Setup development for spectral response measurement on multijunction solar cells

Conference Paper · September 2010

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SETUP DEVELOPMENT FOR SPECTRAL RESPONSE MEASUREMENT ON MULTIJUNCTION SOLAR CELLS

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ABSTRACT: This work presents the development of a facility to measure spectral response on III-V solar cells for space applications. This development was performed in the frame of a cooperation agreement between the Argentine National Atomic Energy Commission (CNEA) and the Argentine National Commission for Space Activities (CONAE), which is addressed in these first stages to SAOCOM and SAC-D satellites. The setup is particularly oriented to measure triple junction (TJ) InGaP/GaAs/Ge cells, the same type that will be used in the next CONAE satellites solar arrays, but it can be utilized to measure other devices. The equipment is based on narrowband interference filters and two dichroic lamps as bias light source to select the subcell to be measured, whereas a simple incandescent lamp is used to generate the monochromatic light beam. Signal is measured on an appropriate resistance inserted in a serial circuit using a lock-in amplifier. Measurement is fully automated, which allows operator independent results. Preliminary results show the good performance of this setup.

Keywords: Spectral Response, Multijunction Solar Cell, Space Cells

1 INTRODUCTION

The Solar Energy Group (GES) of the Argentine National Atomic Energy Commission (CNEA) performs R&D activities related to photovoltaic solar energy conversion for space and terrestrial applications. Different contracts subscribed between CNEA and the National Commission for Space Activities (CONAE) allowed the development of photovoltaic devices for satellites. Activities in this field have included: development of computational codes for solar array design and performance prediction, test of solar devices in Argentine satellites, on-ground radiation damage experiments, and development of characterisation and device simulation techniques. Some related developments can be seen in selected previous contributions [1-7]. In this report, the design, final development and first results of an equipment to measure spectral response on multijunction solar cells is presented.

Home made equipment, initially designed to measure the spectral response of silicon solar cells, based on narrow band optical filters and a lock-in amplifier, was modified in order to measure III-V multijuntion solar cells of monolithic structure. The complexity of the measurement and possible artifacts are extensively described in the work of Meusel et al. [8].

The spectral response measurement requires measurements of a calibrated reference cell and the cell under test. The spectral response is then calculated by:

$$SR^{cel}(\lambda) = \frac{A^{ref}}{A^{cel}} \cdot \frac{V^{cel}(\lambda)}{V^{ref}(\lambda)} \cdot SR^{ref}(\lambda) \qquad (1)$$

where V^{cel} y V^{ref} are the lock-in voltage readings (proportional to the short-circuit current of the cell and the reference respectively), A^{cel} y A^{ref} are the areas of the cell and reference respectively and REref is the absolute spectral response of the reference cell.

The equation (1) is then consecutively applied to measure the subcells of a multijunction solar cell, if this is the device type to be measured.

Modifications in the optical setup and improvements in the electrical circuitry have enable to the equipment to perform spectral response measurements on III-V based solar cells of quite different areas.

As it is known, the trick to measure the spectral response of each subcell in a monolithic structure is based on finding both, the appropriate spectral content of the bias light that makes the corresponding subcell to limit the current of the entire cell, and the external bias voltage to ensure the short-circuit condition of the subcell to be measured, being the last condition more relevant to the case of Ge subcell.

Thus, the main aspect of the setup modification was to provide the equipment with the ability to bring three appropriate spectra for the bias light in order to measure each subcell of one triple junction (TJ) InGaP/GaAs/Ge solar cell.

Incidentally, a second filter wheel was added to extend the range of the measure from 1100nm to 1900nm (the original range conceived for silicon cells was from 300nm to 1100nm). Finally, the filter wheels were automated using two stepper motors controlled by a PC, and especially developed software performs the measure automatically.

