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THE CONSORTIUM FOR ADVANCING RENEWABLE ENERGY TECHNOLOGY (CARET)

by

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PROGRESS REPORT

INTRODUCTION:

The Consortium for Advancing Renewable Energy (CARET) is a research and education program which uses the theme of renewable energy to build a minority scientist pipeline. CARET is also a consortium of four universities and NASA Lewis Research Center working together to promote science education and research to minority students using the theme of renewable energy. The consortium membership includes the HBCUs (Historically Black Colleges and Universities), Fisk, Wilberforce and Central State Universities as well as Kent State University and NASA Lewis Research Center. The various stages of this pipeline provide participating students experiences with a different emphasis. Some emphasize building enthusiasm for the classroom study of science and technology while others emphasize the nature of research in these disciplines. Still others focus on relating a practical application to science and technology. And, of great importance to the success of the program are the interfaces between the various stages. Successfully managing these transitions is a requirement for producing trained scientists, engineers and technologists. Presentations describing the CARET program have been given at this year's HBCU Research Conference at the Ohio Aerospace Institute and as a seminar in the Solar Circle Seminar series of the Photovoltaic and Space Environments Branch at NASA Lewis Research Center. In this report, we will describe the many positive achievements toward the fulfillment of the goals and outcomes of our program. We will begin with a description of the interactions among the consortium members and end with a description of the activities of each of the member institutions .

INTERACTIONS AMONG CONSORTIUM MEMBERS:

An important feature of this consortium is its structure in which a coordinator is solely dedicated to promoting and facilitating interactions among the members of the consortium. This has resulted in the maintenance of an active interaction among the consortium members. This has enabled us to guide students through the pipeline causing Wilberforce and Central State students to share a class, have a Central State student attend a summer program at Fisk and have both Wilberforce and Central State students participate in a Kent summer internship. An example that is even more in line with the pipeline aspect of CARET is the Wilberforce graduate who will be attending graduate school in the School of Technology at Kent State University this fall. This student received encouragement from many consortium participants, not just from those at Wilberforce and Kent State. This active interaction has also resulted in a very real and beneficial research collaboration, where one group can focus on materials preparation, another on materials characterization and laser ablation and a third on radiation effects on these same materials.

Two more extremely beneficial things have resulted from this active interaction. The first of these is the more efficient utilization of resources. As we will address in subsequent sections, the Consortium is using solar panels that were from a completed NASA research study for its renewable energy

demonstration units. While these solar arrays are obsolete from NASA's standpoint, they are clearly perfectly capable of being used for teaching students about renewable energy. A second example of this is that Central State U. has an instrument which it no longer uses but for which Fisk University sees a good use. It seems likely that through the Consortium, we will be able to arrange the transfer of this instrument to the institution where it will be more fully utilized.

The second additional beneficial result has been the affiliations we have been able to develop. Through the different contacts of different participants, CARET has established a number of affiliations. These affiliations include the Glen Helen Ecology Institute where we are situating a solar power facility as a community outreach project. This will expose more than 100,000 visitors annually to the CARET program and to renewable energy. Another affiliation is with Vanderbilt University, which will give student researchers exposure to additional research facilities and the environment at an elite research university. Also included are affiliations with Bay Mills Community College (a tribal college) and the Grand Traverse Band of Ottawa and Chippewa Indians. The prospects of this affiliation were so positively received within NASA that funding has been provided for these institutions to work with us to advance their educational programs around renewable energy. And finally, we are currently exploring an affiliation with Cleveland's African American Museum in which we would work with the Museum to implement solar powered illumination of displays.

We have regularly invited these affiliates to participate in our CARET meetings and we are encouraged by their frequent attendance. We believe that these affiliations are clearly increasing the impact of the CARET program and provide a strong incentive for us to continue to promote such active interaction within the Consortium and among its affiliates.

WILBERFORCE UNIVERSITY CARET ACTIVITIES:

The main objectives of the CARET program at Wilberforce University are to use the theme of renewable energy to:

1. Increase the number of entering minority students with interests in NASA related fields.
2. Increase the number of minority students majoring in NASA related fields.
3. Increase the number of minority graduates entering graduate school in NASA related fields.
4. Establish collaboration among the consortium members to improve student experiences.
5. Increase opportunities for student experiences in science and technology.
6. Increase public awareness of renewable energy technologies.

To accomplish these goals, several activities were planned for the first year of the grant. These activities include:

1. Install renewable energy systems on the Wilberforce University campus and at the Glen Helen Ecology Institute.
2. Offer a new course called "Applied Renewable Energy Technology" whose main goals are the education of students in renewable energies by way of the design and installation of renewable energy systems on campus and at the Glen Helen Ecology Institute.

3. Renovate a small prep lab into the NASA Renewable Energy Center.
4. Have faculty and students conduct summer research in photovoltaic materials.
5. Collaborate with Central State University in their high school student summer program.

Most of these activities have been accomplished or are in the process of being accomplished at the writing of this report and the following gives detailed accounts of each activity.

The first activity was the installation of renewable energy systems on the Wilberforce University campus and at the Glen Helen Ecological Institute. At Wilberforce University, a hybrid wind/solar power generating system is in the process of being installed. This system will be is used to power the newly renovated NASA Renewable Energy Center. Currently, all of the equipment has been purchased. The inverter that converts the DC electricity from the turbine and the array to AC has been installed and wired. The storage batteries of the system have also been installed. Within the next few weeks, the foundation for the array will be built. A trench will be dug to connect the array to the inverter. The computer system and software that will continuously monitor the array and turbine is functioning. The data from the energy systems such as energy being produced will be automatically downloaded to the CARET web page. The turbine will also be installed within the next few weeks. At the Glen Helen Ecology Institute where a solar array is being installed, good progress is also being made. Here again, the inverter and the storage batteries of the system have been installed and wired. And, like the system on the Wilberforce campus, the foundation for the array will be built within the next few weeks.

The second activity was to offer a course called "Applied Renewable Energy Technology". A group of students was recruited and this course was offered during the spring of 1998 and taught by Dr. Eric Lang from The Why Not corporation who serves as a consultant on this project. Enrolled in the course were four Wilberforce University students and four Central State University students. Because Central State University is on a quarter system, the class actually was extended beyond the normal semester to compensate for this. The main objectives in the course were to install the renewable energy systems while educating the student on the various technologies involved. The students have developed web pages discussing the various renewable technologies. These web pages are linked to the main CARET web page on the Wilberforce computer network. The students are still assisting Dr. Lang and will do so until they finish the installation of the energy systems. Then the students will begin research with a group of faculty.

The third action item was to renovate a small lab into the NASA Renewable Energy Center. This room has been renovated. It is equipped with furniture and will be used as a Math/Science tutorial facility at the university. All of the electricity for the room will come from the solar array/wind turbine once they have been completely installed. The batteries and the inverter for the energy system are located in this room, and can be observed through a plexi-glass protector. The room will not only be used by our students, but we plan to provide classes to the public on the installation of renewable energy systems. Thus, the room will be used as a display for incorporating renewable energy systems into existing buildings. Further, we plan to invite area high school students in the autumn during CARET's second year to spend a day at the University learning about renewable energy systems.

The fourth activity was to have faculty and students conducting research in photovoltaic materials. Three such projects are currently being done. For the first project, Dr. Buffinger has purchased the equipment and chemicals needed to prepare copper indium disulfide and copper indium diselenide using a microwave synthesis approach. This will provide a quick method for producing this photovoltaic material in bulk. The material will then be purified by single crystal growth from a suitable flux. These materials will then be turned over to consortium member Fisk University for further analysis and utilization in a study on the properties of semiconductors on the nanocrystal scale. In project #2, Dr. Habash has been setting up an HPLC instrument to analyze polymeric materials that are being prepared at NASA Lewis Research Center and studied for possible incorporation into energy production & storage systems for electronics applications. Finally, Dr. Griffith is working on an electrochemical cell to prepare photovoltaic materials via an electrochemical approach. Once the students from the Applied Renewable Energy Technology class have finished the installation of the energy systems, they will be assisting the faculty in their summer research projects.

