FESC Research, Education and Outreach Project Progress Reports

(Attachment to Main Report)

May, 2013

FESC
Florida Energy Systems Consortium

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Florida Atlantic University

Southeast National Marine Renewable Energy Center (SNMREC)

(Progress Report)

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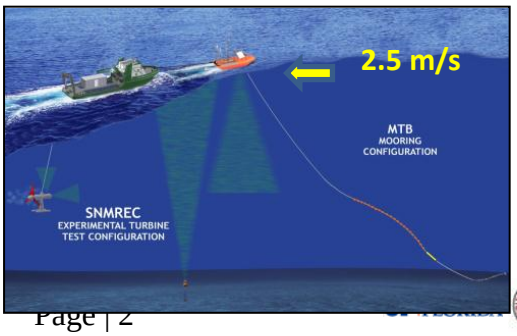
Students: Student listing is appended

Description: The Southeast National Marine Renewable Energy Center (SNMREC) at Florida Atlantic University (FAU) was established by an award from the US Department of Energy in 2010 as an extension of FAU's Center for Ocean Energy Technology, which was originally founded in 2007 by the 2006 Florida State University System Center of Excellence Program. The SNMREC is investigating harnessing power from ocean currents, such as the Gulf Stream, as well as ocean thermal energy conversion to generate base-load electricity, thereby making a unique contribution to a broadly diversified portfolio of renewable energy for the nation's future. Key drivers for investigation are determined by the regulatory process at State and Federal levels and by market and technology gaps needed to commercialize MRE. The SNMREC's role is to bridge the gap between concept and commercial deployment of ocean energy technologies by providing at-sea testing facilities and technology development for both ocean current and thermal energy systems. Research areas span environmental, resource, economic, education, and technology topics.

Budget: $8,750,000
Universities: Florida Atlantic University, collaborating with the University of Central Florida, Florida State University, University of South Florida, Embry-Riddle Aeronautical University, University of Miami, Oregon State University, University of Washington, Pennsylvania State University, University of New Hampshire, University of Hawaii, University of Edinburgh, Heriot-Watt University, Nova Southeastern University, Virginia Polytechnic Institute and State University, and Florida Institute of Technology.

External Collaborators: Numerous industry partners, state and federal government agencies, FFRDCs such as the National Renewable Energy Laboratory, Oak Ridge National Laboratory, Woods Hole Oceanographic Institution, U.S. Department of Energy (Office of Energy Efficiency and Renewable Energy), U.S. Department of Interior (Bureau of Ocean Energy Management, Regulation, and Enforcement), U.S. Department of Commerce (National Oceanic and Atmospheric Administration), the Florida Fish and Wildlife Commission, and Florida Departments of Agriculture and Environmental Protection.



Bi-annual Progress Report: October 1, 2012 – April 15, 2013

The Southeast National Marine Renewable Energy Center is developing an open-ocean energy laboratory and test capability to advance research on marine and hydrokinetic (MHK) ocean current energy and thermal

potential energy. An offshore scaled device test berth (approximately 12 nm offshore of Ft. Lauderdale, FL) is under construction and will be installed to accommodate up to 100kW max instantaneous power production and/or 7m rotor diameter turbine testing. This initial group of industrial devices will provide insight into individual device extraction methods, dynamics, and basic system operability. A generic 20kW experimental research turbine is also under construction which will allow for subsystem or component testing and development and will be the initial test vehicle. In addition, it will provide methodology and support infrastructure available for commercial 1:20 scale prototype device testing.

The SNMREC is moving forward with strategically selected research, developing and testing key technology, infrastructure and systems as well as standards criteria to meet this need. The successful implementation of an in-water testing infrastructure for MHK off the coastline of Florida will be the first and only such capability globally. A centralized, standardized testing capability will be provided for testing current energy conversion prototypes; initially, scaled versions and eventually full-scale devices. In addition, critical environmental measurements will be obtained on a continuous basis from the observational platform and submerged instrumentation. Companies from both the U.S. and internationally are working with the SNMREC in defining test requirements based on their design, as well as both short term occupancy in Florida and potentially longer term manufacturing and grid connection options in developing arrays for commercial enterprises.

An MHK lease application on the outer continental shelf (OCS) initially submitted to the US Department of Interior, Bureau of Ocean Energy Management (BOEM) in 2010 will form the model for future lease applications. As this is the first such application in the U.S., BOEM decided to conduct the Environmental Assessment (EA) in-house in order to fully develop future guidelines for subsequent lease applications for the OCS. BOEM has been responding to comments from Florida State and Federal agencies, as well as other interested parties, and is nearing completion of the EA. It is anticipated that a Notice of Availability of a Final EA will be released in the Federal Register within this quarter. The State if Florida will conduct a Consistency Determination following the release of the EA; however SNMREC has continued to conduct ongoing dialogue with Florida State agencies to provide the most up to date information. Presuming a favorable EA outcome, SNMREC has been moving forward with a review of the general lease terms awaiting specific stipulations from the EA.

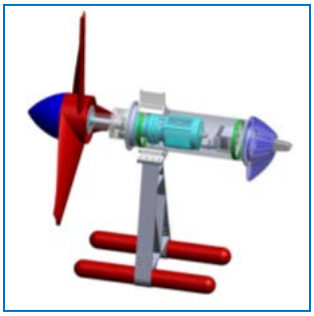


FIGURE 2. SNMREC 3-METER DIA ROTOR, 20KW INSTANTANEOUS MAX POWER PROTOTYPE TURBINE

A 3-meter rotor diameter, 20kW generically designed experimental research turbine (Figure 2) will provide a non-proprietary platform for component development at small scales. The test procedure/plan is laid out to incorporate monitoring and failure prediction systems, to gain experience in at-sea operations of this nature, and to support standards and protocol development. Industrial beneficiaries will be able to use the results of testing to enhance and accelerate prototype development. .

The SNMREC is engaged in sensor and instrument acquisition, deployment, and analysis to more fully characterize offshore energy resources, and the benthic and pelagic environment. Second, fabrication of a small-scale

hydrokinetic turbine system is in the final stages of completion. Testing is ongoing for components, sub-systems, and major systems of the turbine. Assembly and tow testing of the prototype prior to deployment of the test infrastructure is on hold pending completion of the EA.

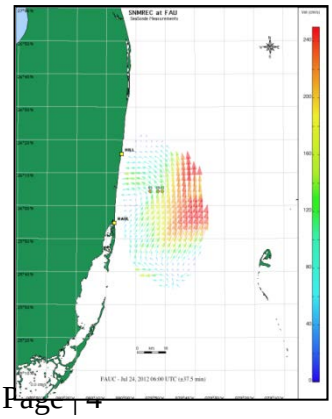
Sea trials were successfully conducted of a mooring and telemetry buoy to ready it for at-sea deployment. In-lab technology testing is underway with a scaled generator dynamometer which provides a platform to test offshore electrical systems before use and simulate offshore grids. Aerial surveys are being conducted to determine offshore turtle and marine mammal distribution and activity prior to install/test of MHK devices. Sub-sea surveys of installation sites are helping to identify deep water coral distribution and determine appropriate anchor areas.

One of the biggest unknowns in the operation of ocean current turbine (OCT) systems concerns the behavior of the generator sub-system as it experiences both variable loads and the torque differentials associated with changing currents acting on the rotor. In order to provide a capability to test generators and/or associated instrumentation under realistic conditions, the

SNMREC has developed a computer-controlled dynamometer system, located at the FAU SeaTech facility in Dania Beach. This basic capability, subtask 10-1.3, has been further enhanced with simulated oceanographic conditions to emulate rotor behavior on the test stand as it would occur in an actual ocean current. The 20 kW dynamometer has been fitted with the SNMREC's experimental research turbine power quality and health management systems, and has continued generating data for Prognostics and Health Monitoring (PHM) research. In addition, preliminary work has been completed to emulate rotor behavior in wave conditions and from collected offshore measurements. A laboratory capability feasibility study for ocean current turbine testing was completed, and the results are available in an M.S. Thesis format.

On May 22nd three Acoustic Doppler Current Profiler (ADCP) buoys were deployed. All three buoys were recovered in December. Velocity magnitude and direction with respect to time and depth data has been made available online. The plan is to refurbish the three buoys, add a fourth buoy and redeploy the buoys in a diamond configuration in May to begin to assess upstream and downstream flow variation for a six-month duration over the summer and fall.

As of mid-July of 2012, SNMREC's 12 MHz SeaSonde® radar system has been collecting ocean surface current measurements (see figure for location of ADCP buoys in relation to SeaSonde® coverage area). The SeaSonde® system has been operating intermittently this quarter during its initial tuning phase where the primary focus is on evaluating and optimizing the surface current data quality. With the passage of Hurricane Sandy, however, wave action at the Hillsboro site caused serious beach erosion and, in the process, the northern of the two antennas was destroyed. However, data were obtained before the unit's loss to allow initial attempts to validate the SeaSonde® data by comparing to data collected from the ADCPs which were recovered in December. Early results suggest that, at least during periods of



variable winds, such as during the passage of the storm, there is no correlation between CODAR-measured surface currents and currents throughout the water column. It appears that it will be necessary to adopt other strategies for continuous monitoring of the current.