2 OPTICAL SETUP

2.1 Monochromatic light

The monochromatic light is generated by a single 250W tungsten halogen lamp fed by a stabilized DC power source. To fit out an appropriate light beam, a converging quartz lens and narrow band interference filters are aligned with the lamp (fig. 1). The filters, of

2x2 inches size, are mounted in a rotating wheel. Their bandwidth is typically 10nm-15nm and their central wavelength are separated by 50nm, covering the silicon response range of 300nm-1100nm.

To modulate the light beam, a rotating disc with slots (chopper) is used, and it is situated in the lower focus of the converging lens. One important aspect of the setup is the size ratio between the image of the lamp filament formed by the lens at the chopper plane and the size of the slot of the chopper, because the resulting monochromatic light waveform is not square, but triangular. This case is better, considering the minor harmonic content of the signal and their subsequence measurement [9].

To extend the wavelength range of the equipment, a second rotating wheel was introduced, covering in this way the entire spectrum in which a triple junction solar cell is sensitive. The filters are 1 inch circular and range from 1150nm to 1900nm.

At last, the necessary spatial uniformity of the monochromatic light on the sample plane is below ±2.5%, according to the ASTM standard requirement [10].

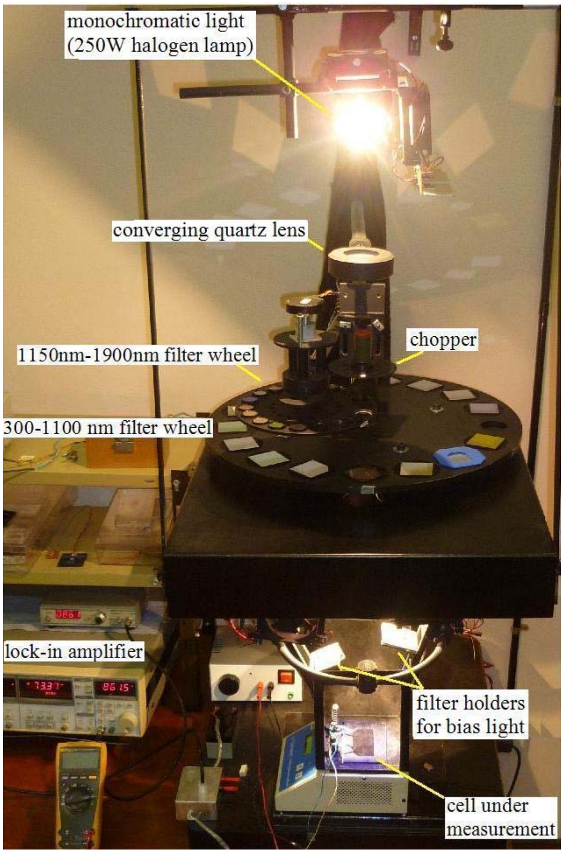

Figure 1: General view of the measurement equipment. The monochromatic light is aligned with all pieces: the converging lens, the chopper disc, the first and second filter wheels and, finally, the sample on the thermostated base plate.

2.2 Bias light

The main idea for the spectra and the intensity of the bias light was to put the cell under measure in the nearest real work conditions. This was the starting point of the development.

Bias light is produced by two 250W dichroic lamps, where, each one is fed with stabilized DC power source and has a filter holder allowing the use of different shortpass and longpass filters. The combination of the lamps spectra and the appropriate filter determines the subcell to limit the TJ current. In all cases, the short-circuit current generated is at a similar level of the operating short-circuit current under AM0 spectrum.

To generate the suitable spectra for the bias light, several computer simulations were done, combining the spectrum of the dichroic lamps (measured in the lab) with the transmittance of several commercial bandpass filters.

Bias spectra used to allow cell selection were previously published in [5], and calculations to determine cell selection were based on the spectral response published in [11]. Table I shows a summary of the relative short-circuit currents generated by each subcell when a selector spectrum is used and compared with the relative theoretical values generated using the AM0 spectrum.

