


REAP

Renewable Energy Academic Partnerships


August 7, 2006

REAP Student Summer Research Program Review Meeting

Denver, Colorado

NREL/BK-520-40389

Minority University Research Associates 2006

National Renewable Energy Laboratory
Golden, Colorado

2006 NREL-MURA Summer Research Associates

Top row, left to right:
Carl Eloi, Central State University
Tsega Gebre-Egzi, North Carolina Central University
Kenyatta S. Williams, Southern University and A&M College, Graduate

Bottom row, left to right:
Gilda Jimenez, University of Texas at Brownsville
Thurston Melson, Central State University
Michael Speed, Central State University

Conference and Review Meeting Description

Program Overview

The DOE-NREL Minority University Research Associates Program (MURA) is an undergraduate research program that encourages minority students to pursue careers in science and technology. In this program, undergraduate/graduate students perform renewable energy research projects during the academic year with principal investigators at their university and are awarded summer internships in industry or at national laboratories such as NREL during the summer. Once accepted into the program, students can work on a research project for 1-3 years. By providing renewable energy research opportunities, the program has proven to be very successful in retaining minority undergraduate students in the science and technology areas and helping many students reach their educational and career goals.

The MURA program is open to all minority-serving colleges and universities including Tribal Colleges-Universities, Hispanic, Alaska Native, and Hawaiian Native serving colleges and the Historically Black Colleges and Universities. Each university will conduct research in 1-3 areas: Basic Research, Photovoltaic Panel Measurement and Testing, and Solar Radiation Profile Study. Expansion to other solar energy technologies such as wind, bioenergy, and geothermal will provide additional solar energy project opportunities and internships. Students involved in research excel in the classroom learning experience and are committed to contribute to the development of renewable energy technologies to create a sustainable environment.

For 10 weeks during the summer, students are given the opportunity to work with laboratory scientists and engineers as members of research teams at NREL or at another DOE national laboratory, university, or industry partner. The program is intended to provide additional training and skill development needed to prepare students with the necessary education and experience that will enable them to pursue science and technology careers in the renewable energy fields.

At the close of the summer internship program, advisors, students, and NREL professionals participate in an annual Renewable Energy Academic Partnership (REAP) review meeting conference to discuss and share their research papers, future opportunities, and the national and global role of renewable energy in ensuring a secure and sustainable environment.

This symposium focuses on NREL/DOE-funded projects at eight minority-serving colleges and universities: Central State, Fisk University, Howard University, North Carolina A&T State University, North Carolina Central University, Southern University and A&M College, University of Texas, Brownsville, and University of Texas, El Paso.

This year, the REAP Student Summer Research Program Review Meeting (REAP-SSRM) marks the second meeting organized and operated by the students. Held as part of the 16th Workshop on Crystalline Solar Cells and Modules in Denver, Colorado, the REAP-SSRM presents students with a unique opportunity to be involved in the organization and management of a conference. Additionally, this meeting provides students the opportunity to network and be mentored by professional scientists and engineers, an opportunity not generally afforded them.

U.S. Department of Energy (DOE)
National Renewable Energy Laboratory (NREL)
Renewable Energy Academic Partnership (REAP) Student Summer Research Program Review Meeting

Sixteenth Annual Workshop on
Crystalline Silicon Solar Cells & Modules: Materials and Processes
August 6-9, 2006

Denver Marriott Hotel
Denver, Colorado

Monday, August 7, 2006

7:30 - 8:30 a. m.	**Continental Breakfast; REAP Registration (Presentation CDs submitted)**
8:30 - 8:40 a.m.	**Welcome – Syl Morgan Smith, NREL Public Relations** **Fannie Posey-Eddy, NREL-MURA Project Leader**
8:40 - 10:00 a.m.	***Technical Presentations*** ***Moderator*****:** Kenyatta Williams, NREL–MURA Graduate Research Associate, Southern University and A&M College, Graduate
8:40 - 8:50 a.m.	***Overview of the DOE NREL Minority University Research Associates Program*** Kenyatta Williams
8:50 - 9:10 a.m.	***Overview—Central State University Renewable Energy Research Associates Program*** Clark Fuller, Principal Investigator (PI), Central State University
9:10 - 9:30 a.m.	***Correlation Between Minority Carrier Lifetime and Minority Carrier Diffusion Length Measurement of Silicon Wafers*** Carl Eloi, NREL–MURA Research Associate
9:30 - 9:50 a.m.	***The Influences of Surface Roughness on the Accuracy of Dislocation Density by Using PVSCAN*** Thurston Melson, NREL–MURA Research Associate
9:50 - 10:10 a.m.	***Cross-Sectioning for Characterization of a Finished Solar Cell*** Michael Speed, NREL–MURA Research Associate
10:10 - 10:20 a.m.	***Break***
10:20 - 12:00	***Technical Presentations*** ***Moderator*****:** Tsega Gebre-Egzi, NREL-MURA Research Associate, North Carolina Central University
10:20 - 10:50 a.m.	***An Intelligent Customer Power Management System*** James A. Momoh, Peter Bofah, Anthony Bantamoi, and Eshovo Momoh Howard University
10:50 - 11:10 a.m.	***Comparing the Simulated Performance of a 2.5 kW Grid-Tied Photovoltaic System with Actual Data*** Cynthia Prince, North Carolina A&T University, Electrical Engineering Ghasem Shahbazi, PI, Director, Bioenvironmental Engineering Program
11:10 - 11:30 a.m.	***Proton Conducting (PC) Perovskite Membranes for Hydrogen Separation and PC-SOFC Electrodes and Electrolytes***

	B. Rambabu and Hrudananda Jena, Southern University and A&M College Ramsey Saunders, University of West Indies –St. Augustine Campus Trinidad MURA Participants: Mr. Jeremy Gilmore and Snowden India
11:30 - 1:00 p.m.	***Lunch***
1:00 - 3:00 p.m.	***Technical Presentations*** ***Moderator*****:** Carl Eloi, NREL–MURA Research Associate, Central State University
1:00 - 1:20 p.m.	***Proton Transport in Nanocrystalline Bioceramic Materials: An Investigative Study of Synthetic Bone with that of Natural Bone*** B. Rambabu and Hrudananda Jena, Southern University and A&M College Ramsey Saunders, University of West Indies –St. Augustine Campus Trinidad MURA Participants: Jeremy Gilmore and Snowden India
1:20 - 1:40 p.m.	***Studies on Optical Processing for Fire-Through Metallization*** Kenyatta S. Williams, NREL–MURA Graduate Research Associate, Southern University and A&M College, Graduate
1:40 - 2:00 p.m.	***Current Status of Tonatiuh—A Computer Program for the Simulation of Solar Concentrating Systems*** Dr. Blanco, PI, University of Texas Brownsville
2:00 - 2:20 p.m.	***Studies on Generation of Internal Photoresponse Maps of Si Solar Cells by PVSCAN*** Gilda Jimenez, NREL–MURA Research Associate
2:20 - 2:40 p.m.	***An Overview of Research Progress on the Development of QD Sensitized Metal Oxide Nanorods Based Organic Solar Cells*** Richard Mu, PI, Fisk University
2:40 - 3:00 p.m.	***The Fabrication and Characterization of ZnO Nanowires for PV Cells*** Tam'ra-Key Francis, Fisk University Department of Physics
3:00 - 3:20 p.m.	***Break***
3:20 - 5:30 p.m.	***Technical Presentations*** ***Moderator*****:** Michael Speed, NREL–MURA Program Research Associate, Central State University
3:20 - 3:40 p.m.	***CdTe Nanoparticles Fabricated by Pulsed Electron-Beam Ablation*** Enrique Jackson, Fisk University Department of Physics
3:40 - 4:00 p.m.	***Investigation of Photovoltaic and Thermophotovoltaic Semiconductors at North Carolina Central University*** Dr J. M. Dutta, PI, North Carolina Central University
4:00 - 4:20 p.m.	***Study of Hydrogen Evolution from SiN:H during Fire-Through Metallization*** Tsega Gebre-Egzi, NREL–MURA Research Associate
4:20 - 4:40 p.m.	***High Efficiency Photovoltaic Cells Quantum Dots at North Carolina Central University*** Dr. Branislv Vlahovic, North Carolina Central University
4:40 - 5:00 p.m.	***Ultrafast Pulsed Laser Production of Silicon Nanoparticles*** W. Yohanes, M. Wu, J. M. Dutta, and B. Vlahovic Department of Physics, North Carolina Central University
5:00 - 5:20 p.m.	***Pulsed Laser Fabrication of Zero and One-Dimensional Nanostructures*** M. Wu and B. Vlahovic; North Carolina Central University
5:20 – 5:30 p.m.	**CLOSING: NREL-MURA Research Associates**