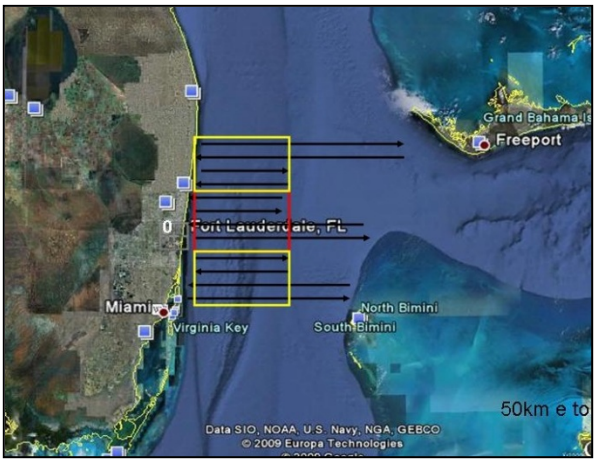


FIGURE 3. AERIAL SURVEY AREAS OFFSHORE FT. LAUDERDALE, TO DETERMINE SEA TURTLE AND MARINE MAMMAL POPULATION

Monthly aerial diversity and distribution surveys are being conducted to assess sea turtle and marine mammal populations. The surveys employ the currently accepted protocol – human observers viewing transect areas from a plane flying approximately 500 ft. from the ocean surface. Twenty-four months of cross-channel and over 40 coastal surveys have been completed to date. Additional along-shore surveys with available historical data are underway. Because preliminary data suggests significant population activity near shore, these transects will provide higher resolution data to support analysis efforts. The research team is working with the National Oceanic and Atmospheric Administration's, National Marine Fisheries Service to evaluate the SNMREC's enhanced approach as an expansion of currently accepted methods. The survey areas currently being assessed are depicted in Figure 3.

The SNMREC, with FAU's Harbor Branch Oceanographic Institute (HBOI) has established an internship program for up to 4 United States Coast Guard Cadets. The cadets will participate during their summer rotation, starting in the summer of 2013. The cadets have submitted applications to participate in the program, and the SNMREC and HBOI are currently reviewing the applications for selection to the program. This program will enhance cooperation between the U.S. Coast Guard and the SNMREC while educating future officers about projects which will be installed in coastal areas.

SNMREC staff is working with professors and students at FAU's School of Communications and Multimedia Studies' to create an interactive educational display game. A kiosk is being designed for the Ocean Discovery Center at FAU's Harbor Branch Oceanographic Institute. The kiosk will create a hands-on experience which educates the public about future ocean energy projects. This effort will be leveraged to provide similar kiosks to science and discovery museums. The intent is to provide an opportunity to engage all ages in a hands-on, fun and educational experience about ocean renewable energy production. The kiosks will increase knowledge of real, cutting- edge research in renewable energy from the ocean as well as, incorporating valuable Science Technology Engineering & Math (STEM) content to inform the public.

The Center developed a curriculum for upper-division high-school students to introduce the topic within secondary education. An additional topic on policy and social interaction with renewable energy, with an emphasis on ocean energy, will be added this summer.

Over fifty upper-division graduates and Principle Investigators have been engaged in research in marine renewable energy (MRE) to date. Approximately a dozen of these students have secured positions in energy-related companies. One of the PhD students was selected as a Knauss Fellow after graduation and is currently serving in the U.S. Department of Energy's

Energy Efficiency and Renewable Energy focus in the Wind and Water Power Program. Partnerships between the SNMREC and the marine industry continue to expand.

More than 45 Non-Disclosure Agreements (NDA) have been signed with companies across the global marine industry. Language within the NDAs does not allow for the release of information of the details of the collaborations at this time. Industry sponsored funding is at a level of $155,000.

Funding Leveraged

To date, with the State of Florida funding, the SNMREC has successfully leveraged $5,455,675 of U.S. Department of Energy funds. DOE has identified an additional $250,000 pending development of a Statement of Work and associated detailed budget against the current grant. Three proposals are in process and will be submitted in May and June.

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University of Florida

Database Infrastructure for Integrative Carbon Science Research (Updated)
(Progress Report)

PI: Sabine Grunwald **Co-PI:** Timothy A. Martin
Students: C.W. Ross (M.S. completed); X. Xiong (Ph.D., completion expected in 2013)
Technical staff: Brandon Hoover and Risa Patarasuk
Post-Docs: Nichola M. Knox

Description: Rising CO_2 concentrations in the atmosphere and effects on global climate change have been well documented, and future impacts are uncertain but potentially devastating. Florida's natural and agro-forest ecosystems have much potential to sequester carbon in biomass and soils due to unique climatic and landscape conditions. However, research gaps exist to accurately assess carbon pools and fluxes at coarse scales, ranging from county to the region and larger. The overarching objective of this project is to address these obstacles by developing a terrestrial carbon information system (called "TerraC") for the carbon science community, focused on ecosystems in Florida. The information system will be administered through the UF Carbon Resources Science Center (http://carboncenter.ifas.ufl.edu), a multi-disciplinary Center dedicated to research in support of enhanced agricultural and natural resource carbon management.

Budget: $199,440
Universities: UF
External Collaborators: Natural Resources Conservation Service-U.S. Department of Agriculture

Progress Summary

Improvements of the TerraC (Terrestrial Carbon Information System) since the last reporting phase are manifold. Several large carbon and environmental datasets were integrated into TerraC and the code for displaying and downloading data had be adapted to accommodate the amount of data to display, search, and store, and download. Large data in web databases are peculiar and required adjustments to the streaming procedures (server-based coding adjustments). In addition we made improvements to the user interface. To that end, the column wizard has been continuously adjusted so that users can build their data tables easily.

In an effort to create a community where users are able to find and understand the data they are looking for to aid their research, new functions have been added at the project level. The first of these functions is a citations list. This list is where project owners can add citations to articles that have been published using the data in their project. The second function added to TerraC is the ability to upload more descriptive PDF documents to each data table so that other users can fully understand project data with one portable document.

The following climate data, extracted to site-specific locations, were added to the TerraC system that complement tier 1 data for which historic tree growth data have been assembled in the system (see below).

PRISM (Parameter-elevation Regressions on Independent Slopes Model)
These data sets were created using the PRISM climate mapping system, developed by Dr. Christopher Daly, PRISM Climate Group director. PRISM is a unique knowledge-based system that uses point

measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters. Continuously updated, this unique analytical tool incorporates point data, a digital elevation model, and expert knowledge of complex climatic extremes, including rain shadows, coastal effects, and temperature inversions. PRISM data sets are recognized world-wide as the highest- quality spatial climate data sets current l y available. PRISM is the USDA's official climatological data. http://prism.oregonstate.edu
Variables representing 1970-2010 included in the PRISM dataset are: Precipitation (average monthly), Minimum Temperature (average monthly), Maximum Temperature (average monthly), Dew Point Temperature (average monthly), Mean Temperature (average of Minimum and Maximum Temperature)(average monthly) , Vapor Pressure (average monthly) .

Idaho Geospatial
This gridded data set was developed by Dr. John Abatzoglou from the Univerisity of Idaho. These climate data combines spatial attributes of gridded climate data f rom PRISM with temporal attributes of a region-al-scale and daily gauge -based precipitation. The gridded was based on observations from various weather stations including RAWS, AgriMet, AgWeatherNet and USHCN-2. The dataset is intended for users who require daily climate data to drive ecological or hydrological models as well as other applications. The original files came in a netCDF format . Then these netCDF were reformat ted and imported in ArcGIS. http://inside.uidaho.edu/webapps/search/epscor_browse.aspx
Variables representing 1979-2011 included in the Idaho Geospatial dataset are: Precipitation (average monthly) , Precipitation(total monthly accumulations), Maximum Relative Humidity (average monthly) , Minimum Relative Humidity (average monthly), Specific Humidity (average monthly), Downwelling Short wave Radiation at Sur face (average monthly) , Wind Direction (average monthly), Minimum Temperature (average monthly), Maximum Temperature (average monthly) , Wind Speed (average monthly) .

NARCCAP (The North American Regional Climate Change Assessment Program)
NARCCAP is a joint international program that aims to produce climate change simulations in order to investigate uncertainties in regional scale projections of future climate and generate climate change sce-narios. NARCCAP is a database that hosts climate change projections for North America. NACCAP dataset are generated by various GCMs (Global Climate Mo d e l s) , f rom which, various climate change projections (scenarios) a re derived. GCMs use grids of spatial resolution e.g. , 300 km * 150 km grids. These GCMs are downscaled by various RCMs (Regional Climate Models) to spatial resolution of 50 * 50 km grids.
NARCCAP projections have been made for two 30-year time period using each GCM-RCM combination. These are : 1) Current time period of 1971-2000, usually known as the "baseline" projection, and is re-ceived by forcing the GCMs with historic CO2 emissions, till the year 2000. A perfect GCM-RCM combination should simulate a climate almost identical to the climate that was actually observed during the period of 1970-2000. 2) The future time period of 2041-2070 representing projections into the future under various assumptions for scenarios.
The NARCCAP climate variables are projected in a very high temporal resolution. For example, tempera-ture, precipitation and surface pressure are all represented on a 3-hourly time scale. However, other variables such as minimum/maximum surface air temperature are represented on a daily scale (http://www. narccap.ucar.edu/data/data-tables.html).
The original data set comes in netCDF format. Ferret (from NOAA) and Cdat (from NCAR) were used to aggregate the data into the monthly scale. Some variables such as the monthly minimum temperature were derived from the NARCCAP daily data. Then these aggregate monthly scales were imported to ArcGIS.
Variables available in the NARCCAP dataset are: Sur face Air Temperature, Precipitation, Downwelling Shortwave Radiation at Surface, Surface Pressure, Specific Humidity, Minimum Surface Air

Temperature, Maximum Surface Air Temperature. PINEMAP has derived the following: Number of Frost Days, Average Minimum Surface Air Temperature, Average Maximum Daily Sur face Air Temperature.

