Study unveils factors limiting the voltage of polycrystalline CdSeTe solar cells

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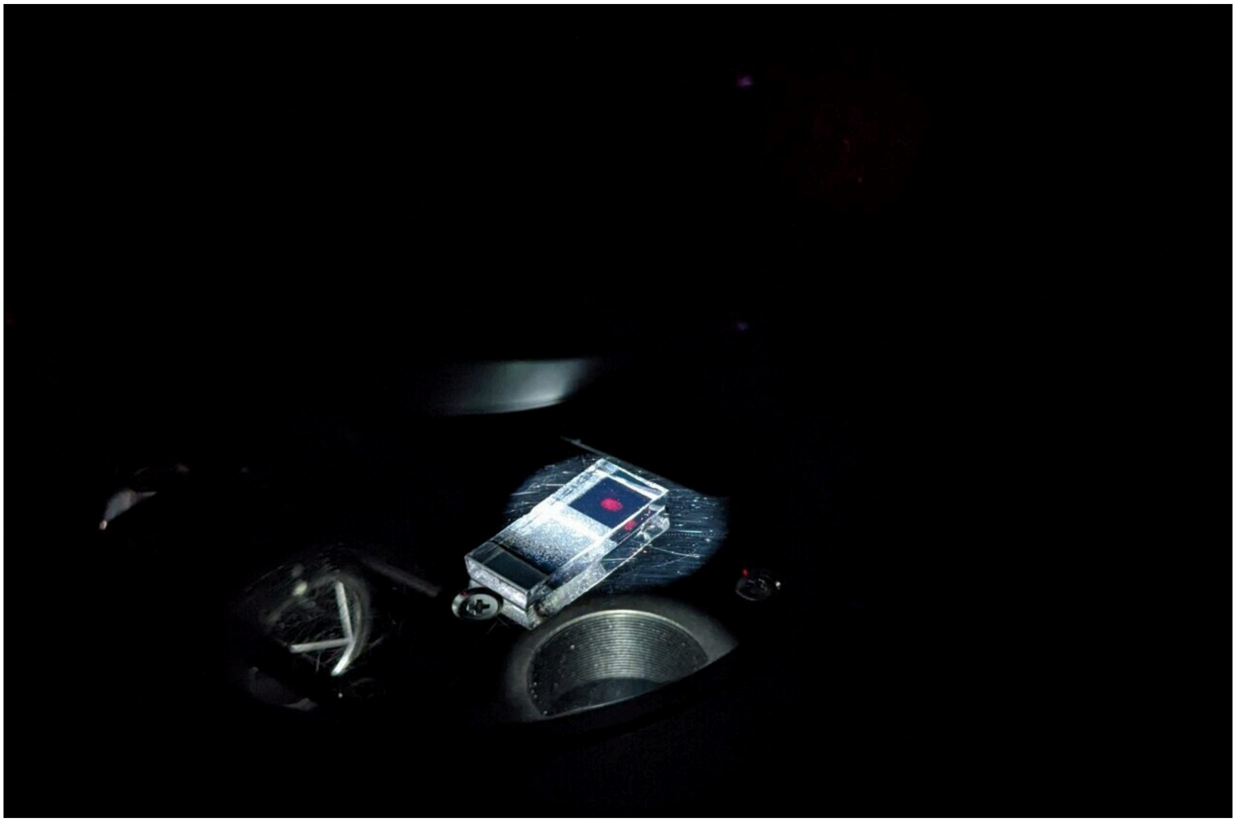

One of the cells fabricated at CSU during characterization. The white beam is the bias light ("the sun"), the red dot is the probe laser. Credit: Onno et al.

So far, solar cells based on polycrystalline cadmium selenide telluride (CdSeTe) have exhibited some crucial limitations, despite their low fabrication costs and advantageous qualities. Most notably, these solar cells exhibit higher voltage losses than other mature photovoltaic technologies (crystalline silicon, for example) and this considerably impairs their performance and efficiency.

Researchers at Arizona State University (ASU), Colorado State University (CSU), the National Renewable Energy Laboratory (NREL) and First Solar Inc. have recently carried out a study aimed at better understanding the reasons for the voltage deficits observed in CdSeTe solar cells. Their paper, published in *Nature Energy*, offers new insight that could help engineers to improve the performance of these solar cells in the future.

"The idea for this project came to us during a previous partnership with CSU," Arthur Onno, Assistant Research Professor at ASU, told TechXplore. "Our team, which has its roots in silicon photovoltaic (PV) solar cells, is accustomed to parsing losses (including voltage losses) to identify what is the issue limiting the efficiency of our cells and guide their optimization (think about identifying the low hanging fruits). We realized that the CdSeTe community did not have similar techniques to systematically parse voltage and efficiency losses and were having a blind spot when trying to optimize their solar cells."

While reviewing past efforts aimed at creating CdSeTe solar cells, Onno and his colleagues observed that often engineers developing these technologies associated voltage losses with the malfunctioning or limitations of specific cell components. However, very few studies tried to clearly identify the mechanisms behind observed voltage losses or quantify their impact.

To fill this gap in the literature, the researchers used an optical, non-destructive and contact-less technique, called External Radiative Efficiency (ERE) measurement. ERE is a valuable metric that describes how good a solar cell is at reemitting absorbed light at open circuit (when current is not extracted from it). Thus, it quantifies how reversible the conversion of the solar resource into an electrochemical potential is.