North Carolina A&T State University

Comparing the Simulated Performance of a 2.5 kW Grid-Tied Photovoltaic System with Actual Data

Cynthia Prince, Student, Electrical Engineering
Ghasem Shahbazi, PI, Director, Bioenvironmental Engineering Program
North Carolina Agricultural & Technical State University, Greensboro, NC

A 2.5-kW photovoltaic (PV) system with battery storage was designed. Installed, and connected to a 1200-ft^2 apartment unit to test the performance of a grid-connected PV system. The power generation system was interconnected with the local electric utility grid to allow for the grid to be used as a supplemental source of electric power. The actual net PV generation for a period of one-year was 2927.25 kilowatt-hour (kWh), with a yearly normalized yield of 1170.9 kWh/kW$_p$. Assuming a 25-year useful life on equipment, based on the findings from the test of the system, the electricity that was produced cost about $0.4661 per kWh. This cost is much higher than the unit price of electricity (about 8 cents per kWh) charged by the local utility. It is possible that the costs could be decreased by using different system components. There are, for example, three types of silicon PV panels.

The three primary types of silicon photovoltaic solar cells available commercially are monocrystalline silicon, polycrystalline silicon, and thin-film amorphous silicon. In monocrystalline silicon technology, individual cells are cut from large single crystals or ingots of crystalline silicon. Polycrystalline silicon, in contrast, consists of several smaller crystals or grains, which introduce boundaries. These boundaries impede the flow of electrons and reduce the power output of the solar cell. Although polycrystalline cells are generally less efficient than those of single-crystal silicon, they can be less expensive to produce. In thin-film technology, the PV material is deposited on glass or thin metal that mechanically supports the cell or module. Thin-film cells work according to the same general principles as crystalline silicon cells, but they require less material. Thin-film modules are much simpler and less expensive to manufacture, but are the least efficient of the three.

Computer programs that model PV systems are used to simulate the performance of PV generation systems. Results can be used in feasibility studies undertaken to determine whether PV can be used in specific projects. The simulation tool used in this study is TRNSYS (TRaNsient SYstems Simulation), a whole-building energy analysis tool. The three different types of silicon PV modules are modeled and the results are compared. The simulations are compared with the actual data to analyze the relative benefits of each type of module. The usefulness of TRNSYS in simulating the system is analyzed, as well.

The overall goal of this project was to install and test a grid-connected photovoltaic system in Greensboro, North Carolina, to provide one-half of the energy needed in a 1200-ft^2 apartment unit. The specific objectives of this study were to simulate the performance of the PV generation system using TRNSYS simulation software, as follows:

a) Create an input file for the existing PV generation system using thin-film modules, poly-crystalline modules, and single crystalline modules
b) Simulate the PV generation using the TRNSYS simulation software
c) Compare the actual PV generation with the simulation results for the above three options

d) Prepare the performance curves for actual generation and simulation results
e) Recommend an alternative power conversion system to improve system efficiency.

TRNSYS illustrated the trade offs in choosing a PV module: if output is held relatively constant, as efficiency increases, module area decreases and price increases. The results are summarized in the following table.

	Monocrystalline	**Polycrystalline**	**Thin Film**
Nominal Efficiency (%)	13.1	10.9	5.2
Peak Output (kWh_p)	2.55	2.52	2.58
Area (m^2)	19.5	23.1	47.4
Annual Output (kWh)	3300	3380	3310
Price ($)	15,690	14,868	11,640

Future work will include investigation of the three different types of PV systems using RETScreen. The RETScreen International Renewable Energy Project Analysis Software is another simulation tool that can evaluate the energy production for various types of renewable energy technologies (RETs). The RETScreen results will be compared with the corresponding TRNSYS results and the actual data. RETScreen and TRNSYS will be analyzed to determine which package is preferable in terms of cost versus accuracy.

Central State University

Overview—Central State University Renewable Energy Research Associates Program

Clark Fuller
Associate Director & Principal Investigator
Office of Sponsored Programs & Research
cfuller@centralstate.edu

Undergraduate renewable energy research at Central State University (CSU) focuses on two themes: 1) renewable energy technology applications for the transportation industry, and 2) economic development challenges in developing countries. During Fiscal Year 2006, Central State University focused on involving students in projects related to those two themes, while at the same time developing strategies to leverage additional funds to provide internship opportunities for students at national laboratories.

During 2005/2006, Central State used NREL program support funds to strengthen and continue its introductory Renewable Energy laboratory Course and expand its Summer Transportation Institute (STI). As an overlapping goal, one of the laboratory projects involved improving the design of a solar-energy charging station that will be constructed on campus. Although still in progress, the project attempts to incorporate components of both the transportation theme and the international theme. And although the research topic is primarily related to renewable energy in transportation, aspects of the project directly relate to energy projects CSU directs in some locations in West Africa. Nearly 15 college students completed the eight-week laboratory program and 35 high school students completed the STI program.

Since 1991, Central State University has had collaboration agreements with academic institutions and non-governmental organizations in various countries in West Africa. These organizations include World Vision International/Senegal, Cheikh Anta Diop University (UCAD) in Dakar, Senegal, and the University of Zambia in Lusaka, Zambia. Summer research programs involving Central State faculty and students were designed to strengthen these relationships. The program has been sponsored through the NREL MURA program, but all travel funds have been provided through Central State University, the U.S. Department of Education and the National Nuclear Security Administration. During the summers of 2005 and 2006, two CSU professors and two CSU students have traveled to Senegal and Zambia to accomplish the following primary objectives:

- Promote existing collaboration between CSU and its collaborating partners in Senegal and Zambia;
- Conduct training and research in renewable energy applications;
- Conduct hands-on training in rural areas with indigenous institutions.
- Identify different areas of renewable energy research/projects to invest and implement in Africa;
- Strengthen the position and enhance the experience and capability of CSU to compete for energy research grants and projects in developing countries.

The NREL/MURA program has also expanded Central State's capability to provide internship opportunities for undergraduate students at several national research laboratories. During 2006, three students from Central State University will have spent seven months each at the National Renewable Energy Laboratory performing research in areas related to renewable energy technologies.

An Overview of Research Progress on the Development of QD Sensitized Metal Oxide Nanorods Based Organic Solar Cells

Richard Mu (PI)
Nano-PV Program, Department of Physics, Fisk University

We have proposed a high-efficiency solar cell design in which semiconductor quantum dots with several sizes are the efficient absorbers of the sunlight, and the positive and negative charge carriers created by the light absorption are to be separated and transferred to the electrodes. For the high-efficiency solar cell, ZnO nanowires (NWs) are the important building parts that create the charge separation and carrier pathways to the electrodes.

For the fabrication of ZnO NWs, we have used Si wafers as smooth surface substrates. Gold was deposited on to the substrates with an electron-beam evaporator, because it is known that gold particles can serve as the catalyst to grow ZnO NWs on substrates in the vapor-liquid-solid (VLS) method. In the VLS method, the mixture of ZnO powder and graphite was placed at 1100^{o}C and the substrates were at 800^{o}C in a two-zone furnace. The reduction of ZnO of the source generates Zn vapor that moves toward gold particles, and the oxidation of Zn-Au alloy grows ZnO crystals. The gold-deposited area has ZnO crystal growth, and the gold particles play the role of nucleation sites. ZnO crystals have dimension of a few hundred nm thick and 2-3 μm long under this particular condition. The ZnO crystal shapes and sizes are very sensitive to the growth conditions: the gold particle size and density, temperatures for the source and substrates, distance between the source and substrates, quantity of the source, deposition time, and so on. SEM, AFM, XRD, PL and Raman spectroscopy have been used for characterization.

In the semiconductor quantum dot fabrication front, CdTe, which has a bandgap of 1.56 eV, is a front-runner photovoltaic material because it has already attained efficiencies above 16%. CdTe nanoparticles are a good candidate for the development of an organic/nanocrystal composite active layer and also for sensitization of wide band gap semiconductors. We employ the pulsed electron-beam deposition (PED) technique to fabricate CdTe nanoparticles. Despite its unique features, PED is not yet a well-explored technique in fabricating semiconductor nanostructures. Its system cost is less expensive and it can be used for a wider range of materials as compared to pulsed laser deposition (PLD). In this work, we investigate using AFM, the effect of background gas pressure (P) and charging potential (U) on the particle shape, size, and particle density of the CdTe nanoparticles deposited on silicon. We also measure the optical absorbance of CdTe films on glass deposited at different P and U and correlate the results with particle size and distribution obtained from AFM characterization. Our results may provide useful insight on the application of PED for fabricating semiconductor nanoparticles.

