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PV Cell and Module Calibration Activities at NREL

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ABSTRACT

The performance of PV cells and modules with respect to standard reference conditions is a key indicator of progress of a given technology. This task provides the U.S. terrestrial PV community with the most accurate measurements that are technically possible in a timely fashion. The international module certification and accreditation program PVGap requires certification laboratories to maintain their calibration traceability path to groups like this one. The politics of a "world record" efficiency requires that an independent laboratory perform these measurements for credibility. Most manufacturers base their module peak watt rating upon standards and reference cells calibrated under this task. This task has been involved in reconciling disputes between manufacturers and their cell suppliers in terms of expected versus actual performance. This task has also served as a resource to the PV community for consultation on solar simulation, current versus voltage measurement instrumentation, measurement procedures and measurement artifacts.

1. Objectives

The key indicator of PV performance is the peak watt rating. For meaningful comparisons among technologies the peak watt is defined as the maximum electrical power produced under a set of standard reference conditions defined by a reference total and spectral irradiance and reference temperature.[1] The most accurate procedures involve an accurately calibrated photovoltaic reference cell to set or measure the light level with a spectral correction factor.[1-3] For measurements under natural sunlight the reference device is a photovoltaic cell or a thermal detector such as a cavity radiometer or pyranometer and the spectral correction factor is computed after the measurement. For multijunction devices the challenge is to be able to ensure that each junction is operating at the correct photocurrent.

This lab is one of four laboratories in the world that are certified for calibrating World Photovoltaic Reference Cells (WPVS). The world-wide terrestrial PV community calibration traceability path for efficiency and the peak watt rating is to these cells or other primary reference cells calibrated at NREL or at one of the other three labs. The other three WPVS labs are the primary calibration facility for their countries: AIST in Japan, PTB in Germany, and TIPS in China. The TIPS laboratory has not participated in international calibration activities in recent years.

For an internationally recognized calibration traceability path, NREL's primary reference cell, secondary reference cell, and secondary module calibrations must be accredited to ISO 17025 standards. This process was started several years ago with certification by the American Association for Laboratory Accreditation (A2LA) for secondary reference cell calibration using primary reference cells calibrated at NREL. In July 2005, the scope of the accreditation was expanded to include calibration certificates for primary reference cell calibration and secondary module calibration. The procedures are in compliance with U.S., ASTM, and International Electrotechnical Commission standards. This calibration service is critical to module certification and qualification laboratories and to any manufacturer with a quality system that requires traceable calibrations. Certification also assures customers that do not need an ISO17025 accredited calibration that the laboratory follows a formal quality assurance program.

Certification requires a formal quality system that describes the organization, quality system, document control, purchases, complaints, nonconforming calibration work, preventative actions, corrective actions, record control, audits, and review. The technical requirements include work instructions, checklists, forms, diagrams, proof of traceability to a national calibration lab (National Institute of Standards and Technology), and an uncertainty analysis of all measurements producing a numerical result. To prevent a calibration lab from deluding itself that its results are more accurate than claimed, periodic intercomparisons or proficiency testing are required. For our lab, this involves comparing our primary and secondary reference cell calibrations with those of labs of comparable uncertainty around the world.

2. Technical Approach

The equipment used by this group has been described elsewhere.[4,5] A spectrally adjustable simulator is required to accurately determine the I-V characteristics of multi-junction cells or modules with respect to a reference spectrum. This has been implemented for 1-sun cells. For modules, the spectral error is computed for each junction with the efficiency based upon the current limiting junction. For concentrator cells, the lamp voltage is adjusted to minimize the spectral error and the efficiency is based upon the 1-sun current. Linearity is not assumed because a linear reference cell is used in the concentrator simulator.[6]

The scope of ISO 17025 accredited calibrations is limited. Primary reference cells must be packaged following the WPVS design or part of the WPVS sample set and be submitted by national PV calibration facilities. Secondary reference cells must

be packaged with wires and a temperature sensor attached with a maximum size of 20 cm by 20 cm, open-circuit voltage (V_{oc}) less than 40 V, and short-circuit current (I_{sc}) between 1 mA and 15A. Photovoltaic modules must be less than 150 by 120 cm in size, have a V_{oc} between 0.4 V and 290 V, and I_{sc} between 0.1 A and 50 A. A cell with a relative spectral responsivity representative of the module must be supplied with the module. This can be a bare cell, a packaged cell, or a single cell in the module with external wires. All ISO 17025 calibrations require a cover letter with the sample requesting the measurement and providing details about the sample and contact information.