Onno and his colleagues collected ERE measurements on CdSeTe cells developed at CSU. Interestingly, they found that the primary mechanism limiting their voltage is not recombination on defects within the bulk of the cell, as engineers creating CdSeTe cells have long assumed, but instead an issue with selectivity. More specifically, the team observed that a non-negligible fraction of electrons inside the cell appeared to move in the "wrong" direction and thus canceled each other's charge while leaving the cell.

"This finding is important, as it will hopefully broaden the approach that the CdSeTe community (industry included) takes to improve their devices, with a deeper physical understanding of why the voltage of CdSeTe solar cells is not higher," Onno said. "This is both a significant problem and a significant opportunity: as of right now, CdSeTe lags behind most established solar cell technologies in terms of voltage losses, which is a problem, but with the biggest headroom for improvement, which is an opportunity."

A solar cell's structure consists of a light-absorbing material sandwiched between semi-permeable membranes, which are known as "contacts." The key function of these membranes is to ensure that excited electrons leave the absorbing layer from only one of the two electrodes in the cells, and that they only come back into the cell from the other. When this does not happen (i.e., if electrons exit or enter the cell from the "wrong" electrode), energy is lost.

"In the absorber, bound electrons get excited into a free electron-hole pair when they absorb photons (particles of light)," Onno explained. "The electron-hole pair needs to get back to the bound (ground) state eventually, we cannot 'pump' them with light into the excited free electron-hole pair state indefinitely, there is and must be a reciprocal process called recombination. This recombination can happen in the absorber, in that case the energy of the absorbed photon is lost, or we can gather the electron at an electrode, use some of the energy in the form of electricity to power a load, and bring back the electron through the other electrode at the other end of the cell where it will recombine with a free hole."

The experimental method used by Onno and his colleagues allowed them to access the internal voltage of CdSeTe cells. A cell's internal voltage is the difference in free energy (i.e., chemical potential) between populations of electrons and holes within the absorber.

"If electrons and holes recombine through defects in the bulk of the absorber or at interfaces, this internal voltage decreases," Onno said. "So, the internal voltage is a measure of how defects reduce your voltage from the ideal thermodynamic limit. The external voltage, on the other hand, corresponds to the internal voltage minus voltage losses due to the semi-permeable membranes being imperfect (i.e., losses due to electrons exiting at the wrong electrode or coming back at the wrong electrode)."

When a cell's semi-permeable membranes are operating perfectly, its internal and external voltages match. If they are malfunctioning, however, the external voltage is lower than the internal voltage.

"In extreme cases, you can imagine a symmetric structure where the semi-permeable membranes are the same on both sides," Onno explained. "In this case, symmetry dictates that the potential will be the same on both sides of the cell and the external voltage will be zero even if your internal voltage is high. The catch is that the external voltage can easily be measured with a voltmeter, but the internal voltage is trickier to access."

One of the most notable achievements of the recent work by this team of researchers is that they introduced a simple method to measure the internal voltage of solar cells. This allowed them to shed more light on the mechanisms underlying voltage losses in CdSeTe solar cells.

"With the support of a $1.5 million research grant that we received from the U.S. Department of Energy, we first developed the technique and showed that it worked well on silicon, a well-known material system on which we could easily cross-checked our results with state-of-the-art techniques," Onno added. "Then, with our collaborators at NREL and CSU, we started looking into CdSeTe solar cells fabricated at CSU, with the goal of comparing their internal and the external voltages. 3 years of work, 75 samples fabricated, and close to 900 solar cells measured later, we came to the conclusions outlined in our paper."

The researchers also collaborated with First Solar, the largest U.S.-based solar module manufacturer. First Solar sent them solar cell samples with different doping concentrations, which they could use to validate some of their findings.

In their experiments, Onno and his colleagues found that contacts to CdSeTe solar cells are not necessarily perfect, as many researchers assumed, as they often contribute to voltage losses in the devices. In addition, the results of their analyses suggest that the bulk absorber in these cells is highly promising, but its performance is not fully realized without excellent semi-permeable membranes.

"Finally, we found that Se and As alloying have detrimental material effects that limit the achievable voltage independent of the other sources of losses," Onno said. "Understanding the origin of this issue and mitigating it will be key to push the CdSeTe technology further."

In the future, the methodology used by Onno and his colleagues could be employed by other teams to investigate the factors causing voltage losses in a variety of different solar cells. In addition, the findings gathered in this study could help to design more efficient cells based on CdSeTe.

The researchers are currently working to make the technique they developed available to other research teams and companies worldwide, for instance by building a replica of their measurement technique that could be used by solar cell manufacturers. Their work recently received additional funding from the State of Arizona's New Economy Initiative (NEI).

"We now plan to extend our research to other photovoltaic absorbers, such as perovskites, which are a hot research topic right now," Onno concluded. "We also plan to use the technique on silicon solar cells because, as opposed to other similar charaterization techniques, our technique can be used on any type of samples (e.g., unfinished cell precursor, finished device, cells encapsulated in modules, etc.). For example, we can imagine taking a module that has been producing power in the field for 20 years and investigating it with our technique."

More information: Arthur Onno et al, Understanding what limits the voltage of polycrystalline CdSeTe solar cells, *Nature Energy* (2022). DOI: 10.1038/s41560-022-00985-z

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