

# ModuLab<sup>®</sup> XM PhotoEchem

## Technical Note

### ModuLab<sup>®</sup> XM PhotoEchem IPCE (Incident Photon to Current Conversion Efficiency) Module - IPCE Measurement Techniques

#### Introduction

Incident Photon to Current conversion Efficiency (IPCE) measurements are an important tool in the understanding of solar cells. Such measurements are used to correlate the discrete efficiency of the cell as a function of wavelength with the Short Circuit current measurements of cells under one sun illumination. Furthermore, since the measurements are steady state, they can be used to determine other important properties of the cell such as the diffusion length.

This technical note highlights some of the features of the ModuLab XM IPCE module and compares it with traditional IPCE measurement instrumentation.

#### Traditional IPCE measurement systems

Most IPCE instruments use a broadband light source such as a Xenon or Halogen lamp that is coupled to a monochromator to produce a near monochromatic beam. The beam is then passed through an optical light chopper. This signal stimulates the cells and the response of the cell is measured using a phase sensitive lock-in amplifier (LIA). It should be noted that our Signal Recovery lock-in amplifier systems are often the systems of choice for high end QE measurement systems for testing Silicon Cells. A set-up with dual phase detection LIA is presented in Figure 1: Typical Setup for IPCE system

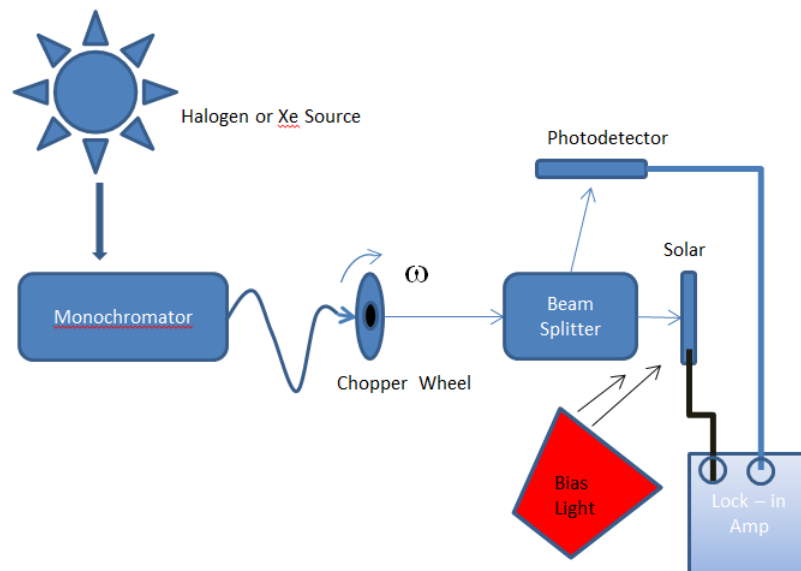


Figure 1: Typical Setup for IPCE system

The following measurement principles apply:

- A broadband source such as a Xe or Halogen lamp is focused into a Monochromator to produce a near monochromatic signal.
- The monochromatic signal is passed through an optical chopper with rotation speed in the order of 50-100 Hz
- The chopped light may or may not pass through a reference beam splitter. In essence, the beam splitter produces two identical light beams – one to act as the reference (photons in) signal and one to stimulate the cell under test (electrons out).
- A white bias light illuminates the cell. This is an important feature especially if the cell's QE response is a non-linear with the light intensity.
- The reference and measurement signals are detected and analysed using a Lock-In amplifier.

While this measurement technique is ideal for Silicon and many thin film technologies, there are issues using this technique with the third generation cells. The issues include:

- The RC constants of the device under test are usually slower than the rotation rate of the choppers. Therefore special optical choppers are required that can operate down to 1Hz
- Lock-In amplifiers use a technique called AC coupling to remove DC signals. This technique works well above 20 Hz BUT must be turned off below this frequency to avoid filtering the response from the cell. This is important if white light bias is used. This may result in very noisy data.
- If the Lock-In uses pre-amplifiers for low frequency bias rejection (<20 Hz), these are almost always manual and cannot auto-range. This makes measurements of organic cells under white bias quite difficult for novice users.

Therefore, in order to address some of these issues, we have developed the IPCE technique making use of our auto-ranging Frequency Response Analyzers.

## **Solartron Measurement Technique**

At the heart of the Solartron system is the Frequency Response Analyzer (FRA). It has the ability to apply and measure sinusoidal signals whilst simultaneously rejecting time invariant signals. The FRA has a number of advantages over traditional, Lock In Amplifier / Light Chopper based techniques including:

- Bias rejection capability makes the FRA ideally suited to measure the IPCE of solar cells under white light bias.
- Auto-ranging of measured current and voltage – no need for end user to optimise measurements manually.
- Dual – channel analysis allows simultaneous measurement of photon flux and current – this eliminates the possibility of errors due to lamp degradation between experiments.

