Solar cell measurements at high temperature

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***Abstract* — Photovoltaic (PV) power technology is in principle capable of operating in a high temperature environment, but little work has been done to understand how to adapt currently available device and system technologies for extreme conditions. The objective of this work is to look at the performance of a multi-junction concentrator solar cell operating at high temperature and to find promising approaches to increase the efficiency of a solar cell under extreme conditions.**

***Index Terms* — High Temperature Photovoltaics, Multi-junction Solar Cell.**

I. Introduction

Solar cells usually operate with a higher efficiency at low temperature. The short-circuit current of a solar cell is not strongly temperature-dependent. However, the open circuit voltage is strongly temperature-dependent. For example, in the case of a typical silicon solar cell, the short-circuit current increases by about 0.06 mA/C whereas the open circuit voltage decreases by 2.3 mV/C. [1] Solar cells are in principle capable of operating at high temperature. However, due to the decrease in efficiency, very little work has been done related to high temperature photovoltaics. Concentrator solar cells are usually designed to operate up to 110C and solar cell manufacturers usually recommend using active cooling to drive the temperature down and therefore the efficiency up. In certain circumstances where any type of cooling is challenging, solar cells will need to operate at high temperature. G. A. Landis et al. have studied the impact of high temperature operation on commercial triple junction space solar cells for Venus applications where temperatures over 400C are observed. [2, 3] As expected, the efficiency of the solar cell significantly decreased. In this work, we are studying commercial triple junction concentrator solar cells (CPV) to be used as a topping device for a thermal energy converter. The waste heat of the solar cell is used as an input for the thermal energy converter located underneath. We look at the efficiency of a bare solar cell while raising the temperature up to 500C in order to observe the variation in the different parameters of the solar cell, namely the short circuit current (Isc), the open-circuit voltage (Voc) and the fill factor (FF). The combination of all these parameters shows the impact on the overall efficiency of the solar cell. In addition, we will determine the failure mechanism that occurs in the high temperature environment and propose solutions to ensure high reliability and long lifetime of the solar cell at high temperature.

II. Experimental Setup

The high temperature photovoltaics experimental setup is depicted in Fig. 1. On a ceramic plate, we attach a steel plate with two heaters that can accurately raise the temperature up to ~500C. The solar cell rests on the steel plate and is mechanically held with steel bars on the lateral busbar of the solar cell to ensure uniform illumination of the solar cell area.

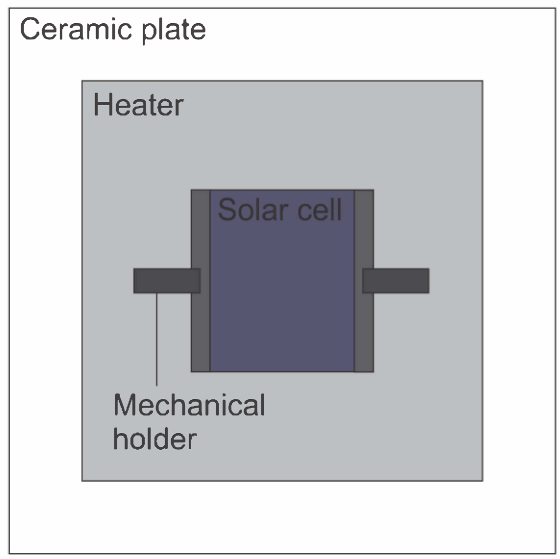

Fig. 1. Experimental setup of the solar cell on the heater for high temperature measurement.

The design of the mechanical holder was done to avoid any paste that can react at high temperature. The ceramic plate acts as a thermal barrier. Thermocouples are used as a feedback loop to vary the temperature of the steel plate and to record the actual temperature of the solar cell. To avoid any reaction with the surrounding environment, the setup is mounted under a Bell Jar that can handle vacuum or inert environment such as nitrogen (N2) or argon (Ar). For characterization, the solar cell is illuminated using a ScienceTech solar simulator through a pyrex view port with a simulated uniform 1 a.u. (astronomical unit) close to AM0 solar spectrum . The mechanical holder also acts as a front contact for the solar cell and a wire is connected to an intermediate steel plate between the solar cell and the heater and is used as a back contact. For accurate current-voltage (IV) measurement, a four-point probe

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TABLE I

SUMMARY OF THE EXPERIMENTAL RESULT ON THE SOLAR CELL.