Funds leveraged/new partnerships created

TerraC is now providing the data infrastructure for a $20 million integrated research, education, and extension project. This large-scale project funded by the United State Department of Agriculture (USDA) – National Institute of Food and Agriculture (NIFA) – Agriculture and Food Research Initiative (AFRI) Regional Project "PINEMAP: Integrating Research, Education and Extension for Enhancing Southern Pine Climate Change" (2011-2016) allows to populate TerraC and will cross-fertilize several research idea centered around carbon budgets and assessments, carbon change in dependence of global climate change and other stressors, and carbon sequestration and regulation as an ecosystem service. Many other similar synthesis projects will be facilitated through TerraC-PINEMAP.

The PINEMAP project goals are to create, synthesize, and disseminate the necessary knowledge to enable southern forest landowners to:

- harness pine forest productivity to mitigate atmospheric carbon dioxide
- more efficiently utilize nitrogen and other fertilizer inputs
- adapt their forest management approaches to increase resilience in the face of changing climate.

PINEMAP has a multi-tier data structure representing different scales including:

- Tier 1 (historic measurements of tree response in dependence of treatments at about 700 locations across the southeastern U.S.)
- Tier 2 (new base measurements at hundreds of sites across the southeastern U.S.)
- Tier 3 (high-intensity measurements to capture water and carbon cycle at 4 sites)

Peer-reviewed Publications:

1. Cao B., S. Grunwald and X. Xiong. 2012. Cross-regional digital soil carbon modeling in two contrasting soil-ecological regions in the U.S. *In* **Minasny B.**, B.P. Malone, and **A.B. McBratney (eds.).** CRC Press, Taylor and Francis, 2012. ISBN: 978-0-415-62155-7.
2. Patarasuk R., S. Grunwald, T.A. Martin and B. Hoover. 20__. Integrative modeling of tree response along geographic and ecological trajectories in the southeastern U.S. Ecological Modeling J. (in preparation).
3. Ross C.W. 2011. Spatiotemporal modeling of soil organic carbon across a subtropical region. M.S. thesis. University of Florida, Gainesville, FL.
4. Ross C.W., S. Grunwald, and D.B. Myers. 20__. Spatiotemporal modeling of soil carbon stocks across a subtropical region. Soil Sci. Soc. Am. J. (in review).
5. Xiong X., S. Grunwald, D.B. Myers, J. Kim, W.G. Harris and N.B. Comerford. 2012. Which soil, environmental and anthropogenic covariates for soil carbon models in Florida are needed? *In* **Minasny B.**, B.P. Malone, and **A.B. McBratney (eds.).** CRC Press, Taylor and Francis, 2012. ISBN: 978-0-415-62155-7.
6. Xiong X., S. Grunwald, D.B. Myers, J. Kim*, W.G. Harris and N.B. Comerford. 2012. Which soil, environmental and anthropogenic covariates for soil carbon models in Florida are needed? The 5th Global Workshop on Digital Soil Mapping 2012, Sydney, Australia, April 10-13, 2012.
7. Xiong X., S. Grunwald, D.B. Myers, J. Kim, W.G. Harris and N.B. Comerford. 20__. Optimal selection of predicting variables for soil carbon modeling in Florida, USA. Geoderma (in review).

Presentations

1. Grunwald S. 2012. Soil carbon variability across large landscapes. Soil and Water Science Research Forum, Gainesville, FL, Sept. 7, 2012.
2. Grunwald S., B. Hoover, and R. Patarasuk. 2012. Terra C and Pinemap data resources. Webinar series Pinemap project. Gainesville, FL, July 13, 2012.
3. Grunwald S. 2011. Geospatial and spectral soil carbon modeling across large regions. NRCS, National Soil Survey Center (NSSC), Lincoln, NE, May 13, 2011.
4. Grunwald S., T. A. Martin, B. Hoover, G.M. Vasques, B. Zhong, and D.L. DePatieJr. 2010. Terrestrial carbon (TerraC) information system. 2010 Florida Energy Systems Consortium (FESC) Summit, Orlando, FL, Sep. 27-29, 2010.
5. Grunwald S., T.A. Martin, G.M. Vasques and B. Hoover. 2009. Database infrastructure for integrative carbon science research. Florida Energy Systems Consortium Summit, Tampa, FL, Sept. 29-30, 2009.
6. Hoover B., S. Grunwald, T.A. Martin, G.M. Vasques, N.M. Knox, J. Kim, X. Xiong, P. Chaikaew, J. Adewopo, B. Cao and C.W. Ross. 2011. The Terrestrial Carbon (Terra C) Information System to facilitate carbon synthesis across heterogeneous landscapes No. 264-10. Symposia Spatial Predictions in Soils, Crops and Agro/Forest/Urban/Wetland Ecosystems, ASA-CSSA-SSSA Int. Meeting, San Antonio, TX, Oct. 16-19, 2011.
7. Hoover B., N.M. Knox, S. Grunwald, T.A. Martin, X. Xiong, P. Chaikaew, J. Kim, and B. Cao. 2011. Synthesis tools for carbon assessment in ecosystems. FESC Summit, University of Florida, Gainesville, FL, Sept 28-29, 2011.
8. Hoover B., G.M. Vasques, B. Zhong, S. Grunwald, T. A. Martin, and D.L. DePatieJr. 2010. The terrestrial carbon (TerraC) information system Vers. 1.0. 11th Annual Soil and Water Science Research Forum, Gainesville, FL, Sep. 10, 2010.
9. Xiong X., S. Grunwald, D.B. Myers, W.G. Harris, A. Stoppe and N.B. Comerford. 2011. Are soil carbon models transferable across distinct regions or scales in Florida? No. 262-8. Symposia Spatial Predictions in Soils, Crops and Agro/Forest/Urban/Wetland Ecosystems, ASA-CSSA-SSSA Int. Meeting, San Antonio, TX, Oct. 16-19, 2011.

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Development of Low-Cost CIGS Thin Film Hot Carrier Solar Cells

(Progress Report)

PI: Gijs Bosman **Co-PI:** Tim Anderson
Students: Yige Hu, PhD.

Description: PV has entered into a period of record growth. Most of the current production is based on crystalline Si technology. However, there are fundamental limits to the ultimate Si costs that may inhibit it from achieving the desired level of contribution to worldwide energy production. In contrast, thin-film PV technology can reach the desired outcome due to fast deposition rates and lower cost. Our study is focused on hot carrier solar cells for cell conversion efficiency improvement in a low cost, high throughput CIGS system. The rapid thermalizaton loss of hot photoexited carriers interacting with the lattice can potentially be reduced through phonon engineering in the absorber layer; the subsequent extraction of the hot carriers may be realized through device engineering of energy selective contacts.

Budget: $ 126,112.00 ($76.6K for this 12 month period)
Universities: UF

Progress Summary

Hot carrier solar cells allow hot carriers to be collected before energy is lost to the lattice. This ultimately leads to a higher open circuit voltage since the average energy of the collected electron is greater than the band gap energy. It also leads to a higher short circuit current, leading to an overall greatly improved efficiency.

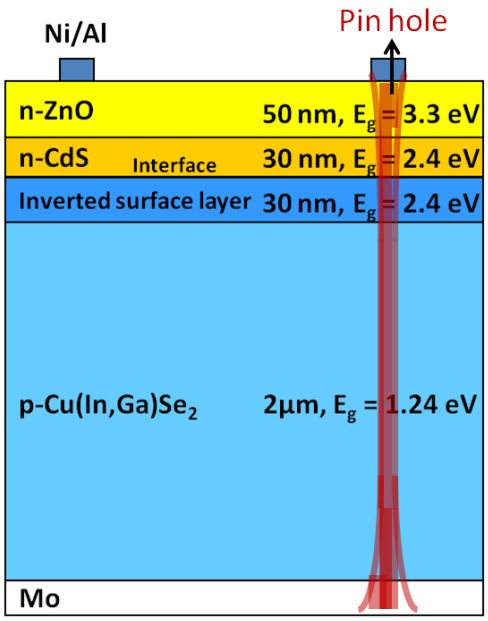

FIGURE 1 CIGS PIN HOLE STRUCTURE

Photocurrent measurements as a function of applied bias were carried out on fabricated CIGS solar cell structures to characterize the hot carrier effect. In a preliminary experiment the CIGS cell is exposed by LED light of wave length 365nm, 455nm, 630nm and 740nm, respectively. The incident photon energy defines the initial hot carrier energy. The resulting current shows a different bias dependency with respect to high energy carriers and low energy carriers. A relationship between the photocurrent and initial hot carrier energy is being formulated from which the relative density of hot electrons and its effect on cell operation can be determined from measured current voltage data.

A study of the reverse bias dark JV characteristic helps in the separation of hot carrier effects from other device phenomena. The commonly used dark current model: $J_{dark} = J_0 \left[e^{\frac{q(V-IR_S)}{nk_BT}} - 1 \right]$ cannot

explain the linear characteristic at low reverse bias and superlinear characteristic at high reverse bias of the CIGS solar cell. Space charge limited current (SCLC) via pinholes in the ZnO and CdS layers consisting of a metal-CIGS-molybdenum structure (Figure1) is proposed as contributing to the reverse bias leakage current [1].