The spatial uniformity of the combined light sources at the sample plane stands below ±10% according to the standard requirement mentioned in reference [10]. Finally, ambient light and possible scattering of the beam arriving to the chopper disc were separated using suitable optic confiners.

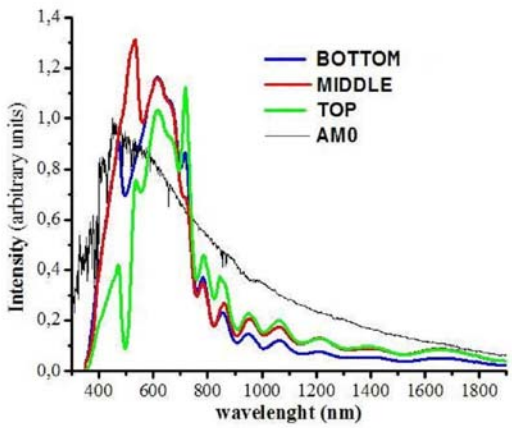

Figure 2: The three bias light spectra used in the subcell selection in an ATJ cell. The reference indicates the subcell that limits the ATJ short-circuit current. The graphs are normalized and compared with the AM0 spectrum.

Table I: Relative short-circuit current generated by each subcell of an ATJ for the three spectra (Sp) showed in the Figure 2 and the AM0 (a typical spectral response was used).

	Sp(AM0)	Sp(Top)	Sp(Mid)	Sp(Bot)
Jsc(Top cell)	1	1	1.33	1.63
Jsc(Middle cell)	1.2	1.51	1	1.49
Jsc(Bottom cell)	2	1.4	1.12	1

3 ELECTRICAL SETUP

The external circuit is composed by a stable resistor and a home made variable voltage source. Their combination allows the subcell to be measured to achieve the short-circuit condition.

The current photogenerated by the chopped light is sensed through the resistor previously mentioned, and pre-amplified by a very low noise operational amplifier stage followed by a low pass filter. The output of this stage is connected to the lock-in amplifier input, giving it a higher dynamic reserve. Tests performed to the entire equipment have shown that the sensitivity of the system is under the 10nA.

The frequency of the chopper light was selected as compromise solution, after doing several tests, considering aspects like optical noise sources (due primary to the ambient), low frequency noise and wideband noise.

4 AUTOMATION SETUP

The filters wheels are moved by two stepper motors, which are commanded by the developed software using the parallel port of the PC. A transistorized driver was made to excite the motors. The software also communicates with the lock-in amplifier throughout the RS-232 interface and reads the voltage values from the amplifier. To improve the reading of the values, when the signal voltage is small enough to produce a fluctuation in the measurement, an appropriated averaging algorithm was introduced. In this way, each measurement from 300nm to 1900nm is performed reliably and automatically.

Finally, the application software, based on a Visual Basic development, shows the complete spectral response of each subcell on the screen, after taking a complete reading of the cell and reference values.

All the measurement procedure, except the bias light filters change, is made automatically.

5 FIRST MEASUREMENTS AND RESULTS

All the measurements are performed at controlled temperature (25ºC), using an appropriate commercial equipment. For the measurement of the Ge subcell, a detailed DC sweep of the external bias voltage was required to maximise the subcell response and, at the same time, to minimise it in a wavelength out of the subcell sensitivity range. Two complete TJ cell calibration set were done using a primary calibrated TJ cell provided by Emcore Corp. The first cell (called Ref1) is a flight qualified cell and the second one (Ref2) is a non flight (of low electrical characteristic) cell. The results of several measurements for the InGaP/AsGa/Ge subcells of these cells are shown in Figure 3.

As a way to estimate the error in the calibration of secondary cells (the exact error value can not be calculated because we do not know the error in the calibration of the Emcore primary reference cell), the triple of the statistical deviation calculated from several measurements was assumed as error. The results showed that in the central zone, where each subcell is sensitive, the error varies from 1% to 3%, reaching about 10% near the cut-off wavelength of each subcell.