Temp (C)	V_{OC} (V)	J_{SC} (mA/cm2)	FF	η (%)
28.07	2.54	17.28	0.845	27.4
50.73	2.35	17.53	0.847	25.7
102.34	2.15	17.65	0.828	23.2
150.81	1.92	17.35	0.814	20.0
200.48	1.75	17.10	0.799	17.7
250.40	1.60	17.07	0.788	15.9
300.29	1.47	17.03	0.765	14.1
350.41	1.36	17.12	0.737	12.5
400.32	1.23	17.25	0.722	11.3
450.61	1.10	17.81	0.674	9.8
500.67	0.98	18.39	0.624	8.3

is used to sweep the voltage and measure the current simultaneously.

III. MEASUREMENT

We mount a commercial multi-junction solar cell on our setup. While the solar cell is connected, under vacuum, and illuminated by the AM0 solar spectrum, we perform an IV measurement at room temperature. The efficiency of the solar cell is

$$\eta = \frac{FF * J_{SC} * V_{OC}}{P_{in}} \quad (1)$$

Where FF is the fill factor, J_{sc} the short circuit current and

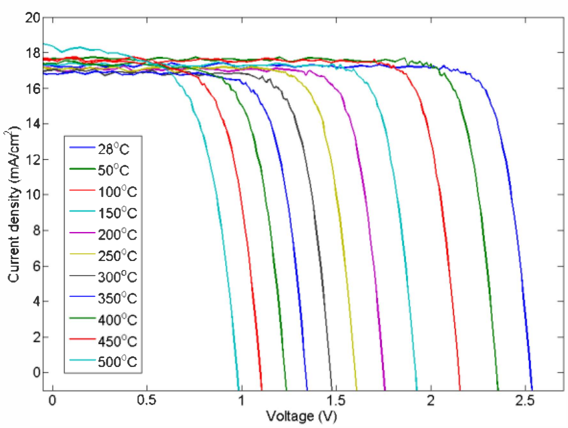

Fig. 2. Experimental result of the current-voltage characteristics of the solar cell measurement between 28C and 500C.

V_{oc} the open-circuit voltage. At 28C, we measure an efficiency of 27.4%. We then gradually increase the solar cell temperature to 50C and by steps of 50C until 500C and measure the IV characteristics of the solar cell under constant illumination to see the impact of the temperature on the solar cell performance. The result is presented in Fig. 2. The equation for V_{oc} can be found by setting the net current equal to zero in the solar cell equation to give

$$V_{OC} = \frac{n * k * T}{q} \ln\left(\frac{I_L}{I_0} + 1\right) \quad (2)$$

Where n is the ideality factor, k is the Boltzmanns constant, T is the temperature, q is the Coulombs constant, I_L is the light generated current and I_0 is the dark saturation current. As can been seen in eq. 2, the temperature has a major impact on the open-circuit voltage and therefore on the efficiency. In our experiment, V_{oc} decreases from 2.54V at 28C down to 0.98V at 500C which as a consequence reduced the efficiency of the solar cell from 27.4% to 8.3%. The measurement results are presented in Table 1. We observe a slight increase for the short circuit current raising from the 17.28 mA/cm^2 at room temperature to 18.39 mA/cm^2 at 500C as the temperature increases.

IV. CONCLUSION

Using a high temperature photovoltaics experimental setup, we are able to measure the impact of temperature on solar cell performance. As expected, the efficiency of the solar cell significantly decreases as the temperature goes up mainly due to a decrease in open-circuit voltage. However, even at 500C, a solar cell can still generate power for applications at high temperature or under extreme conditions. Future work will consist in measuring the lifetime of the solar cell and

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determining the potential failure mechanisms at high temperature.

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