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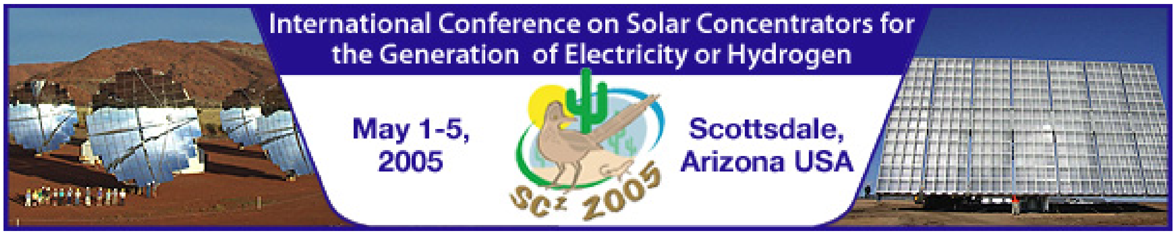

International Conference on Solar Concentrators for the Generation of Electricity or Hydrogen

Book of Abstracts

Conference Chairs:

R. McConnell, M. Symko-Davies, and H. Hayden

Double Tree Paradise Valley
Scottsdale, Arizona
May 1 – 5, 2005

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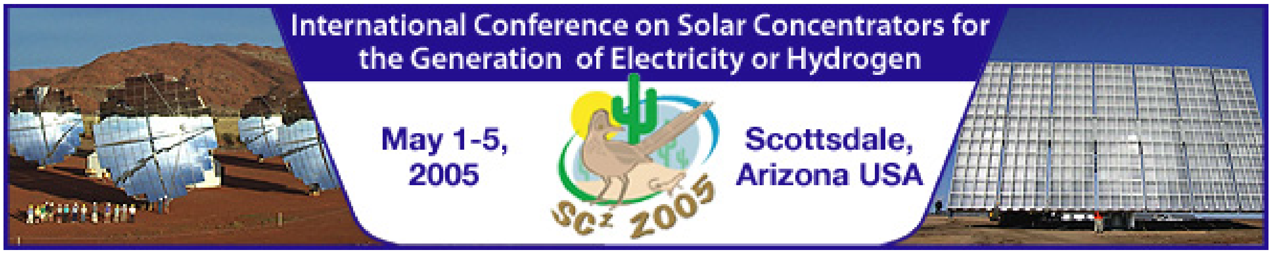


Program Agenda

(All persons listed below are listed as the presenting author.)

Sunday, 1 May 2005

1800 – 2000 **Registration and Reception - Sponsored by Solar Systems, PTY**
Presentations downloaded from CD ROMS or memory stick

Monday, 2 May 2005

0800 **Registration and Continental Breakfast – Breakfast Sponsored by Solargenix**

0830 – 0850 **Welcome - (Arizona or NREL dignitaries)**

0850 – 0900 Robert McConnell, Plenary Session Opening Remarks, National Renewable Energy Laboratory, Golden, Colorado, USA

0900 - 1500 Policy and Marketing for Solar Concentrator Technologies

0900 – 1000 **Southwest Regional Policy Presentations**
Moderator: Ray Williamson, Utilities Engineer, Arizona Corporation Commission, Arizona, USA

- Richard Burdette, Energy Advisor, Office of the Governor, Nevada, USA
- Lynnette Evans, Policy Advisor, Regulatory Affairs, Office of the Governor, Arizona, USA
- Gary Schmitz, Principal Economist, Colorado Public Utility Commission, Office of the Governor, Colorado, USA
- Ned Farquhar, Energy/Environment Advisor, Office of the Governor, New Mexico, USA
- TBD: Speaker representing California

1000 – 1030 *Coffee Break* – **Sponsored by Solargenix**
(You may begin setting up your poster at 11:00 a.m. on Monday morning.)

1030 – 1130 **Roundtable and Audience Discussion with Southwest Regional Policy Panel**
Moderator: Ray Williamson, Utilities Engineer, Arizona Corporation Commission, Arizona, USA

1130 – 1330 *Conference Luncheon* – **Sponsored by Amonix**

Vahan Garboushian, "Marketing Concentrating Solar Systems – Challenges and Opportunities," Amonix, Inc., Torrance, California, USA

1330 – 1715 Market Entry for Solar Concentrator Systems

1330 – 1400 David Holland, "Picking Up the Pace," Solar Systems Pty. Ltd., Hawthorne, Australia

1400 – 1430 Raed A. Sherif, "Commercialization of Concentrator Multijunction Photovoltaics," Spectrolab, Inc., Sylmar, California, USA

1430 – 1500 Peter Johnston, "The Role of CSP in Filling APS' Future Solar Energy Needs," Arizona Public Service, Tempe, Arizona, USA

1500 – 1515 *Coffee Break* – **Sponsored by Solargenix**

1500 – 1655 Related Marketing Issues for Solar Concentrators

1515 – 1535 Vicente Díaz, "The Path for Industrial Scale Production of Very High Concentration PV Systems," ISOFOTON, SA, Málaga, Spain

1535 – 1555 Hans-Joerg Lerchenmüller, "Cost and Market Perspectives for FLATCON® Systems," Concentrix Solar, Freiburg, Germany

1555 – 1615 Kenji Araki, "CPV Using 3J III-V Cells and Fresnel Lenses – Reliability, Applications and Perspectives," Daido Steel Co., Nagoya, Japan

1615 – 1635 David Faiman, "The Triple Sustainability of CPV Within the Framework of the Raviv Financing Model," Ben-Gurion University, Sede Boqer, Israel

1635 – 1655 Gilbert Cohen, "SolarGenix Concentrating Solar Thermal," SolarGenix, LLC, Raleigh, NC, USA

1800 – 2000 **Poster Session and Reception - Sponsored by Spectrolab**
(See Poster List Below)

Tuesday, 3 May 2005

0830 – 1200 Solar Cells for Concentrators

0830 – 0850 Speaker: Robert McConnell, "DOE High Performance Concentrator PV Project," National Renewable Energy Laboratory, USA

0850 – 0910 Mark Wanlass, "GaInP/GaAs/GaInAs Monolithic Tandem Cells for High-Performance Solar Concentrators," National Renewable Energy Laboratory, Golden, Colorado, USA

0910 – 0930 Harry Atwater, "Ultrahigh Efficiency Cells for Microconcentrator PV", Caltech, Pasadena, California, USA

0930 - 0950 Carlo Flores, "GaAs Concentrator Solar Cells for the Italian Electrical System," CESI

S.p.A., Milano, Italy

0950 – 1010	Richard King, "Bandgap Engineering in High-Efficiency Multijunction Concentrator Cells," Spectrolab, Inc., Sylmar, California, USA
1010 – 1030	*Coffee Break* – **Sponsored by Xcel Energy**
1030 – 1050	Jeffrey Gordon, "Ultra-High Concentration Effects in Multi-Junction Solar Cells," Ben-Gurion University of the Negev, Israel, and University of California, Merced, California, USA
1050 – 1110	Daniel J. Friedman, "GaInNAs Junctions for Next-Generation Concentrators: Progress and Prospects," National Renewable Energy Laboratory, Golden, Colorado, USA
1110 – 1130	Timothy Bruton, "Low Cost Concentrator Cells From One Sun Production Cell Technology," NaREC, AG, United Kingdom
1130 – 1150	Lew Fraas, "Efficient Solar Photovoltaic Mirror Modules for Half the Cost of Today's Planar Modules," JX Crystals Inc., Issaquah, Washington, USA
1150 – 1330	Lunch (no speaker)

1330 – 1655 Prototypes and Optics for Low to High Concentration Technologies

1330 – 1350	Valery Rumyantsev, "Practical Design of PV Modules and Trackers for Very High Solar Concentration," Ioffe Physico-Technical Institute, St. Petersburg, Russia
1350 – 1410	Lew Fraas, "New Cassegrainian PV Module Using Dichroic Secondary and Multijunction Solar Cells," JX Crystals Inc., Issaquah, Washington, USA
1410 – 1430	Dan Aiken, "Design, Manufacturing, and Testing of a Prototype Multijunction Concentrator Module," Emcore Photovoltaics, Albuquerque, New Mexico, USA
1430 – 1450	Andreas Bett, "The FLATCON® Concentrator PV-Technology," Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany
1450 – 1510	*CoffeeBreak* – **Sponsored by Excel Energy**
1510 – 1530	Roland Winston, "Planar Concentrators at the Etendue Limit," University of California, Merced, California, USA
1530 – 1550	Ralf Leutz, "Hemispherical Solar Concentrator Corrected for Aberrations," Philipps-University, Marburg, Germany
1550 – 1610	Daniel Feuermann, "Realization of Compact, Passively Cooled, High-Flux Commercial Photovoltaic Prototypes," Ben-Gurion University of the Negev, Be'er Sheva, Israel
1610 – 1630	Ralf Leutz, "One-Axis PV Sun Concentrator Based on Linear Nonimaging Fresnel Lens," Philipps-University, Marburg, Germany
1630 – 1650	Atushi Akisawa, "Design of Non-Imaging Fresnel Lens for 500X Solar

Concentration," Tokyo University of Agriculture and Technology, Toyko, Japan

1730 – 2030 Conference Dinner – **SPONSORED BY ARIZONA PUBLIC SERVICE, Overall Event Sponsor.**

Speaker: Richard J. Schwartz, "The Evolution of High Intensity Photovoltaic Cells from Thermophotovoltaic Applications to High Concentration Solar Applications: Lessons Learned," Purdue University, West Lafayette, Indiana, USA

Wednesday, 4 May 2005

0830 – 1200 Solar Concentrator Designs and Testing

8:30 – 0850 Ignacio Antón," Indoor Characterization of Concentrator Modules: Application on the Production Line," Instituto de Energía Solar, Universidad Politécnica de Madrid, Spain

0850 – 0910 Steve Kusek, "On-Sun Testing of Multijunction PV Cells," Concentrating Technologies," LLC, Owens Cross Roads, Alabama, USA

0910 – 0930 Ignacio Luque-Heredia, "CPV Sun Tracking at InSpira," InSpira, SL, Madrid, Spain

0930 – 0950 William McMahon, "Outdoor Testing of $GaInP_2/GaAs$ Tandem Cells with Top Cell Thickness Varied," National Renewable Energy Laboratory, Golden, Colorado, USA

0950 – 1010 Yen-Chang Tzeng, "The Development of High Concentrating III-V Photovoltaic Modules at INER Taiwan," INER, Taiwan

1010 – 1030 *Coffee Break* – **Sponsored by Navigant Consulting**

1030 – 1050 Giuliano Martinelli, "Dichroic Flat Faceted Concentrator for PV Use," University of Ferrara & INFM, Ferrara (FE), Italy

1050 – 1110 Yiping Wang, "Performance on Concentrating Photovoltaic/Thermal Systems Using Solar Cells Immersed in Dielectric Liquid," Tianjin University, Tianjin, China

1110 – 1130 Liang Ji, "Representative Samples for Concentrator Photovoltaic Module Qualification Testing," Arizona State University East, Mesa, Arizona, USA

1130 – 1150 Geoff S. Kinsey, "Optimization of High-Concentration Multijunction Solar Cells," Spectrolab, Sylmar, California, USA

1150 – 1330 Lunch (no speaker)

1330 – 1650 Hydrogen, Space and Innovative Concentrators

1330 – 1350 Mark J. O'Neill, "ENTECH's Stretched Lens Array (SLA) for NASA's Moon/Mars Exploration Missions, Including Near-Term Terrestrial Spin-Offs," ENTECH, Inc., Keller, Texas, USA

1350 – 1410 D. Buie, "Combining the Tools for Solar Thermal and Photovoltaic Power Generation – The Experimental and Computational Facilities at the University of Sydney," University of Sydney, Sydney, Australia

1410 – 1430 Gregor Lengeling, "The agiceiver™ – A New Approach for Hydrogen Production by Concentrated Sun Light," AGRISOLAR, Aachen, Germany

1430 – 1450 Sergey Vasylyev, "Nonimaging Reflective Lens Concentrator," SVV Technology Innovations, Inc., Sacramento, California, USA

1450 - 1510 *Coffee Break* – **Sponsored by Navigant Consulting**

1510 – 1530 Yoshihiro Nakato, "Recent Progress of Electrochemical Solar Water Splitting with Photoelectrodes and Photocatalysts," Osaka University, Osaka, Japan

1530 – 1550 Jamal R.Thompson, "Hydrogen Electrolysis Using Concentrated Solar Energy," Howard University, Washington, D.C., USA

1550 – 1610 Robert McConnell, "Summary of Conference Highlights," National Renewable Energy Laboratory, Golden, Colorado, USA

