ASIA-PACIFIC
SOLAR RESEARCH CONFERENCE

Temperature-dependent Suns-V_{oc} and Suns-PL method for advanced characterization of solar cells

Johannes P. Seif[1], Thomas G. Allen[2], and Ziv Hameiri[1]

[1]*University of New South Wales, High St Kensington, NSW 2052, Australia*
[2]*King Abdullah University of Science and Technology, Thuwal 23955-6900, Saudi Arabia*
E-mail: j.seif@unsw.edu.au

The standard testing conditions (STC) used for solar cell characterisation specify a testing temperature of 25°C. Yet, regardless of their design, the optimization of photovoltaic devices relies on the precise knowledge of their performance under conditions encountered in the field. Depending on module installation location, module temperatures can easily reach temperatures as high as 70–90°C [1]. It is therefore crucial to characterise solar cells also at elevated temperatures. Although temperature-dependent measurements have been used to assess temperature loss mechanisms in the past [2, 3], a significant knowledge gap still exists regarding the comparison of terminal and implied voltages of the device. To address this issue, we present a new method utilizing three complementary techniques: temperature-dependent light current-voltage measurements [*I*-*V*(*T*)], and a specially designed characterisation tool that combines illumination-dependent open-circuit voltage [Suns-$V_{oc}(T)$] and photoluminescence [Suns-PL(*T*)] measurements.

Each of these measurement techniques provides information about either the terminal or implied voltage.
The contactless Suns-PL measurement measures the light emitted by radiative recombination inside the absorber material. This is directly related to the implied open circuit voltage (iV_{oc}). Its advantage compared to the standard photoconductance decay method is its capability to measure both non-metallized *and* metallized samples [4]. In this study, we benefit from its capability to measure the effective iV_{oc} of metallized samples without the impact of the entire contact stack. This enables us to probe possible effects ensuing from metals influencing the carrier concentration at the wafer surface. In contrast to Suns-PL, the Suns-V_{oc} measurement provides the terminal voltage. The light *I*-*V* data contains information about all the loss mechanisms found in a photovoltaic device. Comparing these methods with one another can shed light on how the terminal voltage, the fill factor as well as the voltage-dependent ideality factor (*m*) of a device are affected by the temperature. This can help to understand which components of the device impact its temperature behaviour.

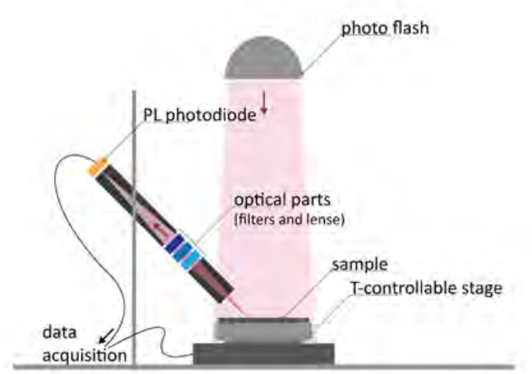

Figure 1 Simplified sketch of the setup used in this study. The arrows indicate the path of the light or signals.

We use a specially designed temperature-controllable Suns-V_{oc} stage, from Sinton Instruments, in combination with a PL photodiode. The latter is equipped with filters to select the PL signal from the background (see Figure 1). To maximize the injection range, a white box is installed around the setup to scatter the light diffusely and channel it towards the sample. This configuration can reach an intensity of up to 100 suns, measured by a monitor cell placed in proximity to the device. This is two orders of magnitude larger than without the white box, the configuration that is used for the measurements up to 1 sun. Hence, two separate measurements are necessary. The *I*-*V*(*T*) measurements are performed separately.

