I-V MEASUREMENTS OF DYE-SENSITIZED SOLAR CELLS (DSSC) – EFFECTS OF SCAN RATE AND SCAN DIRECTION

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2

ABSTRACT: In the work results of both light as well dark I-V measurements performed in *SolarLab* of Wroclaw University of Technology of dye-sensitized solar cells manufactured by ML System Ltd. company are presented. The strong impact of scan rate and direction on the shape of I-V curves and resulting cell electrical parameters is pointed out.

Keywords: Dye-sensitized solar cells characterisation

1 INTRODUCTION

Dye-sensitized solar cells (DSSC) are well known for the problems with basic I-V measurements due to their very high internal capacitance resulting in a very slow response of these devices both to changes of both light intensity as well as bias voltage. Hence the time required to properly scan full I-V curve is usually incomparably higher then it is the case for other solar cells as silicon or nonorganic thin-film. This causes need to develop a well described, clear procedures how DSSCs are to be measured in order to characterize their basic electrical parameters.

At the end of the last year ML System Ltd. Company begun a small scale production of DSSCs, mainly for building integrated PV (BIPV) applications. Both on the research stage of their work as well as later, when moving up to commercialization, they needed well described, reliable and routine procedures to characterize their samples and products. In the frame of the common project with ML System, SolarLab is working on developing of I-V measurement procedures for DSSC characterization that can be directly implemented by ML System.

2 APPROACH AND RESULTS

Measurements were performed under Yamashito Denso AAA class steady light solar simulator using I-V system based on Keithley 2401 Sourcemeter. The system was specially developed by *PV Test Solutions* company (*www.pvmeasurement.com*) for organic and dye-sensitized solar cell measurements. It enables multiple repeating of I-V scans, changing direction of scan as well as control of the scan rate in a very wide range (from seconds to minutes).

Example results of measured I-V curves presented in Fig. 1 show effects related to scan rate and/or direction. Scan rate has been controlled by either changing time interval between bias steps or/and by changing bias voltage step. The plots on Fig. 1 show also effect of scan direction, which can be either from reverse to forward bias ($I_{SC} \rightarrow V_{OC}$) or opposite, i.e. from forward to reverse bias ($V_{OC} \rightarrow I_{SC}$), respectively. As can be seen in case when the I-V scan is suitably slow direction of the scan does not affect the shape of measured I-V curve.

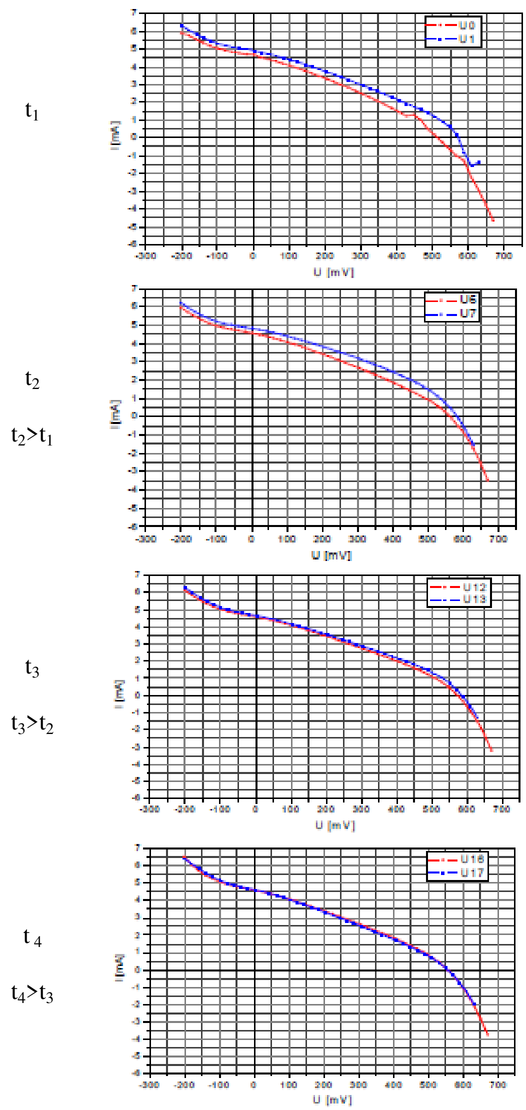
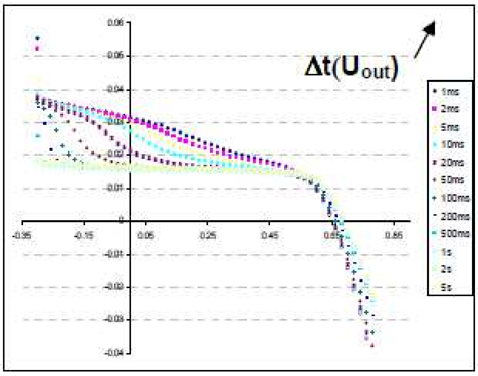