1610 – 1630 Herb Hayden, "Recommendations for Further Action," Arizona Public Service, Phoenix, Arizona, USA

1630 – 1650 Instructions for tomorrow's field trip

Thursday, 5 May 2005

0830 – 1500 **Site Visits**

0830 – 0845 Board Buses

0830 – 1500 Site Visits:
Arizona Public Service (APS)
- APS Star, Tempe
- APS Facility, Prescott

Posters

1 H. Song, "One Step Method to Produce Hydrogen by Tandem Amorphous Silicon Solar Cells," Nankai University, Tianjin, China

2 C. S. Solanki, "Solar Irradiation Potential for PV Concentrator Systems in India," IIT Bombay, Munbai, India

3 C. S. Solanki, "PV Concentrator Systems – A Database Search," IIT Bombay, Munbai, India

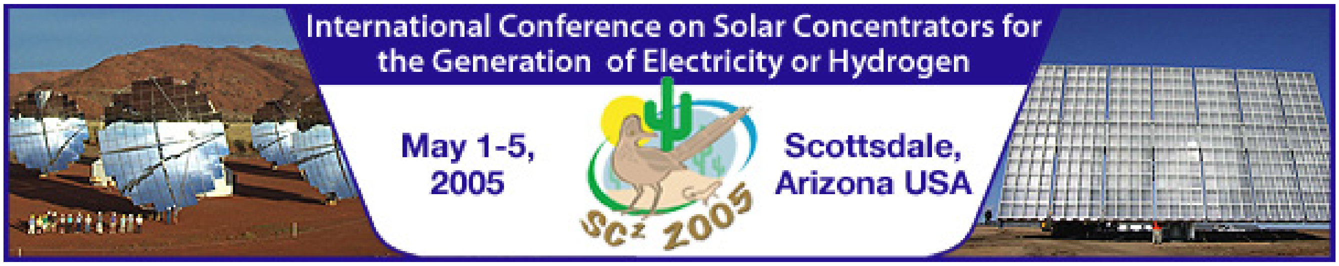
4 Carlo Privato, "Plastics Structured Optics for Solar Concentrating in PV System," ENEA Centro Ricerche, Portici (NA), Italy

5 Angelo Sarno, "Design, Realization and Preliminary Performance Analysis of the PhoCUS-5 Standard Unit," ENEA Research Center, Portici, Napoli, Italy

6 Huacong Yu, "Research on Graded Optical Band Gap (GBG) in na-Si:H Solar Cells Prepared by PECVD," Shanghai Jiaotong University, Shanghai, China

7 Kemal Koknar, “Increased Solar Collector Efficiency Through SunTrap™ Technology,” Radiant Power, LLC, Santa Clara, California, USA

8 Manuel J. Blanco, “Design Principles of Tonatiuh, an Open Source Computer Program for the Design and Analysis of Solar Concentrating Systems,” The University of Texas at Brownsville, Brownsville, Texas, USA



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Poster Papers

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Marketing Concentrating Solar Systems -
Challenges and Opportunities

Vahan Garboushian – Amonix, Inc.
3425 Fujita Street, Torrance, CA 90505
310-325-8091 - vahan@amonix.com

The implementation of today's Concentrating Solar Systems offer customers increased performance at the lowest cost in photovoltaic energy generation. Tomorrow's advanced systems offer still more. The challenge is to educate customers on the proper utilization of these systems and avoid the pitfalls of 'overselling' in a highly competitive market. Standard flat-plate technology is internationally well established and has opened the door for superior concentrating systems. Specialized marketing strategies are needed. Accurate knowledge at the customer level is required to advance Concentrating Solar market entry. This paper will present lessons learned from over 10 years of utility field trials and offer suggestions for the Concentrating Solar community in the area of national and international marketing.

Picking Up The Pace

Dave Holland
Solar Systems Pty., Ltd., Hawthorne, Australia
Email: dholland@solarsystems.com.au

Abstract:

Solar energy is more plentiful, more predictable and is less site specific than wind. Despite solar's advantages and our best intentions, wind farms are commonplace while "sun farms" are still a rarity. It seems inevitable that the scales will tip but the natural time scales are too long (for the author at least). How do we pick up the pace.

This paper presents the author's view of the solution, which includes a mixture of technology, commercial management, capital, collaboration and influence (not to mention a good dose of courage, excellence and perseverance).

Dave Holland is the Managing Director of Solar Systems and a Director of Renewable Energy Generators Australia – an industry group that represents more than 90% of Australia's renewable energy based generation assets.

Commercialization of Concentrator Multijunction Photovoltaics

Raed A. Sherif, Richard R. King, Chris M. Fetzer, Hector L. Cotal, Geoff S. Kinsey, Jeff Peacock, and Nasser H. Karam

Spectrolab, Inc., 12500 Gladstone Avenue, Sylmar, CA 91342-5373
Email: rsherif@spectrolab.com

Abstract:

This paper discusses the issues and opportunities of Concentrator multijunction photovoltaics. It gives an overview of the status of the technology, the status of the multijunction solar cells and receivers, and the roadmap to achieving higher cell efficiencies. The economic benefits of using this technology to produce gigawatts of electricity, and the steps required to achieve that are also presented.

The Role of CSP in Filling APS's Future Solar Energy Needs

Peter Johnston
Arizona Public Service
Tempe, Arizona
Email: Peter.Johnston@aps.com

Abstract not available.

The Path for Industrial Scale Production of Very High Concentration PV Systems

V. Díaz
ISOFOTON SA, La Gitanilla 26, P.I. Santa Cruz. Málaga 29006, Spain

Generally speaking, a common target for building photovoltaic at much lower prices is present inside PV industry as a definitive take off of PV solar energy. Concentration of light over the solar cell, as a way for reducing semiconductor area, (the highest driving cost in a PV module) is one of these strategies.

The very high concentration problem in photovoltaic is an old target reviewed extensively since late seventies [1]. However, now it is being issued thanks to the increased interest evidenced [2] by the potential price reductions of reliable installed systems. Even more, firsts tentative in the industrialization is currently in progress [3] based on III-V solar cells, TIR-R lenses and accurate two axis tracking systems.

ISOFOTON S.A., the Spanish PV manufacturer company, is interested in the exploitation of this technology. It is actively involved in the industrialization of High Concentration PV at really competitive price (below 2,5 €/W_{pk} for installed systems) when mass production issues (10MW/year) are considered. This paper will describe the details concerning the industrialization path from lab scale to mass production. The main focus now is to reduce the time for going to the market.

Brief explanation of the high concentration PV concept

The optics is one of the key issues of every concentration systems. The one chosen for this application is suitable for a very compact solution, (figure 1 and 2) and has been described in detail elsewhere [4]. It is composed of a system of two lenses (TIR-R), manufactured in acrylic by injection molding, where the top one (TIR) works by means of Total Internal Reflection. The second and bottom one works only by refraction and cover completely the solar cell. This system makes that the light impinging over the surface of the solar cell will be increased 1000 times.

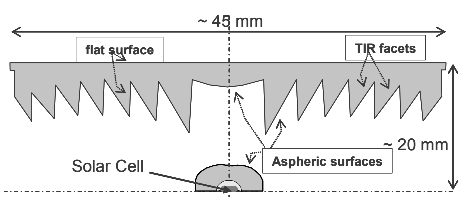

Figure 1. Cross section of the TIR-R system

Figure 2. Solid drawing of the TIR-R system.

Figure 3. Three finished PV concentration modules installed in a two axis tracking system

The size of the PV module under development is 1 m times 0,3 m and for the final installations a two axis tracking system like that of figure 3 is needed. This is due to the requirements of collecting only direct sunlight. Further details of the manufacturing procedures will be addressed for the time of the conference.

References

[1]. E.L. Burgess, M.W. Edenburn, *"One kilowatt subsystem using Fresnel Lens Concentrators"* Proc. of the 12th IEEE PVSC, 1976

[2]. *"Ultra compact high flux GaAs cell photovoltaic concentrator"* HERCULES. JOR-CT97-0123 EC Joule Thermie III .program.1999

[3]. V. Diaz, J.L. Alvarez, J. Alonso, A. Luque, C. Mateos *"Towards a technology for mass production of very high concentrator flat panel"*. Proc. of the 19th European PVSEC Paris. 2004. In press.

[4]. J.L Alvarez, M. Hernández, P. Benitez, J. C. Miñano, *"TIR-R Concentrator: a new compact high-gain SMS design"*, *Nonimaging Optics: Maximum Efficiency Light Transfer VI,* Proc., pp.32-42, (2001).

Cost and Market Perspectives for FLATCON®-Systems

H. Lerchenmüller [a], A.W. Bett [b], J. Jaus [b]

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ABSTRACT

FLATCON® systems are high concentrating photovoltaic units using point focussing Fresnel lenses and multi-junction solar cells. FLATCON® concentrator modules equipped with dual-junction solar cells reached efficiencies of 22,7% under realistic operation conditions. A thorough analysis of production cost was carried out for a 20 MW production line. This paper shows the results of this cost analysis and the calculations of levelized electricity costs in comparison to conventional flat plate PV modules: For large systems at sites with high direct solar radiation the FLATCON® technology is expected to have a clear competitive advantage. In February 2005 the company Concentrix Solar GmbH was founded as a spin-off company of Fraunhofer ISE to manufacture concentrator systems based on the FLATCON® technology.

CPV using 3J III-V cells and Fresnel lenses –Reliability, Applications and Perspectives

Kenji Araki
Daido Steel Co., Ltd.
2-30, Daido-cho, Minami-ku, Nagoya, Japan

ABSTRACT

Almost one year has passed since 550 X CPV system using III-V 3J cells and dome-shaped Fresnel lenses was launced in the test site and began power generation. The 550 X system is the improved product from the 400 X CPV system presented at the previous SCC2003. Reliability and field test result is presented. Applications and future perspectives are discussed.

1. What's new about a 550 X system?

The 550X lens has two improvements from the previ-ous design. First, the facet size was significantly enlarged after improvement of injection molding technique by keep-ing uniformity in polymer fluid in the overall area. The loss from rounded prism peak and valley was significantly re-duced. Second, durability against freezing cycle was im-proved. The previous 400 X injection-molded Fresnel lens had a problem in degradation by fine cracks caused by freezing. The new 550X lens was improved by residual stress and proved a stable outdoor operation for a long time.

The next improvement was durability against concen-trated UV flux and water condensation around the solar cell. Since III-V solar cells are more reactive against envi-ronment than silicon solar cells, they need complete seal-ing from environment. However, the transparent sealing polymer on the solar cell is exposed by concentrated sunlight and may be damaged by UV. Even though the sealing polymer keeps transparency, the mechanical strength would be usually degraded and have a chance of breakage of sealing.

2. Reliability and fail-safe

It was shown that the receiver survives 20 years of accumulated concentrated sunshine (desert area) by UV accelerated test. Various fail-safe tests were conducted including off-axis beam test. Due to advanced non-imaging optics, the temperature rise by off-axis beam was 15K.

3. One year field test

One year observation showed a seasonal fluctuation inherent to MJ cells and stable energy output. The total energy was 264 kWh/m^2 by 1980 hours of sunshine duration. The energy per rating was 940 kWh/kWp (28 % and 1kW rating). The annual efficiency (annual energy generation devided by annual insolation) was 20.5 %. This is almost two times more energy than typical flat-plate system despite the well-known preconceived idea that CPV is not suitable to wet area like Japan.

4. Applications (1) –rooftop on apartment houses

One of the possible applications in Japan is a rooftop on the apartment houses. A new light weight tracker (Figure 1) and light weight module is being developed. The weight is 0.3 kg/w including modules. The weight does not include the base structrue.

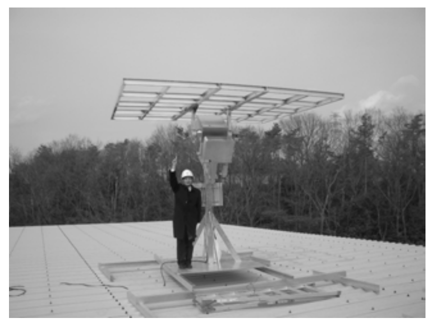

Figure 1. A new 3kW tracker developed by Daido Metal

5. Applications (2) – See-through PV!

Another interesting application is what we call the tree planting PV (Figure 2). The CPV only utilizes direct beam in the sunlight which is often harmful for tree planting. The CPV system without the back cover is transparent to the diffused sunlight. The CPV module shades the strong direct beam and provides rich diffused sunlight to plants. With this transparent module, the area under the module is no longer the dead area. Different from "see-through" flat-plate module, the power generation is not compromised at all..