The final goal of the first year was to assist Central State University's summer program. Central State will have 30 high school students come onto their campus for one week. The Friday of that week, the students will spend half a day at Wilberforce University. The will arrive on our campus at 8:00 in the morning and be given a tour of the university by one of our student researchers. This will last for about an hour. The students will then attend a lecture on applications of renewable energy systems/technologies given by our renewable energy consultant, Dr. Eric Lang of the Why Not Corp. Once the lecture is over, the students will be taken to our general chemistry laboratory to do an actual experiment where they prepare solar cells from silicon wafers. They will use these to power small machines. And finally, there will be an opportunity for the students to ask any questions they may have concerning CARET, Wilberforce and renewable energy as they wrap up their morning at WU with lunch at the cafeteria.

Although it is early to see these activities resulting in fulfillment of the objectives outlined at the beginning of this section, there are some initial signs of an impact. Perhaps most notable is that as a direct result of the ongoing CARET activities, Raymond Haraway, a Wilberforce graduating senior has elected to do a summer internship involving both the School of Technology at Kent State University and the Photovoltaic and Space Environment Effects Branch at NASA Lewis Research Center and he is applying for admission to a Master's degree program in Kent's School of Technology.

With these year 1 activities on schedule for completion by the end of the CARET year in mid-July, Wilberforce University is beginning to prepare for year two of the program. Once the autumn begins, our students will be giving talks to area high schools on their work this past spring and summer. Wilberforce will also be installing a distance learning facility so that our students can register for selected courses at consortium member Kent State University. And finally, the faculty researchers will continue their projects and continue to promote both student participation in CARET activities and collaboration among CARET scientists and technologists.

FISK UNIVERSITY CARET ACTIVITIES:

1. Introduction

The role of the Chemical Physics Laboratory in the CARET program is four-fold: 1) characterize the physical properties of $CuInS_2$ photovoltaic thin films, 2) fabricate quantum dots by laser ablation for applications in solar energy conversion, 3) in a collaborative effort with the Kent State researchers, investigate radiation damage on nanocrystals embedded in dielectric hosts, and 4) engage minority graduate and undergraduate students in the research areas described above.

2. $CuInS_2$ (CIS) Photovoltaic Thin Films

2.1 Electrical properties

The electrical properties CIS films grown by CVD on silica substrates were characterized by four-point-probe measurements to obtain the resistivity, carrier density, mobility, and Hall coefficients. The electrical measurements, performed in a temperature range 252-390 K, indicate that the major carriers are holes and the scattering analysis indicates the CIS films are extrinsic. However, the nature of the defect/impurity is not known at this time. The resistivities, mobilities, densities, Hall coefficients and majority carriers are given in Appendix A as a function of temperature.

2.2 Optical Properties

UV-Vis-NIR transmission measurements were performed to determine the band gap of the CIS films. A value of ~1.53 eV was found to be an approximate value of the band gap, Figure 1. Interference fringes were consistently observed in the transmission studies adding to uncertainty the band gap. However, film thicknesses were calculated from the fringe frequency and were found to be in good agreement with those reported by the group that synthesized the films. Future experiments are planned to tilt the thin films at an angle that eliminates the interference fringe pattern from the thin films. The data acquired in this manner will permit a quantitative analysis of the band gap through a Tauc analysis.

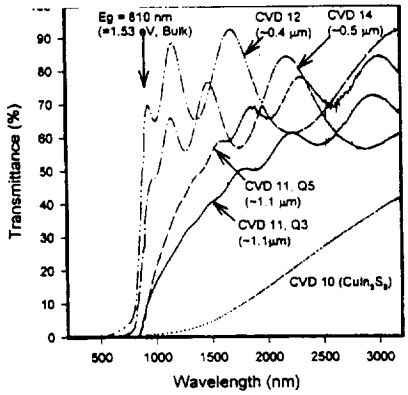

Figure 1. UV-Vis transmission spectra of $CuInS_2$thin films formed by CVD 10 ($CuIn_5S_8$), 11, 12, 14.

Infrared and FTIR-Raman spectra were measured for the CIS thin films. The infrared reflectance measurements revealed three peaks at 225, 291, and 317 cm^{-1} for the unannealed films and films annealed up to 550°C in an Ar (99.9999%) atmosphere. At an annealing temperature of 600°C a new peaks appeared at 325, 363 and 411 cm^{-1}, while those at 225, 291 and 317 cm^{-1} decreased to an intensity level beyond the limits of the detector. The new bands that appear after the annealing cycle are attributed to decomposition products of the CIS thin films. By comparison to the literature values of 323 and 352 cm^{-1} for the TO and LO frequencies, the infrared reflectance spectra reported here are in generally good agreement, although they are redshifted by 32 and 35 cm^{-1}, respectively. The shift, we expect, originates from the anomalous dispersion from the reflectance measurements where change in the refractive index contributes to the reflectance signal as well as changes in the of the extinction coefficient. The extinction spectra and index spectra will be calculated by the Kramers-Krönig transformation and will render more reliable values for the LO and TO frequencies.

To the best of our knowledge, the peak observed at 225 cm^{-1} for the unannealed sample has not been reported in the literature. The origin of this band may be due the intrinsic structure of the CIS film (space group D^{12}_{2d}-1 42d) that will activate phonons of a lower symmetry. Polarization reflectance measurements will help resolve this issue.

Raman scattering spectra on the CIS thin films yield peaks at 295 and 308 cm^{-1}. As in the case of the infrared reflectance spectra, these peaks are in the vicinity of the literature values, but are redshifted from the TO and LO modes by 13 and 29 cm^{-1}, respectively. As there is no anomalous dispersion in the Raman spectra as is in the case of the infrared reflectance spectra, these redshifts most likely represent a resonance of phonons with a symmetry other than those reported in the literature, arising from effects of strain, or possibly departures from the ideal stoichiometry of the thin films. Additional experiments with different samples on various substrates may help resolve the question of strain induced redshifts, while samples prepared with non-stiochiometric composition may help unravel the question of phonons being activated due to departure from the ideal composition of $CuInS_2$. The issue concerning modes being activated from symmetry lowering will require a normal mode analysis to determine the selection rules of allowed transitions.

Clearly, the phonon spectra of the CIS films will provide insight into material composition, film quality, and also importantly, the electron-phonon coupling strength, which plays an important role carrier dynamics. The Frölich coupling parameter, a measure of the electron-phonon interactions given by

$$\alpha = \frac{1}{2}\frac{e^2/(h/2m_c^{\alpha}\omega_{LO})^{1/2}}{h\omega_{LO}}\left(\frac{1}{\varepsilon_\infty} - \frac{1}{\varepsilon_0}\right) \qquad (1)$$

where e is the electron charge, h is Planck's constant, ω_{LO} is the frequency of the LO phonon, m^c is the electron effective mass, and ϵ_∞ and ϵ_0 are the high frequency and low frequency dielectric constants of CIS. However, calculating the Frölich coupling constant requires the static and high frequency dielectric constants, ϵ_0 and ϵ_∞. Niether ϵ_0 or ϵ_∞ appear to have been published and must be determined experimentally. The high frequency dielectric constant can be determined from ellipsometry, while the low frequency dielectric constant will be calculated from the Lydanne-Sachs Teller equation:

$$\omega_{LO} = \left[\frac{\varepsilon_0}{\varepsilon_\infty}\right]^{1/2}\omega_{TO} \qquad (2)$$

By using eqn. 2, the low frequency dielectric constant can be determined from the experimentally determined LO and TO frequencies. Knowing the values of ϵ_0, ϵ_∞, and ω_{LO} allow for calculating the electron-phonon coupling constant α.