The SCLC model helps to better understand the dark current and gives a baseline for separating the photocurrent contribution from dark current components in the CIGS cell. Therefore our hope is that photon induced hot carrier effects can be uncovered and demonstrated.

Annual Progress Report

Hot carrier solar cells allow hot carriers to be collected before energy is lost to the lattice. This ultimately leads to a higher open circuit voltage since the average energy of the collected electron is greater than the band gap energy. It also leads to a higher short circuit current, leading to an overall greatly improved efficiency.

If phonon engineering is successfully applied in the absorber layer, the hot carrier lifetime will be increased significantly. This enhances the chance of hot carriers being collected in the Energy Selective Contacts. The ESCs design requires knowing the most likely energy range of the hot carriers. The incident photon energy only defines the initial hot carrier energy. Immediately after photogeneration carriers will exchange energy until equilibrium levels are reached. As the carriers travel to the ESC, some energy will be lost to lattice collisions. Knowing the final energy reached at the ESCs requires extracting the mean free path of hot carriers colliding with phonons.

The focus of this period is to investigate the presence of possible hot carrier effect on a fabricated bulk CIGS solar cell structure and extract the phonon scattering mean free path by measuring photon current as a function of applied bias under different wavelength on the solar cell.

The current-voltage characteristic of a NREL solar cell under exposed by LED light of wave length 365nm, 455nm, 630nm and 740nm, respectively is shown in Figure 1. The LED light intensity at each wavelength is different as controlled by the supply current. Although a best effort was made to have an approximately consistent distance of LED to solar device and LED power (photons/s), the equipment used was not accurate enough to guarantee that the current was 100% consistent. However the information from the JV curve that characterizes the hot carrier collection lies in the relative rate of increase of the current with voltage. Therefore the light generated photon current density is normalized to its value at a voltage of V=0 to eliminate the nonlinear effect from the light intensity. The current density increases with voltage away from the standard

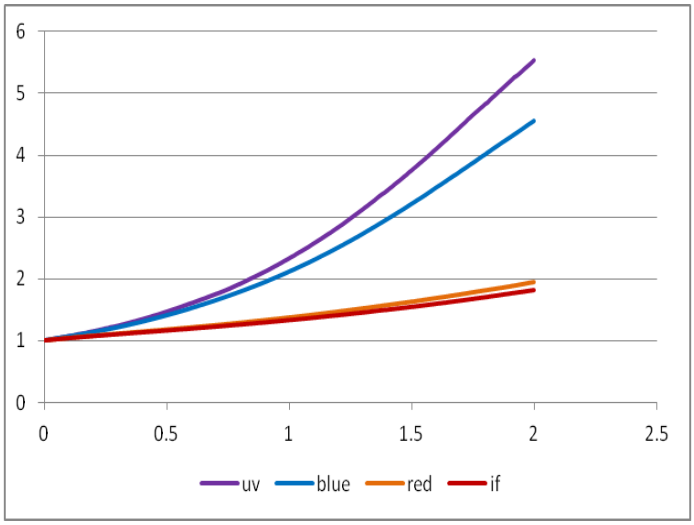

FIGURE 2 REVERSE BIAS IV CHARACTERISTIC OF NREL SOLAR CELL UNDER 365NM(PURPLE LINE), 455NM(BLUE LINE), 630NM(YELLOW LINE) AND 740NM(RED LINE)

exponential curve. This nonlinearity with wavelength dependency is proposed as a hot carrier related effect.

Impact ionization is suggested to be the factor of photocurrent increase in the reverse bias region. The ionization rate α is defined as the electron-hole pairs generated per carrier per unit distance travelled [1]. When the electron ionization rate is a lot larger than the hole ionization rate, the total ionization rate is written as $\alpha = \frac{2}{W_1^2}\frac{d\ln(\frac{M_n}{M_p})}{dE_m}$ [2]. The experimentally obtained ionization rates from I-V measurements with NREL solar cell is shown in Figure 2. The ionization rate for short wavelengths is 10^5 /cm. So the minimum acceleration distance for impact ionization is about 100 nm. Considering that the SCR of the CIGS solar cell is 100 to 200 nm long, most short wavelength photogenerated carriers in the SCR are expected to have impact ionization. The ionization rate for long wavelength is in the range of 2 to 8 × 10^4/cm, resulting in an acceleration distance of 125 to 500 nm. Impact ionization is not expected to take place at low reverse bias due to long acceleration distance required, but at high reverse bias the e-field increases and the SCR expands, impact ionization is expected to occur. The observed ionization rate difference for short and long wavelengths is due to the respective differences in carrier temperatures. The higher the initial energy, the lower the acceleration distance that is needed, corresponding to a high ionization rate.

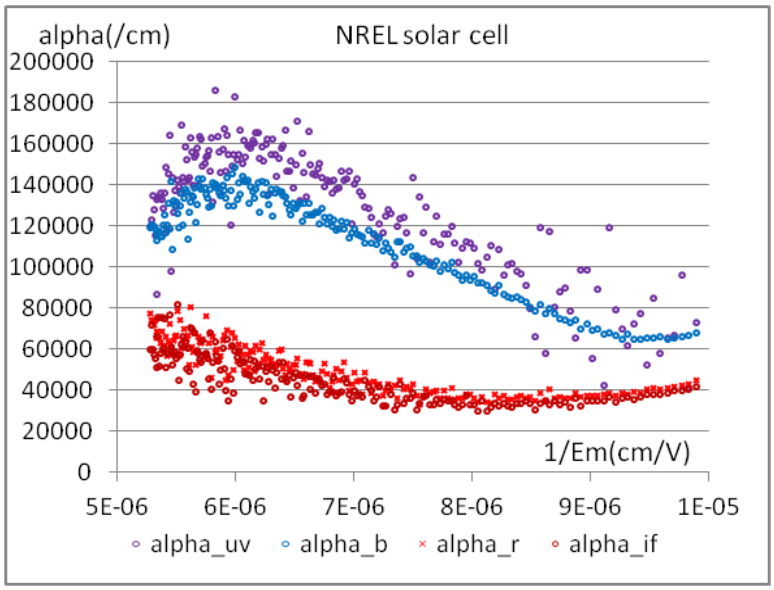

FIGURE 3 IMPACT IONIZATION OF NREL SOLAR CELL WITH ILUMINATION WAVELENGTHS OF 365NM (PURPLE DOT), 455NM (BLUE DOT), 630NM (ORANGE DOT) AND 740NM (RED DOT),

To interpret impact ionization by means of the mean free scattering path, λ, a simple model by Shockley is used to study the probability of an occasional "lucky electron" building up kinetic energy to the impact ionization level. The lucky electron does this by means of not scattering while accelerating in the field, so that it retains all the kinetic energy until the threshold level is obtained. The percentage of electrons that participate in impact ionization is related to the probability of an electron being "lucky". To calculate the "lucky" probability, first the probability of an electron scattering over a distance dx is considered. The probability is proportional to dx and inversely proportional to λ: $P = \frac{dx}{\lambda}$. The probability of an electron not scattering over the distance l, the impact ionization mean free distance, is calculated by sectioning l into lengths of dx, calculating the probability over each length and calculating the overall probability by the product $P_l = \prod_{i=1}^{n}\left(1 - \frac{dx}{\lambda}\right)$. For a given λ choose dx<< λ , $\ln P_l = \sum_{i=1}^{n}\ln(-\frac{dx}{\lambda}) = \sum_{i=1}^{n} -\frac{dx}{\lambda} = -\frac{1}{\lambda}\sum_{i=1}^{n} dx = -\frac{l}{\lambda}$. The kinetic energy gained

from the field for accelerating over distance l to reach the threshold energy is given by $q\varepsilon l = E_{th}$, which allows the impact ionization rate to be written in terms of the field: $\alpha = \frac{P_l}{l} = \frac{q\varepsilon}{E_{th}} e^{\frac{-E_{th}}{q\varepsilon\lambda}}$. If the equation is re-arranged as $\ln\frac{E_{th}\alpha}{q\varepsilon} = -\frac{E_{th}}{q\lambda\varepsilon}$, it is noticed that the left hand side is negative. Since the termsE_{th}, q, λ and ε are physical constants, which are always positive, $\frac{E_{th}}{q\lambda\varepsilon}$ cannot be negative. Therefore $\ln\frac{E_{th}\alpha}{q\varepsilon} < 0$, which indicates $\alpha < \frac{q\varepsilon}{E_{th}}$. Because α is always less than $\frac{q\varepsilon}{E_{th}}$, the impact ionization rate is limited by the field. However, the ionization rate shown in Figure 2 is much higher than allowed by the field. Therefore electrons are believed to have an initial energy higher than room temperature to compensate for lacking energy from the electric field for ionization.

