KESTERITE SOLAR CELLS

High voltage, please!

Kesterite solar cells are low-cost alternatives for photovoltaics, based only on abundant metals, but they exhibit limited voltages. A new wide-gap kesterite solar cell provides a much higher voltage at a good efficiency.

Susanne Siebentritt

Kesterite solar cells are a thin film photovoltaics (PV) technology based on the semiconductor $Cu_2ZnSnSe_4$, sometimes alloyed with sulfur. Its raw materials are abundant in the Earth's crust, making it an attractive material for PV deployment at the gigawatt to terawatt scale. The efficiency of kesterite solar cells has increased rapidly between 2009 and 2013, when the current best efficiency, 12.6%, was achieved[1]. However, one of the main issues with kesterite solar cells has always been their low voltages. For example, the record device reaches only 513 mV with a band gap of 1.13 eV. While it is possible to increase the voltage by increasing the sulfur content and thus the absorber band gap, so far all the high-voltage devices have shown a lower efficiency than the record device (see Fig. 1a; refs [1–8]). Haight and colleagues from IBM, in the USA, now publish a new development in *Nature Energy*[2], improving the voltage by more than 150 mV while almost conserving the high efficiency of previous devices.

This improvement has been achieved by engineering the back contact. First, the kesterite absorber is grown on a molybdenum-covered glass substrate following well-established procedures. The devices are then cooled slowly, likely resulting in decreasing cation disorder and thus further increasing the band gap[9], in a first step to improving the efficiency. Second, the devices are exfoliated from the Mo-covered glass and are supplied with a new back contact made of molybdenum oxide and gold. The exfoliated devices exhibit a remarkable improvement in the open-circuit voltage, fill factor, and efficiency. While this exfoliation process might be limited to device areas in the cm^2 range, rather than m^2, these small-area solar cells have important and growing applications for the internet of things. Indeed, distributed sensors will require high-voltage energy harvesters in order for their batteries to be charged and to ensure autonomous, long-term operation.

One can go a step further and argue that the improved efficiency combined with higher voltage and band gap is also important in the context of large-scale electricity supply. Indeed, several scenarios envision an immense growth of PV electricity, with deployment rates between 100 and 1,000 GW peak, or GWp, the nameplate capacity, per year[10]. Such large-scale PV deployment requires further reductions of installed peak-power cost, which hangs on two factors: reducing module cost and improving module efficiency. So far, huge advances in Si-wafer technology have driven both. However cost reductions will eventually come to an end, and it is of enormous importance to also increase the efficiency. Tandem solar cells offer a disruptive way to improve efficiency[11]. They require efficient top cells with a wide band gap and thus a high voltage.

The production of these 100 to 1,000 GWp a year will require substantial amounts of energy and raw materials. Thin-film solar modules based on $Cu(In,Ga)Se_2$ or CdTe have a significantly lower carbon footprint than crystalline Si technologies[12]. The pressure on materials supply also requires development of thin-film solar cells based on abundant raw materials, such as kesterite solar cells. However, in order to be used as top cells of tandem solar cells, kesterite solar cells would need to reach efficiencies close to 20%, much higher than those achieved today, and with much higher voltages[13]. The device presented in the work of Haight and colleagues is a clear step forward to a thin-film top cell in a tandem solar cell. What makes this new device particularly interesting in this context is that the newly developed method to prepare the back contact offers the potential to add transparent back contacts that are a prerequisite for use as a top cell in a tandem solar cell.

A major factor limiting the efficiency of kesterite solar cells to date is the difference between the absorber band gap and the open circuit voltage (V_{OC}) of the solar cell. This so-called V_{OC} loss falls in the range ~600–800 meV in the best kesterite solar cells (Fig. 1b). It relates to the existence of band tails in the electronic structure of the kesterite material[14]. Interestingly, the V_{OC} loss increases with the band gap of the kesterite absorber, that is, with its sulphur content. This suggests that the electronic quality of high band gap, high-sulfur-content kesterite absorbers needs to be improved, and in particular the band tailing needs to be reduced in order to make substantial progress in the efficiency of these devices.