2.3 Surface Morphology

Preliminary surface morphology investigations of CIS deposited on silica have been performed for the as-deposited film and for a film annealed at 600°C by tapping mode atomic force microscopy. The images are shown in fig. 2. The as deposited film reveals elongated grains ranging in length from 0.8 μm to 0.4 μm and from 0.2 μm to 0.1 μm in width. The images of the sample annealed at 600°C in an Ar atmosphere for five hours indicate that the grains have an aspect ratio (length/width) closer to unity and the surface roughness appears to have decreased substantially according to the gray scale of the image. The change in the aspect ratio of the grain size and the decrease in the surface roughness is not attributed to smoothing of the grain boundaries by inter-grain wetting, but rather to a decomposition of the film itself. This observation is supported by the infrared reflectance spectra which illustrate dramatic changes in the position and number of phonons observed after annealing the films at 600°C. Consequently, the decrease in the surface roughness after annealing at 600°C is likely due to the formation of a new material or change in the CIS stiochiometry.

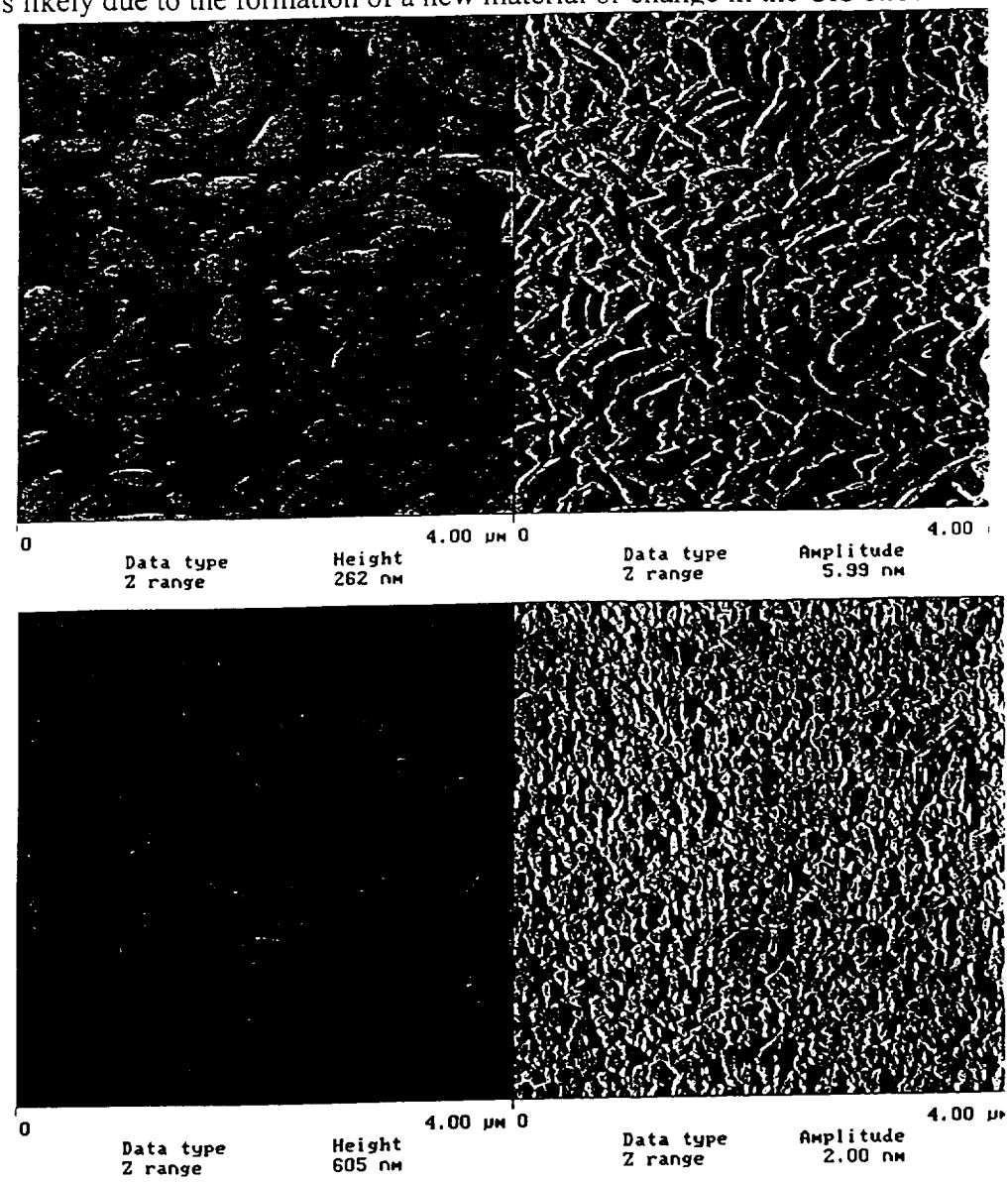

Fig.2 Atomic force microscopy images of CIS: Top before annealing, bottom after annealing at 600°C in an 5% H_2+95% Ar atmosphere.

2.4 Rutherford Backscattering

Rutherford backscattering data were acquired for six films of CIS grown on quartz substrates. The primary finding from these studies is that there is a loss of sulfur when the thin films are annealed at 600°C. The other films studied indicate that the samples are nearly stiochiometric within 10% error.

2.5 X-ray Photoelectron Spectrometry (XPS)

XPS measurements were made on two sets of samples of CIS deposited at flow rates of 2.7 and 4.7 LPM. The XPS showed that the as-prepared samples are sulfur rich. Etching the samples with a 7 KeV Ar^+ beam for 20 and 50 seconds revealed a nearly stiochiometric ratio of Cu:In:S of 1:1:2 and a substantial decrease of 30% in the atomic concentration of carbon and a decrease in the oxygen concentration by 50%. Carbon is a common contaminant in XPS measurements and it not possible to determine quantitatively how much of the carbon signal originates from impurities in the synthesis.

2.6 Construction of the Laser Ablation Vessel

The blueprints for the laser ablation vessel are given in Appendix B. The main components in the vacuum vessel not shown in the blueprints are: 1) a substrate heating stage for thermally controlling the substrate temperature up to 900°C; this stage can be rotated by 90° for overcoating quantum dots with a dielectric material, 2) a rotating target holder for laser ablation, 3) an electron beam gun for evaporating dielectric materials for overcoating quantum dots, 4) a thickness monitor for controlling the thickness of the overcoating layer on the quantum dots, 5) optical ports for performing *in situ* ellipsometry and photoluminescence, 6) optical ports for laser ablation and 7) additional ports for other types of optical characterization.

2.7 Radiation Effects on Nanocrystals

Gold nanocrystals embedded in MgO <100> single crystals were irradiated with 1 MeV electrons at a dose of $2x10^{16}$ electrons/cm^2. The optical absorption spectra were recorded before and after irradiation. The transmission spectra in the 185-1200 nm region revealed a peak at 560 nm for the unirradiated sample with a transmission of ~20%. This peak is attributed to the surface plasmon absorption (SPA) of gold nanocrystals. Following e^- irradiation the transmission of the SPA decreased to ~17.6%, while the transmission at 442 nm decreased from 36.4% to 32.0% indicating the presence of e^- beam induced defects.