The traditional source of the impact ionization energy is the field, but the proposed additional source is the photon energy with phonon scattering losses considered. A new lucky electron model includes a term for the initial energy of electrons as a result of a higher energy photon. The impact ionization threshold comes from the field acceleration and the initial photon energy: $E_{th} = q\varepsilon l + E_{av}$, where E_{av} is the equilibrium electron energy from high energy photons and phonon scattering: $E_{av}=E_{photon}-E_g-E_{phonon}$. For the modification, E_{th} is substituted by E'_{th} , where $E'_{th} = E_{th} - E_{av}$, which results in $q\varepsilon l = E'_{th} = E_{th} - E_{av}$. With the new expression of Eth, the ionization rate is expressed as $\alpha = \frac{q\varepsilon}{E'_{th}} e^{\frac{-E'_{th}}{q\varepsilon\lambda}}$. The terms λ and E_{av} are used as fitting parameters for the ionization rates of different wavelengths of NREL cells, which is shown in Figures 3-6. In the figure 7, λ is plotted against $E_{av,}$ which turns out to have a linear relationship. As a general trend, the hotter an electron is, the more frequently it scatters (smaller λ). Based on the data analysis, the mean free path seems to decrease inversely proportional with increasing Eav. To confirm that the fitting result is reasonable, the obtained λ is compared with published data. The relaxation time of hot

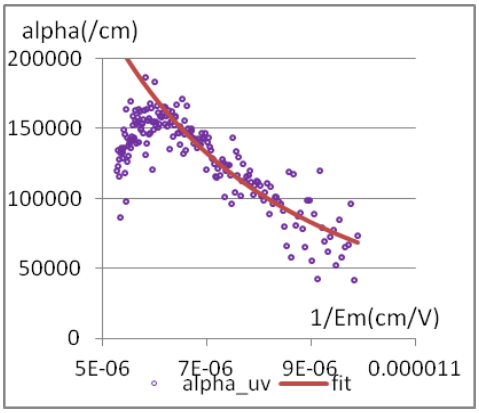

FIGURE 3 IONIZATION RATE WITH FITTING CURVE UNDER 365NM ILLUMINATION

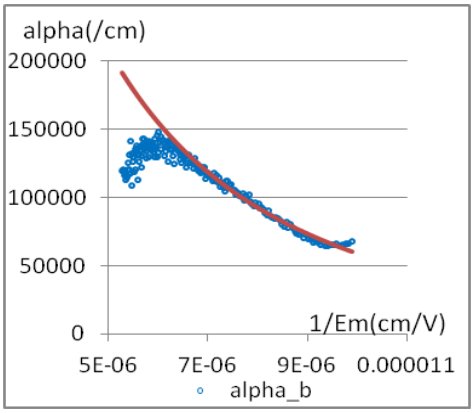

FIGURE 4 IONIZATION RATE WITH FITTING CURVE UNDER 455NM ILLUMINATION

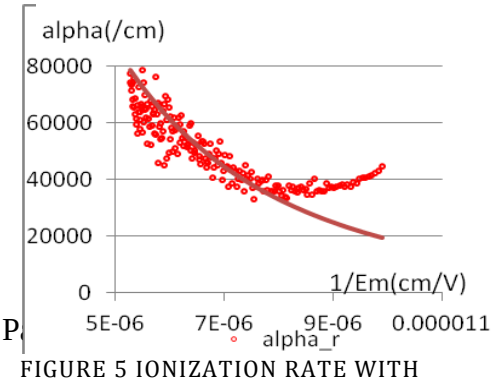

FIGURE 5 IONIZATION RATE WITH FITTING CURVE UNDER 630NM ILLUMINATION

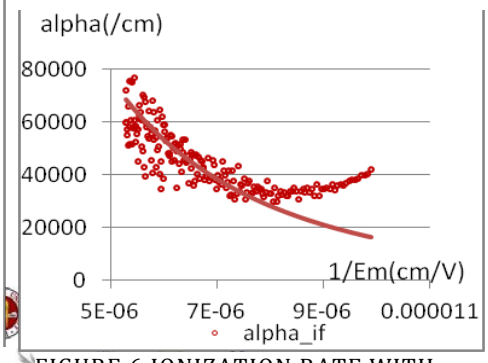

FIGURE 6 IONIZATION RATE WITH FITTING CURVE UNDER 740NM ILLUMINATION

carriers is on the order of 0.1ps. The mean free path of phonon scattering is then $0.1ps \times 10^{7} cm/s = 10^{-6} cm$. The number agrees well with the NREL sample fitting. Once the phonon mean free path is obtained, it can be used to calculate the energy of hot carriers reaching the contacts.

Reference:

[1] W.Maes, K. De Myer and R. Van Overstraeten, "Impact ionization in silicon: a revew and update", Solid State Electronics Vol.33, pp. 705-718, 1990.

[2] R. D. Baertsch, "Noise and Multiplication Measurements in InSb Avalanche Photodiodes", J. Appl. Phys. Vol.38, pp.4267, 1967.

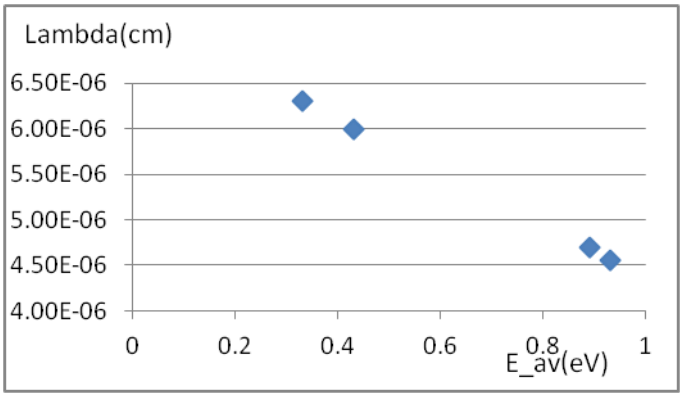

FIGURE 7 PHONON SCATTERING MEAN FREE PATH VS. CARRIER ENERGY

[1] M.A.Lampert, "Universality of non-Ohmic shunt leakage in thin-film solar cells," *Journal of Applied Physics*, vol. 108, Dec. 2010, pp. 124509-124509-10

[2] O. Breitenstein, J. Bauer, A. Lotnyk, and J. Wagner, "Defect induced non-ideal dark characteristics of solar cells," *Superlattices and Microstructures*, vol. 45, 2009, pp. 182 – 189

FESC
Florida Energy Systems Consortium

University of Florida

Development of Novel Water Splitting Catalysts for the Production of Renewable Hydrogen

(Progress Report)

PI: Helena Hagelin-Weaver
Students: Justin Dodson (Ph.D.)

Description: This project focuses on the development of iron-based catalysts for the thermochemical splitting of water into hydrogen and oxygen. The thermochemical process of splitting water is particularly well-suited for the utilization of solar energy to provide the heat for the reaction and is a way to produce a renewable hydrogen fuel. As hydrogen is difficult to transport and store, producing hydrogen on site for power plants using proton exchange membrane (PEM) fuel cells or internal combustion engines to generate electricity or for the production of chemicals, such as liquid hydrocarbon fuels, is a very attractive approach. The project uses a two-step process in which water is passed over a reduced iron oxide to generate hydrogen while the oxygen is taken up by the oxygen-deficient iron oxide (Step 1: $FeO_{x-1} + H_2O \rightarrow FeO_x + H_2$). In the second step the resulting iron oxide is heated to desorb oxygen and regenerate the oxygen-deficient iron oxide to close the catalytic cycle (Step 2: $FeO_x \rightarrow FeO_{x-1} + ½O_2$). The main objectives of the project are to develop mixed metal oxide catalysts that 1) will release oxygen at temperatures lower than 1500°C (Step 2), while still maintaining water-splitting activity (Step 1) and 2) are stable up to the temperature necessary for the oxygen desorption step.

Budget: $ 100,000
Universities: UF

Progress Summary

Several different catalysts have been fabricated and tested during several cycles using the completed reactor system described in our previous report. Iron oxide was precipitated onto three commercial zirconia supports (nanoparticle ZrO_2, yttria stabilized zirconia (YSZ) and pellet ZrO_2), since zirconia is known as a stable material at high temperatures. These catalysts were tested for activity in the water-splitting reaction. These tests were comprised of 10 reduction-oxidation cycles, where the catalyst is first thermally activated by heating to 1500°C. This activation step produces an oxygen-deficient iron oxide, which is active in the water decomposition step. The water decomposition step reoxidizes the oxygen-deficient iron oxide to Fe_3O_4 while producing hydrogen. Each cycle therefore consists of an activation step and hydrogen production (water decompostion) step.

As zirconia is known as a material stable at high temperatures, iron was deposited onto a pellet ZrO_2 (Alfa Aesar) catalyst support and was tested for activity and stability. While the activation step generated oxygen, there was no hydrogen production from this catalyst. Additionally, the pellet zirconia was unstable and collapsed into a powder at some point during cycling. This is thus not a suitable support in this reaction.

Iron catalysts supported on nanoparticle zirconia and yttria-stabilized zirconia were therefore prepared and tested for activity. The oxygen evolution during selected activation steps is shown in Figure 1 for these catalysts. The sharp oxygen evolution peak at temperatures below 1500°C during the first activation step is due to oxygen evolution from Fe_2O_3 on the fresh catalyst, rather than from Fe_3O_4 which is present

after the water decomposition step. After the first activation step, the oxygen evolution is fairly constant for the 10 wt% iron on yttria-stabilized zirconia, while the iron on pure zirconia shows a slight decrease in oxygen evolution also after the second cycle. The oxygen evolution from the 20 wt% iron loading is shown to be significantly smaller compared to the catalysts 10 wt% iron loading. This indicates that higher iron loadings are not beneficial in this reaction.

