

REPORT

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**Commissioning of a solar
simulator facility**

FERNANDO A. CASTRO

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Commissioning of a solar simulator facility

Fernando Araujo de Castro
Materials Division

ABSTRACT

A solar simulator testing facility was purchased and tests undertaken to evaluate its reliable functionality. Measurements of a commercial Si solar cell were performed at different sample temperatures. Current-voltage characteristics corresponded well to the expected behaviour. It was found that for more reliable results a heat sink has to be added for better control of device temperature and a standard reference solar cell should be used for light intensity control. The setup will be used to support NPL's activities in photovoltaics, including current projects on nanoscale properties vs. performance of organic and dye sensitized solar cells.

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National Physical Laboratory
Hampton Road, Teddington, Middlesex, TW11 0LW

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Approved on behalf of the Managing Director, NPL
By Robin Hart, Director, *Materials Division*

1. INTRODUCTION

The increase in world energy demand and the concerns about limited fossil fuel reserves and their negative impact on the environment have made the investments in renewable energy increase tremendously over the last decades^{1,2}. Although the solar cell industry has been growing by over 30 % per year, it is still a tiny fraction of the world energy supply (below 1%)³. High costs are the main bottleneck for disseminating the use of photovoltaics. Among several different materials being investigated as alternatives for high cost crystalline silicon cells, organic and dye sensitized cells are expected to have a major impact in terms of production costs reduction^{4,5}. Although their efficiencies are not yet competitive with more traditional cells, the rapid improvement observed in recent years has attracted the interest of many organisations, including BP Solar, G24i, Johnson-Matthey and Corus. Also, several start-ups have received multimillion investments and progress in the field has speeded up in the last couple of years⁶.

Since the industry in this field is not mature, standards are not yet fully defined and NPL has the potential to play an important role. Current research is mainly focused on the development of nanoscale characterization techniques for organic photovoltaics, since these devices are strongly influenced by the morphology of the active layers (with typical thicknesses below 100 nm and component intermixing in the 10-20 nm range). However, for the nanoscale measurements to be meaningful, they need to be correlated with the macroscale properties of the device. Therefore a solar simulator testing unit has been purchased and we describe the setup and testing of this facility herein. This equipment is also envisaged to play an important role in planned future activities in degradation studies of solar cells.

2. TEST FACILITY

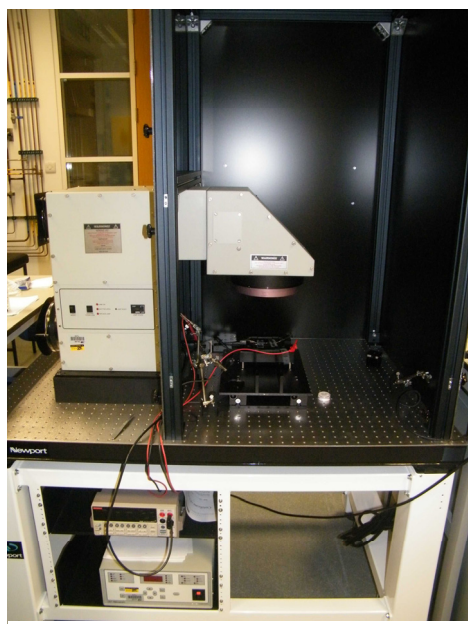


Figure 1: NPL solar simulator setup located in F8 L13.

A commercial (Newport) Oriel Class A solar simulator (model 91195 A) was setup on a vibration-isolated workstation (IsoStation™ Newport). The solar simulator (figure 1) consists of 450 W Xe ozone free lamp, AM1.5G Air Mass filter (10 cm x 10 cm output beam size), cell chucks, Keithley source/meter 2440, thermistor, probing assembly and measurement software. A calibrated (NIST traceable) thermopile detector and an optical power meter were also acquired to check light intensity. A black box was designed and manufactured by the workshop at NPL to surround the solar simulator and avoid user exposure to high UV levels.

The solar simulator delivers uniform ($\pm 2\%$) and stable ($\pm 2\%$) illumination intensity over a 10 cm x 10 cm area (collimation $\pm 4^\circ$) allowing for characterization of solar cells up to this size. The

lamp spectrum is corrected to match the solar spectrum at AM1.5G ($\pm 25\%$) using a set of filters. A thermistor monitors the test cell temperature.

IV test station software

The system operates in a four-wire mode, two wires connected to the anode and two to the cathode, so that voltage and current can be applied/measured separately. As in a four-probe resistance measurement this decouples the effect of wires (contact resistance) reducing measurement errors. The LabView software provided for the test station is simple and efficient. There are few parameters to control: sample area, current limit (compliance), light irradiance, maximum value of reverse bias, number of sweep points and direction of applied bias (forward-to-reverse or reverse-to-forward). Cell temperature and light exposure time are constantly updated on the front screen. The shutter can be manually operated, which allows control over the exposure time. A time delay before the voltage sweep can also be programmed. After running the current-voltage (IV) measurement, the curve is displayed together with fittings to calculate solar cell parameters. Relevant statistical data is calculated and displayed and can be saved together with curve points. Overall it is an excellent platform for testing solar cells, however it does not allow variations on the measurement, such as checking for hysteresis effects, choice of maximum forward bias or IV characteristics in the dark. Additional control and specific measurements can be achieved with this system but require homemade software development.