2.8 Undergraduate Student Participation

Currently, two summer intern students, Faquita Neblett (Central State University) and Racquel Cruz (University of Puerto Rico, Maguayez) are working on CARET projects for a period of two months. Faquita Neblett's project involves the spectroscopy of phosphorous nanocrystals embedded in a dielectric matrices. Racquel Cruz is working on the nonlinear optical properties of metal nanocrystals isolated in fused silica matrices and will obtain the nonlinear dispersion curves for these materials using the output of an optical parametric oscillator pumped with the third harmonic of a ps Nd:YAG laser.

2.9 Graduate Students

Taravia Taylor (2nd year graduate student) and Dennis Denmark (1st graduate student) are working

on the optical response of nanophase materials. Ms. Taylor's project focuses on nanophase bismuth impregnated into porous Vycor glass, while Mr. Denmark is investigating the electronic and vibrational spectra of phosphorous colloids. His project will ultimately aim at fabricating and characterizing indium phosphide quantum dots in optical matrices.

3.0 Papers and Abstracts

Three abstracts have been submitted to the American Vacuum Society Meeting, two to the Electrochemical Society Meeting, The Fifth International Meeting on Quantum Confinement, November 1-6, one to the Fall Materials Research Society Meeting, 1998 (invited) and one to the SPIE International Symposium, July 13-16, 1998 (invited); see Appendix C. Full manuscripts will be submitted for publication in J. AVS, J. ECS, SPIE Proceedings, and MRS Proceedings.

CENTRAL STATE UNIVERSITY CARET ACTIVITIES:

At the outset of CARET, it was anticipated that through its ongoing experience and resources developed via its renewable energy, technology transfer and linkages programs, CSU would advance the objectives of the Consortium by serving as a student resource in the CARET consortium pipeline. Within this context, Central State University has developed 4 major goals associated with its role within CARET. These 4 goals are to:

1. Use the CARET program to encourage an enrollment increase.
2. Have CARET contribute to retention in NASA related fields.
3. Encourage graduate study for CSU graduates.
4. Provide a mechanism to promote new opportunities for CSU participation in renewable energy based water management projects in Africa.

In order to achieve these goals, Central State developed a plan to do five things. A brief description of each of these items and its current status follows.

Item A. The first item was to provide a work-study environment in which CSU students (primarily Water Resources and Manufacturing Engineering majors) will be exposed to renewable energy technology and other technical fields appropriate to the CARET and NASA objectives. This has been achieved in two ways. First, a group of four students was selected and supported to participate in the combined work and educational program represented by the Wilberforce course called "Applied Renewable Energy Technology", which was described in the section on Wilberforce activity. Here, the students received intensive exposure to the process and techniques involved in designing and installing renewable energy systems. Student prepared quarterly technical reports are available and on file for review. The CSU students attending were:

Hakim Evans, Senior, Water Resources Major
Justin Woods, Senior, Water Resources Major
Daniel Milo, Senior, Manufacturing Engineering Major
Sheila Wallace, Senior, Water Resources Major

The four students named above were also hired on as work-study students to perform work as part of Central State's CARET and NREL Research Associates program.

The second way in which Item A has been achieved is that the students who support the Office of Sponsored Research at CSU have been exposed to the renewable energy design and installation process as Central State has pursued the water pumping system described in item C.

B. Graduate at least 2 students per year who will continue masters degree programs at consortium member graduate schools. It is with this item that we are having the greatest trouble at this early stage, although we do believe that we are making progress and have some positive things to show for our efforts. We were very close to having a student attend graduate school at Kent State. He briefly planned to do so but had to adjust his plans due to some financial obligations. We have encouraged our students to examine the graduate programs within the consortium and have developed some interest in them. We planned, coordinated and scheduled a trip for nine Central State and Wilberforce students to Kent State University to explore the graduate school opportunities there. A student trip report is available and on file for review. We also invited Central State students to a briefing by a Fisk representative describing some Fisk programs. Through this and other efforts, we have achieved an important first step towards having CSU students pursue graduate studies within the Consortium. That first step is to have students participate in summer internships at these institutions. This summer, CSU students are attending summer internships at both Kent State and Fisk Universities. These experiences can have a strong influence on students' selection of their postgraduate pursuits.

One (1) Central State University student (Scott Montgomery, Senior, Water Resources Major) applied and was accepted as a summer intern at Kent State University. Mr. Montgomery is serving as a temporary research assistant in the School of Technology. He works closely with faculty from the Water Resources Department while pursuing research in water and environmental related issues.

Four CSU students applied, two were accepted and one (1) (Sekiuta Neblett, Freshman, Biology Major) elected to attend Fisk University's Research Experience for Undergraduates/Summer Research Program 1998. Ms. Neblett participates in physics research activities at Fisk, takes part in a research lecture series given by faculty and research staff in the physics department and attends and presents weekly research seminars presented by participants in the program.

Another accomplishment that supports our efforts in this area, but which is not directly part of the CARET program is that two (2) CSU students (Hakim Evans, Senior, Water Resources Management and Amonie Akens, Manufacturing Engineering) were selected to participate in the Renewable Energy and Environmental Protection (REEP) program hosted by Texas Southern University. The program included tutoring high school students in renewable energy technology and participating in the visit to renewable energy facilities in South Africa during 1997 and 1998. Student technical reports are available and on file for review.

C. Design and construct an on-campus renewable energy hybrid facility that will display and demonstrate (to current consortium students/faculty, prospective consortium students, and to

community outreach affiliates) the water resources technology appropriate for use by Developing Countries. Good progress has been made toward completing this item. The design has been completed and the materials necessary to complete the design have been ordered and assembly is underway. To-date, construction activities have included the completion of an 85 ft. drilled borehole, the installation of a 65 ft. section of galvanized 3" steel pipe, 84 ft. of fiberglass pump rod, a dual mechanical and electrical water lift pump, the erection of a 33 ft. windmill tower, and the installation of a wind driven mechanical motor with 12 ft. diameter wheel. Continuing construction includes the erection of solar panel sections and the installation of electrical regulators and control boxes. The installation of 500 ft. of chainlink fence will complete the facility. A final positive feature of this system is that we were able to use solar panels that were recycled. They had been part of a design experiment at NASA Lewis Research Center and although the design experiment was complete, the solar panels were still capable of producing electricity.

D. Work in partnership with consortium members in the design and execution of a five (5) day community outreach program that will expose prospective high school students and graduates to renewable energy and environmental sciences technology and related academic opportunities available at consortium universities. This program is only a few weeks away and all the planning and preparations including student recruitment are nearly complete. Thirty (30) high school students are to spend a week on the Central State University campus during July 12-17, 1998 to experience hands-on and classroom instruction regarding the basic principles of renewable energy technology. Participants will live, learn and work on both the Central State University and Wilberforce University campuses. A visit to the Glenn Helen Ecology Institute is also planned. A complete course agenda is attached as Appendix D.

E. Facilitate a marriage of parallel, on-campus technical and academic resources (lab facilities, faculty expertise, and on-going community outreach activities, i.e., Upward Bound, Governor's Institute, Adopted School Program, etc.) that will support and enhance CARET objectives. As an example of the achievements in this area, CSU has made available the lab facilities of the International Center for Water Resources Management and other appropriate University facilities to support consortium member research and outreach activities, including the summer program described in Item D. And, although this is a less concrete item than many of the others, we have also worked to encourage interaction with other programs and have formed proposals such as one to NREL's Photovoltaic Associates program to enhance CARET goals and activities.

As described here, Central State University is completing the action items that have been identified as leading to the achievement of the University's goals within the CARET program. It has had a direct positive impact on a number of students and has been benefitting the institution as a whole. We look forward to continuing these items to completion by the end of the second year of the program in July of 1999 and to building a longer term future for the Consortium.

KENT STATE UNIVERSITY CARET ACTIVITIES: At the inception of the Consortium, Kent State University was assigned three roles to play. Those three roles were to serve as a recipient of students in the pipeline, to participate in the research of the consortium and to assist Wilberforce

University in expanding its course offerings in the area of technology via a distance learning approach. Progress has been made in all these areas.