To obtain improved efficiencies, it is desirable to have an interpenetrating network of electron-accepting and hole-accepting components within the device. In this work, we sandwiched an active layer of MEH-PPV/CdSe nanocrystal composite between a transparent ZnO film and Al electrode and measure the photocurrent at zero bias voltage. By doing this, electron-hole separation can occur at the ZnO/polymer interface, CdSe/polymer interface and ZnO/CdSe/polymer interface. Thus, we investigate whether the use of a ZnO transparent electrode can improve the efficiency by acting as an acceptor of photogenerated electrons from both CdSe nanocrystals and conjugated polymers. The effect of varying the concentration of CdSe nanocrystals in the composite will also be discussed.

The Fabrication and Characterization of ZnO Nanowires for PV Cells

T. Francis, A. Ueda, R. Aga, Z. Pan, W. E. Collins, and R. Mu (PI)
Nanoscale Materials and Sensors Group, Department of Physics, Fisk University

In our currently funded research project, we have proposed a high-efficiency solar cell design in which semiconductor quantum dots with several sizes are the efficient absorbers of the sunlight, and the positive and negative charge carriers created by the light absorption are to be separated and transferred to the electrodes. For the high-efficiency solar cell, ZnO nanowires (NWs) are the important building parts that create the charge separation and carrier pathways to the electrodes.

ZnO nanowires were fabricated via vapor-liquid-solid (VLS) method, which was recently developed with relatively simple equipment [1-3]. In the VLS method, Au small particles are used as a catalyst for the nucleation site of ZnO nanowires. As atomically flat substrates, we used Si (100) wafers etched with HF solution to remove SiO_2 layer. An electron-beam evaporator (Thermionics, 100-0030) was used for the thin-film deposition of Au with thickness of 2 nm at the vacuum level of ~ $2x10^{-6}$ torr. The Au-deposited Si substrates were pre-annealed at 800^oC in air for 1 hour to form Au particles from thin films. The source material is a mixture of ZnO and graphite powders of 1:1 molecular ratio. The source material in an alumina boat was placed at 1100^oC and the substrates were placed at 800^oC in a quartz tube in a two-zone furnace (Mellen, TS-15) with Ar gas flow. The following chemical reaction is assumed to form ZnO nanowires [4]: the graphite reduces ZnO to create Zn vapor, and Zn vapor can diffuse into Au particles to form a solid solution of Zn and Au on the substrate. Residual oxygen can oxidize the Au/Zn alloy to form ZnO nanowires. X-ray diffraction (XRD) measurement was performed to evaluate the crystallinity of ZnO nanowires.

Figure 1a shows an SEM image of ZnO nanowires on a Si substrate, and the size of nanowires is 200 nm wide and several μm long. Each ZnO nanowire shows hexagonal crystal facets and growth direction was not regulated by the growth condition. Figure 2a shows that the Au-deposited region has ZnO nanowires grown, whereas the region without Au deposition does not grow ZnO nanowires. Therefore, Au deposition is necessary to grow ZnO nanowire for nucleation.

In Fig. 2, the XRD spectrum of one of samples is shown, which indicates the sample is crystalline ZnO. The relative peak intensities show that the crystal orientations are not aligned perpendicular to the substrate and it is consistent with the SEM image in Fig. 1(a).

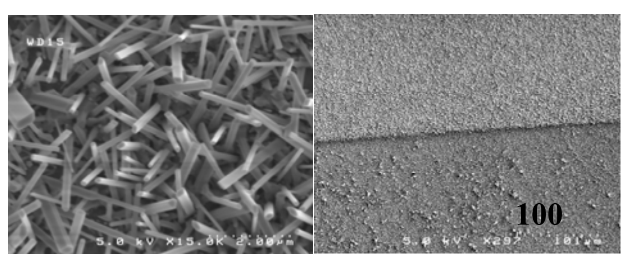

Fig. 1 SEM images of ZnO nanowires. (a) The higher magnification of ZnO nanowires on a Si substrate. (b) The region with Au deposition (top) has ZnO nanowire growth, while the region without Au showed no ZnO growth. (100 nm)

Photoluminesce (PL) from ZnO nanowire sample were measured, as the sample was annealed in air with increasing annealing temperature from room temperature up to 1000^oC. The annealing time for each temperature was 20 min. The excitation photon wavelength was 325 nm. The center of the green broad band was located around 520 nm, and the weak exciton band was located 380 nm, as shown in Fig. 3. The green band has been attributed to the defect (the singly ionized oxygen vacancy) [5];

therefore, we expected that the green band would decrease as the annealing temperature increased. However, the green band did not significantly change its intensity until the annealing temperature reached 800°C, while the exciton band became weaker. At 900°C, the green band became weak, and the exciton band essentially disappeared. It is possible that the ZnO nanowires have been destroyed at this temperature (900°C), although the melting point of bulk ZnO is T_m=1975°C.

In conclusion, we have fabricated ZnO nanowires on Si substrates by using vapor-liquid-solid (VLS) method or vapor-phase transport process (VPT) by heating the mixture of ZnO and graphite powders in a two-zone furnace. However, the conditions to control the shapes and orientation of ZnO crystals are not so easy a task. Especially, to make suitable ZnO nanowires into high-efficiency solar cells is challenging. We found that the morphology of ZnO NWs changed after being annealed at 800°C. The properties of ZnO nanowires, depending on the ambient temperature, will be important for the applications. If these devices are used in space such as artificial satellites, the temperature dependence and stability of the ZnO nanowires could be an important issue.

Acknowledgments

This research is supported in part by NREL/DOE ACQ-4-33623-03, DOD/ARO Contracts of W911NF-05-1-0453, -51-1-0040, -04-1-0400, and NSF-CREST.

References

[1] H. J. Fan, W. Lee, R. Scholz, A. Dadger, A. Krost, K. Nielsch, and M. Zacharias, Nanotechnology **16**, 913 (2005).

[2] Y. Xia, P. Yang, Y. Sun, Y. Wu, B. Mayers,B. Gates, Y. Yin, F. Kim, H. Yan, Adv. Mater. **15**, 353 (2003).

[3] J.H. Park, H.J. Choi, Y.J. Choi, S.H. Sohn, J.G. Park, J. Mater. Chem. **14**, 35 (2004).

[4] D. Zhao, C. Andreazza, P. Andreazza, J. Ma, Y. Liu, and D. Shen, Chem. Phys. Let. **408**, 335 (2005).

[5] K. Vanheusden, W.L. Warren, C.H. Seager, D.R. Tallant, J.A. Voigt, B.E. Gnade, J. Appl. Phys. **79**, 7983 (1996).

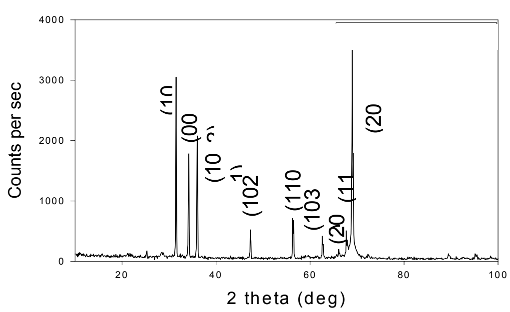

Fig. 2 XRD spectrum of ZnO nanowires. Shortened indices were used.

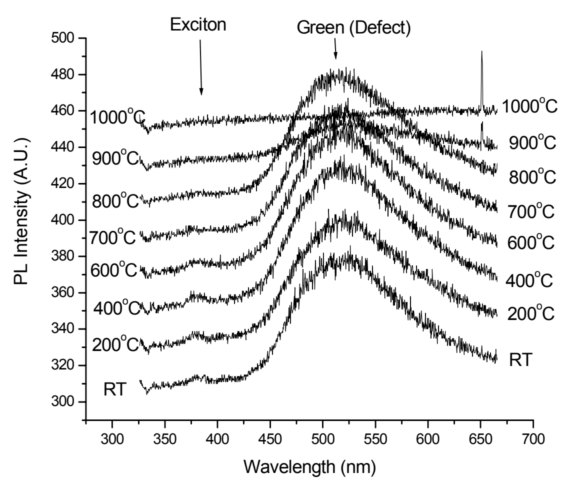

Fig. 3 Photoluminescence from ZnO nanowires on Si wafer as annealing temperature increased. The excitation photon wavelength was 325 nm. The annealing time for each temperature was 20 min.