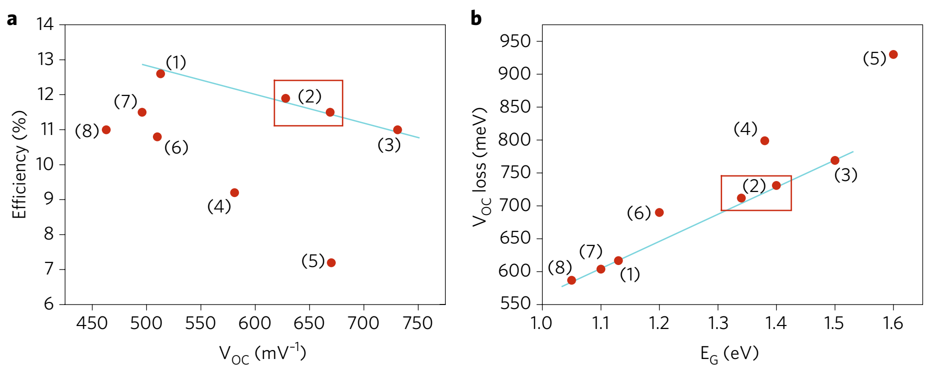

Fig. 1 | Voltage and efficiency of kesterite solar cells. a, Correlation between efficiency and open-circuit voltage (V_{OC}) for the best kesterite solar cells, including those with cation substitution instead of sulfur substitution. **b**, For the same devices, correlation between the band-gap energy E_G and the voltage loss (that is, the difference between E_G and eV_{OC}, the open-circuit voltage multiplied by the electron charge). The blue lines are guides to the eye, linking best devices; the results from Haight and colleagues are highlighted with red boxes. Fig. 1a: data from refs [1–8].

Improving the bulk of the semiconductor is particularly needed now, since the recent high-band-gap devices are no longer limited by interface recombination[15]. ❐

Susanne Siebentritt
The Laboratory for Photovoltaics, Physics and Materials Science Research Unit, University of Luxembourg, 4422 Belvaux, Luxembourg.
e-mail: susanne.siebentritt@uni.lu

Published online: 6 November 2017
https://doi.org/10.1038/s41560-017-0031-x

References

1. Wang, W. et al. *Adv. Energy Mater*. **4**, 1301465 (2014).
2. Antunez, P. D., Bishop, D. M., Luo, Y. & Haight, R. *Nat. Energy* https://doi.org/s41560-017-0028-5 (2017).
3. Green, M. A. et al. *Prog. Photovoltaics Res. Appl* **25**, 668–676 (2017).
4. Su, Z. et al. *Adv. Energy Mater.* **5**, 1500682 (2015).
5. Guchhait., A. et al. *ACS Energy Lett.* **1**, 1256–1261 (2016).
6. Larramona, G. et al. *Adv. Energy Mater* **5**, 1501404 (2015).
7. Haass, S. G. et al. *Adv. Energy Mat*. https://doi.org/10.1002/aenm.201701760 (2017).
8. Giraldo, S. et al. *Energy Environ. Sci*. (in the press).
9. Rey, G. et al. *Appl. Phys. Lett.* **105**, 112106 (2014).
10. Creutzig, F. *Nat. Energy* **2**, 17140 (2017).
11. Albrecht, S. & Rech, B. *Nat. Energy* **2**, 16196 (2017).
12. de Wild-Scholten, M. J. *Solar Energy Mater. Solar Cells* **119**, 296–305 (2013).
13. Platzer-Björkman, C. *Curr. Opinion Green Sust. Chem* **4**, 84–90 (2017).
14. Siebentritt, S. *Sol. Energy Mater. Sol. Cells* **158**, 126–129 (2016).
15. Sun, K. et al. *Adv. Energy Mater* **6**, 1600046 (2016).