A comparative study of *Suns-$V_{oc}(T)$* and *I-V(T)* for the analysis of temperature- and illumination-dependent performance of solar cells

Johannes P. Seif[1], Thomas G. Allen[2], Rabin Basnet[3], **Anh Huy Tuan Le[1]**, Simon M.F. Zhang[1], and Ziv Hameiri[1]

[1]University of New South Wales, Sydney, NSW 2052, Australia
[2]King Abdullah University of Science and Technology, Thuwal 23955-6900, Saudi Arabia
[3]The Australian National University, Canberra, ACT 2601, Australia

Introduction

- Knowledge regarding the temperature and illumination dependence of solar cell performance is essential for their optimization and for the prediction of the power output from photovoltaic systems.
- It is required to understand benefits and limitations of different cell technologies in diverse operating conditions, when selecting modules for a specific location.
- **In this study, we (1) introduce an advanced characterization tool - the temperature-dependent *Suns-V_{oc}* [*Suns-$V_{oc}(T)$*], (2) apply this characterization method to different cell structures, and (3) compare results obtained by *Suns-$V_{oc}(T)$* and *I-V(T)*.**

Methodology

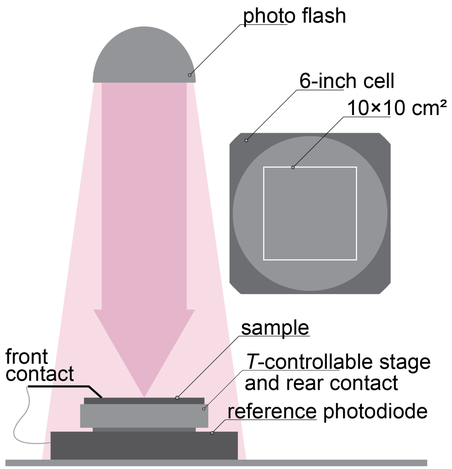


Fig. 1. Sketch of the temperature-dependent *Suns-V_{oc}* tool.

Suns-$V_{oc}(T)$ system allows measurement of both the temperature (from 25 to 200 °C) and illumination (from 10^{-3} to 10^{2} suns) dependence of solar cells.

Results and discussion

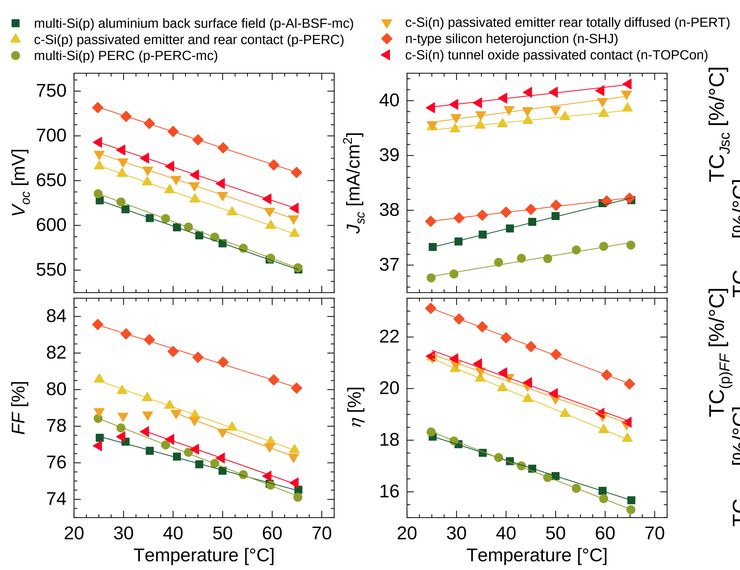


Fig. 2. Cell parameters as a function of temperature obtained from *I-V(T)* measurements.

- As expected, with increasing temperature:
  - The open-circuit voltage (V_{oc}) and the fill factor (*FF*) drop due to an increase of the effective intrinsic carrier concentration.
  - The short circuit-current density (J_{sc}) increases due to band gap narrowing.
  - The cell efficiency (η), dominated by V_{oc}, decreases as well.
- Passivating contact cell structures, *i.e.* SHJ and TOPCon, show better V_{oc} and efficiency across the entire temperature range.