Figure 2. CPV for "Breeding Plants" that collects direct beam and provides diffused sunlight to the underneath plant.

6. Where are we going?

The direction of future CPV will be discussed.

The Triple Sustainability of CPV Within the Framework of the Raviv Financing Model

David Faiman[1], Dov Raviv[2], Roy Rosenstreich[2]
[1]Ben-Gurion University, Jacob Blaustein Institute for Desert Research
[2]MST, Ltd.
Email: faiman@bgumail.bgu.ac.il

Abstract: In a recent series of remarkable presentations [1,2,3], Dov Raviv has shown that CPV can be highly cost-effective, in a subsidy-free manner, if introduced on a sufficiently large scale. Raviv¹s model involves financing via an open credit line that is repaid with interest entirely from revenues that accrue from a steadily increasing number of Very Large Solar Photovoltaic (VLS-PV) power plants. Within the framework of an International Energy Agency (IEA) Task 8 PV Specialists Group study, we have recently applied this model to various countries in the Middle East [4]. Although those countries have different population growth rates and electricity needs, a number of common features emerged from that study that will be the focus of the present paper. Specifically, we found that CPV can be sustainable in three completely independent ways. First is the familiar meaning of sustainability that solar energy in general promises compared to the steadily dwindling reserves of fossil fuel. Second, we find that within the context of the Raviv model, because the credit line and interest are paid back well within the expected lifetime of the VLS-PV plants, revenues from the latter are sufficient to continue funding the construction of new plants without the need for any further investment. The second sense in which CPV becomes sustainable is therefore that it is a technology that can eventually "breed" itself without external funding. Thirdly, we find that revenues from the steadily increasing number of VLS-PV plants become so large that they are even capable of fully financing the construction of TWO new plants per year: one to keep pace with rising electricity needs and the other to replace a 30-year old plant that has reached the end of its assumed useful life. The third sense in which CPV technology becomes sustainable is therefore its ability to renew itself at the end of effective system life, once again without external funding.

SolarGenix Concentration Solar Thermal

Gilbert Cohen
SolarGenix, LLC.
Phone (919) 871-0423

Abstract not available.

DOE High Performance Concentrator PV Project: III-V Multijunction Concentrators

Robert McConnell* and Martha Symko-Davies
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO USA 80401-3393

The U.S. Department of Energy (DOE) initiated the High-Performance Photovoltaic (HiPerf PV) Project to substantially increase the viability of photovoltaics (PV) for cost-competitive applications so that PV can contribute significantly to both our energy supply and environment. To accomplish such results, the National Center for Photovoltaics (NCPV) directs in-house and subcontracted research in high-performance polycrystalline thin-film and multijunction concentrator devices with the goal of enabling progress of high-efficiency technologies toward commercial-prototype products. We will describe the details of the subcontractor and in-house progress toward exploring and accelerating pathways of III-V multijunction concentrator solar cells and systems toward their long-term goals. By 2020, it is anticipated that this project will have demonstrated 33% system efficiency and a system price of \$1.00/W_p for concentrator PV systems using III-V multijunction solar cells with efficiencies over 40%.

GaInP/GaAs/GaInAs Monolithic Tandem Cells for High-Performance Solar Concentrators

M. W. Wanlass, S. P. Ahrenkiel, D. S. Albin,
J. J. Carapella, A. Duda, J. F. Geisz, Sarah Kurtz, T. Moriarty, and M. J. Romero

National Renewable Energy Laboratory (NREL), 1617 Cole Blvd., Golden, CO 80401
Email: mark_wanlass@nrel.gov; Phone: (303) 384-6532; Fax: (303) 384-6430

Abstract:

The performance of state-of-the-art, lattice-matched (LM), triple-junction (TJ), GaInP/GaInAs/Ge concentrator tandem solar cells could be improved substantially by replacing the Ge bottom subcell with a subcell having a bandgap of ~1 eV. For the last several years, research has been conducted by a number of organizations to develop ~1-eV, LM GaInAsN materials to provide such a subcell, but, so far, the approach has proven unsuccessful.

In this paper, we present a new TJ tandem cell design that addresses the above-mentioned problem. Our approach involves inverted epitaxial growth to allow the monolithic integration of a lattice-mismatched (LMM) ~1-eV GaInAs/GaInP double-heterostructure (DH) bottom subcell with LM GaAs (middle) and GaInP (top) upper subcells. A transparent GaInP compositionally graded layer facilitates the integration of the LM and LMM components. Handle-mounted, ultra-thin device fabrication is a natural consequence of the inverted-structure approach, which results in a number of advantages, including robustness, improved thermal management, incorporation of back-surface reflectors, and possible reclamation of the parent crystalline substrate.

Our initial work has concerned GaInP/GaAs/GaInAs tandem cells grown on GaAs substrates. In this case, the 1-eV GaInAs experiences 2.2% compressive LMM with respect to the substrate. Specially designed GaInP graded layers are used to produce 1-eV subcells with performance parameters nearly equaling those of LM devices with the same bandgap. Preliminary ultra-thin tandem devices (0.237 cm^2) have already been demonstrated with NREL-confirmed, one-sun efficiencies of 31.3% (global spectrum) and 29.7% (AM0 spectrum). Concentrator devices have been fabricated and are currently being tested. Realistic performance modeling of GaInP/GaAs/GaInAs tandems shows that practical efficiencies exceeding 40% should be achieved for terrestrial concentration ratios of a few hundred suns.

Ultra-High Efficiency Cells for Microconcentrator PV

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Abstract not available.

GaAs Concentrator Solar Cells for the Italian Electrical System

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Abstract

This paper describes the research and development activities carried out in Italy in the field of high efficiency solar cells based on GaAs compounds. This activity is funded by the Research Fund for the Italian Electrical System established with Ministry of Industry Decree in year 2000.
The research is focused on the development of concentrator solar cell components derived from the production of space solar cells of CESI. Three fields of investigation are presently considered:

- GaAs and InGaP single junction cells for special concentrator systems.
- InGaP/InGaAs/Ge triple junction cells.
- InGaP/InGaAs dual junction cells on Si substrates.

The cells under development are tested in laboratory as well as in natural light using both Fresnel lenses and large dishes. Aim of the activity, however, is not the development of modules and systems but the development of reliable solar cell components for the Italian market.

Bandgap Engineering in High-Efficiency Multijunction Concentrator Cells

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International Conference on Solar Concentrators for the Generation of Electricity or Hydrogen,
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Sunlight is an energy resource with a wide geographic distribution, making it easily accessible for solar electricity generation in many communities. However, it is also distributed over a wide range of wavelengths, complicating efficient photovoltaic energy conversion. Multijunction solar cells divide the solar spectrum into narrower wavelength bands, allowing more efficient conversion by the individual subcells, each with bandgap energy tuned to the photon energies in the corresponding band. The GaInP/GaInAs/Ge 3-junction cell is a multijunction (MJ) cell configuration combining III-V and group-IV subcells, that has achieved record efficiencies (37.3%, 175 suns) under the terrestrial AM1.5D low-AOD standard spectrum. Efficiencies over 40% and even 50% are possible in principle if a different combination of subcell bandgaps can be used to partition the solar spectrum. Group-III sublattice ordering phenomena, and the use of unconventional semiconductor materials such as metamorphic GaInP and GaInAs, and ~1-eV GaInNAs with dilute nitrogen composition, are discussed to achieve the desired combination of bandgaps in new types of high-efficiency terrestrial MJ solar cells. Concentration ratios of ~500X, delivered by a variety of reflective and refractive schemes now deployed in the field, reduce the cost of such cells dramatically by reducing the cell area required. Investigation of new semiconductor materials and device structures to reach new heights in cell efficiency holds the promise to break through to photovoltaic system costs competitive with conventional power sources.

Ultra-High Concentration Effects in Multi-Junction Solar Cells

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Abstract

We report results of ultra-high flux photovoltaic characterization of monolithic triple-junction $GaInP_2$/GaAs/Ge and tandem GaInP/GaAs solar cells using a new high-flux real-sun probe predicated on mini-dish fiber-optic concentrators. Our aims were to investigate the sensitivity of the cell efficiency to the flux level and distribution.

Radiation on the cell was moderated with an iris on the concentrator's window. Near-perfect flux uniformity was achieved with a square cross-section kaleidoscope. Irradiating the cell directly from the distal fiber tip and varying fib/er height above the cell, we could realize a wide range of flux distributions, including the extreme localized irradiation limit of contact with the cell such that radiation projected beyond the fiber tip was negligible. The localized irradiation method allows mapping inhomogeneities in cell construction, e.g., via the spatial sensitivity of current-voltage curves.

Our uniform-irradiation and localized-irradiation measurements yield characteristic plots for the flux dependence of efficiency that are similar to those reported previously for the same fully-irradiated cells, but provide additional information on cell dynamics. The increase of the flux values at which efficiency peaks in localized-irradiation tests can be predicted from fundamental solar cell modeling, and bodes well for the high-efficiency performance of future generations of smaller-area concentrator cells.

In one instance, ultra-high-flux localized-irradiation measurements (at 3200 suns and above) revealed a sharp degradation in cell performance that can uniquely be associated with the inadequacy of one of the cell's tunnel diodes. This in turn led to the first predictable and reversible observation of hysteresis in photovoltaic current-voltage curves. The ramifications of these findings for photovoltaic design and diagnostics are addressed, and a non-destructive determination of the peak and valley threshold current densities of tunnel diodes is presented.

GaInNAs Junctions for Next-Generation Concentrators: Progress and Prospects

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We discuss progress we have made toward the development of GaInNAs junctions with performance good enough for application in the next generation of multijunction concentrator cells. The short diffusion lengths in GaInNAs have stymied the achievement of the near-100% quantum efficiencies required for current matching in the GaInP/GaAs/GaInNAs/Ge four-junction ("4J") structure. A significant development is the demonstration of very wide depletion widths in GaInNAs junctions using MBE growth, making possible p-i-n junctions with 3-µm-wide i-layers. The resulting drift field yields near-100% internal QEs, a significant proof-of-concept advance for GaInNAs junctions. The width and low doping of the i-layers raises the concern that the resulting series resistance could make such junctions incompatible with concentrator operation. Fortunately, testing of our p-i-n junctions at high currents shows these devices not to suffer significant voltage losses under concentrator operation. We explain this result by considering the high density of carriers injected into the i-layer at high operating currents, and show that in general, a GaInNAs p-i-n junction which has near-100% QE can be expected also to have a small voltage loss under concentration.

For the MBE-grown p-i-n junctions, bandgaps as low as 1.15 eV have been demonstrated, but 1.0 eV will need to be achieved for current matching in the 4J structure. Likewise, the ~80% QEs of the MOVPE-grown junctions need to be increased to near 100% for current-matching to the 4J structure. An alternative approach to next-generation multijunction cells, under development at Spectrolab and Fraunhofer, uses a five-or six-junction ("6J") structure with lower current-matching requirements than the 4J structure. We project what the efficiencies of the 6J structure would be if the state-of-the-art MBE- and MOVPE-grown GaInNAs junctions can be incorporated into this structure.

Low Cost Concentrator Cells from One Sun Production Cell Technology

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The present silicon shortage creates an opportunity for concentrating systems but to be adopted systems costs must be comparable. It is axiomatic that in concentrating systems lower cell cost can be achieved and this pays for the added complexity of the concentrating system relative to flat plat. These cell cost reduction have proved elusive in reality. Modifying one sun technologies offers a route to volume manufacture of concentrator cells with low overheads for short production runs. The LGBC cell technology is particularly suitable for concentrator technology as high current carrying capacity can be structured into the cell with minimal shading by the metallization. The laser cutting technology also means a range of sizes can easily be cut from the basic 125 x 126 mm p-square wafer. The technology has proved adaptable to a range of concentrating systems. Good results have been obtained for 112 X6 mm cells in untracked CPC 2.4 x modules for BIPV. Half one sun cells have worked well in the ARCHIMEDES 2x passively tracked system. Cells 115x45 mm have demonstrated efficiencies between 18 and 20% for concentration between 20 and 30x in both linear Fresnel lens and Parabolic reflector systems. Recent good results have been achieved at 100X for point focus systems. Assuming a cell manufacturing cost of $2/Wp for a one sun cells then cell prices fall from $1/Wp at 2x through $0.27/Wp for 20x to below $0.1/Wp at 100X. Major production facilities are not required and even the modest 50KW/p.a pilot facility at NaREC could produce over 100 MWp of concentrating cell with modest investment.