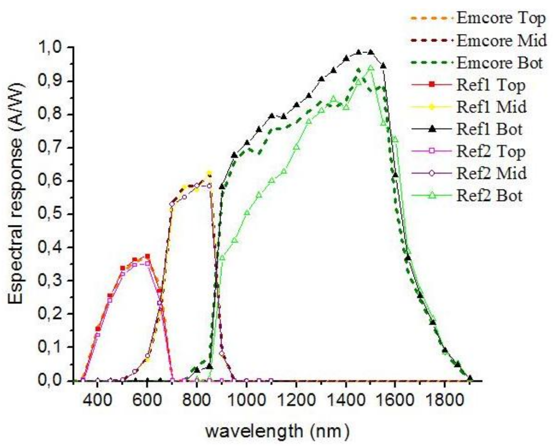

Figure 3: Spectral response measurements of two secondary cells using as reference a calibrated ATJ cell provided by Emcore Corp (also shown). For the bottom cell, external bias voltage was needed.

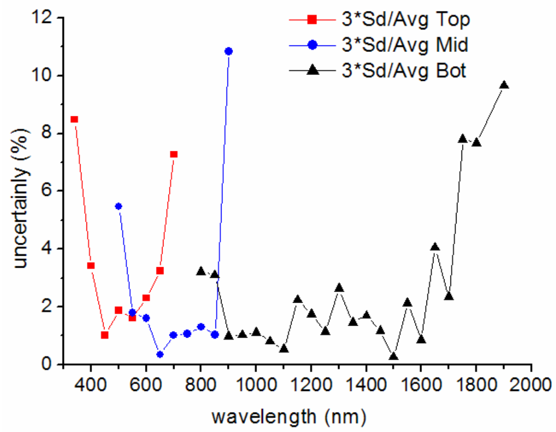

Figure 4: Spectral response error estimated using several measurements.

In order to measure the spectral response of very small area cells (1mm square InGaP cell, provided by the IES-UPM, under a scientific cooperation framework) ,the setup was adapted to provide a more powerful monochromatic light to obtain a strong enough signal. To achieve this, a second quartz converging lens was introduced near the sample, giving as result, near its focus, a 10x monochromatic light, without losing the uniformity nearby the sample. A similar area reference silicon cell was also previously calibrated and used to perform the measurement. Obviously, this reference allows the measure in the 300nm-1100nm range. The measured spectral response of two InGaP cells, with and without anti-reflective treatment, is shown in fig. 5.

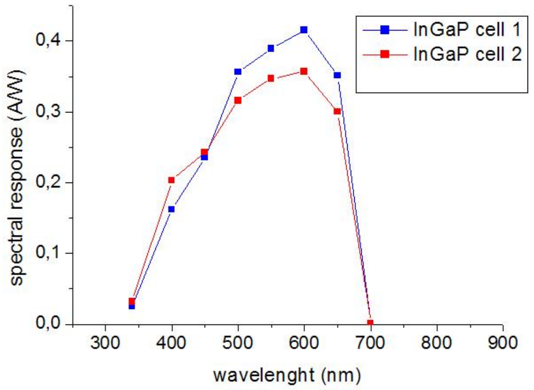

Figure 5: Spectral response of 1x1mm InGaP cell using 10x concentrated monochromatic light.

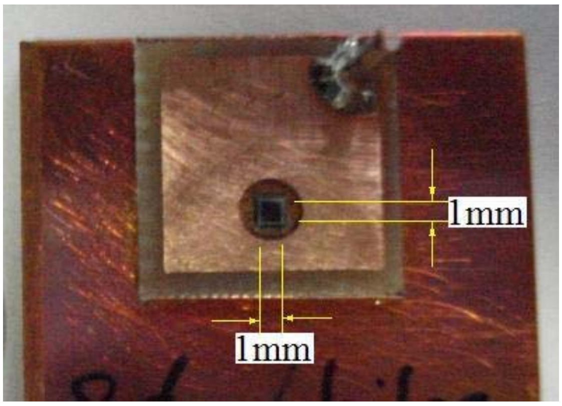

Figure 6: 1x1mm InGaP solar cell, provided by the IES-UPM.