CdTe Nanoparticles Fabricated by Pulsed Electron-Beam Ablation

E. Jackson,[1] R. Aga, Jr.,[1] A. Steigerwald,[1] A. Ueda,[1] D. Coffey,[2] L. Allard,[2] Z. Pan,[1] W.E. Collins,[1] and R. Mu (PI)[1,]
[1] Department of Physics, Fisk University, 1000 17th Ave N, Nashville TN 37208 USA
[2] Oak Ridge National Laboratory, Oak Ridge TN 37830-8071 USA

Solar cell technology has long been dominated by silicon but is now being challenged by new concepts based on nanomaterials. This is driven by the need to accelerate the development of advanced photovoltaic (PV) materials and designs to achieve appropriate levels of cost and efficiency. Affordable and efficient PV technology is the key toward the widespread use of clean solar energy. One promising concept for less-expensive PV technology is the hybrid design. This often uses an interpenetrating network of electron-donor and electron-acceptor nanomaterials, such as a blend of ZnO nanoparticles and conjugated polymer. Another concept is the sensitization of wide-bandgap semiconductors. These materials can be sensitized by quantum dots (semiconductor nanoparticles exhibiting quantum confinement effects) to access the visible or even the near-infrared region of the solar spectrum and thus maximizing the sunlight-to-electricity conversion. A very promising nanoparticle material for this concept is cadmium telluride (CdTe). It is a direct-bandgap semiconductor with an absorption onset at 826 nm, which corresponds to a bandgap energy of 1.56 eV. CdTe nanoparticles with narrow size distribution can be synthesized by solution-based methods. In certain applications however, nanoparticles dispersed in solution are unsuitable due to possible contaminations. For sensitization, it is desirable to have a good electrical contact between the two different materials to minimize energy loss during charge injection. Thus, techniques for fabrication and deposition of nanoparticles on solid surfaces are necessary. In this paper, we employed the pulsed electron beam deposition (PED) technique to fabricate CdTe nanoparticles. Despite being commercialized, PED is not yet a well-explored technique for nanoparticle fabrication. This technique may become an attractive alternative to PLD.

Ablation of the CdTe target was performed in a PED system equipped with a channel-spark source (PEBS-20) from Neocera. The source has the following specifications: background gas pressure (P) = 5-20 mTorr, charging potential (U) = 8-20 kV, and pulsed width = ~100 ns. The CdTe target was a 1-inch-diameter disk with 0.125-inch thickness, purchased from Lesker. It was properly grounded. The substrates were optical glass and silicon (Si) wafer approximately 4 mm x 4mm in size. They were mounted next to each other on a substrate holder, which has a variable distance from the target. For this particular work, the substrate-to-target distance was fixed around 30 mm. Two values of P were chosen for investigation, 11 mTorr and 19 mTorr. For each P, four pairs (a pair is glass and silicon substrates) of samples were prepared corresponding to four different U values of 9 kV, 11 kV, 13 kV, and 15 kV. For each pair, the number of shots was 1000 at 2 Hz. The samples on optical glass were characterized by UV-visible spectrophotometer, whereas the samples on Si were characterized by atomic force microscopy (AFM) and scanning electron microscopy (SEM) equipped with energy-dispersive spectroscopy (EDS).

The bulk CdTe is black, but the small amount of this material deposited on the glass substrates is brownish. The optical transmission (%T) spectra of the samples on glass are presented in Fig. 1. For comparison, the %T spectra of glass substrates are also included. It can be observed from the figure that the samples fabricated at U = 9 kV have the highest %T at 900 nm, but drops significantly at U = 11 kV, especially for P ~ 19 mTorr. When U is further increased to 15 kV, %T only changes moderately. The %T at 900 nm, which is above the absorption onset of bulk CdTe (826 nm), provides qualitatively the amount of material that scatter the incident light. It should be noted that the curvature of %T above 826 nm is due to the specular reflectance, which is not corrected from Fig. 1. Our results indicate that the amount of CdTe deposited on the substrate has a nonlinear increase with *U*. This is not surprising because the pulse energy increases nonlinearly with *U*. It should be realized that *U* determines the average kinetic energy (e*U*) of each electron in the beam. The background gas plays a role in the deposition in two different ways. It can reduce the beam current due to electron collision with the gas and it can also moderate the kinetic energy of the plume atoms via collision. *P* has a notable effect in the deposition using 9 keV electrons. In Fig. 1(b), %T at 900 nm for *U* = 9 kV is roughly 88% and this drops to about 70% when *P* is reduced to 11 mTorr [Fig. 1(a)]. This suggests a significant increase in the deposited material. However, at *U* values of 11, 13, and 15 kV, the effect of *P* is not very strong, as observed in the optical transmission measurement. All the samples exhibit quantum confinement effects as implied from the %T spectra. They have an absorption onset near 500 nm, as shown by the symbols. These results are similar to the CdTe nanocrystalline (nc) films fabricated by electrodeposition. The CdTe films obtained from this method also showed broad absorption onset around 500 nm, with measured average crystal size of about 7 nm. Thus, the PED parameters we have employed in this work may also yield the same nc-films.

AFM, SEM, and EDS measurements were also done and will be presented at the meeting. In summary, we have fabricated CdTe nc-films using PED technique that exhibit quantum confinement effects. In addition to this nc-film, larger nanoparticles with diameters varying from 40 nm to 500 nm were also deposited on the substrate. They are responsible for the absorption onset at the bulk bandgap energy. However, they can be reduced at higher background pressure.

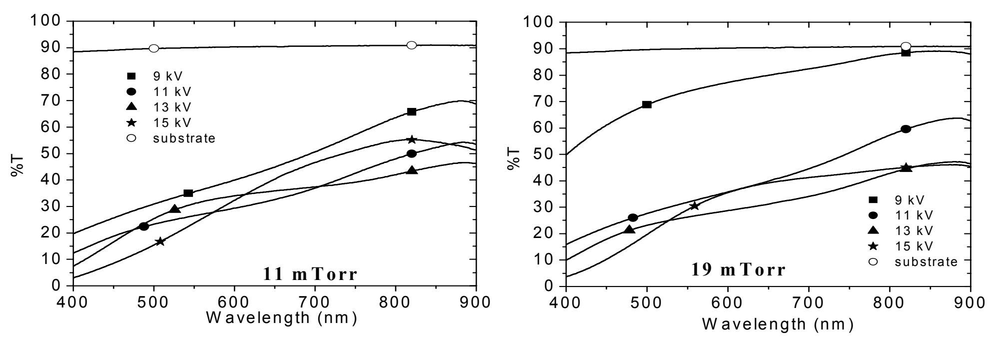

Fig. 2 Optical transmission spectra (%T) of samples fabricated at (a) *P* ~ 11 mTorr and (b) *P* ~ 19 mTorr.

Acknowledgements The authors would like to acknowledge the financial supports in part by NREL/DOE ACQ-4-33623-03, DOD/ARO Contracts of W911NF-05-1-0453, -05-1-0040, and -04-1-0400, and NSF-CREST. Research sponsored by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of FreedomCAR and Vehicle Technologies, as part of the High Temperature Materials Laboratory User Program, Oak Ridge National

North Carolina Central University

Investigation of Photovoltaic and Thermophotovoltaic Semiconductors at North Carolina Central University

Dr. J. M. Dutta (P1)

Our primary focus is to train selected students in research in fabricating and characterizing various bulk and nanophase photovoltaic materials. Cross-over phenomena of going from clusters to nanocrystals to the bulk are another focus of the research. The purpose of the program is to facilitate basic research and training in the energy-related technology. Over the last few years, at North Carolina Central University (NCCU), significant progress has been made in developing a semiconductor research program, supported by the National Renewable Energy Laboratory (NREL). Over the past few years we have been successful in acquiring several high-power scientific apparatus that will considerably enhance on-campus research capability for our students and faculty. Brief review of their applications to various scientific projects will be discussed, and some of the important results derived will be presented.

One of our objectives has always been to establish an on-campus facility to fabricate quantum dots (QDs) and capability to deposit multi-layer thin films by pulsed laser deposition (PLD) techniques. For that purpose, the chamber that will be used for the productions of QDs and the deposition of thin films has been designed and assembled at this time. A pulsed laser and a pulsed electron gun are attached to the chamber and used to sputter a sample to a substrate. Progress of this research will be reported, and some of the preliminary results will be presented.