With respect to the first area, KSU has designated Dr. Roberto Uribe as the CARET contact for the purpose of promoting graduate school opportunities for both Bachelor's and Master's graduates of the other Consortium institutions. This provides graduates of the HBCUs the opportunity to pursue advanced degrees in Technology, not just the traditional science disciplines. This opportunity has generated a substantial interest from students within the Consortium. The School of Technology at KSU invited and hosted a visit by students from Wilberforce and Central State Universities to describe the opportunities for graduate study. Nine students attended and a number of students expressed an interest in pursuing studies at a later date and one student has submitted his application for graduate study to begin in the fall of 1998. What's more, under CARET, Kent State has been further cultivating relationships with CARET students through summer internships. Two CARET students are pursuing Kent State summer internships. While one of the students has already indicated that he is applying for graduate study at Kent, we are optimistic that the experience the other student has will significantly increase the likelihood that he will choose to pursue graduate study at Kent.

Faculty of Kent State University have, in fact, participated in the research of the consortium, fulfilling the activities of the second role for the University. In particular, the Consortium has utilized the expertise of Dr. Roberto Uribe in the area of radiation physics. He carried out radiation experiments on gold quantum dot samples prepared by the Fisk University research team, the results of which were addressed in the Fisk section. It is through these studies that we are gaining insights into the radiation effects on materials on the quantum dot scale.

The third role of Kent State University was to assist Wilberforce University in expanding its course offerings in the area of technology via a distance learning approach. Several members of the KSU community have met with other consortium members including the coordinator to help identify both the physical setup which would be required for Wilberforce students to participate in Kent State School of Technology classes but also to identify an appropriate class with which to begin this pilot program. The School of Technology was fully prepared to offer the course "Electronic Communication" to Wilberforce students in the fall of 1998. Since it now appears that Wilberforce will be unable to get the hardware up and running in time for the fall semester, we will work with them to identify a suitable class for the spring semester.

Through these activities within the three roles which Kent State plays in the CARET program, we believe that we have not only lived up to our assigned activities but significantly contributed to the interactions within the Consortium and through these interactions, significant accomplishments for the Consortium.

THE NASA LEWIS RESEARCH CENTER ACTIVITIES: CARET is very fortunate to have in Dr. Aloysius Hepp an enthusiastic and hands-on technical monitor who contributes significantly to the functioning of the Consortium. Dr. Hepp has helped in numerous ways beyond the normal responsibilities of his role as technical monitor. He has actively participated in the research of the Consortium, even supplying samples of $CuInS_2$ and $CuInSe_2$ from his research to the research team

at Fisk University for further study and analysis. He has also hosted meetings of the Consortium and served as a co-mentor with Kent State and Florida Institute of Technology faculty of a CARET summer intern. And, he arranged for the Consortium to acquire and recycle solar panels from a completed NASA research project and he has been a dedicated advocate for the Consortium which has assisted us in developing the affiliations which are mentioned in the next section. All of these contributions are helping CARET have a greater impact than would otherwise be possible.

CONCLUSION:

In this report, we have described many of the accomplishments of the CARET consortium. We believe that these accomplishments are in line with the successful completion of the program as described in the original proposal and its addenda. In fact, these accomplishments are rather remarkable in view of the fact that award notification was not received for more than 2 months after the award date, so they represent less than 10 months work. Through the diligent efforts of all of the participants, we have kept the program on target. And, we have not neglected the longer term goal of developing further support for the Consortium, so that it may continue beyond the initial funding period. Toward that end, we have prepared and submitted two white papers, one an unsolicited proposal describing an expansion of CARET to include a program to install hybrid renewable energy water pumping systems in Senegal and train the local villagers on the maintenance and management of the system. The second white paper was a more traditional research proposal on radiation effects on quantum dot materials that was submitted in response to the Fiscal 1999 DoD Multidisciplinary Research Program of the University Research Initiative BAA.

Although we are proud of the accomplishments achieved to date, we look forwarding to the prompt awarding of the second year funding so that we can maintain our momentum and continue to demonstrate dramatic progress toward our goals.

Appendix A

MMR Hall and Van der Pauw Measurement System

250-300K, hall

Hall Effect Measurement
Fixed Parameters:
Temperature Ramp (K/min) ,60
Field (G) ,1500
Field Ramp Const. ,5000
Sensitivity (V/kG) ,.00917
Thickness (microns) ,.5
K20 Time Constant ,150
Current (A) ,3.23E-08
Advanced Parameters:
Number of repetitions,1
Soak Time (min.),0
Reading Delay (sec.),0
Temperature setting accuracy (K),0.1
Field setting accuracy (%),2
Number Of Data Points,6

Data Point # ,1
Variable Temperature (K) ,252.71

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2333E-08,3.2329E-08,3.2333E-08,3.2325E-08,
Voltage 1 (V) ,.9938,.75706,1.01,.78716,
Current 2 (A) ,-3.2341E-08,-3.2341E-08,-3.2337E-08,-3.2344E-08,
Voltage 2 (V) ,-.93235,-.76644,-.98022,-.86246,
Resistance (Ohm) ,2.978245E+07,2.355806E+07,3.077501E+07,2.550867E+07,
Ratio ,.7910049,.7654932,.8288759,.8565,
Form Factor ,.9972401,.9960024,.9985756,.9992186,
Resistivity (Ohm*cm),6027.279,6131.815,6368.364,6260.086,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2333E-08,3.2337E-08,3.2329E-08,3.2447E-08,
Voltage 1 (V) ,-.246,.2576,-.25279,.26092,
Current 2 (A) ,-3.2341E-08,-3.2337E-08,-3.2337E-08,-3.2344E-08,
Voltage 2 (V) ,.16403,-.21828,.1653,-.20753,
Resistance (Ohm) ,-6339952,7358136,-6465376,7230171,
Field (G) ,1481.6,,-1489,

Temperature (K),252.71
Resistivity (Ohm*cm) ,6196.886
Mobility (cm2/Vs) ,34.41208
Density (cm-3) ,2.927204E+13
Hall Coeff. (cm3/Coul) ,213247.7
Sheet Number (cm-2) ,1.463602E+09
Sheet Res. (Ohm/cm2) ,1.239377E+08
Type of Carriers ,holes

Data Point # ,2
Variable Temperature (K) ,259.95

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2337E-08,3.2344E-08,3.2337E-08,3.2295E-08,
Voltage 1 (V) ,.90633,.68218,.88283,.67554,
Current 2 (A) ,-3.2341E-08,-3.2341E-08,-3.2341E-08,-3.2279E-08,
Voltage 2 (V) ,-.89061,-.676,-.88775,-.50617,
Resistance (Ohm) ,2.778286E+07,2.099683E+07,2.737531E+07,1.830009E+07,
Ratio ,.7557476,.7669989,.668489,.6586827,
Form Factor ,.9954516,.9960835,.9883905,.9873381,
Resistivity (Ohm*cm),5502.039,5459.533,5115.35,5155.498,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2329E-08,3.2352E-08,3.2333E-08,3.2333E-08,
Voltage 1 (V) ,-.20413,.21062,-.20636,.21343,
Current 2 (A) ,-3.2344E-08,-3.2341E-08,-3.2341E-08,-3.2341E-08,
Voltage 2 (V) ,.1649,-.19821,.16477,-.19677,
Resistance (Ohm) ,-5706091,6319540,-5738473,6342580,
Field (G) ,1481.8,,-1487.8,
Temperature (K),259.95
Resistivity (Ohm*cm) ,5308.105
Mobility (cm2/Vs) ,1.481718
Density (cm-3) ,7.936561E+14
Hall Coeff. (cm3/Coul) ,7865.116
Sheet Number (cm-2) ,3.96828E+10
Sheet Res. (Ohm/cm2) ,1.061621E+08
Type of Carriers ,holes