Efficient Solar Photovoltaic Mirror Modules for Half the Cost of Today's Planar Modules

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ABSTRACT

1. Opportunity and Solution

The demand for solar photovoltaic (PV) cells and modules has far outstripped PV cell supply, e.g. Germany and Japan are buying everything they can find and module prices are rising. Solution: JX Crystals Inc has a 3-sun mirror module design that uses 1/3 the cells to triple module production at a lower cost.

2. The Linear Mirror Module Concept

A problem for concentrated sunlight PV systems has been the requirement for investment in special cell and module manufacturing facilities. Herein, we describe a new concentrator module design that uses existing planar cells. We simply cut standard 125mm x 125mm SunPower A300 cells into thirds. In addition, our module design uses standard circuit laminant fabrication procedures and equipment. However, we add a thin aluminum sheet at the back of the laminant for heat spreading. While a standard planar module contains rows of 125mm x 125mm cells, our low concentration modules consist of rows of third-cells with each row now 41.7 mm wide. We then locate linear mirrors with triangular cross sections between the cell rows. The mirror facets deflect the sun's rays down to the cell rows. The result is the 3-sun concentrator module shown in figure 1 below. Since mirrors are over ten times cheaper than expensive single crystal cell material, these 3-sun modules can be made at half the cost of today's solar PV modules.

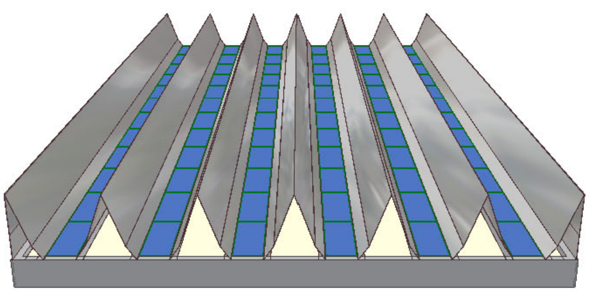


Figure 1: 3-sun mirror module

3. Results to date

As shown in figure 2, we have fabricated and tested 2-sun mirror modules previously. These modules have successfully passed hail stone, thermal cycling, and hi-pot tests at ASU.

Our more recent efforts have been focused on using SunPower A300 cells because they are both higher in efficiency and can be cut into thirds as shown in figure 3.

Figure 2: Two of JX Crystals 2-sun mirror modules on an Array Technologies TR15 sun tracker in outdoor test.

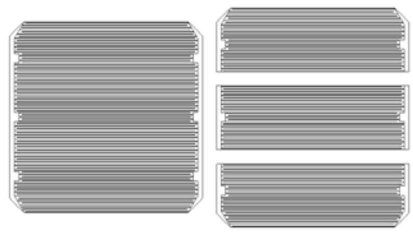
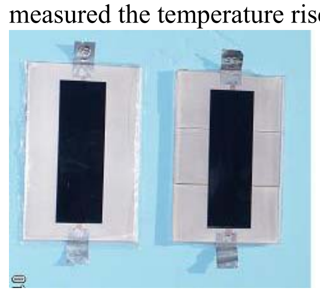


Figure 3: View from the back side of a 125 mm x 123 mm A300 SunPower cell before and after being cut into 3rd cells.

We have now laminated some 3rd cells into test coupons and measured their outputs at 3 suns before and after 50 thermal cycles between -40 C and +90 C. Photos of these test coupons are shown in figure 4 along with the measured power outputs. There was no degradation. We also measured the temperature rise at only 3.3 C.



ID	Efficiency BEFORE 50 Thermal Cycles	Efficiency AFTER 50 Thermal Cycles
T84	19.5%	20.0%
T85	20.1%	19.5%

Figure 4: Tested coupons.

4. Summary

This design has the following major advantages:

- $1.50 per W instead of $3 per W for today's modules
- Evolutionary design using existing cells and module production methods
- 20% efficient cells immediately available
- Triple production with no new factory
- Pre-qualified by design
- Patent pending
- Compatible with existing trackers

Practical Design of PV Modules and Trackers for Very High Solar Concentration

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ABSTRACT

The following solar PV concepts connected with high concentration approach are under development: small-aperture area and short focal length primary Fresnel lenses; smooth-surface secondary mini-lenses; design for the concentrator modules with III-V tandem cells; close-loop strategy for sun-tracking; solar installations, realizing the above concepts Lens panel formation and cell mounting processes have been developed. The sun trackers for 1 kWp of installed capacity have been built and tested

.

1. Module Design

A concept of small-aperture area concentrator sub-modules in PV module design leads to rise in cell efficiency and saving the semiconductor and structural materials. It may be realized at retention (in the whole) of a distributed character of sunlight conversion and heat dissipation– similar to the case of systems without concentration In our design, refractive-type concentrators (Fresnel lenses) have a composite structure: microprisms are formed from transparent silicone rubber contacting with front glass sheet as a protective superstrate. Quantities of the lenses are arranged on a common superstrate in a view of lens panel. The smooth-surface secondary minilenses arranged as an intermediate composite (glass-silicone) or monolithic (glass) panel are inserted between panel of the primary Fresnel lenses (each lens of 40 x 40 mm^2) and panel of the solar cells. The cells as small as 1.2 mm in designated area diameter operating at very high concentration ratio (more than 1000x) can be used in the PV modules with secondary lenses. Developed formation process allows fabricating the modules of total area up to 0.5 x 0.5 m^2. Air interspace between front and rear glass plates have no hermetical sealing with respect to atmosphere, so that environmental protection of the cells is carried out due to hermetical sealing a thin air gap between rear glass plate and trough-like shaped metallic heat sinks. Heat dissipation takes place immediately to the surroundings, by-passing the rear glass plate (see Fig. 1).

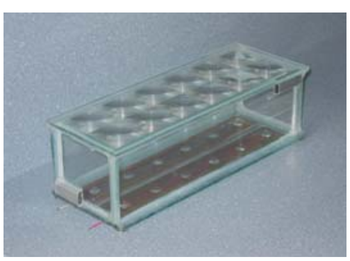

Figure 1: Experimental module with primary and secondary lenses equipped with two ventilation tubes.

2. Trackers Design

High accuracy of tracking to the sun is a specific feature of the high-concentration PV method. Each our tracker is equipped with main (accurate) sensor and additional one, both operating as a part of a close-loop system. Main sensor can align the tracker with the sun to within 0.05 degree of arc accuracy with acceptance angles of ±70° in both horizontal and vertical directions. Additional sensor makes wider the “East/West” turning angle (up to 270°, if necessary). Both sensors are mounted on the suspended frame together with PV modules. They are not sensitive to variations in illumination level, caused by presence and movement of clouds, as well as to parasitic light reflected from various objects during a day. For this, main sensor includes two sub-channels in both horizontal and vertical channels equipped with tandem-type III-V cells with increased output voltage. Differential signals are generated in correspondence with misalignments of the installation to the sun in azimuth and elevation. Additional sun sensor consists of three tandem PV cells.

In construction of the trackers the cheapest structural materials are used, such as roll-formed perforated channels and angles, made of zinc-protected steel. All members are no longer than 2 meters. Tracker consists of two main moving parts (see Figure 2): a base platform moving around vertical axis, and a suspended one with PV modules moving around horizontal axis. The base platform is equipped with three wheels one of which is connected with azimuth drive. Only a flat territory is necessary for tracker operation. The suspended platform is a frame where concentrator modules are installed as three steps of a stair. Position of the suspended frame can vary in the range of ±45° symmetrically about a horizontal plane

Figure 2: Sun tracker with concentrator PV modules installed on the roof of the Ioffe Institute. A similar tracker has been delivered to NREL (USA) and deployed in the frame of the IPP Program under Subcontract AAT-3-32614-01.

New Cassegrainian PV Module using Dichroic Secondary and Multijunction Solar Cells

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ABSTRACT

1. General Objective

Our objective is to demonstrate a 33% efficient solar concentrator PV module using 40% efficient multijunction (MJ) solar cells. This very high efficiency module can then produce cost competitive solar electric power.

2. The Cassegrainian Module Concept

Herein, we describe a new concentrator PV module that provides conveniently for two cell locations so that ideal 3J (=2J+1J) and 4J (=2J+2J) cell efficiencies can potentially be obtained. A new module design using a Cassegrainian mirror configuration is shown in figure 1. This Cassegrainian configuration splits the sun's spectrum using a dichroic hyperbolic secondary mirror providing two focal points, one for the near visible and the second for the infrared (IR). The 2J GaInP/GaAs cell can be located at the near visible light focus and a GaSb IR booster cell or a GaInAsP/GaInAs lattice matched 2J cell can be located at the long-wavelength infrared (IR) focal point.

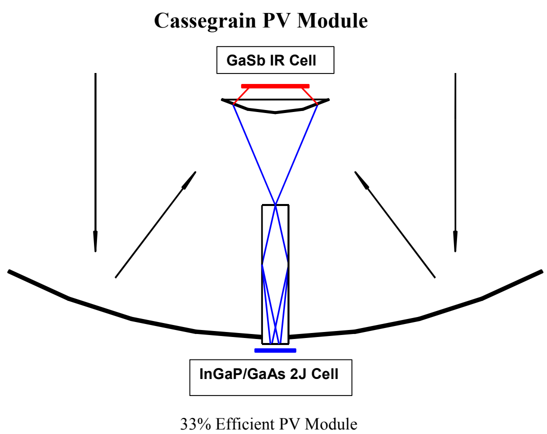

Figure 1: Cassegrainian PV Module Concept uses a dichroic hyperbolic secondary mirror to split the spectrum into short and long wavelength bands to create two focal points.

The first advantage of the Cassegrainian module is that the dichroic secondary either transmits or reflects. There are no absorption or shading losses for the IR cell. A second advantage for this Cassegrainian design is that the GaInP/GaAs cell is now a straightforward design with gridlines on top and full metal on back. A third advantage is in thermal management in that the heat load is now divided into two separate locations.

3. Cassegrain Module with GaInP/GaAs-GaSb Cells

A preliminary design for a 32.4% efficient module that is based on today's existing GaInP/GaAs and GaSb cells is shown in figure 2. Detailed drawings for the various components have now been completed and we are now ordering the parts required to implement this design. The primary mirror size in this module is 25 cm x 25 cm.

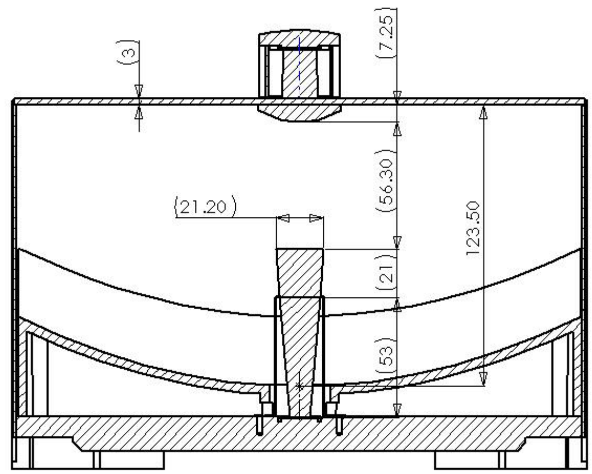

Figure 2: Cassegrain module design with dimensions (mm).

4. Projected Performance

Table 1 summarizes the projected performance for this near term module. The efficiencies of the component cells sum to 38% and given module optical losses, a module efficiency of 32.4% is predicted. The result is a prediction of 20 W for a 25 cm x 25 cm unit module.

Table 1: Projected Module Performance

	GaInP/GaAs 2J cell	GaSb IR cell	TOTAL
Input Solar Flux STC 25 x 25 cm^2 Primary	62.5 W	62.5 W	
Cell Efficiency	30%	8%	38%
Optical Efficiency	85%	86%	
Combined Efficiency	25.5%	6.9%	32.4%
DC Power Out	15.9 W	4.3 W	20.2 W

5. Conclusions

In conclusion, the Cassegrainian PV module design provides two separate cell locations, and makes achieving near ideal efficiencies for 3J and 4J cells practical. (38% near term with 30% GaInP/GaAs + 8% GaSb). The ideal efficiency under concentration for hybrid 3J cells = 2J + 1J is 47% while the ideal efficiency for hybrid 4J cells = 2J + 2J is 52%.

Design, Manufacturing, and Testing of a Prototype Multijunction Concentrator Module

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Abstract:

As a commercial manufacturer of III-V multijunction solar cells, Emcore has made a business case for a vertically integrated approach to the commercialization of high concentration PV modules using III-V multijunction cells. Towards this goal we have leveraged both internal and external (NREL HiPer PV program) funding to make technical advances in three areas: the development of high-concentration multijunction cell technology, design and construction of a prototype module, and the establishment of on-site, on-sun testing capability. Complete module prototypes have been designed and constructed, including copper-based receivers for electrical interconnect and thermal management, PMMA Fresnel primary lenses of 520 cm^2 aperture area, and reflective secondary optical elements for beam homogenization and improved tracking tolerance. These elements have been incorporated into both single cell and 4 cell module prototypes. On-sun testing has resulted in over 24% module-level efficiencies.