In QD-based photovoltaic (PV) cells, the relaxation dynamics of the photogenerated carriers is markedly affected by carrier energy quantization effects that give rise to sharply discrete energy spectra of the electron and hole and an enhanced overlap of their wave functions. This results in a low threshold current density, high temperature stability of the threshold current, higher material and differential gain, and enhanced nonlinear optical effects for QD PV cells. In addition, the hot-carrier cooling rates are known to be dramatically reduced in spatially confined quantum systems, thus allowing the impact ionization to come into play and to enhance the efficiency of the photon conversion by creating at least two excitons per one absorbed photon. These intrinsic properties make QD-based solar cells sufficiently robust and ideal to design very-high-efficiency solar cell (VHESC) QD-based devices of at least 50% solar energy conversion efficiency.

Our efforts have been focused on developing pulsed laser deposition (PLD) and pulsed electron beam deposition (PED) schemes. We focused on these techniques because PLD is a proven technique for producing high-quality, size-controlled nanocrystalline materials. QDs ranging from 1 to 50 nm, a size range critical for tuning absorption bands of semiconductors through the visible and near-infrared region, of both single element and compound semiconductors have been successfully produced by PLD. The advantages over competing techniques for QD production, including the commonly used wet-chemical synthetic and strain-induced (Stranski-Krastanow) growth methods, are: QDs grown by PLD are ultra-clean (no precursors are needed for most materials), and there are no extraneous reagents in the high-vacuum growth chamber. QDs produced by PLD also exhibit strong quantum confinement in three dimensions, as opposed to strain-induced QDs, which typically are considerably larger in the lateral dimensions than height. PED is a newly emerging technology that retains the advantages of PLD, but has potentially lower production costs. The physical mechanism of material ablation by PED is a subject of further investigation, however, and comparison with PLD-produced nanomaterials also needs a thorough examination. Nanoparticles produced by ablation of a silicon wafer target under vacuum conditions using the output of a regeneratively amplified, 40 femtosecond pulsed width, Ti:Al_2O_3 laser were collected on Si substrates. Produced particle sizes and densities, investigated by AFM, will be discussed. Techniques of pulsed laser production of zero and one-dimensional nanostructures will be discussed, and experimental results for high fluence pulsed laser production of Si and InAs QDs will be presented.

Capacitance measurements of depletion layers in semiconductors are widely used in characterizing electrically active levels due to the presence of impurities and point defects. By time-resolved capacitance spectroscopy and deep-level transient spectroscopy (DLTS), electronic properties as such levels, activation energy, carrier capture, and emission processes can be studied directly. DLTS also gathers information on trap concentrations, and the depth profile of the trap concentration. We used DLTS for investigating deep levels in polycrystalline edge-defined film-fed-grown (EFG) silicon (low-cost solar cells), as well as monocrystaline Czochralski and float-zone silicon. Some of our recent research on EFG samples will be presented.

High Efficiency Photovltaic Cells Quantum Dots Program at North Carolina Central University

Dr. Branislv Vlahovic
North Carolina Central University
1801 Fayetteville Street, Durham, NC 27707
*Phone: 919–530–7252; Fax: 919–530–7472; E-mail: vlahovic@nccu.edu

The REAP program for Photovoltaic Research and Education at North Carolina Central University (NCCU) is a multi-disciplinary program that encompasses theoretical and experimental research on photovoltaic nanostructured materials and devices. The program integrates modern science, advanced research and competitive education. Through NREL support are formed strong experimental and theoretical groups with expertise in: (1) theory and computer simulations of optoelectronic and thermo-mechanical properties of semiconductor and carbon low-dimensional nanostructures; (2) nanostructure formation and characterization; and (3) production of novel high-quality nanomaterials and nanoscale devices. Experimental research projects are closely related to the theoretical projects. Advanced theoretical models are developed and large-scale molecular dynamics simulations together with numerical modeling are performed to predict physical properties and thus to provide guidance for the experimental effort. This synergy enables the fabrication of nanostructures with well-defined characteristics and optimum device performance at NCCU. The studies of the fundamental issues, such as coherent dynamics of optically excited electronic and excitonic states in semiconductor quantum dots, current instabilities and entanglement in atomically doped carbon nanotubes, open paths for novel applications of semiconductor and carbon nanostructures in nanophotonics, quantum information processing and quantum communication technologies. At NCCU and collaborating institutions, novel semiconductor and carbon nanomaterials have been produced by a number of methods, including ultrafast pulsed laser and pulsed electron beams deposition, strain-induced growth techniques, nanopatterning using scanning probe microscopy, nanotemplated deposition, and chemical synthesis. At NCCU, nanostructures have been characterized by structural, electrical, and optical probes and applied to the development of high-performance novel nanoscale devices for NASA needs such as: fast quantum-dot infrared photodetectors with high sensitivity, high-efficiency quantum-dot solar cells, and highly selective and sensitive biochemical sensors.

The PAIR program enhanced the participation of minority students in engineering and technology areas, where they are critically underrepresented. Besides fundamental advances in nanoscience, the program provided a qualified nanotechnology work force including highly skilled minority and socially underrepresented groups. The program expanded academic and research at the interface between traditional disciplines, where many scientific opportunities are emerging. It resulted in improved graduation rates, especially among African American students, women, and socially and economically disadvantaged students, and provided graduates the flexibility in career choices and job opportunities. The NASA PAIR program enhanced research support across multiple disciplines at NCCU and spurred collaborations in nanoscience throughout the region. An HBCU nanotechnology network was created that will increase the opportunities for student participation in advanced research and facilitate connection between HBCU faculty and students. Educational improvements arising from these activities include: enhancement of Master degree programs and establishment of a physics Ph.D. program at NCCU; strengthening of the curriculum for undergraduate students in the STEM disciplines, development of an annual two-week summer workshop for high school and undergraduate students and faculty; and initiation of a nanotechnology seminar series and outreach activities targeting minority communities.

Pulsed Laser Fabrication of Zero and One-Dimensional Nanostructures

M. Wu and B. Vlahovic
Department of Physics, North Carolina Central University
Durham, NC 27707

Zero and one-dimensional nanostructures are increasingly relevant to the development of advanced optoelectronic devices. Use of these materials in devices including infrared photodetectors, biochemical sensors, and photovoltaics has been predicted to greatly improve performance, leading to intensive research in these areas. Pulsed laser deposition (PLD) presents an intriguing alternative to conventional techniques, such as metal-organic chemical vapor deposition or molecular-beam epitaxy, for producing nanostructures for device applications. Techniques of nanostructure production using pulsed lasers will be described, and experimental results will be presented for high-fluence pulsed laser production of Si and InAs quantum dots. We will also present research directions for the near future for pulsed laser growth of zero and one-dimensional nanostructures.

Ultrafast Pulsed Laser Production of Silicon Nanoparticles

W. Yohanes, M. Wu, J. M. Dutta, and B. Vlahovic
Department of Physics, North Carolina Central University
Durham, NC 27707

Use of semiconductor nanoparticles ("quantum dots") in the active regions of solar cells is predicted to improve the efficiency of photovoltaic energy conversion through a variety of mechanisms, including multiple exciton generation, formation of intermediate bandgaps, and increased optical absorption. These improvements are predicted to occur with quantum dots under strong quantum confinement conditions, where the size of the dot in all three spatial dimensions is comparable to its bulk Bohr exciton radius. This condition is difficult to achieve using conventional growth techniques, such as chemical vapor deposition or molecular-beam epitaxy. We report here on the production of silicon nanoparticles by femtosecond pulsed laser ablation. Nanoparticles produced by ablation of a silicon wafer target under vacuum conditions using the output of a regeneratively amplified, 40 femtosecond pulsed width, Ti:Al_2O_3 laser were collected on Si substrates. Laser pulse energy density and laser wavelength were varied to assess the effect of these parameters on average nanoparticle size and the width of the size distribution, as measured by tapping-mode atomic force microscopy. Particle size was found to be strongly correlated with laser pulse energy density and distance of the sampling site from the central axis of the plume of ablated material. Smaller particles were also observed using ultraviolet (266-nm) pulses than for near-infrared (800-nm) pulses. The surface of the target, which was also imaged using atomic force microscopy after exposure to single laser shots to investigate the mechanism of nanoparticle formation, exhibited nanostructuring dependent on laser pulse energy density.