Figure 1 Effect of scan time ($t_1 < t_2 < t_3 < t_4$) and scan direction on the shape of measured I-V curve;

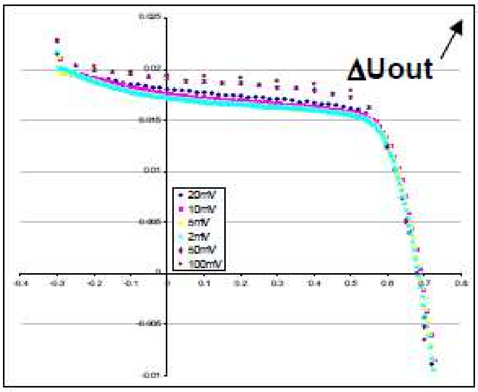
red color means curves measured from reverse to *forward bias ($I_{SC} \rightarrow V_{OC}$) whereas curves plotted as blue mean opposite direction of I-V scan, i.e. from forward to reverse bias ($V_{OC} \rightarrow I_{SC}$);*

This part of work allowed to select suitable scan parameters for tested DSSC structures.

Fig. 2 shows separately effects of time delay before change of bias $\Delta t(U_{OUT})$ (Fig. 2 a) and bias step ΔU_{OUT} (Fig. 2 b) on the shape of resulting I-V curve. In both cases suitably slow scan rate, i.e. either large Δt or small ΔU, allow to achieve correct I-V curve with repeatable shape. This is well illustrated in Fig.3 for two cell parameters - I_{SC} and V_{OC} - where it can be seen that at suitably slow scan rate measured values of cell parameters do not depend on scan direction. Unfortunately, slow scan rate needed to obtain correct I-V curve means long measurement time which causes undesired and hardly controllable increase of cell temperature.



a)



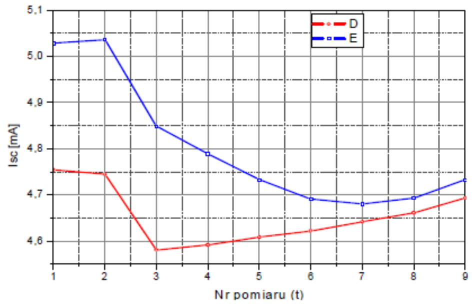
b)

Figure 2 Distortion of the I-V curves caused by either: a) too fast bias changes (insert table shows time delay values Δt after change of bias voltage by ΔU_{OUT} step) or

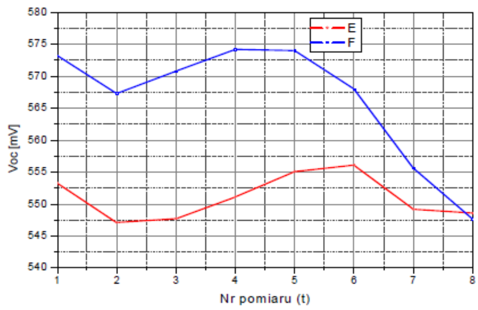
b) too large bias steps ΔU_{OUT} (insert table shows values of bias voltage step ΔU_{OUT});

scans were performed in direction from reverse to forward bias ($I_{SC} \rightarrow V_{OC}$);

Usually, in standard I-V test systems measurement starts once the shutter is open and stable illumination of the whole cell area is ensured. In case of dye-sensitized solar cells such approach may not be correct as the cell needs significant time to respond to abrupt change of irradiance conditions. This is illustrated in Fig. 4 presenting strong dependence of the open-circuit voltage V_{OC} of dye solar cell on the time delay after opening the solar simulator shutter, i.e after change of irradiance conditions. In case when the shutter was not closed after each I-V measurement (Fig. 4 a) the V_{OC} depended only on scan rate – the slower was scan the higher was V_{OC}.



a)



b)

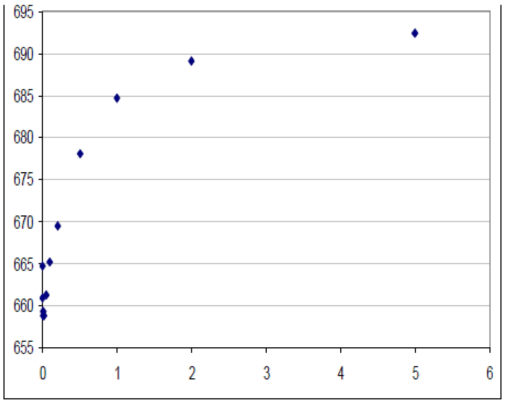
Figure 3 Effect of I-V scan rate and direction on the measured cell parameters: a) I_{SC} and b) V_{OC}; at suitably slow scan rate measured values of cell parameters do not depend on scan direction

larger number of scan means lower scan rate;