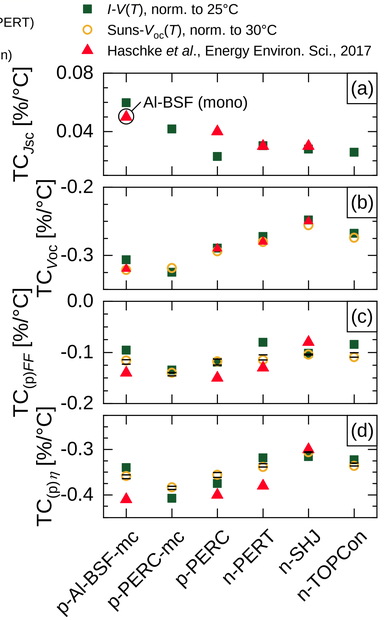
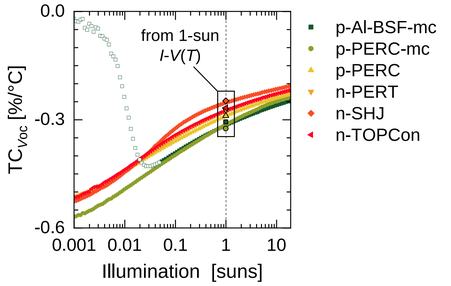


Fig. 3. Temperature coefficients of (a) J_{sc}, (b) V_{oc}, (c) (pseudo, p) *FF*, and (d) (pseudo, p) η extracted from the data obtained by *Suns-$V_{oc}(T)$* and *I-V(T)*.

Suns-$V_{oc}(T)$ vs *I-V(T)*:

- A good match for the temperature coefficient of V_{oc} (TC_{Voc}) values.
- Differences between the temperature coefficients of pseudo *FF* (TC_{pFF}) and *FF* (TC_{FF}) can be used to assess the contribution of the cell's series resistance.



- TC_{Voc} becomes increasingly negative with increasing illumination intensity. Hence, the investigated cells are more sensitive to temperature variation at lower illumination intensities.
- For most of the illumination range, passivating contact cell structures, *i.e.* SHJ, and TOPCon, show better TC_{Voc} compared to cell structures without passivating contacts.

Fig. 4. TC_{Voc} as a function of illumination intensity measured by *Suns-$V_{oc}(T)$*. Open symbols are the data points with R-squared of linear fits lower than 0.95.

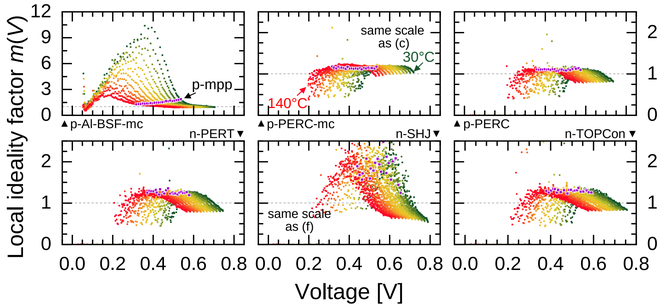


Fig. 5. Temperature-dependent ideality factor *m(V)* as a function of cell voltage measured by *Suns-$V_{oc}(T)$*.

- Local ideality factor (*m*) decreases, and the peaks are shifted to lower voltage with increasing temperature, indicating an increase of the saturation current density of the second diode.
- Larger humps (*m*>2) in the case of p-Al-BSFmc cells indicate the effect of the cell's shunt resistance.

Conclusions

- *Suns-$V_{oc}(T)$* enables the analysis of the temperature and illumination dependence of the cell performance simultaneously.
- Passivating contact cell structures, *i.e.* SHJ and TOPCon, show better TC_{Voc} compared to the ones without passivating contacts.
- The investigated cells are more sensitive to temperature variation at lower illumination intensities.
- *m*(*V*) at different operating temperatures obtained by *Suns-$V_{oc}(T)$* distinguishes the resistance and dark saturation current density related effects.

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