Southern University and A&M College

Proton Conducting (PC) Perovskite Membranes for Hydrogen Separation and PC-SOFC Electrodes and Electrolytes

B. Rambabu and Hrudananda Jena
Solid State Ionics Laboratory, Department of Physics
MURA Participants: Jonathan Dooley, Jashua DuBois, and Ms. Badero Olego

Dense perovskite membranes made of mixed electronic and protonic conductors provide a simple, efficient, and cost-effective means to separate hydrogen from gas streams. High proton conductivity has been reported for various perovskite-type oxides such as cerates and zirconates in hydrogen/humid atmosphere. However, only a few, if any, satisfy both high protonic conductivity and thermodynamic stability that are prerequisites for the application of such membranes as successful separators. This paper/presentation deals with the study and development of dense, thin ceramic membranes of: 1) proton-conducting perovskites ($A^{2+}B^{4+}O_3$) as hydrogen separation membranes, and 2) mixed [electron and H^+] aliovalent ion-substituted perovskites ($A^{2+}{}_{1-x}M_xB^{4+}{}_{1-y}N_yO_{3\pm\delta}$) as electrode (porous) and electrolyte for proton-conducting (PC)-SOFCs.

The limitations of the perovskites used as electrolytes in PC-SOFCs are: 1) high grain-boundary resistance observed in the case of ytteria-doped $BaZrO_3$ (BYZ), which leads to reduced ionic conductivity, and 2) stability of the B-cation in the 4^+ oxidation state in cerates, which influences the ionic conductivity and structural distortion of the crystal lattice. To overcome these limitations, we have adopted novel wet chemical methods of synthesis, including: 1) sonochemical, 2) hydrothermal, 3) gel-to-crystallite conversion, and 4) regenerative sol-gel methods to achieve nanoparticles for improving sintered density while stabilizing high-symmetry single-phase structures (alkali and rare-earth-substituted strontium cerates, composite $Ba(Zr,Ti)O_3$) with enhanced proton conductivity at low temperatures. The mechanism of proton conduction and the influence of preparation conditions on the microstructure and proton conductivity of the $A^{2+}B^{4+}O_3$ perovskites and its doped compositions are reported.

$BaCeO_3$, $SrCe_{1-x}M_xO_3$ compositions were synthesized by sonochemical treatment following hydrothermal method, and sintering is done by microwave heating. CeO_2-hydrated gel was obtained from Ce(IV) ammonium nitrate and mixed with $Sr(OH)_2$ and sonicated for 30 min, then the reactants were subjected to hydrothermal treatment at 150^0C for 4 h. $SrCeO_3$ was found to form orthorhombic perovskite above 1200^0C of heat-treatment. The 10% substitution of dysprosium at Ce site does not form a single phase. Instead, Sr_2CeO_4 is formed along with $SrCeO_3$. The electrochemical and surface chemistry, cell testing measurements were performed using advanced spectro-electrochemical characterization techniques such as XRD, HRTEM, STM, AFM, XPS, EXFAS, CV, and EIS techniques. The effect of ball milling was also studied on sintering of the pellets.

Acknowledgements: BRB acknowledges the support of U.S-DOE-NREL for supporting his undergraduate students. Dr. Jena thanks the IGCAR for granting extraordinary leave for exchange visitor assignment at Southern University, USA.

Proton Transport in Nanocrystalline Bioceramic Materials: An Investigative Study of Synthetic Bone with that of Natural Bone

Hrudananda Jena and B. Rambabu

Ramsey Saunders
Health Physics Section, Department of Physics
University of West Indies–St. Augustine Campus, Trinidad

MURA Participants during Summer 2006: Jeremy Gilmore and Snowden India

Hydroxy apatite, $Ca_{10}(PO_4)_6(OH)_2$ (Ca-HAp), is a bio-ceramic and is an alternative candidate for stainless-steel and titanium-based materials being used for replacement of fractured bones. In this study, an attempt is made to synthesize nano-composites of Ca-HAp with varying Ca to PO_4 ratio and alkaline earth (Ba, Sr and Mg) doping at Ca-site of the HAp by using sonochemical, hydrothermal, followed by microwave, sintering. The powders obtained in all these routes were characterized by X-ray diffraction (XRD) and transmission electron microscopy (TEM). The formation of single-phase HAp was confirmed by XRD analysis. XRD peak broadening and TEM examination of the powders confirmed the nano-crystalline nature of the powders. The hydrothermal method (autoclave heated at 150^0C) of synthesis yielded single-phase powders without further heat-treatment. The urea combustion method needed heat-treatment of the pre-cursor at 400^o-800^oC. The sonochemically treated starting materials before proceeding to hydrothermal treatment yielded needle-shaped HAp. The needle-shaped nano-rods may be of great importance to fabricate high-strength bone material. Electrical transport properties of these compositions were carried out by an ac impedance technique. The conductivity of CHAp is observed to be 0.05 mS/cm at 500^0C. The measurement of various properties of $Ca_5Sr_5(PO_4)_6(OH)_2$, $CaMg_5(PO_4)_6(OH)_2$ $CaBa_5(PO_4)_6(OH)_2$ compositions is to be carried out to find its suitability to justify its use as biomaterials for vertebrates. The presence of protons in the lattice has been investigated by proton nuclear magnetic resonance (NMR) and Fourier transform infrared (FT-IR) spectroscopy measurements. The structural and transport properties were correlated with the natural human bone powder measured under identical experimental conditions. The ordering mechanism of hydroxy groups in hydroxy-apatite $Ca_{10}(PO_4)_6(OH)_2$, which is the major constituent of mammalian bones and tooth enamel, has been discussed. Apart from its use as biomaterials, Ca-HAp may be a candidate for future proton conductors for proton-conducting ceramic fuel cell application, as well as the composite electrolyte in direct methanol fuel cells.

Acknowledgements: BRB acknowledges the support of U.S-DOE-NREL for supporting his students at SUBR. Mr. Jena thanks the IGCAR for granting extraordinary leave for exchange visitor assignment at Southern University, USA.

University of Texas at Brownsville

Current Status of Tonatiuh—A Computer Program for the Simulation of Solar Concentrating Systems

Manuel J. Blanco,* Gilda P. Jimenez, and Cesar E. Cantu
Department of Engineering
The University of Texas at Brownsville, Brownsville, Texas
manuel.blanco@utb.edu

As stated in the Concentrating Solar Power section of the *"Solar Program Multiyear Technical Plan 2003-2007 and beyond"*, many of the existing models used for the technical and economic analysis of parabolic-trough and solar tower systems need to be updated and validated. This includes models for collector optics and thermal performance, among others.

The Tonatiuh software development project is intended to improve 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, under a DOE-NREL Minority Research Associate (MURA) subcontract, is the design, development, implementation, verification and validation of Tonatiuh, an open-source advanced object-oriented Monte Carlo ray tracing program to assist in the design and analysis 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.

This paper presents the results accomplished in the development of Tonatiuh during the two years elapsed since the start of the project. It shows that Tonatiuh is well underway not only to fulfill but to exceed all of its promises. Thus, it is expected that, when finished, Tonatiuh will become a very valuable tool to assist solar researchers in the design and analysis of solar concentrating systems.

Some relevant features already incorporated into Tonatiuh addressed in this paper are:

- *Robust computational scheme.* Within the framework of geometric optics, Tonatiuh's computational scheme provides models of the concentrating system, the incoming solar radiation, and the interactions between both, which are not only very generic and flexible but amenable to efficient computational treatment.
- *Clean and flexible software architecture.* Among the main features of Tonatiuh's architecture are a complete separation of the GUI from the kernel, and a decoupling of the representation of the solar illumination from the geometry.

- *Operating System independence.* From the same C++ source code, it is possible to generate executable versions of Tonatiuh that runs under Windows XP, Mac OS X, and several flavors of Linux.
- *Advanced 3D-GUI.* Among other things, Tonatiuh's Graphic User Interface provides the user with a three-dimensional, interactive, and realistic view of the concentrating system being modeled.