The FLATCON® Concentrator PV-Technology

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ABSTRACT

This paper reports about the actual technology status of the FLATCON®-technology developed at Fraunhofer ISE. This includes the fabrication of multi-junction lattice mismatched concentrator solar cells. An efficiency of 35.2 % @ 300-600 suns was recently achieved for this type of cell. FLATCON® -modules are based on an all-glass design. Completely hermetically sealed modules and modules using a special filter were tested. Results of more than two years of outdoor experiences as well as testing in climate chambers will be presented. Recently, the optical efficiency of the Fresnel lens was slightly improved to 82 %. Together with the new triple-junction cells we expect operating efficiencies up to 28 %. In February 2005 the company Concentrix Solar GmbH was founded aiming to manufacture concentrator systems based on the FLATCON® technology.

Extended description

The FLATCON® technology has been developed during recent years at Fraunhofer ISE in a co-operation with the Ioffe-Institute, St. Petersburg and is now ready for the market.

Fraunhofer ISE has a more than 15 year experience in the development of III-V based concentrator solar cells. Starting with LPE-grown GaAs single-junction solar cells in the 80ies, we developed multi-junction concentrator solar cells using MOVPE technology in the year 2000. From the very beginning we were focusing on lattice mismatched $Ga_{0.35}In_{0.65}P$ and $Ga_{0.83}In_{0.17}As$ material grown on GaAs or Ge. The reason for choosing this path of research is simply that higher cell efficiencies are theoretically achievable compared to the commonly used lattice matched $Ga_{0.51}In_{0.49}P$ and GaAs materials. In 2001 we achieved an efficiency of 31.1. % @300 suns (AM1.5d "old", area of 0.1326 cm²) for a $Ga_{0.35}In_{0.65}P$/$Ga_{0.83}In_{0.17}As$ dual-junction concentrator solar cell. This had proven the validity of the use of lattice mismatched material for high efficiency concentrator solar cells. Those dual-junction solar cells are still the working horse in our current FLATCON® -modules under test. However, very recently we started to manufacture triple-junction solar cells growing the lattice mismatched $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ structure on activated Ge-substrates. An efficiency of 35.2 % @ 300-500 suns (AM1.5d, low AOD) was achieved on circular 2 mm cells. This cell type is optimised for the use in our FLATCON® -modules, thus not aiming for record efficiencies. For example, the front grid was designed assuming a Gaussian illumination profile with a 5 times higher intensity in the centre (as compared to the averaged intensity). This leads to a higher metalisation in the centre of the cell lowering the efficiency under a homogeneous illumination in the laboratory. An interesting feature of this cell is that all the three sub cells ($Ga_{0.35}In_{0.65}P$, $Ga_{0.83}In_{0.17}As$ and Ge) generate nearly the same amount of current, as determined by external quantum efficiency measurements.

However, in contrast to flat plate PV in concentrator PV we have to consider the interaction between concentrating optics and the cell. Thus, we have to optimise the concentrator system. Fraunhofer ISE is one of the few institutes world wide which is developing all components: cells, modules, tracking system control and BOS. As mentioned, circular cells 2mm in diameter and designed for operation under 500x are used in our **F**resnel **L**ens **A**ll-glass **T**andem cell **CON**centrator (FLACTON®) modules. A special technology was developed for the concentrating optics: 48 Fresnel structures (4x4 cm² each) are stamped into a 0.2 mm thin silicone film on glass. The frame of the modules are made from glass plates with a height of 75 mm. The cells are soldered on a copper plate and subsequently glued to a glass sheet using pick and place machines. The module is sealed with structural silicone. While at the beginning we used hermetically sealed modules we recently introduced a small filter to allow for pressure exchange. The modules were tested on our tracking system for more than 2 years and we carried out indoor tests in climate chambers. We have found that the FLACTON® -modules work reliable and we measured an efficiency of 22.7 % under operating conditions using dual-junction solar cells. However, at the conference we will present the first results of FLACTON®-modules using the recently developed triple-junction cell as well as an improved optical efficiency. Thus, we expect module efficiencies higher than 25 % up to 28 %. In combination with the relatively simple manufacturing technologies we expect costs below 2.5 €/W_p assuming a 20 MW fabrication capacity. In order to go this fabrication path the company Concentrix Solar GmbH was founded as a spin-off company of Fraunhofer ISE.

Planar Concentrators at the Etendue Limit

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Abstract

Aplanatic imaging concentrators recently proposed by Gordon et al are integrally combined with nonimaging flux boosters to produce an ultra-compact planar concentrator that performs close to the etendue limit. Such designs are attractive for high-efficiency multi-junction solar cells. Current commercial fabrication technologies can realize cell efficiencies of 40% at high flux (hundreds to thousands of suns) in cells of order one square millimeter. The all-dielectric designs presented here should be capable of (a) generating about one watt from such a one square millimeter cell, (b) accommodating liberal optical tolerances, (c) realizing the fundamental compactness limit of a 1/4 aspect ratio (f-number), (d) completely passive cooling, (e) a concentrator mass that is equivalent to a 5 mm thick pane of glass, as well as (f) precision mass production via existing glass and polymeric moulding techniques.

Hemispherical Solar Concentrator Corrected for Aberrations

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1. What Diocles Didn't Know

When Diocles around 200 B.C. compared the 'burning-power' of a hemispherical and a paraboloidal mirror, he knew everything about their geometries. He didn't know that it is possible to analytically find the shape of a secondary concentrator for the hemispherical primary, which would correct spherical aberrations.

The secondary's shape was not found until 1957 [1]. We use this shape, and optimize its position relative to the primary and the target. The result is a solar concentrator for medium to high concentration, with the inherent advantages of the spherical shape, i.e. the geometry is easier to make because of its constant local slope, and the primary may be constructed as stationary concentrator, with only the secondary tracking the sun.

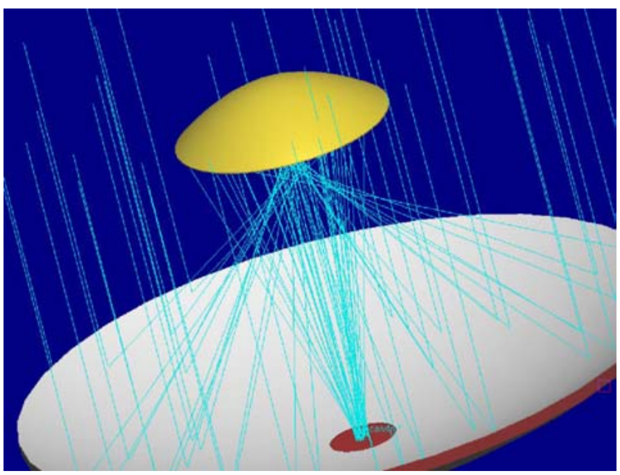

Figure 1: Spherical primary mirror with secondary concentrator. Version with medium concentration 1000 X, receiver out of the rays' paths, integrated into the primary mirror for cooling

2. Correction of Coma Using a Secondary

Head's solution is valid only for a point source. For small extended sources, such as the sun, the aberration caused by non-paraxial incidence is coma. Coma can be corrected by adhering to the Abbe-sine-condition.

Our design follows this principle. We find two separate maxima to an objective function, incorporating the deviation from the Abbe-sine-condition, the concentration ratio, and three types of shading.

Other configurations are possible, such as the version with medium concentration of 1000 X in Fig. 1, where the receiver is integrated into the primary for cooling and constructive reasons. This is an example of a system with a tracking primary.

3. Performance Comparison with the Paraboloid

The ideal paraboloid remains superior in optical performance to the spherical primary with secondary for all but the highest concentration ratios. A typical irradiance distribution is given in Fig. 2. Both systems' performances are close, and a practical decision must include the manufacturability of the respective geometries, and the operational advantage of the spherical concentrator.

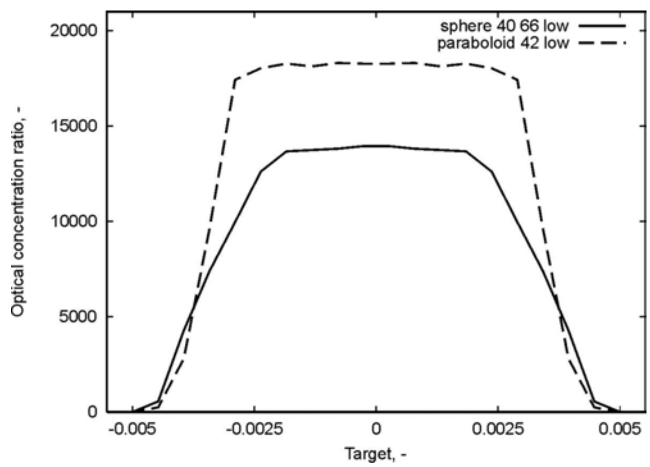

Figure 2: Irradiance distribution on the target of spherical primary with secondary concentrator, and ideal parabolidal concentrator of high concentration >10 000 X

4. Conclusions

We have designed a new class of spherical primaries with corrective secondary mirrors for solar concentration. The systems are competitive with paraboloidal geometries of medium and high concentration ratios.

References

1. Head, A.K., *A new form for a giant radio telescope.* Nature, 1957. **179**: p. 692-693.

Realization of Compact, Passively Cooled, High-Flux Commercial Photovoltaic Prototypes

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Abstract

We report on the materialization of a recent conceptual advance in high-flux photovoltaic concentrators into first-generation commercial prototypes. The design strategy employs a tailored imaging dual-mirror system, with a tapered glass rod that boosts concentration and accommodates greater concentrator optical errors. The final designs were severely constrained by the need for ultra-compact (minimal aspect ratio) modules, simple passive heat sinks, liberal optical tolerances, employing commercial off-the-shelf solar cells, and practical considerations of inexpensive fabrication technologies. Each concentrator has a geometric concentration of 625 and irradiates a single 100 mm^2 square triple-junction high-efficiency solar cell at a net flux of 500 suns.

One-Axis PV Sun Concentrator Based on Linear Nonimaging Fresnel Lens

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This paper is the result of a fruitful cooperation, and will be presented by both leading authors.

1. The Concentrator Concept

The arched nonimaging Fresnel lens [1] has been prototyped and tested (Fig. 1) with the intention to create a marketable solar concentrator for one-axis tracking.
The concentrator system is based on PV cell technology proprietary to Day4 Energy Inc. The cell is best suited for low concentration ratios between five and ten.

Figure 3: Nonimaging arched Fresnel. The reflective paper is held approximately at the receiver level, while the hands demonstrate the size of the concentrator

2. The Nonimaging Fresnel Lens

The Fresnel lens is based on nonimaging design principles, namely the edge-ray principle for extended sources. The lens has design acceptance half-angles of $\theta = 6°$, and $\theta = 18°$ in the cross-sectional plane and the plane perpendicular to it, respectively. It features minimum deviation/dispersion prisms. The design is matched to the one-axis azimuthal tracking of the concentrator.

3. The PV Cell

The 10-cm wide PV receiver employs conventional monocrystalline half-finished PV cells with Day4 proprietary current collecting front and rear side electrodes which allow the PV cell to operate under up to 10 suns concentrated solar radiation without conversion efficiency decline.
Day4 PV cells production technology is applicable for mass production, thus offering a distinctive cost advantage for sun concentrator application.

4. Performance in Simulation and Experiment

The optical concentration ratio of the arched nonimaging Fresnel lens (i.e. its geometrical concentration ratio multiplied by its optical efficiency) is 6.1 for normal incidence, including Fresnel losses at the surfaces and reflection losses at the kaleidoscope secondary. The simulation of other combinations of incidence angles is shown in Fig. 2. Experiments with a first prototype revealed a design flaw, resulting in a dark. The problem was solved for the second lens generation.
The sun concentrator with water cooled PV receiver was tested on 1-axis tracker of Array Technologies Inc. with tracking accuracy of ±1.5°. The PV concentrator demonstrated an efficiency of 18.2% at 32°C relative to solar radiation within half-angle $\theta = 6°$.