6 CONCLUSIONS

The modifications to the original equipment, previously developed to measure the spectral response of silicon solar cells, had finalized. This setup has enabled to successfully measure the spectral response of III-V based multijunction solar cells. The main aspect of this work was the achievement of suitable bias light conditions, which allowed the selection of the subcell of interest. As a result, three spectral conditions which put the subcells under near work conditions were founded and verified. Furthermore a comprehensive study of the possible noise sources (optic as well as electrical noise) was carried out, and many corrections were performed. Also, the final setup proved to be easily adaptable to perform measures of different types of solar cells and over a great area range.

The errors in the measurements, for the case of commercial cells size (for instance, the Emcore cells), were evaluated and estimations showed a typical uncertainly of 1% to 3% into the sensitive range of each subcell, while near the cut-off wavelengths it increases up to 10%.

7 ACKNOWLEDGEMENTS

The authors thanks to Ignacio Rey-Stolle from the IES-UPM, Madrid, Spain, for the provision of the InGaP CPV cells used in this work. This work was funded by CNEA, CONAE, and the subsidies PIP2009-2011 Nº 02318 (CONICET) and PICT2007 Nº 01143 (ANPCyT).

8 REFERENCES

1. C.G. Bolzi et al., “First experiment of argentine solar cells in space: modules fabrication, characterisation, and telemetry data analysis from SAC-A satellite”, Solar Energy Materials and Solar Cells 73, 269 (2002).
2. M. Alurralde et al., “Experimental and theoretical radiation damage studies on crystalline silicon solar cells”, Solar Energy Materials and Solar Cells 82, 531 (2004).
3. M. Alurralde et al., “Advances in the development of photovoltaics for space applications in Argentina”, Proceedings of the 22nd European Photovoltaic Solar Energy Conference and Exhibition, Milan, Italy, page 687 (2007).
4. J. Plá, M. Barrera, F. Rubinelli, “Influence of the InGaP window layer on the optical and electrical performance of GaAs solar cells”, Semiconductor Science and Technology 22, 1122 (2007).
5. M. Barrera, J. García, H. Socolovsky, F. Rubinelli, E. Godfrin, J. Plá, “Activities on simulation and characterization of multijunction solar cells for space applications in Argentina”, Proceedings of the 23rd European Photovoltaic Solar Energy Conference and Exhibition, Valencia, Spain, page 781 (2008).
6. M. Alurralde, et al., “Solar array qualification models for Aquarius/SAC-D satellite mission”, Proceedings of the 23rd European Photovoltaic Solar Energy Conference, Valencia, Spain, page 785 (2008).
7. M. Alurralde, et al., “Flight Model for Aquarius/SAC-D satellite mission”, Proceedings of the 24th European Photovoltaic Solar Energy Conference, Hamburg, Germany, page 695 (2009).
8. Meusel M., Baur C., Bett A. W., Warta W. y Fernández E. (2003) Spectral response measurements of monolithic GaInP/Ga(In)As/Getriple-junction solar cells: measurement artifacts and their explanation.Progress in Photovoltaics: Research and Applications 11, 499-514
9. K.D. Benjamin, et al., “Harmonic errors associated with the use of choppers in optical experiments”. Measurement 39 (2006) 764-770
10. ASTM Standard E1021-84, “Standard Methods for Measuring the Spectral Response of Photovoltaic Cells” (1985).
11 D. L. King, B. R. Hansen, J. M. Moore, D. J. Aiken, “New methods for measuring performance of monolithic multi-junction solar cells”, Proceedings of the 28th IEEE Photovoltaic Specialists Conference, Alaska, EE.UU., 1197 (2000).