Characterization of Solar Cells by Means of Improved Frequency Resolved Techniques - CIMPS

C. A. Schiller, M. Multerer, W. Strunz

Zahner-elektrik GmbH & Co. KG

Introduction

The conversion of light- into electrical energy is one of the most promising task in the field of non polluting energy production. For this type of energy conversion, silicon based solar cells (SC) are well established in the market since many years. Besides this inorganic type of photovoltaic device, organic- (OSC) as well as dye-sensitized solar cells (DSSC) are currently subject of intense research in the field of renewable energy sources.

In standard electrical characterization techniques of SC devices, the DC current-voltage curves are monitored under different incident light intensities. DC techniques however do not provide any information about the internal dynamics of a SC. Therefore, additional information can only be obtained using transient- or frequency dependent techniques. For the latter technique, a small amplitude perturbation of varying frequency of voltage, current or light intensity is used. Analysis of the frequency dependent spectra delivers information of the different time constants of the internal processes.

Optimizing SC - IMVS and IMPS

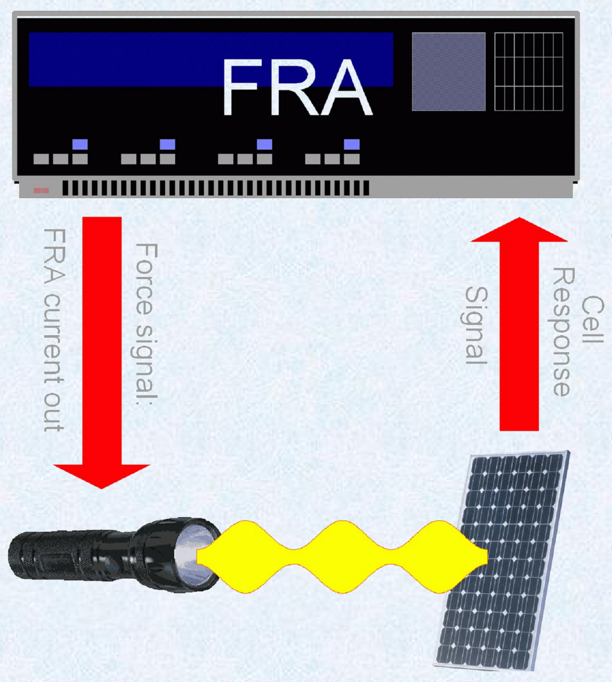
Concerning the mechanisms in a DSSC, the electron-recombination and the electron-diffusion process are assumed to determine the efficiency. Two particular frequency domain characterization methods are suited to study the dynamic behavior of SC devices.

IMVS (**I**ntensity **M**odulated photo-**V**oltage **S**pectroscopy) is the measurement of the transfer function ($H_{UP}(\omega)$) between the modulated light intensity and the AC voltage response, most often at **O**pen **C**ircuit **V**oltage (OCV). Under this condition, the electron recombination and therefore the corresponding time constant τ_R dominates.

IMPS (Intensity **M**odulated **P**hotocurrent **S**pectroscopy) is the measurement of the transfer function ($H_{IP}(\omega)$) between the modulated light intensity and generated AC current response at short-circuit. Under this condition, the electron diffusion and the corresponding time constant τ_C dominates.

Due to their flexibility, **L**ight **E**mitting **D**iodes (LED) are used for illumination. In traditional realizations of these techniques, the current through the LED is introduced into the transfer function as a substitute for the light intensity and therefore the cell current (or voltage) is correlated with the LED current to calculate the photo-electrochemical transfer function H(ω). **However,** the actual light intensity and modulation are uncertain. Since the efficiency determining rate constants for recombination and diffusion can not be measured simultaneously, their ratio may be uncertain, too.

$$H_{UP}(\omega) = \frac{Cell\ voltage^*}{LED\ current^*} \qquad H_{IP}(\omega) = \frac{Cell\ current^*}{LED\ current^*}$$



The current output of a Frequency Response Analyzer (FRA) supplies a LED light source with modulated current. Therefore, the basic light intensity as well as the superimposed frequency modulated perturbation are functions of the current through the LED and the interrelation must be calibrated anyway.
The electrical response of the SC then is analyzed by a FRA.