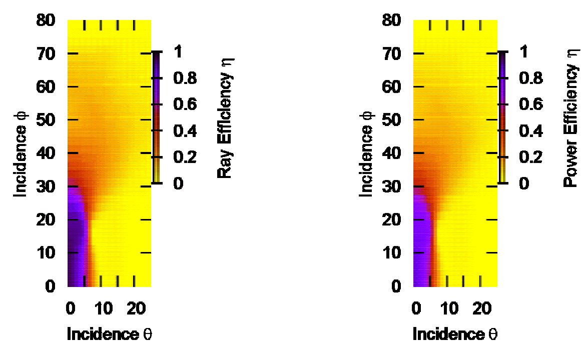

Figure 4: Optical performance of the linear nonimaging Fresnel lens with kaleidoscope secondary

5. Conclusions

Optimzed linear Fresnel lenses perform well in solar collectors of low to medium concentration. This is confirmed in simulation and experiment with an arched nonimaging Fresnel lens for one-axis tracking. A kaleidoscope secondary increases the homogeneity of the irradiance and the concentration of the system.
It is crucial to utilize PV cells designed for this low range of concentration, and match the optics with the cell.

References

1. Leutz, R., Suzuki, Akio, *Nonimaging Fresnel Lenses: Design and Performance of Solar Concentrators*. Optical Sciences. 2001, Berlin: Springer Verlag.

Design of Non-Imaging Fresnel Lens for 500X Solar

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Abstract not available.

The Evolution of High Intensity Photovoltaic Cells from Thermophotovoltaic Applications to High Concentration Solar Applications: Lessons Learned

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The foundations of the current designs for silicon solar cells used for high-flux concentrator systems can be traced to developments that occurred more than thirty-five years ago in the development of high intensity thermophotovoltaic cells that were operated under continuous illuminations of greater than 30 Wcm^{-2}. The Interdigitated Back Contact Cell, developed for the high flux conditions of TPV systems, was directly applied to silicon high concentration terrestrial applications. These silicon cells were operated, in 1974, under continuous conditions at flux densities of greater than 30 Wcm^{-2} with efficiencies of 18%. The IBC cells were the direct precursor to the point contact cell, which still holds the record for efficiency for silicon cells under concentration. One and two dimension computer models developed to design these cells were the first solar cell numerical models to provide contact-to-contact models of both minority and majority carrier current flows. Many of the lessons learned in the design of these high flux cells have a direct influence on today's cell designs.

Indoor Characterization of Concentrator Modules: Application on the Production Line

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ABSTRACT:

New concepts of concentrator modules have been proposed in the last years based on high concentration refractive optics and cost effective III-V devices at such high concentration levels. The concentration ratio in these approaches is higher than 300X, and therefore, the maximum acceptance angle of the system is very narrow, in the range of one degree. A consequence is that a sun tracking system is required in normal operation. Nevertheless, outdoor characterization could be adequate for research work but it is not practical for its use on the production line so the well-know flash lamp technique has been explored in this work. The main difference with conventional panels is that not only the irradiance requirement must be fulfilled, but also the angular size of the light source is essential. This last condition becomes harder when combined with large area modules (larger than 500 cm^2). For example, a point light source should be placed at a quite fair distance (more than 20 m) to illuminate the whole aperture within the acceptance angle and the practical power of commercial lamps would not allow to reach the irradiance values of 0.1W/cm^2 in the module. Several approaches have been studied and one based on a large area optical device to fulfill both illumination conditions has been chosen. The requirements of the light source, the design and manufacturing of the optical device are the most novel contributions of this work.

[1] Bett AW, Baur C, Dimroth F, Lange G, Meusel M, Riesen S van, Siefer G, Andreev VM, Rumyantsev VD, Sadchikov NA. FLATCON-MODULES: Technology and Characterization, *Proceedings of the 3rd WCPEC,* 2003.
[2] Andreev V, Ionova E, Rumyantsev V, Sadchikov N, Shvarts M. Concentrator PV Modules of "All-Glass" Design with Modified Structure. *Proceedings of the 3rd WCPEC,* 2003.
[3] Díaz V, Alonso J, Hernández M, Álvarez JL, Labrador M, Blen J, Mohedano R, Benítez P, Miñano JC, Preuss W, Gessenharter A. Progress in the Manufacture of Ultra Flat Optics for Very High Concentration Flat Panels. *Proceedings of the 29th IEEE PVSC*, 2002; 1580-1583
[4] Araki K, Kondo M, Uozumi H, Yamaguchi M. Development of a Robust and High Efficiency Concentrator Receiver. *Proceedings of the 3rd WCPEC,* 2003.

On-Sun Testing of Multijunction PV Cells

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ABSTRACT

Concentrating Technologies, LLC (CT) is developing a solar power conversion system using reflective optics and high efficiency PV cells for utility-scale use. This high concentration PV (HCPV) system uses a small-footprint power conversion unit (PCU) that can be combined to form a myriad of power levels on two-axis tracking systems.

CT has performed extensive test work with Arizona Public Service and Spectrolab (SL) over the past five years to try and identify potential issues with using SL's multijunction cells in a utility environment. CT started working with dense arrays and the preferred design has changed into a single cell PCU at about 500x. On-sun testing has led to improvements in the basic designs for the receiver, heat exchanger, optics, and cell. The specific power has climbed from about 5 W/cm^2 to almost 14 W/cm^2 with an $850W/m^2$ sun. The test program has given confidence that the latest Spectrolab triple-junction PV cells are ready for long-term utility-scale deployment.

CPV Sun Tracking at InSpira

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ABSTRACT

This paper presents a general overview of the projects developed at Inspira in the field of sun tracking for photovoltaic concentration technologies. Being sun tracking, Inspira's major point of contact with CPV efforts up to now, the development of the *EPS-Tenerife* sun tracking control unit for BP Solar's *EUCLIDES*™ constitutes our first attempt in this domain which concludes with the production in 1998 of 14 sun tracking control units for the 480kWp *EUCLIDES* plant in Tenerife. Second significant landmark, is the development, still under progress, of a complete sun tracking solution for Isofoton's micro-concentrator modules. Always working on hybrid approaches, based in an ephemeris computation core complemented by some sort of feedback, both adaptive and model based strategies have been developed. These developments, presently being supported by several EC initiatives, such as *Fullspectrum* or the *Marie Curie Fellowship* programme, are also being customized and tested in new concentrator prototypes such as *PV-Fibre* or *Proteas.*

Outdoor Testing of $GaInP_2$/GaAs Tandem Cells with Top Cell Thickness Varied

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ABSTRACT:

To maximize the performance of $GaInP_2$/GaAs tandem cells and $GaInP_2$/GaAs/Ge triple-junction cells, the top $GaInP_2$ cell must be "thinned" slightly to allow some above-band-gap photons to pass through to the GaAs cell. Because the terrestrial solar spectrum changes throughout the day, different top cell thicknesses (t_{top}s) are optimal for different times of the day. This raises two questions: "What t_{top} is best for my application?" and "How critical is that choice?"

To help determine the best t_{top} for a given application, a set of $GaInP_2$/GaAs tandem cells with different t_{top}s were mounted on a collimated two-axis tracker for direct comparison outdoors over the course of several days. We find that cells designed for Low AOD, "Clear Sky", or AM 1.5G standard spectra all work quite well. The AM 1.5D spectrum is a poor choice, unless maximizing morning and/or evening power production is a priority. Model results support these conclusions.

The Development of High Concentrating III-V Photovoltaic Modules at INER Taiwan

By

Yen-Chang Tzeng, Chih-Hung Wu, Hwa-Yuh Shin, Hwen-Fen Hong and Chieh Cheng

ABSTRACT

Concentrating photovoltaic modules are fabricated successfully at INER Taiwan through the use of triple-junction solar cell. The module is composed of the Fresnel lens, a secondary collimator, a triple-junction solar cell (supplied by Spectrolab Incorporation) and heat sink. Photovoltaic characteristics of the module are measured. The output power of the module having a 1x1cm^2 solar cell is 4.1W with a geometrical concentration ratio 144x when measured at 10:00 AM outdoors; while an output power of 5.2W can be obtained as the geometrical concentration ratio is 245x when measured at 13:40 AM outdoors. Additionally, the characteristics of the triple-junction solar cells under various illuminations and temperatures are investigated experimentally. Based on the study, a new 100x geometrical concentration ratio solar module is also developed. A module efficiency of 19.98% is obtained with the aid of a second collimator. An array of 1x9 modules is also developed. A module efficiency of 19.9% for the 1x9 array is measured under DNI=778 W/cm^2. In this report, details of the related experimental results are also described.

KEYWORDS: Concentrating photovoltaic module, Triple-junction solar cell, Photovoltaic characteristics

Dichroic Flat Faceted Concentrator for PV Use

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Keywords: Spectral splitting, concentrated solar, photovoltaic, flat mirror, composite dish

ABSTRACT

Reflective concentrator systems has been demonstrated offering an interesting approach to cost reduction for solar photovoltaic. Still, the efficiency of concentrator system is limited by the inherently low efficiency of silicon that does not exceed 24%, even at 250 suns. The use of tandem cells is still prohibitive from the point of view of costs and, due to the cell series connection, suffers from spectral fluctuations in the earth received solar radiation.

We present a system which split the solar spectrum in different parts and send each part to the most suitable concentrator solar cells module.

Such a division is obtained, in the presented prototype, at the primary concentrator that employs a specifically designed double dichroic mirror generating two illuminated areas providing a cost effective solution to the problem.

The theory, design, numerical simulation and first results of the system installed in Ferrara will be presented at this meeting as well as some projection on costs.

Performance of Concentrating Photovoltaic/Thermal Systems Using Solar Cells Immersed in Dielectric Liquid

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ABSTRACT

Solar cells immersed in a dielectric liquid under certain conditions have an increasing operating efficiency. This kind of immersion operation of solar cells is suitable for photovoltaic concentrator and hybrid PV/Thermal applications. An experimental apparatus was set up to evaluate the system thermal and electric performances. The system consists of parabolic dish concentrator, PV/T module and liquid tank. The liquid can provide an effective cooling to the cells through combination of the spectrally selective liquid that can absorb unwanted solar radiation from reaching solar cells and the convection heat transfer between the liquid and the solar cells. The immersion operation can maintain the working temperature of ordinary solar cells under concentrating conditions while the concentration ratio limits to 20. The system makes full use of the spectrum of solar radiation and improves the overall system efficiency.

Representative Samples for Concentrator Photovoltiac Module Qualification Testing

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ABSTRACT: This paper reports the developmental status of a new test standard IEC 62108, titled "Concentrator Phhotovoltaic (CPV) Receivers and Modules - Design Qualification and Type Approval." The IEC CPV working group, TC82/ WG7, is currently exploring the possibility and validity of using small representative samples in place of large/actual product for the design qualification testing. By using appropriately designed and fabricated representative smaller samples, the qualification tests can be conducted to considerably reduce the testing costs and/or time to the manufacturers, while maintaining a reasonable engineering confidence level on the results. In the year 2000, the flat-plate PV module working group, TC82/WG2, developed a Retest/Similarity Test Guideline. This guideline has been accepted and adopted by the worldwide PV community including the independent testing laboratories. Based on this guideline, after the largest type/model from a given flat-plate module family passed a full sequence in the qualification test program, other smaller types/models in the same family can be fully qualified by running a fewer tests on fewer samples. This larger-representing-smaller approach, however, can not be directly applied to CPV, because many CPV systems are in the range of several kilowatts, and their sizes are much larger than available test equipment can handle, primarily environmental chambers. The intention of TC82/WG7 is to apply the "similarity" approach to the CPV qualification but in the reverse order, that is, smaller-representing-larger. This paper discusses the potential failure mechanisms under different testing sequences, and then gives some suggestions on how to design and fabricate appropriate smaller representative samples. This new approach will be discussed within TC82/WG7 for a possible incorporation in the IEC 62108 standard, and then submitted for an international voting.

Optimization of High-Concentration Multijunction Solar Cells

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A methodology for the design of high-concentration solar cells is presented. The current densities present in concentrator multijunction solar cells routinely exceed 1000 mA/cm^2. At these levels, careful design of the solar cell structure to minimize resistive power losses is essential. Increasing the doping in the upper multijunction layers decreases the resistivity of the semiconductor and therefore reduces the resistive power loss in the semiconductor. However, excessive doping leads to a decrease in blue response (due to free carrier absorption) in the top subcell that can offset any reduction in resistive power losses. Optimization of these two competing factors will lead to the highest overall cell efficiency. This methodology has been applied to several high-efficiency solar cell designs. Results from the latest concentrator multijunction solar cell design will be presented along with the modeling data.