Many systems do not include white bias measurement capability. For some cells such as Silicon cells, this is acceptable. However, for many cells such as the organic cells, the IPCE measurement often shows intensity dependence. To illustrate this point, the IPCE/QE response of an Ionic liquid based cell measured as a function of different white light bias intensities is presented in Figure 2: QE as a response of WHITE BIAS INTENSITY

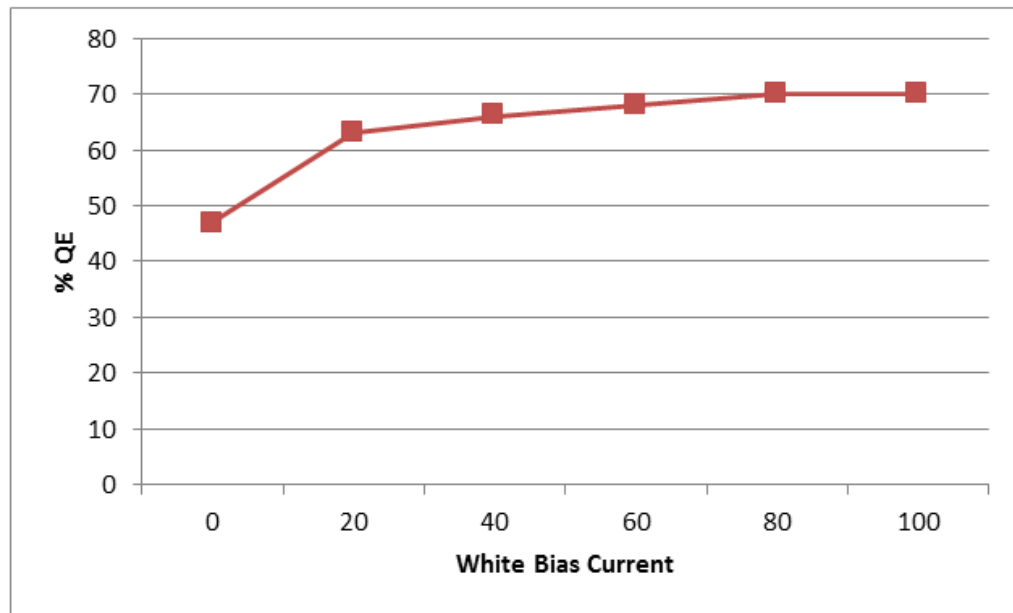


Figure 2: QE as a response of WHITE BIAS INTENSITY

In this experiment, the intensity of the white bias was changed with the use of Neutral Density filters. This produced a steady state current on the cell. The IPCE response of the cell was recorded at the peak efficiency wavelength (520 nm) as a function of steady state current (White Bias Intensity). Clearly the results indicate that the IPCE/QE response of the cell is not independent of white bias intensity until the system is illuminated with light or produce a steady state current in the order of 80  $\mu\text{A}$ . Therefore it is important to determine the intensities at which the IPCE response is independent of white light bias. In this instance,  $I_{sc} > 80 \mu\text{A}$ .

A comparison of the QE response of an ionic cell as a function of wavelength is shown in Figure 3: QE response of Ionic Liquid cell WITHOUT (RED) and WITH (BLUE) White Light Bias.

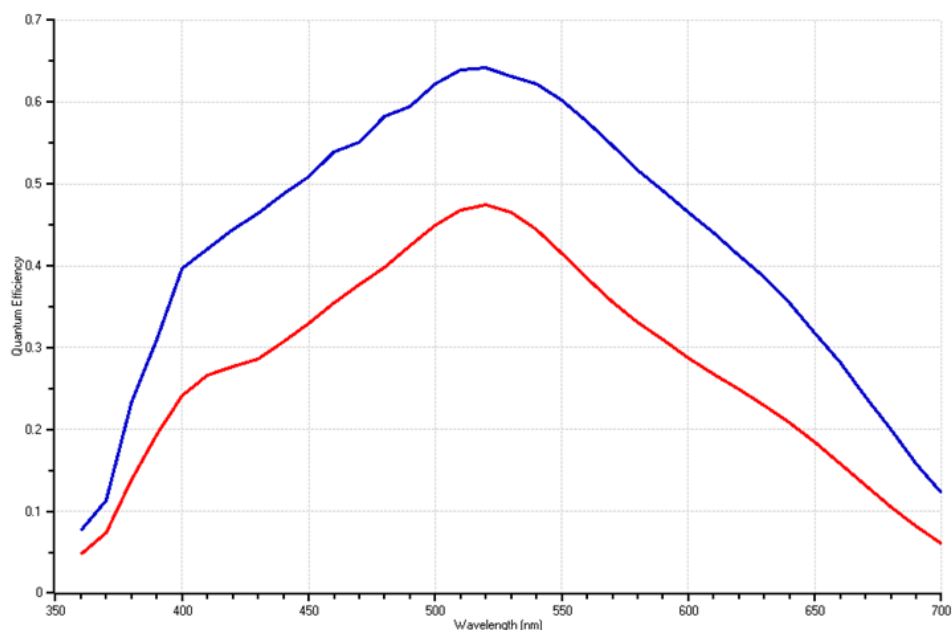


Figure 3: QE response of Ionic Liquid cell WITHOUT (RED) and WITH (BLUE) White Light Bias

## Calculation of Short Circuit Current

The data from the IPCE measurements can be used to estimate the short circuit current at AM1.5 light according to:

$$I_{sc} = \int_{\lambda_1}^{\lambda_n} IPCE (\%) \cdot n_p \cdot e \cdot d\lambda$$

Where,

$I_{sc}$  is the short circuit current in  $\text{cm}^{-2}$

IPCE is in percent

$n_p$  is the number of photons in the wavelength interval  $d$

$e$  is the charge on an electron

For the cell used in this experiment, the Short circuit current was estimated as  $7.8 \text{ mA cm}^{-2}$ . The quoted value from the manufacturer using a AAA solar simulator was  $7 \text{ mA cm}^{-2}$  and therefore good agreement exists between the two techniques.

### Summary

The addition of the IPCE module the ModuLab XM PhotoEchem system allows end user to conveniently determine the wavelength dependence of the cell and correlate data with Solar Simulator measurements.

### References

- 1) Dye Sensitized Solar Cells, EPFL, Lausanne, 2010

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