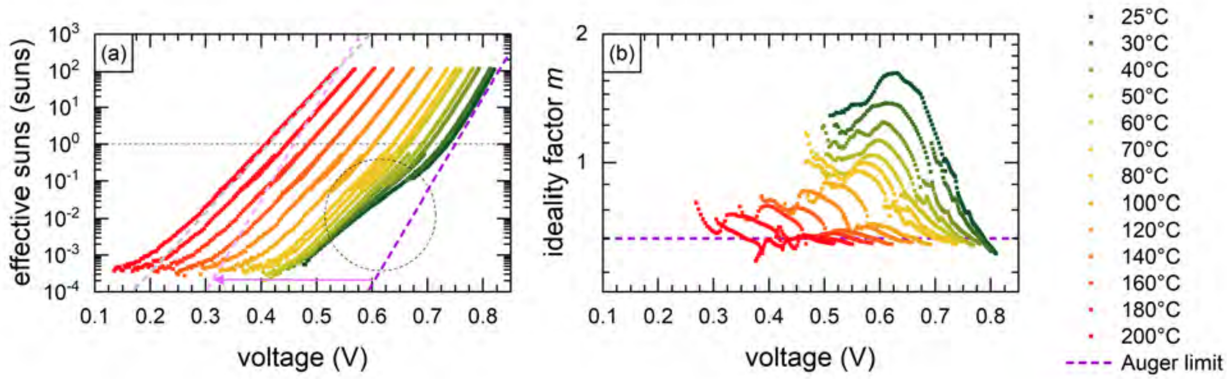

Figure 2 (a) Temperature-dependent Suns-V_{oc} data with different slopes indicated by dashed lines. (b) Voltage-dependent ideality factor *m* calculated from Figure (a). Note that the data has been cropped and *m* calculated averaging over 13 points.

We demonstrate the usefulness of this unique setup by measuring a state-of-the-art silicon heterojunction solar cell. The Suns-V_{oc} data for set temperatures from 25–200°C (accuracy of ±2°C) is shown in Figure 2(a). While the *actual* cell temperature may differ from this value, we are confident that cell temperature is close to the setpoint.

A few interesting features are already apparent from this set of measurements. First, we observe the expected shift towards lower voltage with increasing temperature. This is explained by the increase of the intrinsic carrier density n_i that causes the voltage to drop. From the temperature dependence of V_{oc} at 1 sun, we determine a temperature coefficient (TC) of −1.85 mV/°C (range 25–200°C), which is similar to what is reported in literature [3]. Second, taking a closer look, we observe a strong voltage drop at lower sun values for the lower temperatures leading to an s-shaped curve [see dashed circle in (a)]. This s-shape character is less pronounced with increasing temperature. A possible explanation for this behaviour is thermal activation of dopants in the amorphous silicon layers; a deeper investigation is required to confirm this. Third, Figure 2(b) shows data of the voltage-dependent ideality factor *m*. A value of 2/3—as indicated by the purple dashed line—defines pure Auger recombination at high operating voltages. As expected, a clear deviation from this recombination pathway is apparent for lower operating voltages at which $m > 2/3$. Reducing the operating voltage, *m* first tends towards a value of 2 before returning towards 1 (Shockley-Read-Hall recombination). For higher temperatures, however, the device becomes increasingly Auger-limited and *m* peaks at lower values.

Here, we presented a versatile tool to investigate temperature-dependent effects in photovoltaic devices. Further, more in-depth investigations—including *I-V* and Suns-PL—are currently ongoing and will be shown at the conference.

[1] S. Kurtz *et al.*, "Evaluation of high-temperature exposure of photovoltaic modules," *Progress in Photovoltaics,* vol. 19, no. 8, pp. 954-965.
[2] J. Haschke *et al.*, "The impact of silicon solar cell architecture and cell interconnection on energy yield in hot & sunny climates," *Energ Environ Sci,* vol. 10, no. 5, pp. 1196-1206.
[3] J. P. Seif *et al.*, "Amorphous/crystalline silicon interface passivation: ambient-temperature dependence and implications for solar cell performance," *IEEE Journal of Photovoltaics,* vol. 5, no. 3, pp. 718-724.
[4] R. Dumbrell *et al.*, "Extracting metal contact recombination parameters from effective lifetime data," *IEEE Journal of Photovoltaics,* vol. 8, no. 6, pp. 1413-1420.