ENTECH's Stretched Lens Array (SLA) for NASA's Moon/Mars Exploration Missions, Including Near-Term Terrestrial Spin-Offs

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ABSTRACT: Since 1986, ENTECH has been developing photovoltaic concentrator arrays for space power. ENTECH's arrays utilize ultra-light Fresnel lens optics to focus sunlight onto multi-junction solar cells. An ENTECH mini-dome lens array (using Boeing cells) on the NASA-USAF PASP-Plus flight experiment in 1994-95 demonstrated the best performance and durability of 12 advanced array types in a high-radiation orbit. An ENTECH line-focus lens array (*SCARLET*, integrated by ABLE using TECSTAR cells) on NASA's Deep Space 1 probe in 1998-2001 demonstrated exceptional performance in powering both the spacecraft and its ion engine for 38 months, enabling rendezvous with both an asteroid (Braille) and a comet (Borrelly). Our latest technology, the Stretched Lens Array, offers substantial improvements over SCARLET. NASA's Exploration Systems Mission Directorate recently selected SLA for a major Technology Maturation Program. SLA and its many attributes will be discussed in the paper, as will potential terrestrial spin-offs from this exciting space technology.

Combining the Tools for Solar Thermal And Photovoltaic Power Generation— The Experimental and Computational Facilities at The University of Sydney

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ABSTRACT

Solar concentrator power generation represents a crossing point between the concerns of solar thermal and photovoltaic power generation. Problems ranging from the design of solar collectors, flux uniformity and heat transfer are common to both fields. In particular, the recent interest in hybrid concentrator PV/thermal power generation has broadened the outlook of both the solar thermal and photovoltaic communities. This paper presents the models and test facilities designed for thermal systems to concentrator photovoltaic or hybrid thermal/photovoltaic systems, with particular emphasis on the facilities and the modelling capabilities at the University of Sydney.

1. Assessment and design of solar concentrators

The design of solar energy systems is not necessarily governed by creating the most efficient configuration to convert solar energy into electricity, but in designing a system that produces electricity at the lowest cost. Computer modelling forms an important aspect of efficient and cost effective concentrator design and an array of computational tools have been developed at the University of Sydney to specifically address these issues.

This paper will present the tools that provide a framework for identifying optimal optical designs and absorber profiles. The models accurately predict the high flux distributions in 3 dimensions about the absorber plane (Figure 1 – cross section), which is essential in the determining the performance and longevity of absorber modules. In this paper, we will illustrate the latest simulations of surfaces illuminated with an homogenous distribution, critical for concentrating PV applications.

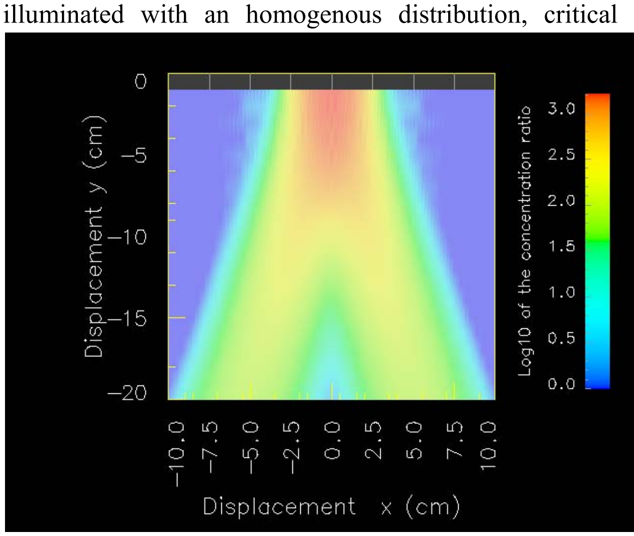

Figure 5: Simulation of the cross-section of the flux passing through the imaging plane of the experimental facility at the University of Sydney (The orientation of the simulation can be seen in Figure 2).

Thermal management of the absorbers forms the operating basis for efficient solar thermal collectors and an important issue for PV systems. The University of Sydney is applying its considerable experience in heat transfer simulation of thermal absorbers to the problem of cooling PV under concentrated sunlight.

In complement to the optical and thermal design, it is important to understand and accurately simulate the response of a PV device under solar concentration. A model has been developed that can simulate both single junction and multi-junction concentrator devices from basic semiconductor considerations. The model can be scaled from the cell level to an entire module. The model is also linked to an outdoor concentrator PV test database, allowing realistic simulations to be readily performed with rapid comparison against experimental results.

2. Experimental facilities

The Solar Energy Group is in the final stages of characterising a high flux Fresnel parabolic solar concentrator (Figure 2) that will be used as a platform for the experimental evaluation of devices and surfaces under realistic conditions. The concentrator consists of 18x0.6m diameter circular mirrors that can provide tuneable fluxes ranging from 200-1000 suns uniformly over an area of $10cm^2$.

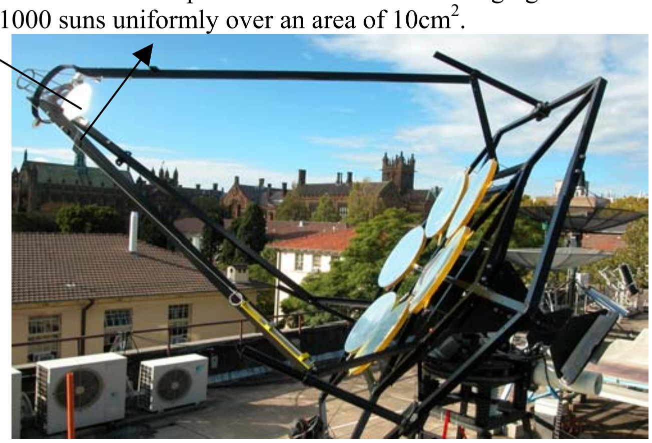

Figure 2: The high flux solar concentrator at the University of Sydney (6 mirror mode). The arrows indicate the x and y displacement as seen in Figure 1.

3. Summation

A complete set of computational tools have been developed at the University of Sydney that allow virtually any concentrating system to be analysed, in terms its thermal and/or photovoltaic power generation. These computational tools are backed up by experimental facilities capable of fabricating and assessing a range of concentrator devices and materials. This paper presents the most recent results in experimental and computational modelling of high flux PV simulations.

The agiceiver™ − a New Approach for Hydrogen Production by Concentrated Sun Light

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ABSTRACT

The agiceiver™ is a special receiver for concentrated sun light. It combines a properly tailored semiconductor solar cell and an electrolysis cell on top of which the solar cell is mounted. Efficient cooling by the electrolyte allows for high concentration factors. An additional thermo-electric voltage contributes to its overall efficiency. The electrode is a metallic conductor rather than a semiconductor. First results indicate that the agiceiver™ might be useful for concentrations to 4000X or even above. This approach allows omitting all electronic circuits to match the electrical characteristics of the solar cell and the electrolysis cell. By directly producing hydrogen rather then providing electrical energy this device might contribute to fuel the growing number of hydrogen powered cars in an environmentally friendly way. This paper is presented at an early stage of our development. It is rather meant to fuel a discussion in the community than to present final results.

Nonimaging Reflective Lens Concentrator

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A new rear-focus concentrator design is discussed. The concentrator consists of an array of relatively narrow reflectors redirecting the incident sunlight downward and thus acting together like a non-imaging lens. It is shown that one-stage concentrations between 20 and 40 suns (in a linear configuration) and above 1,000 suns (for a point focus design) are achievable for a PV receiver positioned below the concentrator. We also demonstrate that the concentrated flux can be substantially homogenized without the use of secondary optics although simple secondaries can be employed to further increase concentration and improve flux uniformity. A point-focus reflective lens can also be used in high-temperature furnaces and water-splitting hydrogen production applications to deliver highly concentrated fluxes (>1,000 W/cm^2) directly to the reactor. Results of prototyping and testing of several linear-focus PV concentrators based on this concept are also presented.

Recent Progress of Electrochemical Solar Water Splitting with Photoelectrodes and Photocatalysts

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Abstract:

Solar water splitting into hydrogen and oxygen with a semiconductor/electrolyte junction has merits in that (1) inexpensive thin-film semiconductor materials can easily be used, and (2) no current collection (and hence no expensive transparent conductive oxide film) is necessary, in contrast to thin-film solar cells. The main problem is that it is not easy to find efficient and stable semiconductor electrodes or photocatalysts operating in aqueous solutions. In the present talk, I will review recent progress of studies on electrochemical solar water splitting, though the present achievements are still far from the ideal goal. The talk will include the effective stabilization of n-Si by a combination of surface alkylation and metal nano-dot coating without any loss in the efficiency, solar water splitting with a composite Si/metal-oxide semiconductor electrode, and visible-light responsive metal oxide semiconductors effective for water photooxidation or photoreduction.

Hydrogen Electrolysis Using Concentrated Solar Energy

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The use of electrolysis to separate hydrogen from water is one of the most energy intensive hydrogen production processes. With the majority of the United States' grid power being generated from natural gas and coal fired power plants, the use of grid power in the electrolytic production of hydrogen defeats the purpose of developing a hydrogen economy. Therefore, the development of efficient, pollution free methods of producing hydrogen are essential to the success of the hydrogen economy. Since the feedstock for electrolysis is water, there is no pollution in the generation or use of the fuel. Furthermore, it has become evident that concentrator photovoltaic (CPV) systems have a number of unique attributes that could shortcut the development process and increase the efficiency of hydrogen production to a point where economics will then drive the commercial development to mass scale.

Concentrating solar energy to produce electricity can occur at quite high solar conversion efficiencies. The highest efficiency for solar concentrator cells, as measured at NREL, is now above 37%. In production, similar cells have efficiencies above 30% and are currently in widespread use for powering satellites. Solar Systems has exhibited a 40% boost in hydrogen production by stripping away the solar infrared radiation incident on concentrator solar cells and using it as the heat source for a solid oxide electrolyzer cell operating above 1100 Celsius. With today's solar cell technologies, it is therefore feasible to expect a 50% conversion efficiency of the solar energy to hydrogen through high temperature electrolysis.

With gasoline prices constantly increasing, the cost associated with producing hydrogen is becoming more and more favorable. At $3.10/kg, the cost of producing hydrogen through wind electrolysis is already competitive with that of gasoline. It is expected that hydrogen production through thermal-CPV electrolysis will be equally attractive, if not more so. Details of a cost analysis for such a hydrogen generation system will be presented.

One Step Method to Produce Hydrogen by Tandem Amorphous Silicon Solar Cells

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Abstract

A new direct one step method to split water into hydrogen and oxygen by using tandem amorphous silicon solar cells with p-i-n-p-i-n-p-i-n on glass substrate .The nickel-iron oxide film layer as OER catalyst, which is deposited on the surface of SnO_2 by DC magnetron reactively sputting, and CoMo as HER catalyst is deposited on n-layer of the cell using the same method, as shown in figure 1.

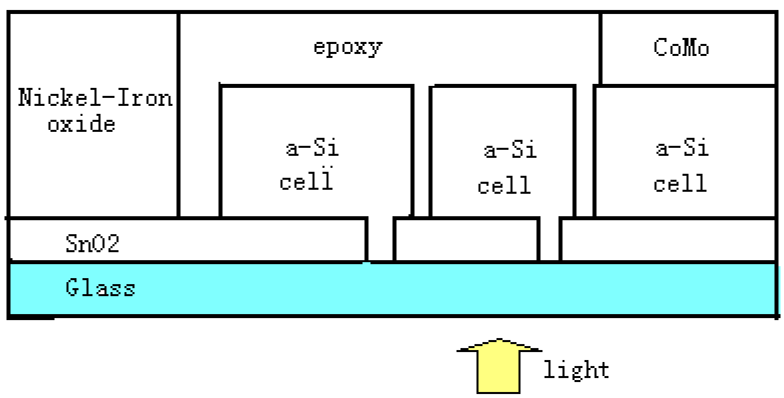

Fig.1 the schematic diagram of photoelectrochemical cell for production hydrogen

The electrochemical load is represented by:

$$V=\eta_{HER}+Veq+J\bullet R(KOH)+\eta_{OER}$$

Where Veq, the decomposition potential for water, is 1.23v; R is the combined resistance of the Helmholtz layer , electrolyte and membrane ; η_{HER} and η_{OER} are the overpotential at the anode and cathode surfaces of the hydrogen and oxygen evolution reaction.

Nickel-iron oxide film electrode, which is as anode of OER, was deposited at room temperature by DC magnetron reactively sputtering device at various oxygen content and pressure. it was charactered by using XRD, XPS and SEM method, and its electrochemical and electric property was measured also. Its property was changed with the processing condition. When the current density is 10-20mA/cm^2, its overpotential is about 0.32V, and this film electrode has good anticorrosion property in alkaline electrolyte also.

The XPS spectra of iron-nickel oxide films indicated Ni in the films existed as +2 and +3 value, and Fe existed as +3 value.