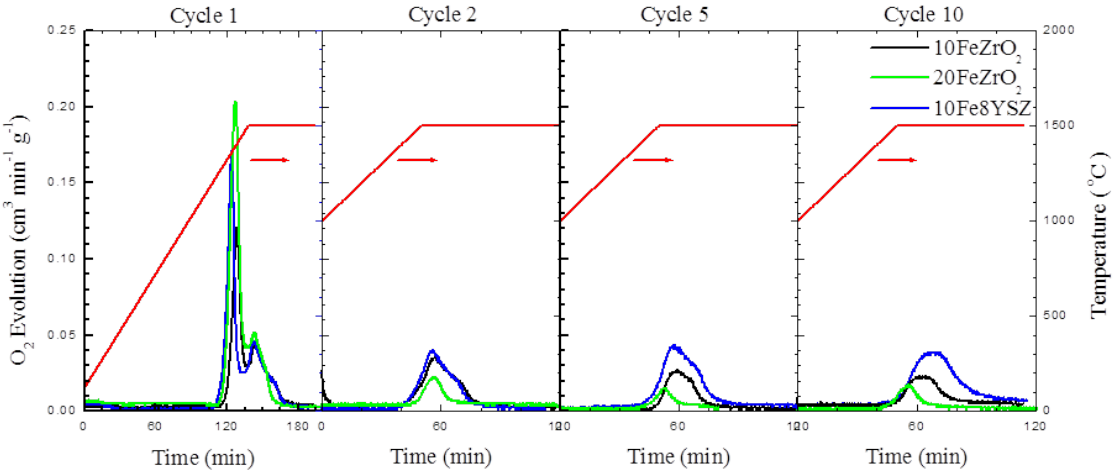

Figure 4: Activation step for cycles 1, 2, 5, and 10.

The hydrogen production steps, which follow each of the activation steps of Figure 1, are shown in Figure 2 for the same catalysts. The 10wt% Fe precipitated onto an 8% YSZ support is consistently the most productive catalyst over the 10 cycles, as the hydrogen evolution from this catalyst is higher than that of the other catalysts tested. However, the amount of hydrogen released during each cycle decreases with increasing number of cycles. In contrast, the hydrogen evolution from the 10wt% iron precipitated onto n-ZrO_2 is almost constant after the first three or four cycles. After 10 cycles, the hydrogen evolution from the iron on the yttria-stabilized zirconia is therefore close to that of the iron on zirconia. As expected from the oxygen evolution data, the 20wt% Fe loading on ZrO_2 has an inferior performance compared to the catalysts with a 10wt% Fe loading, and after 10 cycles the hydrogen evolution from this catalyst is very low.

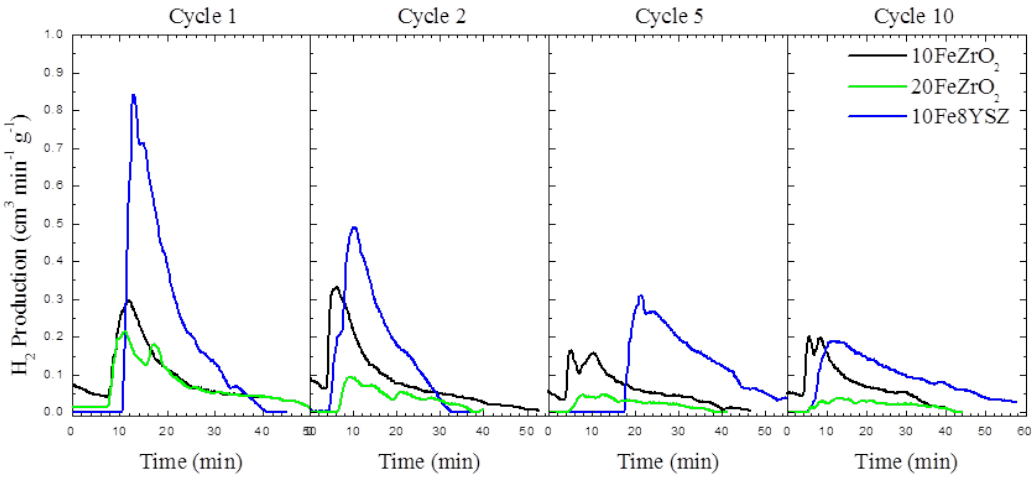

Figure 2: Hydrogen production step for cycles 1, 2, 5, and 10.

While sintering, i.e. partice growth, is observed on this catalysts, most of the catalysts are still in powder form after the 10 consecutive cycles of activation and water decomposition (Figure 3).

Figure 3: Spent catalyst after 10 cycles. Left: 10wt% Fe precipitated onto n-ZrO_2 and Right: 20wt% iron precipitated onto n-ZrO_2.

The powder catalysts will be characterized using BET, XRD, XPS, SEM, and ICP to determine the degree of sintering of each catalyst and the variation within the iron oxide between the fresh and the spend catalysts. This information will provide insight into the advantage of a zirconia support and high temperature stable materials. The characterization will assist with the fabrication of foams which will be used to support these powdered iron oxide catalysts. The purpose of using high-temperature foams to support the catalysts is to introduce pores that will not sinter or collapse at the high temperatures of this reaction.

University of Florida

UFTR Digital Control System Upgrade for Education and Training of Engineers and Operators

(Progress Report)

(Project was initiated by Dr. Aliriza Haghighat and Dr. Gabriel Shita. Dr. Haghighat left the University of Florida. The project was transferred to Dr. Kelly Jordan. FESC provided an additional $45K as equipment support towards the completion of the project. The new project title is **"Equipment Support for the University of Florida Training Reactor Digital**")

PI: Kelly Jordan

Original Project Description: The goal of this project is to contribute to a major initiative on design, licensing and construction of a fully digital control system for the University of Florida Training Reactor (UFTR). This makes the UFTR the first operating nuclear power plant in the United States that uses a fully digital control system. This facility will provide for the training and education of the necessary workforce in the area of digital control and instrumentation for nuclear reactors. With this effort, a new focus/certificate on digital control and instrumentation will be developed at the Nuclear and Radiological Engineering (NRE) Department. Further, the UFTR facility will offer training courses for community colleges (Central Florida, Indian River, and Jacksonville) in the State of Florida, personnel from nuclear utilities and government agencies including the Nuclear Regulatory Commission (NRC). The project has already received significant funding from industry and government in form of grants, contracts, equipment/systems, and engineers' time.

Budget: $308,000 +$45,000 new
Universities: UF
External Collaborators: Several engineers from AREVA NP Inc & Siemens Corporation

Progress Summary

The UFTR proposes to implement the first-ever fully digital control and safety system at a nuclear reactor in the United States. This is the key piece in a full renovation of the facility, which has been in operation since 1959. This upgrade will replace the analog system with a digital control system from Siemens Energy. This facility will provide for the training and education of the necessary workforce in the area of digital control and instrumentation for nuclear reactors. The upgrade ensures that the UFTR is on a footing to continue its research and education missions over the next decades, and will open up new revenue streams to put it on a sustainable financial path. FESC is supporting this project with a grant to help provide for critical infrastructure equipment, in this case, new reactor shutdown blade drives which will interface to the new digital system.

Funds leveraged/new partnerships created:

New collaborations		
Partner name	Title or short description of the collaboration	Funding, if applicable
Swiss Federal Institute of Technology, Lausanne	**Validation of Reactor Physics-Thermalhydraulics Coupled Calculations in Water-Cooled Research Reactors with Laminar Flow Regimes**	$200,000 in funding for Ph.D. student and postdoc at EPFL

(EPFL)		

Proposals					
Title	Agency	PI, Co-investigators and collaborators	Funding requested	Project time frame (1 year, 2 years, etc.)	Date submitted
Validation of Reactor Physics-Thermalhydraulics Coupled Calculations in Water-Cooled Research Reactors with Laminar Flow Regimes	swiss*nuclear*	PI – K. Jordan, UF Collaborators – A. Pautz and G. Girardin, Swiss Federal Institute of Technology, Lausanne	10,000	3 months	April 1,2013
Plutonium Assay In Spent Fuel Using Multispectral Active Neutron Interrogation Analysis	DOE	K. Jordan, PI	800,000	3 yrs	Jan 13
Experimental Evaluation Of Methods For Digital I&C Software Reliability Characterization	DOE	K. Jordan, PI	400,000	2 yrs	Jan 13
Multiphysics-Based Optimization of SCWR-SMR Fuel Assemblies	DOE	D. Schubring, PI UF	400,000	2 yrs	Jan 13
Advanced Calculational Methods in Nuclear Analyses	NRC	S. Goluoglu, PI UF	200,000	2 yrs	Jan 13
Beyond High-k Dielectrics: Basic Science of Radiation Effects in Materials for Multi-Functional Nanoelectromechanical Switches	DTRA	J. Jones, PI UF	1,050,000	4 yrs	Jan 13

Grants Awarded					
Title	Agency	Reference Number	PI, Co-investigators and collaborators	Period of Performance	Funding awarded
Nuclear Safeguards Education at UF	ORNL		S. Goluoglu, K. Jordan	1 yr	$100,000

Annual Progress Report:

Blade drives are equipment that control the neutron absorber blades in the core of the reactor. By inserting and withdrawing the blades, the reactor can be shut down or the power level changed. As part of both the digital control project and the general modernization of the UFTR, the reactor blade drives will be replaced with modern components that can interface with the new control system. The first design phase of the digital system is nearly complete. The Engineering design began in April 2013 for the new blade drives, with manufacturing and install to be completed before the end of the year.