Data Point # ,3
Variable Temperature (K) ,269.96

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2341E-08,3.2337E-08,3.2325E-08,3.236E-08,
Voltage 1 (V) ,.7426,.57079,.70682,.57453,
Current 2 (A) ,-3.2337E-08,-3.2348E-08,-3.2337E-08,-3.2299E-08,
Voltage 2 (V) ,-.71502,-.57491,-.71136,-.57407,
Resistance (Ohm) ,2.253657E+07,1.771199E+07,2.19322E+07,1.776396E+07,
Ratio ,.7859223,.8075793,.8099489,.7882285,
Form Factor ,.9970163,.9978944,.9979789,.9971192,
Resistivity (Ohm*cm),4546.917,4482.585,4488.842,4553.258,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2337E-08,3.2337E-08,3.2337E-08,3.2337E-08,
Voltage 1 (V) ,-.13301,.13951,-.13535,.13984,
Current 2 (A) ,-3.2344E-08,-3.2348E-08,-3.2348E-08,-3.2344E-08,
Voltage 2 (V) ,.12088,-.14979,.12083,-.14796,
Resistance (Ohm) ,-3925264,4472444,-3960424,4449529,
Field (G) ,1477.5,,-1489.1,
Temperature (K),269.96
Resistivity (Ohm*cm) ,4517.9
Mobility (cm2/Vs) ,10.83253
Density (cm-3) ,1.275472E+14
Hall Coeff. (cm3/Coul) ,48940.28
Sheet Number (cm-2) ,6.377361E+09
Sheet Res. (Ohm/cm2) ,9.035801E+07
Type of Carriers ,holes

Data Point # ,4
Variable Temperature (K) ,280.12

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2337E-08,3.2337E-08,3.2329E-08,3.2337E-08,
Voltage 1 (V) ,.6015,.47435,.58891,.47828,
Current 2 (A) ,-3.2341E-08,-3.2348E-08,-3.2386E-08,-3.2375E-08,
Voltage 2 (V) ,-.59188,-.4792,-.59265,-.4792,
Resistance (Ohm) ,1.84511E+07,1.474144E+07,1.82579E+07,1.479602E+07,
Ratio ,.7989466,.8074006,.81039,.8019047,
Form Factor ,.9975677,.997888,.9979943,.9976831,
Resistivity (Ohm*cm),3751.865,3731.225,3737.795,3758.469,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2341E-08,3.2352E-08,3.2337E-08,3.2352E-08,
Voltage 1 (V) ,-.11073,.11511,-.11126,.11466,
Current 2 (A) ,-3.2352E-08,-3.2356E-08,-3.2352E-08,-3.2333E-08,
Voltage 2 (V) ,.10042,-.11919,.099124,-.11833,
Resistance (Ohm) ,-3263877,3620882,-3252238,3601917,
Field (G) ,1482.8,,-1489.8,
Temperature (K),280.12
Resistivity (Ohm*cm) ,3744.839
Mobility (cm2/Vs) ,1.645158
Density (cm-3) ,1.013204E+15
Hall Coeff. (cm3/Coul) ,6160.853
Sheet Number (cm-2) ,5.066018E+10
Sheet Res. (Ohm/cm2) ,7.489678E+07
Type of Carriers ,holes

Data Point # ,5
Variable Temperature (K) ,289.94

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2344E-08,3.2341E-08,3.2348E-08,3.2344E-08,
Voltage 1 (V) ,.51086,.40317,.49739,.4034,
Current 2 (A) ,-3.2352E-08,-3.2352E-08,-3.2337E-08,-3.2352E-08,
Voltage 2 (V) ,-.50231,-.40672,-.50167,-.40168,
Resistance (Ohm) ,1.566048E+07,1.251898E+07,1.5445E+07,1.244405E+07,
Ratio ,.7993994,.8105518,.8057005,.7946149,
Form Factor ,.9975857,.998,.9978259,.9973922,
Resistivity (Ohm*cm),3185.276,3162.233,3153.21,3176.191,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2344E-08,3.2341E-08,3.2341E-08,3.2341E-08,
Voltage 1 (V) ,-.094818,.097537,-.096839,.098407,
Current 2 (A) ,-3.2348E-08,-3.2348E-08,-3.2352E-08,-3.2352E-08,
Voltage 2 (V) ,.085483,-.10063,.086406,-.10155,
Resistance (Ohm) ,-2787068,3063380,-2832532,3090860,
Field (G) ,1482.9,,-1487,
Temperature (K),289.94
Resistivity (Ohm*cm) ,3169.228
Mobility (cm2/Vs) ,4.776801

Density (cm-3) ,4.123319E+14
Hall Coeff. (cm3/Coul) ,15138.77
Sheet Number (cm-2) ,2.06166E+10
Sheet Res. (Ohm/cm2) ,6.338455E+07
Type of Carriers ,holes

Data Point # ,6
Variable Temperature (K) ,300.08

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2344E-08,3.2341E-08,3.2356E-08,3.2352E-08,
Voltage 1 (V) ,.42972,.33702,.41774,.33672,
Current 2 (A) ,-3.2352E-08,-3.2356E-08,-3.2497E-08,-3.2356E-08,
Voltage 2 (V) ,-.42194,-.3403,-.42282,-.33523,
Resistance (Ohm) ,1.316403E+07,1.046911E+07,1.2961E+07,1.038434E+07,
Ratio ,.7952815,.8077391,.8011989,.7888421,
Form Factor ,.9974198,.9979002,.9976559,.9971462,
Resistivity (Ohm*cm),2670.938,2649.268,2639.037,2660.628,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2341E-08,3.2348E-08,3.2341E-08,3.2352E-08,
Voltage 1 (V) ,-.083911,.084873,-.085659,.085391,
Current 2 (A) ,-3.2348E-08,-3.2695E-08,-3.2356E-08,-3.2382E-08,
Voltage 2 (V) ,.076164,-.088203,.075908,-.088726,
Resistance (Ohm) ,-2474532,2660948,-2497288,2689731,
Field (G) ,1483.7,,-1488.3,
Temperature (K),300.08
Resistivity (Ohm*cm) ,2654.968
Mobility (cm2/Vs) ,-1.909718
Density (cm-3) ,-1.231145E+15
Hall Coeff. (cm3/Coul) ,-5070.239
Sheet Number (cm-2) ,-6.155723E+10
Sheet Res. (Ohm/cm2) ,5.309936E+07
Type of Carriers ,electrons

MMR Hall and Van der Pauw Measurement System

300-390 K, hall

Hall Effect Measurement
Fixed Parameters:
Temperature Ramp (K/min) ,60
Field (G) ,1500
Field Ramp Const. ,5000
Sensitivity (V/kG) ,.00917
Thickness (microns) ,.5
K20 Time Constant ,150
Current (A) ,3.23E-08
Advanced Parameters:
Number of repetitions,1
Soak Time (min.),0
Reading Delay (sec.),0
Temperature setting accuracy (K),0.1
Field setting accuracy (%),2
Number Of Data Points,10