Howard University

An Intelligent Customer Power Management System

James A. Momoh, FIEE, FNSE, Peter Bofah, Anthony Bantamoi, Eshovo Momoh
Howard University,
2400 Sixth Street, NW, Washington, DC 20059

This work focuses on the quality and relationship of power between the customer and the utility provider. We propose a system that will monitor and help manage power from the customer's side of the grid and also compiles an index for system implementation. The proposed Intelligent Customer Distribution Management System (ICDMS), provides insight and information to customers about the power supplied to their homes. Based on power quality (PQ), a new index is compiled for the proposed system's implementation. Harmonic distortion, voltage disturbance, and system efficiency (Power Factor) are used for the design of the ICDMS index. Harmonic distortion is analyzed based on individual total harmonic distortion (THD), voltage disturbance is analyzed by the magnitude of nominal voltage after a fault has occurred and system efficiency is based on system losses that are determined through power factor of loads, equipment, and the source. To implement the theories for the index the software package Neplan© is used for simulation and analysis of the networks. The tools used within Neplan© are: load flow calculation, short circuit analysis, and harmonic analysis. The networks used for simulation consist of loads, utility generation, other equipment, and distributed generators (DG's-photovoltaic (PV).

In the wake of the recent technology boom in electronics and appliances more and more households and businesses consume high amount of power that can cause overloads and disruptions to the power network. The utility company in response to the changes in the system must react and control the situations. New technologies on behalf of the utility provider are a means to monitor and control come disturbances and changes within the network but not all. For some of the fluctuations in the system the customer needs to make changes. It is valuable if there is a tool that the customer as well as the utility provider can monitor and manage power in a system. Customers being able to monitor and make changes to their home power system would help in eradicating some issues with power overloads. It can also help everyone to save in energy costs and allow for optimal performance of the power network. A proposed system ICDMS will entail applications of power management, monitoring, and correction. The system Intelligent Customer Distribution Management System (ICDMS) allows the customer to monitor and manage the amount and quality of power delivered to their establishment. This requires some guidelines or parameters for the user to interpret information collected from the grid. This work details how the index for the ICDMS system is compiled based on power quality methodologies. Many methodologies are available for determining the quality of power. Some researchers believe that it can be determined by the voltage sag magnitude, occurrence, and duration. This method calls for monitoring the system for a time period and recording the disturbances, outages, and other effects on the system and plotting them using industry standards. Others believe power quality can be determined by analyzing the losses in the system from the source to the loads. This method can be determined through analysis of the power factor of the network. In other cases analyzing the harmonic content of the network can give the conclusion of quality of power in a network. For this work a compilation of all of these methods were used to extract information from the system.

The objective is to design an Intelligent Customer Distribution Management System to aid the customer to pinpoint trouble areas of a power system given a set of measurements. There are many observations (measurements) that pass through the customer's meter that can be used to evaluate the performance of electricity supply. The proposed Intelligent Customer Distribution Management System is new and innovative technology to aide in the management and monitoring of power system networks. The index based on harmonics, power factor, and voltage sag can have other parameters added maybe for a more in-depth analysis of a power network. The ability to see and make changes when necessary will allow for optimal performance of a power network.

Overall Objective—The main objective for the Center of Energy Systems and Control (CESaC) in this project is to develop a research infrastructure in renewable energy to prepare students and faculty in modeling, analysis, and management of Photovoltaic/Renewable Energy units to sustain our national economy. Our objectives include the review of the state of the art models for different PV/Renewable Energy resources and development of models for PV and Renewable energy resources using state of the art techniques. We are also engaged in evaluation of the performance and accuracy of the developed models, design and implementation of a reliable PV based power management scheme in which the evaluation of the performance of the PV model performed under different weather conditions and periods of the day, and application of control for optimal supply of load under different scenarios. Hence, we:

- Developed PV models using MATLAB SIMULINK to evaluate performance of the PV system.
- Designed and implemented a reliable PV based power model for different weather conditions and periods of the day.
- Designed and implemented control schemes that aim at eliminating violations of the power supply quality based on selected indices.
- Designed a scheme to implement energy management options by a customer with DG and other options. This design factors are cost incentive for selecting optimum control options.

The aim of this research is to design an Intelligent Customer Distribution Management System to aid in the customer pinpointing trouble areas of a power system given a table of measurements. There are many observations (measurements) which pass through the customer's meter which can be used to evaluate the performance of electricity supply. In this research we developed several indices for assisting the customer to make choices or assess the quality of power delivered. These indices are power factor, total harmonic distortion, voltage sag, and power quality. The comparison of these indices to acceptable values is done by using NEPLAN software tools for power system simulation and design. The design work included modeling of distributed generators (PV- DG's), development of indices, and selection of tools for computing these indices. Using a set of rules, an implementation of intelligent customer based PV power load management is explored

An Integrated PV charging system for mobile phone with fine tuning and packaging has been designed and built by the Center with participation from our Energy Expert Systems Institute (EESI), a summer outreach pre-engineering program for high school students. Mobile phone usage is a common commodity for personal and business contacts. The function of the mobile phone depends solely on an energy source, without which it is totally useless. Our aim this summer is to design a back-up PV charger to replace the main supply from the utility. PV energy is a renewable energy source available everywhere, with the presence of sunshine. It can easily serve as a charger to power mobile phones for continuous usage.

Our work in this project is to work in groups of 3 to design, build and test a PV powered mobile phone charger with the following capabilities and specifications for each group.

Group 1: Evaluate the charging circuit of mobile phone currently in use and determine appropriate voltage and design a corresponding PV (solar cell) tracking to supply the circuit for continuous supply as appropriate.

Group 2: Design and build voltage regulating circuit as a component of the charger.

Group 3: Design the Display Unit using LED to monitor the charging states of the mobile phone.

All Groups put the integrated charging package together for a prototype design and testing.

References

1) "Impacts of Distributed Generation on Power System Transient Stability", by Slootweg and King, 2002, pp. 862-865
2) "Understanding the Potential Benefits of Distributed Generation on Power Delivery System", by Peter Daly and Jay Morrison, pp. A2-3 –A2-5
3) "Placement and Penetration of Distributed Generation under Standard Market Design", International Journal of Emerging Electric Power Systems, vol.1, iss.1, 2004, article 1004, pp. 4-9
4) "Design and Implementation of PV Based Power Management Scheme", by Dr. Momoh & Ayo Ishola-Salawu, pp. 2-6
5) "Survey of Harmonic Distortion from Power Quality Measurements and the Application of Standards Including Simulation," C. Gopalakrishnan, Anna University, India
6) "Voltage Sag Analysis Taken into account in Distribution Network Design,"P. Heine, 2001 IEEE Porto Power Tech Conference
7) "Impact of Voltage Sags in Practical Power System Network," C. Radhaknighnc
8) "Three Phase Power Flow for Distribution Systems with Dispersed Generation," A. Abur, 14th PSCC June 2002.
9) Demand-Side Management and Electricity End-Use Efficiency, Anibal T. DE Almeida, et al, 1987.

Studies on Generation of Internal Photoresponse Maps of Si Solar Cells by PVSCAN

Gilda Jimenez, University of Texas at Brownsville
Bhushan Sopori, National Renewable Energy Laboratory

Photovoltaic efforts to optimize the performance of solar cells and the silicon wafers from which they are made are approaching success with the PVSCAN 5000. In the past, mapping the defect parameters of solar cells was complicated and impractical; PVSCAN is an instrument that may offer these valuable data. PVSCAN 5000 can map the defects in the material, such as dislocations and grain boundaries, laser-beam induced-current (LBIC), and minority-carrier diffusion length. Grain boundaries are the boundaries between separate grains in multicrystalline silicon. Dislocations are breaks in the crystal pattern within an individual grain. Laser-beam-induced current (LBIC) is a technique for mapping photo-response by illuminating small areas and measuring current output (alternative EBIC or electron-beam-induced current). Minority-carrier diffusion length, which is the average distance that a minority carrier will travel within a semiconductor before recombining, is a key measure of performance of semiconductors and solar cells. The next stage in this project is the new PVSCAN 6000; this version will have a four times faster response and a double scanning area that the former PVSCAN 5000. The new PVSCAN 6000 has to be assembled. The system will update its software and make new arrangements in the electrical system. I am assisting in developing this new version of the PVSACN 6000 and testing the system performance.