The obvious drawbacks of IMPS and IMVS however are the introduction of the LED current as a substitute for the actual (frequency dependent) light intensity into the transfer function and the absence of a direct "light-proportional" feedback into the perturbation circuitry.

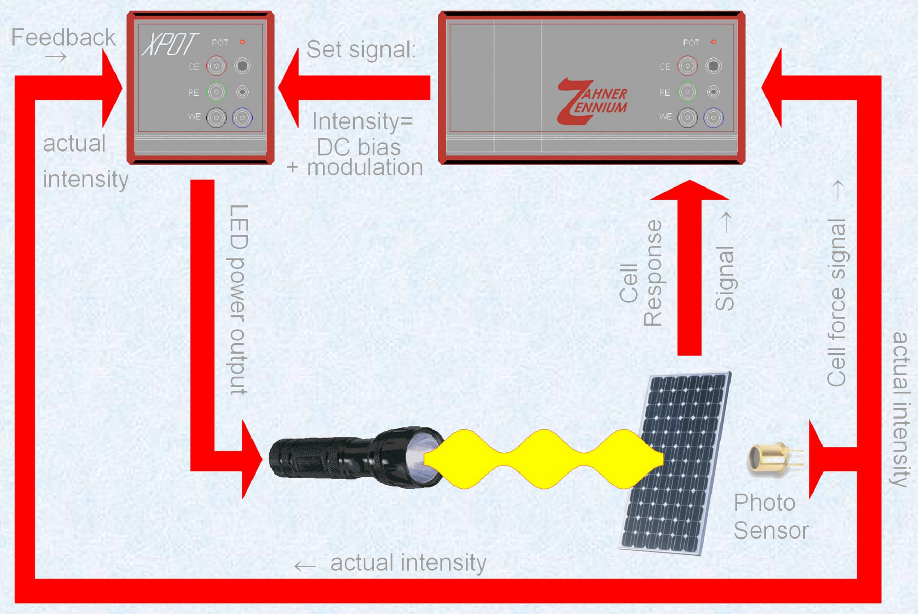
Since IMPS- and IMVS spectra must be recorded subsequently, drift and degradation of the light source may lead to experimental conditions, where the SC is no longer in a comparable stationary state.
This may falsify the evaluation of the ratio of the relevant time constants.

Considering DSSC, the characteristic time constants τ_C and τ_R are both depending strongly on the illumination intensity P. The efficiency determining quotient τ_C / τ_R must get wrong, if the actual intensity changes between both measurements due to LED drift or degradation.
Considering OSC: the high frequency decay of the photo-current response characteristic for the diffusion length and time constants appears typically around some 10-100 KHz. In this frequency range the phase shift between LED current and intensity can not be neglected.

In DSSC and OSC research, a joint modeling of EIS-, photo-current and photo-voltage spectra is desirable. This must fail, if LED frequency response, scale factor uncertainties and drift between the measurements prevent comparability.

Controlled Dynamic Technique – CIMPS

To overcome these drawbacks, the **C**ontrolled **I**ntensity **M**odulated **P**hoto **S**pectroscopy (CIMPS) technique was developed. In CIMPS, the measured intensity is used as force signal information. The actual intensity is controlled with a photo-sensor at the site of the cell and stabilized by means of a feedback loop.
Therefore, the calibrated light intensity itself can be introduced into the equation for the evaluation of the corresponding transfer function.