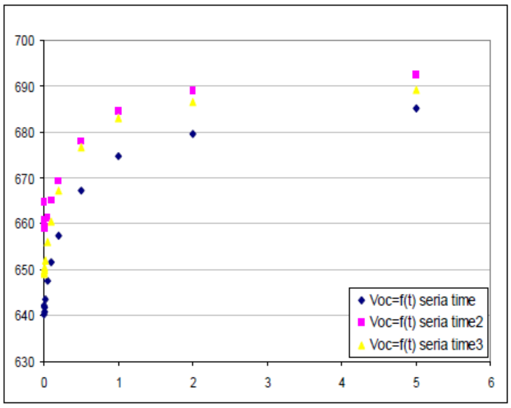
red color means curves measured from reverse to forward bias ($I_{SC} \rightarrow V_{OC}$) whereas curves plotted as blue mean opposite direction of I-V scan, i.e. from forward to reverse bias ($V_{OC} \rightarrow I_{SC}$);

Fig. 4 b) shows situation when the shutter was closed each time after the I-V scan was completed which is most commonly applied setting for solar cell measurements. Measurements were repeated several times with systematically increased time interval between opening the shutter and start of measurement (time<time2<time3).

Proper setting of I-V scan parameters depends also on thickness of the active cell layer, the thicker is electrolyte layer the lower I-V scan rate should be applied. This is illustrated in Fig. 5 where results of "dark" I-V curves measurements are presented for two dye-sensitized solar cell samples with different thickness of absorber layers.



a) shutter open between I-V scans



b) shutter closed after each I-V scan

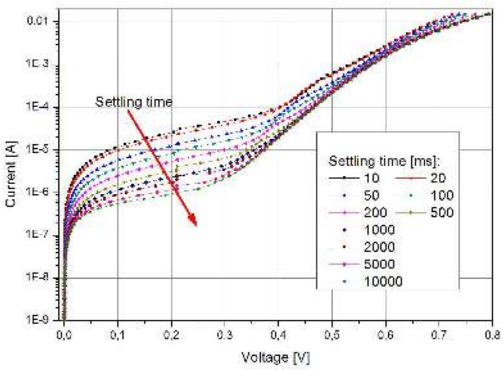
time delay after opening the shutter:
time < time2 <time3

Figure 4 Effect of I-V scan settings on the value of measured dye-cell open-circuit voltage, V_{OC}:

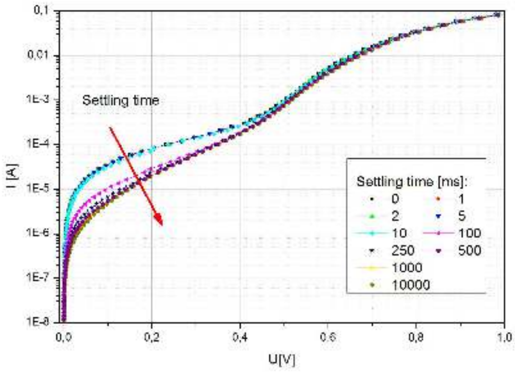
a) shutter remains open between consecutive I-V scans and

b) shutter is closed after each I-V scan and after opening there is time delay before start of the next measurement (time<time2<time3)

larger number of scan means lower scan rate;



a) thicker absorber layer



b) thinner absorber layer

Figure 5 Results of I-V scan rate on dark I-V curves for two cells with different thickenss of active layer; as can be seen for the cell cell with thicker alectrolyte layer (Fig. 5 a) measurement should be much slower;

arrows indicate decrease of scan rate

3 SUMMARY AN CONCLUSIONS

Example results show difficulties in routine characterisation of dye-sensitized solar cells. In order to acquire correct I-V curve suitable test settings like scan rate and scan direction must be carefully predetermined. The appropriate time delay after opening the shutter and before starting measurement is needed as well.

Measurement setting may additionally depend on the thickness of cell's absorber layer. Generally, the thicker is the layer the slower scan rate should be applied.

Another problem caused by slow measurement may be uncontrollable increase of cell temperature due to long exposure to high intensity irradiation.

5 ACKNOWLEDGEMENTS

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