Data Point # ,1
Variable Temperature (K) ,299.95

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2341E-08,3.2348E-08,3.2344E-08,3.2344E-08,
Voltage 1 (V) ,.4269,.33222,.41912,.33363,
Current 2 (A) ,-3.2352E-08,-3.2356E-08,-3.2356E-08,-3.2356E-08,
Voltage 2 (V) ,-.42118,-.33557,-.42366,-.33264,
Resistance (Ohm) ,1.31093E+07,1.032069E+07,1.302597E+07,1.029784E+07,
Ratio ,.78728,.7923169,.7905623,.7855366,
Form Factor ,.9970772,.997296,.997221,.9969988,
Resistivity (Ohm*cm),2647.07,2638.233,2635.452,2644.28,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2352E-08,3.2352E-08,3.2348E-08,3.2299E-08,
Voltage 1 (V) ,-.08842,.089931,-.089965,.090015,
Current 2 (A) ,-3.2352E-08,-3.2348E-08,-3.2352E-08,-3.2382E-08,
Voltage 2 (V) ,.080863,-.092479,.080402,-.092308,
Resistance (Ohm) ,-2616268,2819320,-2633184,2818803,
Field (G) ,1480.6,,-1486.9,

Temperature (K),299.95
Resistivity (Ohm*cm) ,2641.259
Mobility (cm2/Vs) ,5.560297
Density (cm-3) ,4.250388E+14
Hall Coeff. (cm3/Coul) ,14686.18
Sheet Number (cm-2) ,2.125194E+10
Sheet Res. (Ohm/cm2) ,5.282518E+07
Type of Carriers ,holes

Data Point # ,2
Variable Temperature (K) ,309.96

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2344E-08,3.2348E-08,3.2348E-08,3.2348E-08,
Voltage 1 (V) ,.37166,.28553,.36056,.28507,
Current 2 (A) ,-3.2356E-08,-3.2356E-08,-3.2356E-08,-3.2356E-08,
Voltage 2 (V) ,-.3651,-.28759,-.36552,-.28347,
Resistance (Ohm) ,1.138733E+07,8857567,1.122156E+07,8786783,
Ratio ,.7778444,.7893345,.7830267,.7716283,
Form Factor ,.9966376,.9971677,.9968839,.9963265,
Resistivity (Ohm*cm),2286.216,2268.702,2260.061,2277.511,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2348E-08,3.2344E-08,3.2348E-08,3.2348E-08,
Voltage 1 (V) ,-.080738,.080017,-.082305,.081439,
Current 2 (A) ,-3.2356E-08,-3.2356E-08,-3.2356E-08,-3.2356E-08,
Voltage 2 (V) ,.073261,-.082881,.073802,-.083881,
Resistance (Ohm) ,-2380054,2517743,-2412633,2555020,
Field (G) ,1484.9,,-1493.7,
Temperature (K),309.96
Resistivity (Ohm*cm) ,2273.123
Mobility (cm2/Vs) ,-1.73449
Density (cm-3) ,-1.583226E+15
Hall Coeff. (cm3/Coul) ,-3942.708
Sheet Number (cm-2) ,-7.916129E+10
Sheet Res. (Ohm/cm2) ,4.546245E+07
Type of Carriers ,electrons

Data Point # ,3
Variable Temperature (K) ,319.92

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2348E-08,3.2348E-08,3.2348E-08,3.2348E-08,
Voltage 1 (V) ,.32485,.24459,.31429,.24501,
Current 2 (A) ,-3.236E-08,-3.2356E-08,-3.2363E-08,-3.2356E-08,
Voltage 2 (V) ,-.31757,-.24627,-.32081,-.24276,
Resistance (Ohm) ,9927983,7586239,9814405,7538484,
Ratio ,.7641269,.7729698,.768104,.7593167,
Form Factor ,.9959278,.9963952,.9961424,.9956585,
Resistivity (Ohm*cm),1976.438,1964.542,1958.654,1970.516,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2348E-08,3.2352E-08,3.2352E-08,3.2348E-08,
Voltage 1 (V) ,-.077106,.076145,-.080986,.079734,
Current 2 (A) ,-3.236E-08,-3.2363E-08,-3.2356E-08,-3.2356E-08,
Voltage 2 (V) ,.070358,-.080093,.07341,-.082695,
Resistance (Ohm) ,-2278915,2414247,-2386042,2510340,
Field (G) ,1483,,-1492.4,
Temperature (K),319.92
Resistivity (Ohm*cm) ,1967.537
Mobility (cm2/Vs) ,4.71242
Density (cm-3) ,6.732409E+14
Hall Coeff. (cm3/Coul) ,9271.863
Sheet Number (cm-2) ,3.366204E+10
Sheet Res. (Ohm/cm2) ,3.935075E+07
Type of Carriers ,holes

Data Point # ,4
Variable Temperature (K) ,330.00

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2348E-08,3.2352E-08,3.2421E-08,3.236E-08,
Voltage 1 (V) ,.29251,.21126,.28289,.21268,
Current 2 (A) ,-3.236E-08,-3.236E-08,-3.236E-08,-3.2356E-08,
Voltage 2 (V) ,-.28484,-.2136,-.29071,-.21071,
Resistance (Ohm) ,8922390,6565398,8854448,6542278,
Ratio ,.7358339,.7414802,.7388691,.7332427,
Form Factor ,.9941853,.9945639,.9943908,.9940062,
Resistivity (Ohm*cm),1744.702,1737.709,1734.802,1741.783,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2348E-08,3.2779E-08,3.2352E-08,3.2302E-08,
Voltage 1 (V) ,-.082141,.080463,-.088813,.086296,
Current 2 (A) ,-3.236E-08,-3.2321E-08,-3.236E-08,-3.2367E-08,
Voltage 2 (V) ,.074966,-.084545,.078178,-.089988,
Resistance (Ohm) ,-2427938,2534685,-2580526,2725943,
Field (G) ,1481,,-1489.9,
Temperature (K),330
Resistivity (Ohm*cm) ,1739.749
Mobility (cm2/Vs) ,-18.70374
Density (cm-3) ,-1.918327E+14
Hall Coeff. (cm3/Coul) ,-32539.8
Sheet Number (cm-2) ,-9.591633E+09
Sheet Res. (Ohm/cm2) ,3.479498E+07
Type of Carriers ,electrons

Data Point # ,5
Variable Temperature (K) ,340.15

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2352E-08,3.2352E-08,3.2352E-08,3.2348E-08,
Voltage 1 (V) ,.27336,.18585,.2671,.18684,
Current 2 (A) ,-3.2363E-08,-3.2363E-08,-3.2363E-08,-3.2363E-08,
Voltage 2 (V) ,-.26748,-.18649,-.27492,-.1845,
Resistance (Ohm) ,8357260,5753535,8375493,5738437,
Ratio ,.6884476,.6869488,.6851462,.6866409,
Form Factor ,.9903632,.9902229,.9900523,.9901938,
Resistivity (Ohm*cm),1583.472,1585.293,1583.327,1581.507,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2352E-08,3.2352E-08,3.2356E-08,3.2356E-08,
Voltage 1 (V) ,-.094043,.092121,-.099746,.097393,
Current 2 (A) ,-3.2363E-08,-3.236E-08,-3.236E-08,-3.236E-08,
Voltage 2 (V) ,.087802,-.096446,.093261,-.10089,
Resistance (Ohm) ,-2809936,2913942,-2982369,3063895,
Field (G) ,1482.5,,-1486.8,
Temperature (K),340.15
Resistivity (Ohm*cm) ,1583.4
Mobility (cm2/Vs) ,11.95327

Density (cm-3) ,3.298071E+14
Hall Coeff. (cm3/Coul) ,18926.81
Sheet Number (cm-2) ,1.649036E+10
Sheet Res. (Ohm/cm2) ,3.1668E+07
Type of Carriers ,holes