University of Florida

Unifying Home Asset & Operational Ratings: Adaptive Management via Open Data & Participation

(Progress Report)

PI: Mark Hostetler **Co-PI:** Hal S. Knowles, III
Student: Hal S. Knowles, III (Ph.D. Student, UF School of Natural Resources & Environment)

Description: Recent environmental, social, and economic challenges are fostering a wave of interest in maximizing energy efficiency and conservation (EE+C) in existing U.S. homes. Long standing programs, ratings, and metrics are being reapplied into new stimulus initiatives such as the *Recovery through Retrofit*[1] program. Simultaneously, electric and gas utilities are expanding their demand side management (DSM) programs from weatherization and conventional technology replacement incentives to include conservation behavior campaigns with "recommendation algorithms" designed to assist in homeowner energy retrofit decision making. Furthermore, loan programs are emerging to address the financial barriers that commonly limit initiation of the necessary retrofits.

Collectively, these approaches most often project future home energy performance based on engineering models of the physical characteristics of homes (i.e., "asset ratings"). Yet to date, the marketplace is inadequately integrating historical household energy consumption patterns (i.e., "operational ratings") into the decision tree to optimize retrofit program efficacy and consumer benefits. Moving toward the unification of asset and operational ratings is crucial for successful program management, proper monitoring/measurement/verification (MMV), loan risk assessment, and for the persistence of reduced home energy use over time. However, unification will not be easy. This research project combines qualitative and quantitative research methods in social science and building science using Florida case studies to evaluate the opportunities and constraints of asset and operational rating unification and the steps necessary to get there. Relationships between our project and the collaborative, transparent, and participatory nature of "open government" initiatives are also being explored.

Budget: $24,000 over two years ($12,000 from 01/01/2011 to 12/31/2011 and $12,000 from 01/01/2012 to 12/31/2012)
Universities: UF
External Collaborators: Nick Taylor (Ph.D. Student, UF School of Natural Resources & Environment), Jennison Kipp (Assistant In, UF Program for Resource Efficient Communities)

Progress Summary

1. Annual Progress: Summary since October 1, 2012 The conclusion of the 2 years of this research project led to the submission of a supplementary proposal for additional funding from FESC for more in-depth research on the unification of building asset and operational rating systems. This request was awarded at a budget of $32,000 over 18 months (from 04/01/2013 to 09/30/2014) to cover a portion of the salary (at a rate of $22.20/hour) and fringe benefits (at a rate of 26.9%) for Co-PI, Hal S. Knowles, III. This equates to 36% (14.6 hours, or effectively 2 weekdays) of this Co-PIs weekly salary and fringe for the 18 month period.

   This new supplemental research will expand on themes and insights gained through the first phase of this existing FESC project. Specifically, these insights suggest that even when adding operational data

[1] See, http://www.whitehouse.gov/assets/documents/Recovery_Through_Retrofit_Final_Report.pdf

to building asset data, the reductionist approach to evaluating home energy performance by controlling for known variables may continue to offer an incomplete picture of the complexities of performance trends and the influence of unknown and/or misunderstood variables. Furthermore, the home improvement industry may need to consider the possibility that the magnitude of total energy consumption, while a worthwhile metric and with its net reduction a worthwhile goal, is also an incomplete indicator of home energy performance optimization.

As such, this new supplemental phase of our research will look at the nonlinear dynamics of residential energy consumption patterns as a new, complementary, more holistic methodology to detect homes that are performing poorly. First, a discrete nonlinear time-series analysis of high frequency smart grid energy consumption data will be performed for select samples of residential customers within multiple Florida utilities. It is hypothesized that the chaotic, nonlinear pattern inherent to this signal has diagnostic value (e.g., as if it's the heartbeat of the home) that may allow for utilities, local governments, institutions of higher education, and non-governmental organizations to better identify and provide energy assistance to homes based on the presence of either a "healthy" or a "diseased" beat. Second, the nonlinear consumption patterns of homes will be compared to weather indicators to determine whether energy consumption tracks changes in climatic variables. Third, for homes that have undergone home energy improvements, before and after changes in the nonlinear patterns of energy consumption are compared to see if the consumption signature more closely reflects the signature of climatic variables. These analyses will determine whether nonlinear analyses of home energy consumptive patterns are useful in detecting underperforming homes and the impacts of home energy improvements.

To date, we have submitted formal smart meter data requests from Talgov Utility Billing Services Division and JEA in Jacksonville. Both have responded favorably and we expect 30 minute, daily, monthly, and yearly energy consumption data for up to 400 homes. Hal Knowles has begun to explore nonlinear statistical analyses with home energy consumption data (R statistical package).

2. Funds Leveraged/New Partnerships Created (This Period)

New collaborations		
Partner name	Title or short description of the collaboration	Funding, if applicable
Enes Hosgor (Carnegie Mellon University)	UF/PREC is in discussion with this potential collaborator on a variety of potential benefits from improved business incubation on home energy performance monitoring and consumer feedback tools and platforms.	Opportunities under consideration
EcoCity Partners	Active collaboration is ongoing in the development and submission of a grant proposal to the US DOE Better Buildings program.	Minimum of $50,000 over 3 years
FAIRWINDS Credit Union	As seeded by the Osceola Energy Initiative (OEI), an ARRA funded program, UF/PREC has entered a 10-year partnership with FAIRWINDS Credit Union to administer a 7-county, $5 million residential energy efficiency finance program.	Tied to revenue from the delivery of the loan program
Several Building Contractors	UF/PREC is currently building partnerships with building professionals to serve as “Participating Independent Contractors” in the loan program.	Tied to revenue from the delivery of the loan program

Proposal #1						
Title	**Agency**	**Reference Number**	**PI, Co-investigators and collaborators**	**Funding requested**	**Project time frame (1 year, 2 years, etc.)**	**Date submitted**
The BEERE Menu: Pre-Packaged Technology Retrofit Options for PACE Financing	US DOE Better Buildings	DE-FOA-0000829 CFDA #: 81.086	PI: EcoCity Partners Co-PI: Hal Knowles, Craig Miller, Nick Taylor Collaborators: Pierce Jones and Jennison Kipp	$50,000 (tentative) (UF Subcontract portion on a $500,000 overall proposal)	3 year	Due April 24, 2013

Hal Knowles, Co-PI and the primary supported person on this FESC project was a University of Florida Program for Resource Efficient Communities (UF/PREC) point person and contributor to the development of this new proposal. UF/PREC proposed to provide the following major services as a subcontractor for this energy efficiency financing and retrofit program: (1) energy pre-screening; (2) retrofit package specification development and standardization; (3) quality control; and (4) measurement and verification. As summarized on the proposal abstract:

"This project seeks to accelerate commercial property assessed clean energy (PACE) financing by small commercial building owners. We will simplify pathways to project completion and finance by designing and offering standardized, pre-packaged technology retrofit options arranged by building type and size, business type, climate zone and other factors. We will prove the reliability of pre-project estimates of energy and cost savings through post-project audits, monitoring & verification. This will enable us to develop critical informational resources for building owners to select from a menu of options for buying energy-efficiency and renewable energy solutions (the "BEERE Menu").

Successful projects included in the BEERE Menu will generate a minimum of 20% energy savings and be capable of accurate estimation. This will facilitate scalability of small commercial energy-efficiency solutions using PACE financing by streamlining pre- and post-energy audit requirements, and will simplify underwriting, approval and financing. Finally, the project will facilitate easier aggregation of PACE projects for pooled financing arrangements. The results will be made available to other PACE program administrators through a white paper and an industry-targeted webinar.

Grants / Contracts Awarded #1					
Title	**Agency**	**Reference Number**	**PI, Co-investigators and collaborators**	**Period of Performance**	**Funding awarded**
Homeowner Energy	Florida	PO #: S-	PI: Nick Taylor	3 months	$34,650

Interactive Tool	Department of Agriculture and Consumer Services (FDACS) Office of Energy	4200-A1553	Co-PI: Hal Knowles Internal Collaborators: Craig Miller, Jennison Kipp, & Pierce Jones External Collaborators: Acceleration.Net	(from March 28, 2013 – June, 30 2013)	

Hal Knowles, Co-PI and the primary supported person on this FESC project was a major University of Florida Program for Resource Efficient Communities (UF/PREC) contributor to the development of this new proposal and will be a major contributor during the execution of the successfully awarded purchase order. UF/PREC, in support with an external IT partner (Acceleration.Net) is tasked to provide the following scope services:

1. Provide a web-based home energy self-audit survey and response tool to analyze a homeowner's present energy situation using already known or easily attainable information
2. Provide an interactive application
3. Identify resources to help the homeowner put recommendations into action
4. Host, maintain, and troubleshoot the interactive website for one year to ensure a functional product
5. Provide project management services for the design, testing, implementation, and project closure that include, but are not limited to scope, management, risk management, a communication plan, quality assurance, and change management

University of Florida

Chloride Chemical Vapor Deposition of Cu(In,Ga)(Se,S)$_2$

(Progress Report)

PI: Timothy J. Anderson
Student: Christopher P. Muzzillo (Ph.D.)

Description: The intent of the work is to demonstrate chloride chemical vapor deposition (CVD) of chalcopyrite thin films with material quality suitable for use as photovoltaic absorbers. To this end, $CuInSe_2$ films have been grown and characterized.

External Collaborators: Rommel Noufi (National Renewable Energy Laboratory), Bill Shafarman, University of Delaware.