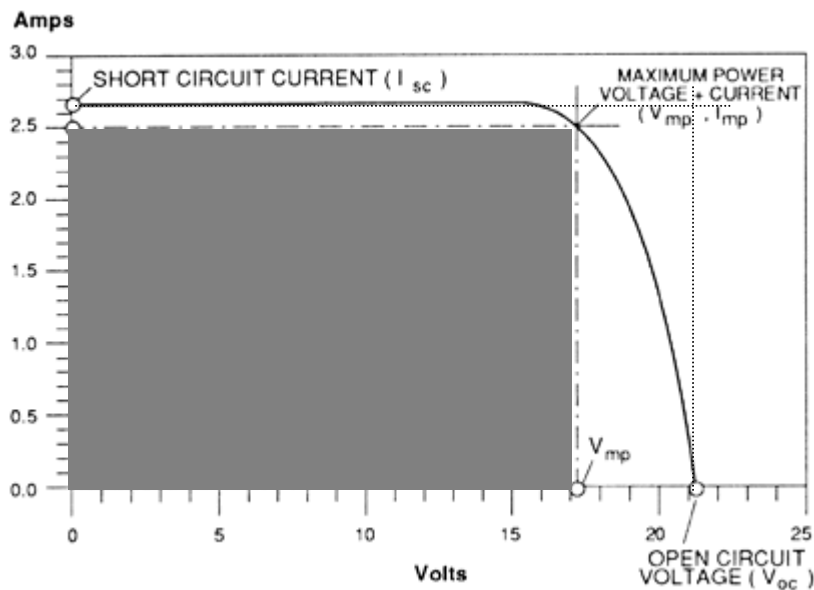


Figure 2: Example of typical IV curve (solid line) from a solar cell under illumination showing important parameters used to characterize device efficiency.

A typical current-voltage curve is shown in figure 2, with some relevant parameters: open circuit voltage (when $I = 0$), the short circuit current (when $V = 0$) and the current (I_{mp}) and voltage (V_{mp}) that defines the maximum power point (maximum electrical power the cell can deliver). The more squared the curve looks, the higher the maximum power point will be. A parameter called Fill Factor (FF) accounts for that and is defined by the ratio between ($V_{mp} \cdot I_{mp}$) and ($V_{oc} \cdot I_{sc}$). The power conversion efficiency (η) is defined as the ratio between the maximum deliverable electrical power ($I_{mp} \cdot V_{mp}$) and the incident light power (P_{in}) and can be calculated directly from the IV curve as:

$$\eta = \frac{I_{mp} \cdot V_{mp}}{P_{in}} = \frac{FF \cdot V_{oc} \cdot I_{sc}}{P_{in}}.$$

3. TEST DETAILS

To check the solar cell simulator, a 3 cm x 1cm commercial polycrystalline solar cell was used. The active surface area was 2.8 cm². Two silver stripes were contacted on the back of the cell and two in front using silver paint. The lamp and electronics were turned on one hour before the measurements. A calibrated thermopile detector was used to check the light intensity at the position of the sample. Full operation of the Xe lamp at nominal 450 W provides 160 mW/cm², which is 60% higher than the standard 1 Sun (100 mW/cm²). Therefore power was reduced to 370 W where light power density reaches 1 Sun. Note that the used thermopile is calibrated for monochromatic light and therefore can induce a small error when measuring broadband white lamp intensity. A calibrated standard reference solar cell will be acquired to provide more accurate numbers.

The sample was placed in the chuck over the thermistor and at the center of the light beam. Tape was used to fix the Ag stripes in order to keep the cell in place. The silver stripes were connected to the Keithley source/meter. The black box was closed leaving the cell in the dark. Room temperature was 22.5 °C, measured by the thermistor in contact with the sample.

The cell was heated by exposing it to light until reaching 40 °C. Then, IV measurements were taken at different sample temperatures as the cell returned to 22.5 °C. Note that the temperature values shown in this report were measured immediately before starting the IV measurement, which took typically 6-7 seconds. Cell temperature increased during the measurement (up to 1 °C), in particular at lower temperatures.

The calculations of parameters made by the software were checked and proved to be correct.

