon cell was used as a reference for the technique, as its implied J - V curve could also be measured with a Sinton photoconductance lifetime tester. The curves differed by less than 5 mV for all implied current densities. As shown in Figure 1a and b, a multimeter can be used to generate pseudo (i.e., series-resistance-free) J - V curves from J_{sc} - V_{oc} measurements performed in concert with the Suns-ERE measurements.

The present state-of-the-art CdSeTe device from our team has the following structure, from front to rear (and in the growth direction): Soda lime glass / FTO / MgZnO / CdSeTe / CdTe / Al₂O₃ / a-Si:H(p) / ITO / Ag. Kuciauskas et al. previously demonstrated lifetimes of several hundred nanoseconds with Al₂O₃ / CdTe / Al₂O₃ double heterostructures, revealing that the absorber quality is, in many cases, better than the CdTe community had long thought [2]. The cells investigated here, which had only 2 nm of sputtered Al₂O₃ so as not to block hole transport through the contact, still had lifetimes of 150 ns, as determined from a bi-exponential fit to time-resolved photoluminescence data. The ERE of these cells reached 0.1%—two orders of magnitude higher than many present CdSeTe devices and comparable to very good silicon cells—corresponding to $iV_{oc} = 0.965$ V. In addition to the excellent-quality CdSeTe absorber and suppressed surface recombination from fixed charge in the Al₂O₃, the ITO/Ag rear reflector boosts ERE by suppressing parasitic absorption of emitted light, and the a-Si:H(p) appears to provide an ERE benefit that we do not yet understand. The measured V_{oc} , however, presently remains at least 100 mV below the iV_{oc} , indicating that one of the contacts is imperfectly selective. We previously demonstrated that a-Si:H(p) can be selective in monocrystalline (epitaxial) CdTe cells, enabling $V_{oc} = iV_{oc} = 1.12$ V [3], and we will present an update at the conference on our progress on replicating this result in our polycrystalline CdSeTe devices.

References

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