Correlation Between Minority Carrier Lifetime and Minority Carrier Diffusion Length Measurement of Silicon Wafers

Carl Eloi, Central State University
Bhushan Sopori, National Renewable Energy Laboratory

The diffusion length measurement of a silicon wafer is acquired from the surface photovoltage (SPV). Surface photovoltage is the result of a surface or insulator charge or work function difference detected by a non-contacting probe. In this case, the surface photovoltage is created from an optical excitation of the silicon wafer. The diffusion length is the mean distance an electron or hole travels before recombining with another hole or electron. The minority-carrier lifetime of a silicon wafer is the average time that the electron-hole pair (minority carrier) exists before recombination. The method of acquiring this measurement is by photo-conductive decay (PCD). The electron-hole pairs are created through optical excitation, and the decay is monitored as a function of time following the cessation of the excitation. As of this point, the SPV device used to measure the diffusion length is repeatable and the readings acquired from the test proved to be accurate for the cell measurement. Further testing will be performed to correct the device for measuring silicon wafers. The importance of making a correlation between these two measurements is to show the following: The values indicate to the manufacturer of silicon wafers how good their wafers are with respect to performance. Furthermore, the correlation also produces the parameters that control the lifetime and diffusion length of a wafer because the measurements correspond to identical properties/characteristics of the wafer (the diffusion length is measured in micrometers and the lifetime is measured in microseconds). Overall, this project shows the relationship between the SPV machine and the PCD testing device.

The Influences of Surface Roughness on the Accuracy of Dislocation Density by Using PVSCAN

Thurston Melson, Central State University
Bhushan Sopori, National Renewable Energy Laboratory

This paper describes what we believe is the fastest, most accurate way to measure dislocations in silicon materials. PVSCAN is a device that has the capacity to characterize silicon solar materials and devices. Light from a laser using 0.630-nm and 0.980-nm wavelengths is projected onto a sample, which gives off a reflection that is captured, and the average dislocation density is computed. Accuracy in this measurement is very important for the photovoltaic industry, because the determination of a batch of samples in the same growth strain can be examined. These outputs would help reduce the time and money put into the production of high-quality silicon material. PVSCAN creates an image of the sample displaying the dislocation distribution based on a color legend that is related to dislocation density to avoid handling excessive amounts of data. These color legend areas of each sample can be compared and evaluated. In silicon materials, for example, ribbon cells have a surface that is not uniformly smooth. PVSCAN should measure the cells with different surface roughness with the same accuracy.

Cross-Sectioning for Characterization of a Finished Solar Cell

Michael D. Speed, Central State University
Bhushan Sopori, National Renewable Energy Laboratory

This paper describes a new method for the rapid production of cross-sectioning samples using single-crystal solar cells. The method consists of taking a 4″x 4″ cell, and dividing it into a sufficient number of samples that are ready to be mounted and polished. The surface area of the polished region is analyzed for characterization of the layers within a solar cell. It is shown that: (i) the method is expedited the smoother the edges are on the intended end of polishing, and (ii) the total time of polishing each cell is related to edge quality and characterization of the layers by a simple linear relationship. An experiment setup is given for high-speed, high-quality, damage-free, polished-surface cross sections. Application of this technique for chemical mechanical polishing of cross sections is also discussed.

Study of Hydrogen Evolution from SiN:H during Fire-Through Metallization

Tsega Gebre-Egzi, North Carolina Central University
Dr. Bhushan Sopopri, National Renewable Energy Laboratory

A SiN coating serves as a perfect antireflection, providing a passivation (deactivation) surface or layer to reduce the layer reconfiguration. It acts as a buffer in a contact metallization, can be fired to increase the lifetime of the silicon cell, and allows diffusion of hydrogen into the cell to deactivate impurities for an improved performance. In impure Si, H reacts with impurities. This property decreases the diffusivity and increases the solubility of Si and H. When a high-temperature metallization firing is applied, some of the H is released from damaged areas and goes back into the Si; the rest escapes to the atmosphere. This damaged surface exchanges H with SiN:H and Si. The high-temperature rapid thermal processing (RTP) firing heals the damaged layer of the solar cell. Fourier transport infrared (FTIR) studies show that firing is preceded by a release of H from the SiN:H surface. As discussed earlier, the SiN:H surface may function as an antireflection coating, allow diffusion of H to impurities and passivation or deactivation, and provide a buffer for contact or screen-printed metallization.

Studies on Optical Processing for Fire-Through Metallization

Kenyatta S. Williams, Southern University and A&M College, Graduate
Dr. Bhushan Sopori, National Renewable Energy Laboratory

In this paper, we thoroughly discuss optical processing for fire-through metallization. It is known that firing causes the metal, which is screen printed on a silicon (Si) wafer, to interact in certain regions of the Si wafer; however, we will intensely explore the principle excitations of controlling the interface of a well-performing cell. This paper offers a brief description of the fire-through process; methods of using several light-intensity time profiles to fire-through screen-printed metallization on solar cells; measurements of I-V characteristics of the cells; and analysis of interface interaction within the solar cell. We will also demonstrate how H is transported from plasma to the bulk of the solar cell. Through theoretical and experimental verification, we will also conclude what determines a good contact and good hydrogen passivation. The focus of this research and paper is driven by the analysis of the interactions on the silver-silicon (Ag-Si) interface. Because temperature and time are so critical in the firing process, we will thoroughly analyze the relationship between the two.

Acknowledgements

The success of the MURA Program would not be possible without the support of the U.S. Department of Energy Solar Energy Technology Program, and key members of the National Renewable Energy Laboratory's National Center for Photovoltaics.

The 2006 MURA Summer Students would like to thank the mentors, *Larry Kazmerski*, *Bob McConnell, Martha Symko-Davies, Bhushan Sopori, Dan Friedman, and Helio Moutinho,* for working diligently with each of the summer students and for their continued support of the MURA Program.

We extend a special appreciation to Ms. Syl Morgan-Smith for her facilitation and guidance in past conferences to prepare us for this opportunity.

We would also like to thank the MURA Project Leader and Program Coordinator, Fannie Posey-Eddy, for her support and guidance throughout our summer experience and in the coordination of the REAP Student Summer Research Program Review Meeting.

This year's meeting would not have been possible without the assistance of the coordinators of the 16th Workshop on Crystalline Silicon Cells and Modules. Therefore, we would like to thank Bhushan Sopori and Sandy Padilla for supporting us in integrating our meeting into their workshop.

Contacts

Fannie Posey-Eddy
National Center for Photovoltaics
National Renewable Energy Laboratory
1617 Cole Boulevard, MS-3214
Golden, Colorado 80401
Phone: 303-384-6773
Email: mailto:fannie_eddy@nrel.gov

Bob McConnell
National Center for Photovoltaics
National Renewable Energy Laboratory
1617 Cole Boulevard, MS-3221
Golden, Colorado 80401
Phone: 303-384-6419
Email: bob_mcconnell@nrel.gov

Martha Symko-Davies
National Center for Photovoltaics
National Renewable Energy Laboratory
1617 Cole Boulevard, MS-1733
Golden, Colorado 80401
Phone: 303-384-6528
Email: martha_symko_davies@nrel.gov

Syl Morgan-Smith
Communications and Public Affairs
National Renewable Energy Laboratory
1617 Cole Boulevard, MS-1733
Golden, Colorado 80401
Phone: 303-384-3001
Email: mailto:syl_morgan-smith@nrel.gov

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
August 2006	Conference Proceedings	August 7, 2006

4. TITLE AND SUBTITLE
Renewable Energy Academic Partnerships (REAP) Student Summer Research Program Review Meeting, August 7, 2006, Denver, Colorado (Program and Abstracts)

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
F. Posey-Eddy

5d. PROJECT NUMBER
NREL/BK-520-40389

5e. TASK NUMBER
PVA60001

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/BK-520-40389

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
The DOE-NREL Minority University Research Associates Program (MURA) is an undergraduate research program that encourages minority students to pursue careers in science and technology. In this program, undergraduate/graduate students perform renewable energy research projects during the academic year with principal investigators at their university and are awarded summer internships in industry or at national laboratories such as NREL during the summer. By providing renewable energy research opportunities, the program has proven to be very successful in retaining minority undergraduate students in the science and technology areas and helping many students reach their educational and career goals. The MURA program is open to all minority-serving colleges and universities including Tribal Colleges-Universities, Hispanic, Alaska Native, and Hawaiian Native serving colleges and the Historically Black Colleges and Universities. Each university will conduct research in 1-3 areas: Basic Research, Photovoltaic Panel Measurement and Testing, and Solar Radiation Profile Study. Expansion to other solar energy technologies such as wind, bioenergy, and geothermal will provide additional solar energy project opportunities and internships. Students involved in research excel in the classroom learning experience and are committed to contribute to the development of renewable energy technologies to create a sustainable environment.

15. SUBJECT TERMS
photovoltaics; renewable energy; science and technology; undergraduate/research program; education and career;

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			
Unclassified	Unclassified	Unclassified	UL		**19b. TELEPHONE NUMBER** *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

F1147-E(12/2004)