Progress Summary

A new CVD reactor (see Figure 1) has been implemented and optimization of growth conditions has been performed. Selenium and cuprous chloride (CuCl) reactant transport was achieved by evaporation into carrier gas (nitrogen), while indium reactant transport was achieved by reacting pure molten indium with hydrogen chloride gas to form volatile indium chloride (InCl). The reaction of hydrogen chloride (HCl) with a pure metal copper source was found to result in inefficient conversion of HCl, which led to problems downstream of the source zone. Specifically, material was etched in the growth zone, making this reactant delivery technique unsuitable. Chalcopyrite α-$CuInSe_2$ films of varying Cu/In ratios were grown (e.g., Figure 2). Crystallinity, texture, and qualitative phase fractions were investigated by powder X-ray diffractometry. Bulk film elemental composition was determined with good precision by inductively coupled plasma atomic emission spectroscopy. Film microstructure, uniformity, roughness, thickness, and rough elemental cross-sectional distribution were investigated by scanning electron microscopy with energy dispersive X-ray spectroscopy. Reasonable control over molar Cu/In ratio was demonstrated, which is crucial for the development of high efficiency solar cells. Optoelectronic characterization of material will be performed to identify key properties or possible issues with the new chloride process, with specific focus on photovoltaic performance.

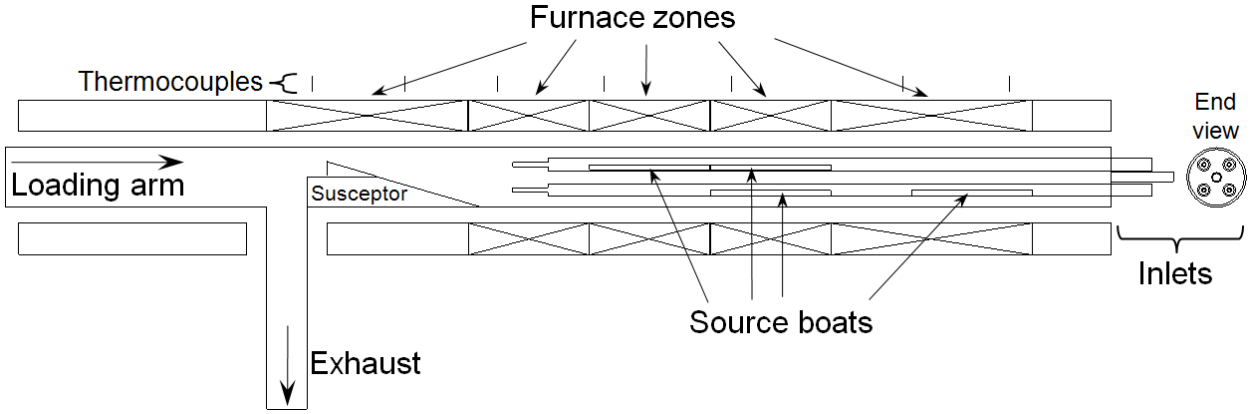

Figure 1. Schematic of CVD reactor

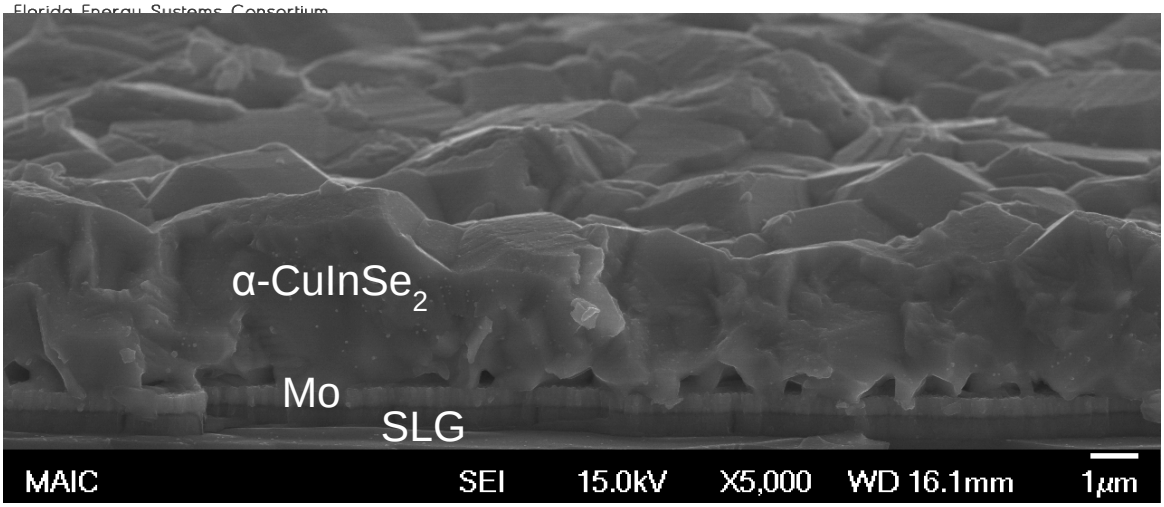

Figure 2. Film grown by chloride CVD of chalcopyrite α-$CuInSe_2$, with molar Cu/In ratio of 0.69, on a substrate of sputtered molybdenum (Mo) on soda-lime glass (SLG)

University of South Florida

Beyond Photovoltaics - Nanoscale Rectenna for Conversion of Solar and Thermal Energy to Electricity

(Final Report)

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Description: The main objective of the proposal is to commercialize and scale up a new technology, the rectenna, to convert waste heat energy to electricity. Although the prediction of highly efficient (~85%) solar rectennas was published almost 30 years ago, serious technological challenges have prevented such devices from becoming a reality. Since the ultimate goal of a direct optical frequency rectenna photovoltaic power converter is still likely a decade away, our plan is to convert optical solar radiation to thermal radiation (~30 THz regime) using an innovative blackbody source. Leveraging the research efforts of the world-class team members, we plan to further develop the rectenna technology that is within reach of efficient radiation conversion at 30 THz. A fully integrated, blackbody converter and a ~30 THz rectenna system will be capable of converting at least 50% of the solar and thermal energy into usable electrical power, clearly demonstrating a truly transformational new technology in the renewable energy technology sector. For the reporting period, emphasis has been placed on the development of the plasmonic emitter that converts solar radiation to infrared radiation, and the diode that acts as the rectifier in the rectenna concept.

EXECUTIVE SUMMARY

The main objective of the proposal is to commercialize and scale up a new technology, the rectenna, to convert waste heat energy to electricity. Although the prediction of highly efficient (~85%) solar rectennas was published almost 30 years ago, serious technological challenges have prevented such devices from becoming a reality. Since the ultimate goal of a direct optical frequency rectenna photovoltaic power converter is still likely a decade away, we can convert optical solar radiation to thermal radiation (~30 THz regime) using an innovative blackbody source. Leveraging the research efforts of the world-class team members, we have pursued the development of the rectenna technology that is within reach of efficient radiation conversion at 30 THz. A fully integrated, blackbody converter and a ~30 THz rectenna system are capable of converting at least 50% of the solar and thermal energy into usable electrical power, clearly demonstrating a truly transformational new technology in the renewable energy technology sector. In this project, emphasis has been placed on the development of the plasmonic emitter that converts solar radiation to infrared radiation, and the diode that acts as the rectifier in the rectenna concept. Metal-insulator-metal diodes were fabricated the self assembly (SAM) and various metal and oxide deposition layers. The results suggest that the large gradual turn on voltage of these diodes or the presence of pinholes in the insulator layer limit the application of these devices to rectennas. On the other hand the development of the infrared plasmon emitter suggests that, with additional research, the development of a suitable emitter that converts the solar spectrum to a narrow infrared range of frequencies is possible.

Detectors and sensors are an integral part of modern electronics and are crucial to highly sensitive applications. Metal-Insulator-Metal (MIM) tunnel junctions have been explored for the past five decades and are still being investigated due to its wide use of applications such as mixers, capacitors, detectors, rectifiers and energy conversion devices. In this research, various designs of thin film based tunnel junctions have been investigated and the optimum one picked for the purpose of a wide band detector up

to 10GHz based on their sensitivities. A modified design with an isolation layer incorporating a self-aligning method to increase fabrication throughput was developed. A mask for the reliability testing of multiple devices with different areas was also developed. Nickel Oxide based insulators with different stoichiometries have been incorporated in the fabrication of the device to identify which stoichiometry gives the best performance for high frequency applications. Nickel Oxide (NiO), Zinc Oxide (ZnO) and the combination of the two have been deposited using reactive sputtering and investigated as insulator materials. The bilayer devices showed increased sensitivities at lower turn on voltages and very good efficiencies at 100MHz and 1GHz. Although, the MIM device provides a simple structure, some of the critical parameters required to quantify the device functionality are still being explored. Based on the parameters, a criterion was developed to help engineer a tunnel device for a desired detectivity.

Control of spectral thermal emission from surfaces may be desirable in some energy related applications, such as nano-scale antenna energy conversion and thermophotovoltaic conversion. There are a number of methods, from commercially available paints to advanced surface gratings that can be used to modify the thermal emission from a surface. To find out the proper emission controlling technique for a given energy conversion method all the surface emission controlling methods are comprehensively reviewed regarding the emission control capabilities and the range of possible applications. Radiation with high degree of coherence can be emitted using advanced surface emission controlling techniques. The entropy of the thermal radiation, and therefore the exergy, is a function of the degree of coherence. A methodology is presented to calculate the exergy of partially coherent wave fields so that the radiation fields can be evaluated based on exergy. This exergy method is extended to develop a rigorous evaluation criterion for thermal emission controlling methods used in frequency dependent energy conversion applications. To demonstrate these developed criteria using actual data, a surface plasmon emitter is designed and fabricated. Also, possible ways of improving the emitter performance and the research needed to be carryout to fabricate cost effective emitters are described.

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