3. Results and Accomplishments

During FY05 the group performed 2173 calibrations on 754 cells and 2481 calibrations on 466 modules. The group also performed 1127 spectral responsivity measurements on 589 cells and modules. The outdoor concentrator IV test bed measured 50,140 IV curves with a direct beam irradiance above 200 Wm^{-2} on 8 concentrator modules.

During FY05 the group expanded its ISO 17025 accreditation from secondary reference cells to include primary reference cells and modules (Fig. 1).

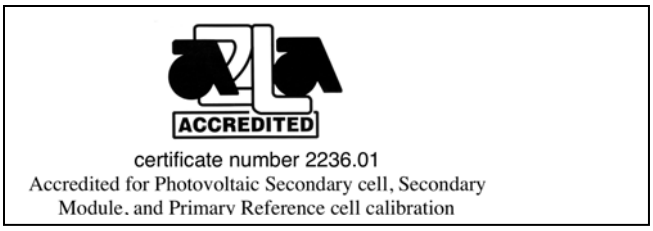

Fig. 1. Proof of accreditation to ISO 17025 standards by the American Association of Laboratory Accreditation.[7]

4. Conclusions

The NREL Cell and Module Performance Characterization Group provides the PV community with state-of-the-art measurements of the spectral responsivity and I-V measurements with respect to standard reporting conditions. The group offers ISO 17025 accredited calibration certificates for cells and modules that fall within the scope.

ACKNOWLEDGEMENTS

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MAJOR FY 2005 PUBLICATIONS

Proc. DOE Solar Program Review Meeting, October 25-28, 2004

W.E. McMahon, K.A. Emery, et. al, "An On-Sun Comparison of $GaInP_2$/GaAs Tandem Cells with Top Cell Thickness Varied"

J. Kiehl and K. Emery, "Characterization of Photovoltaic Concentrators"

Proc. 31st IEEE PVSC, , Jan. 3-7, 2005

K. Emery, et al," Trust But Verify: Procedures to Achieve Accurate Efficiency Measurements for All Photovoltaic Technologies"

S. Bailey, K. Emery et. al, "Standards for Space Solar Cells and Arrays"

W.E. McMahon, K.A. Emery, et. al ,"An on-sun comparison of $GaInP_2$/GaAs tandem cells with top cell thickness varied"

S. Winter, K. Emery, et. al, "The Results of the Second World Photovoltaic Scale Recalibration"

J.A. del Cueto, S. R. Rummel, "Comparison of Diode Quality plus other factors in Polycrystalline cells and Modules from Outdoor and Indoor Measurements"

K. Araki, K. Emery, et. al, "Comparison of Efficiency Measurements for a HCPV Module with 3J Cells in 3 Sites"

M. W. Wanlass, T. Moriarty, et. al, " Lattice-Mismatched approaches for High Performance, III-V Photovoltaic energy Converters "

Proc. International Conference on Solar Concentrators for the Generation of Electricity or Hydrogen, Scottsdale, Arizona, May 1-5, 2005.

M.W. Wanlass, K. Emery, et. al, "GaInP/GaAs/GaInAs Monolithic Tandem Cells for High-Performance Solar Concentrators"

W.E. McMahon, K.A. Emery, et. al, "Outdoor Testing of $GaInP_2$/GaAs Tandem Cells with Top Cell Thickness Varied"

M.A. Green, K. Emery, et. al "Solar Cell Efficiency Tables (version 25)" PIP **13**, 49, 2005.

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