4. RESULTS

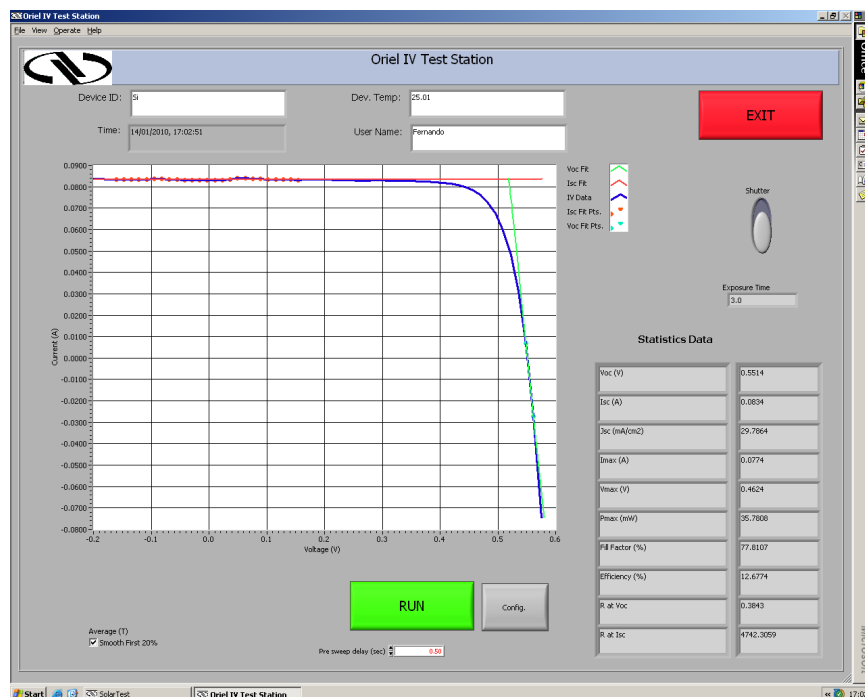


Figure 3: Screen shot of the software after one measurement at 25 °C.

Figure 3 shows a screen shot of the software after one measurement at 25°C. Figure 4 shows several curves of the same cell measured at different temperatures. The Si solar cells behave as expected⁷, with a linear decrease ($2.3 \pm 0.1 \text{ mV} / ^\circ\text{C}$) of the V_{oc} with increasing temperature (figure 5).

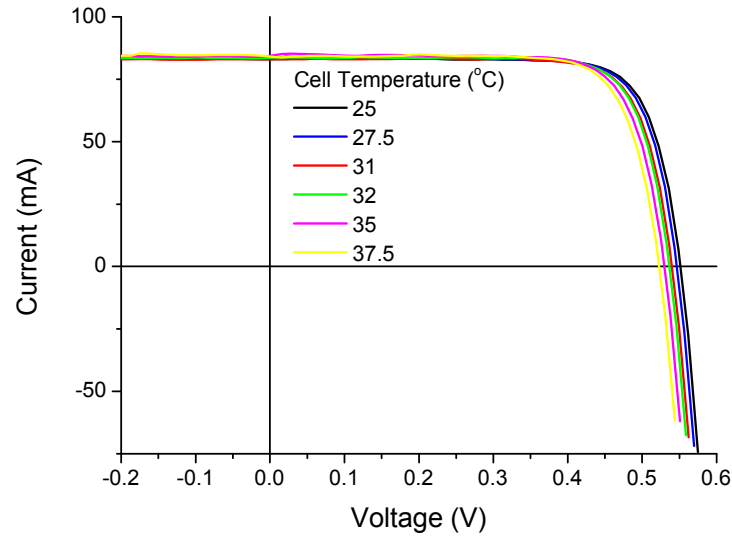


Figure 4: Current voltage curves of a Si solar cell at different temperatures.

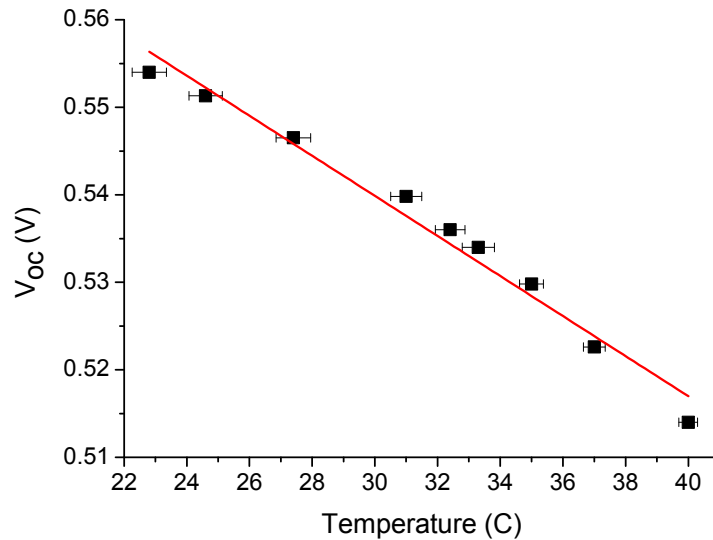


Figure 5: Measured open circuit (V_{oc}) dependence on temperature for a Si solar cell.

Measurements of the same cell at 25°C were not completely reproducible, particularly due to the lack of proper temperature control. However, variations were felt mainly on the V_{oc} and on the estimated values for series and shunt resistances. A controllable temperature stage will be ordered to increase repeatability of the system.

5. CONCLUSION

A solar cell simulator has been set up, tests have been conducted and its functionality has been demonstrated. A heat sink and a reference cell for light intensity calibration will be added to the system to increase reliability. The technique will be used to characterize the efficiency of low cost organic and dye sensitized solar cells in order to correlate this with their nanoscale characterization.

6. REFERENCES

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