The CoMo film electrode as the cathode, its overpotential is about 0.1V. And its surface morphology is smooth and compact.

Considering the electrochemical resistance, the overall voltage of decomposition water is about 1.9V-2.0V. When the light incidented on amorphous crystal silicon cell, the single cell could produce voltage of 0.7V, through tandem three cells, hydrogen and oxygen can be evolved from separated cathode and anode of this system.

Solar Irradiation Potential for PV Concentrator Systems in India

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Assessment of normal beam irradiation is done for application of PV concentrator systems in India. In a year, India receives about 3000 to 3200 hours of bright sunshine in central and North-west India and about 2600 to 2800 hours in most of the other parts of the country. Measured data for global and diffused irradiation from 15 meteorological stations are used to calculate annual beam irradiance on a plane perpendicular to the sun rays, H_b (kWh/m^2/Year) and annual beam irradiation on a one-axis tracked plane, H_{b1x} (kWh/m^2/Year). H_b and H_{b1x} is calculated for 60 points across the country and thus the map of H_b and H_{b1x} has been plotted. The values of H_b is in the range of 1900 to 2300 in central and north-east region and between 1600 to 1900 in most of the other parts of the country except far-east and far-north. Relatively low value of normal beam irradiation is due to absorption and scattering in the sky during pre-monsoon and monsoon period.

PV Concentrator Systems – A Database Search

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PV concentrator (PVC) systems provide lowest cost energy option among all PV technologies. Despite this, its contribution in the PV market is insignificant. A database search for PVC systems has been done to find out the amount of work done on various topics and to identify the areas that require more attention. Electronic database search of INSPEC has revealed the development of PVC systems in three phases, of growth, stability and decline. In total 1151 papers have been published till now, most of them deal with the solar cells. Among 419 papers on solar cells, 119 is on Si and 140 in on GaAs and other III-V compounds. In the category of concentrator optics, 45 papers are based on Fresnel lens and 37 on static concentrators. Surprisingly very less number of papers are published on solar cell cooling. High cell temperature not only reduces the cell performance but also reduces the reliability of the system and probably requires more attention.

Plastics Structured Optics for Solar Concentrating in PV System

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The main advantages of using plastic structured optics for concentrating solar beams on a receiver of a PV system, instead of the more traditional materials like the glass and the quartz, rely on very large mass production, improved structured optics design and manufacturability, less weight, high optical quality, low unit cost.

ENEA in the aim of PhoCUS (Photovoltaic Concentrators to Utility Scale) Project has designed and patented a prismatic PMMA (polymethylmethacrylate) optic. Among all the moulding technologies, the injection process has been selected to produce this optic. Some critical parameters of manufacturing process have been investigated in order to improve the aspect ratios and the optical quality of the moulded prismatic lens.

The resulting samples appear to have a reduced stress, satisfactorily planar surfaces and a little radius of curvature for rounded corners, corresponding to a good optical efficiency, major than 80%. A further improvement will be the deposition of an antireflective hard coating on the incoming surface.

The first production of prismatic lens has been employed to realize the PhoCUS C-module prototypes, today under outdoor testing.

Design, Realization and Preliminary Performance Analysis of The PhoCUS-5 Standard Unit

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The PhoCUS (Photovoltaic Concentrators to Utility Scale) project was launched by ENEA (Italian Agency for Energy, Environment and New Twechnologies) in the late 2001 to develop, in close cooperation with national industrial operators, a low-cost photovoltaic concentrators technology (C-technology). The road-map of the project was outlined to get in medium term a system cost of 4.1 €/Wp with a production of 5 MW/year.

One of the main objectives of the PhoCUS is the development, the design and the realization of the standard unit. The design criteria of the standard unit have been addressed to develop and optimise the most appropriate technologies in order to realize a system able both to work singularly in connection with the low voltage grid and to be parallel connected each to other for a centralized power generation. The peak power of the standard unit has been fixed at 5 kW in order to meet a distributed generation market demand and to limit the PV generator area in such a way as to install it on a single medium size tracking structure.

The innovative components development, like the C-module and the tracking structure, as well as the design and the realization of the prototypes, have been performed by two qualified National industrial operators, namely ENI TECNOLOGIE (formerly Eurosolare) and Galileo Avionica respectively. In both cases, the design guidelines were addressed to meet the target in terms of cost, reliability and performance.

The novel solution developed for the C-module is a plastic housing, based on thermoplastic resin. The lens parquet is fixed on the housing top, while the cells, individually placed on aluminium dissipating elements, are fixed on its bottom. Cost, weight, handling, alignment and scalability considerations have led us to focus on a 24 commercial (SunPower HECO252) cells assembly (6 x 4) of dimensions about 1m x .68 m x .25 m and weight < 30 kg.
The tracking structure developed is based on a pedestal, supporting on its top a network structure of about 35 m^2 where 51 PV modules will be installed. The driving is obtained by means of two stepper motors, while the motion transmission is assured by reduction gears properly designed to meet the desired stiffness requirements against torsional and bending moment stresses and to withstand both the static and dynamic loads. The mechanical carpentry design was performed so as to get the lightest structure, able to meet simultaneously both the desired stiffness values and the national standard requirements.

The installation of the standard unit first prototype was started at Portici ENEA Research Center last November. At present, the setting up and acceptance phases are in progress.
The paper will report the lesson learned by the design, realization and installation of the system. The results coming from specific experimental campaigns both on single component and on whole system will be presented and discussed

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Research on Graded Optical Band Gap (GBG) In Na-Si:H Solar Cells Prepared By PECVD

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Abstract

The paper report the research on the intrinsic hydrogenated nanoamorphous silicon (na-Si:H) layer with the graded band gap (GBG) in p-i-n solar cells prepared by PECVD in varying the processing parameters. The optical band gap (E_g^{opt}) derived from Tauc plot. We have carried out a investigation of the relationships between the E_g^{opt} with the crystallization ratio (Xc) and the E_g^{opt} with the nanocrystalline grain size (D) in na-Si:H thin films grown by PECVD on glass substrates through XRD, Raman scattering, transmission. The E_g^{opt} increase with the decreases of the crystallization ratio (Xc) and the nanocrystalline grain size (D). But with the increase of the DC Bias Voltage. The hydrogen dilution ratio is found to increase basically both the crystallization ratio (Xc) and the nanocrystalline grain size (D). According the simulated and optimized the band gap figure of solar cells by AMPS-1D, we utilized all the relationship to tune the band gap of i na-Si:H layer of p-i-n solar cells prepared by PECVD in varying the processing parameters(the DC Bias Voltage and the hydrogen dilution ratio), got the graded band gap (GBG) in the i type na-Si:H in p-i-n solar cells, then enhanced this kind of solar cell's conversion efficiency to 11.26% (solar cell's active area: 95mm^2, AM1.5,1000W/m^2, 25℃). Two relationships in na-Si:H are discussed by the etching effect of atomic hydrogen in the framework of the growth mechanism and the quantum size effect (QSE) .Because the nanocrystalline silicon speciality, the nanoamorphous silicon solar cells is better temperature and irradiation stability, so it can be used in the concentration solar cells. This result will improve heat sinking, long-term behavior, cell degradation, and reliability, reduced the system cost accordingly.

Keywords: Graded optical band gap (GBG), Hydrogenated nanoamorphous silicon thin films, Nanocrystalline grain, Solar cells, PECVD

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Increase Solar Collector Efficiency Through SunTrap™ Technology

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Abstract:

Radiant Power, LLC (RP) has designed, developed and tested a new solar collection system, which has demonstrated the ability to greatly increase the overall efficiency of photovoltaic (PV) modules.

This process relies on RP's patented SunTrap™ technology, in which PV cells are arranged such that non-absored, incident photons are reflected onto and re-absorbed by additional PVs. The cumulative absorption increases the over-all External quantum Efficiency of the system, thereby increasing the efficiency.

The concept is material and system agnostic, having application to virtually any PV cell material or type, from 1-sun t high concentration. Recent tests with III-V concentrator cells have demonstrated extremely high efficiencies. A description of the SunTrap™ design and results of various tests are presented.

Design Principles of Tonatiuh, an Open Source Computer Program for the Design and Analysis of Solar Concentrating Systems

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ABSTRACT

The Tonatiuh project consists of the design, development, implementation, verification, and validation of Tonatiuh, an open-source advanced object-oriented program, that using distributed computing, Monte Carlo ray tracing, and the best 3D user interface technologies available today, aims to provide a sophisticated and efficient environment for the design and analysis of solar concentrating systems.

The software development effort leading to the development of Tonatiuh started just last summer at the Department of Engineering of The University of Texas at Brownsville under a three-year DOE-NREL Minority Research Associate (MURA) Program subcontract.

Although the first release of Tonatiuh has not been concluded yet –it is scheduled for the end of May, 2005- Tonatiuh's leading design principles have already been established and are being applied consistently in the development of the program.

This paper describes those principles and discusses their implications for the functionality, maintainability, user-friendliness, and scientific relevance of the program.

General Introduction

While a myriad of factors will determine to what extent solar energy will fulfill its potential to contribute to an environmentally benign and sustainable energy future, it is clear that the more cost-effective solar technology becomes the more chances it will have to fulfill its promises. The Tonatiuh project is intended to increase the cost-effectiveness of solar energy technologies by advancing the state-of-the-art of the simulation tools available for the design and analysis of solar concentrating systems.

The objective of the work that is underway at the Department of Engineering of The University of Texas at Brownsville is the design, development, implementation, verification and validation of Tonatiuh, an open-source advanced object-oriented program to assist in the design and analysis of solar concentrating systems.

Support for the development of Tonatiuh is being provided under a three-year DOE-NREL Minority University Research Associate (MURA) Program subcontract entitled *"Tonatiuh: An object-oriented, distributed computing, Monte-Carlo ray tracer for the design and simulation of solar concentrating systems"*.

When completed, it is intended that Tonatiuh, will (a) provide a unifying computational paradigm for the simulation and analysis of virtually any type of solar concentrating system that may be envisioned; (b) be extremely user-friendly, easy to adapt, expand and maintain; and (c) be able to take advantage and efficiently handle any computer power available to it.

Design Principle, Technologies and Tools

One basic design principle for the development of Tonatiuh is to use and leverage available technologies whenever possible. Currently, Tonatiuh is being developed under Linux, but in an Operating System (OS) independent manner.

The standard Graphic User Interface (GUI) is implemented using Trolltech's Qt, while the 3D GUI is implemented using Coin, a C++ 3D graphics library and Application Programming Interface (API), which is essentially an open-source version of the well-known "Open Inventor" 3D toolkit, the industry standard for 3D visualization.

XML is used as the markup language and toolkit for Tonatiuh's inner and outer-process information exchanges and objects serialization.

Software Architecture

The main architectural decisions adopted so far in the development of Tonatiuh are: (a) completely split the program into two main components: the kernel and the user interface; (b) use a tree-structure to provide semantic content through positioning and, therefore, to facilitate the externalization of object-state; and (c) establish a clear distinction between the roles of container and contained C++ classes.

Both components, the kernel and the user interface, are being developed in an OS independent manner using the technologies referred to in the previous section. Thus, when completed they should be able to run separately under the following operating systems: Linux, UNIX, Mac OS X, and Windows.

By decoupling the user interface from the kernel, and by using XML as the standard for information exchange and object persistence, we are aiming to be able to run the user interface and the kernel in separate process environments, which may run in different machines, under different OS. This will pave the way to incorporating parallel and network processing capabilities to Tonatiuh.

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14. ABSTRACT *(Maximum 200 Words)*
The International Conference on Solar Concentrators for the Generation of Electricity or Hydrogen provides an opportunity to learn about current significant research on solar concentrators for generating electricity or hydrogen. The conference will emphasize in-depth technical discussions of recent achievements in technologies that convert concentrated solar radiation to electricity or hydrogen, with primary emphasis on photovoltaic (PV) technologies. Very high-efficiency solar cells—above 37%—were recently developed, and are now widely used for powering satellites. This development demands that we take a fresh look at the potential of solar concentrators for generating low-cost electricity or hydrogen. Solar electric concentrators could dramatically overtake other PV technologies in the electric utility marketplace because of the low capital cost of concentrator manufacturing facilities and the larger module size of concentrators. Concentrating solar energy also has advantages for the solar generation of hydrogen. Around the world, researchers and engineers are developing solar concentrator technologies for entry into the electricity generation market and several have explored the use of concentrators for hydrogen production. The last conference on the subject of solar electric concentrators was held in November of 2003 and proved to be an important opportunity for researchers and developers to share new and crucial information that is helping to stimulate projects in their countries.

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