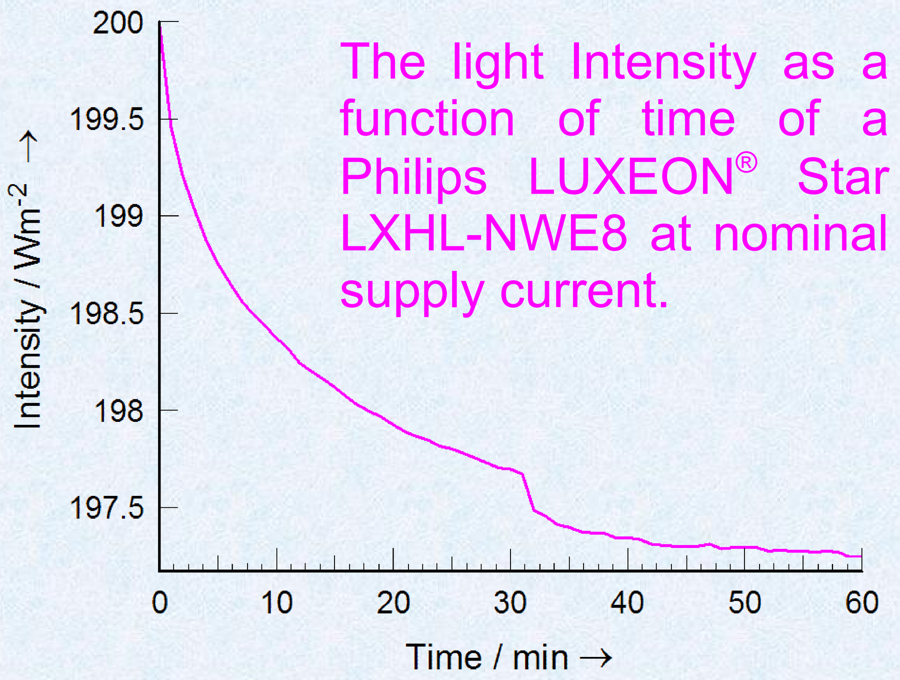


$$H_{UP}(\omega) = \frac{Cell\ voltage^*}{Intensity^*}$$

$$H_{IP}(\omega) = \frac{Cell\ current^*}{Intensity^*}$$

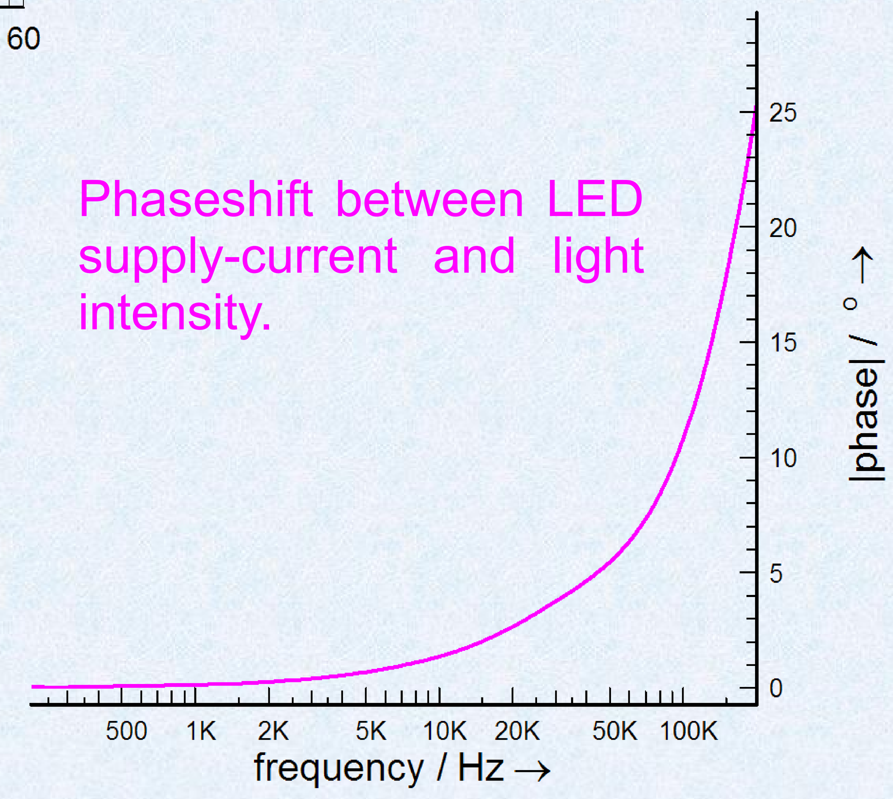
Experimental

Reference measurements on a typical LED



The light intensity is a function of time and degrades non-linearly within the observed time interval

Concerning the frequency range above ~ 500 Hz, the relationship between LED supply current and the light output is not independent from frequency.
The frequency response of the LED superimposes the OSC characteristic.



Conclusion

- CIMPS can produce accurate relationships between EIS-, IMPS-, IMVS-data and illumination intensity.
- CIMPS can produce comparable EIS-, IMPS- and IMVS-results measured at the same state of the systems under test.
- CIMPS enables a reliable determination of the efficiency determining quotient τ_C / τ_R