Data Point # ,6
Variable Temperature (K) ,350.04

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2348E-08,3.2352E-08,3.2123E-08,3.2344E-08,
Voltage 1 (V) ,.26409,.16281,.25428,.16521,
Current 2 (A) ,-3.236E-08,-3.2363E-08,-3.2409E-08,-3.236E-08,
Voltage 2 (V) ,-.25222,-.16967,-.2597,-.16162,
Resistance (Ohm) ,7979075,5137604,7964731,5051157,
Ratio ,.6438847,.6450443,.6341905,.6330504,
Form Factor ,.9856429,.9857804,.9844607,.9843179,
Resistivity (Ohm*cm),1464.9,1463.502,1451.9,1453.289,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2352E-08,3.2356E-08,3.2352E-08,3.2356E-08,
Voltage 1 (V) ,-.10289,.10013,-.10781,.10508,
Current 2 (A) ,-3.2363E-08,-3.2363E-08,-3.2367E-08,-3.236E-08,
Voltage 2 (V) ,.096588,-.10437,.10145,-.10867,
Resistance (Ohm) ,-3082408,3159814,-3233363,3302893,
Field (G) ,1479.6,,-1483.7,
Temperature (K),350.04
Resistivity (Ohm*cm) ,1458.397
Mobility (cm2/Vs) ,4.555965
Density (cm-3) ,9.394662E+14
Hall Coeff. (cm3/Coul) ,6644.408
Sheet Number (cm-2) ,4.697331E+10
Sheet Res. (Ohm/cm2) ,2.916795E+07
Type of Carriers ,holes

Data Point # ,7
Variable Temperature (K) ,360.00

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,

Current 1 (A) ,3.2352E-08,3.2356E-08,3.1822E-08,3.2531E-08,
Voltage 1 (V) ,.24967,.14383,.23929,.1467,
Current 2 (A) ,-3.2367E-08,-3.2363E-08,-3.2352E-08,-3.2356E-08,
Voltage 2 (V) ,-.2404,-.14767,-.24906,-.14529,
Resistance (Ohm) ,7572274,4504087,7609780,4499977,
Ratio ,.594813,.5918813,.5913413,.5942703,
Form Factor ,.9790456,.9786013,.9785188,.9789638,
Resistivity (Ohm*cm),1339.687,1343.238,1342.669,1339.119,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2352E-08,3.236E-08,3.2356E-08,3.2356E-08,
Voltage 1 (V) ,-.1081,.10527,-.11235,.10909,
Current 2 (A) ,-3.2367E-08,-3.2203E-08,-3.2367E-08,-3.2363E-08,
Voltage 2 (V) ,.10211,-.10944,.10623,-.11294,
Resistance (Ohm) ,-3248041,3325589,-3377162,3430677,
Field (G) ,1479.2,,-1490.6,
Temperature (K),360
Resistivity (Ohm*cm) ,1341.178
Mobility (cm2/Vs) ,15.08414
Density (cm-3) ,3.085533E+14
Hall Coeff. (cm3/Coul) ,20230.53
Sheet Number (cm-2) ,1.542767E+10
Sheet Res. (Ohm/cm2) ,2.682357E+07
Type of Carriers ,holes

Data Point # ,8
Variable Temperature (K) ,370.14

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2348E-08,3.2352E-08,3.2321E-08,3.2363E-08,
Voltage 1 (V) ,.24459,.12612,.22479,.13235,
Current 2 (A) ,-3.2363E-08,-3.2367E-08,-3.2291E-08,-3.2493E-08,
Voltage 2 (V) ,-.2073,-.1426,-.23586,-.12941,
Resistance (Ohm) ,6983202,4152104,7129482,4036019,
Ratio ,.5945845,.5823851,.5661027,.577961,
Form Factor ,.9790112,.9771212,.9744337,.9764099,
Resistivity (Ohm*cm),1235.248,1249.059,1232.806,1219.123,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,

Current 1 (A) ,3.2356E-08,3.2436E-08,3.2352E-08,3.2218E-08,
Voltage 1 (V) ,-.10502,.10243,-.017966,.10724,
Current 2 (A) ,-3.2371E-08,-3.2394E-08,-3.2379E-08,-3.2417E-08,
Voltage 2 (V) ,.097007,-.10713,.062938,-.10687,
Resistance (Ohm) ,-3121217,3232454,-1249849,3312602,
Field (G) ,1481.8,,-1489.1,
Temperature (K),370.14
Resistivity (Ohm*cm) ,1234.059
Mobility (cm2/Vs) ,-1330.724
Density (cm-3) ,-3.801139E+12
Hall Coeff. (cm3/Coul) ,-1642191
Sheet Number (cm-2) ,-1.900569E+08
Sheet Res. (Ohm/cm2) ,2.468118E+07
Type of Carriers ,electrons

Data Point # ,9
Variable Temperature (K) ,379.88

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.2356E-08,3.2356E-08,3.2566E-08,3.2337E-08,
Voltage 1 (V) ,.21665,.119,.20942,.12252,
Current 2 (A) ,-3.2371E-08,-3.2367E-08,-3.2394E-08,-3.2436E-08,
Voltage 2 (V) ,-.21108,-.11917,-.21762,-.11577,
Resistance (Ohm) ,6608217,3679836,6573892,3678848,
Ratio ,.5568576,.5597652,.5596149,.5567081,
Form Factor ,.9728203,.9733347,.9733083,.9727938,
Resistivity (Ohm*cm),1134.045,1130.859,1130.719,1133.905,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24|31,13|24,24|31,
Current 1 (A) ,3.2382E-08,3.2314E-08,3.2356E-08,3.2585E-08,
Voltage 1 (V) ,-.094673,.096961,-.10293,.090381,
Current 2 (A) ,-3.2375E-08,-3.2264E-08,-3.2367E-08,-3.2314E-08,
Voltage 2 (V) ,.092144,-.10142,.094768,-.1183,
Resistance (Ohm) ,-2884893,3071960,-3054525,3215473,
Field (G) ,1479.6,,-1487.7,
Temperature (K),379.88
Resistivity (Ohm*cm) ,1132.382
Mobility (cm2/Vs) ,19.43273
Density (cm-3) ,2.836682E+14
Hall Coeff. (cm3/Coul) ,22005.28
Sheet Number (cm-2) ,1.418341E+10

Sheet Res. (Ohm/cm2) ,2.264764E+07
Type of Carriers ,holes

Data Point # ,10
Variable Temperature (K) ,389.89

Process: Four Probes Resistivity Measurement

Probes Source|Meter,12|43,23|14,34|21,41|32,
Current 1 (A) ,3.236E-08,3.2356E-08,3.2356E-08,3.236E-08,
Voltage 1 (V) ,.20056,.12047,.20183,.11487,
Current 2 (A) ,-3.236E-08,-3.2371E-08,-3.2375E-08,-3.2367E-08,
Voltage 2 (V) ,-.17226,-.13026,-.21048,-.11035,
Resistance (Ohm) ,5760508,3873654,6369592,3479537,
Ratio ,.6724502,.608148,.5462731,.604033,
Form Factor ,.9887999,.9809929,.9708928,.9804047,
Resistivity (Ohm*cm),1079.411,1138.591,1083.511,1026.464,

Process: Four Probes Hall Measurement

Probes Source|Meter,13|24,24 31 13|24,24|31,
Current 1 (A) ,3.2363E-08,3.2356E-08,3.2356E-08,3.236E-08,
Voltage 1 (V) ,-.098979,.094711,-.10069,.096897,
Current 2 (A) ,-3.2398E-08,-3.2371E-08,-3.239E-08,-3.2375E-08,
Voltage 2 (V) ,.092014,-.098373,.093757,-.099819,
Resistance (Ohm) ,-2949198,2983052,-3003228,3038789,
Field (G) ,1477.9,,-1486.5,
Temperature (K),389.89
Resistivity (Ohm*cm) ,1081.995
Mobility (cm2/Vs) ,-1.330295
Density (cm-3) ,-4.33675E+15
Hall Coeff. (cm3/Coul) ,-1439.372
Sheet Number (cm-2) ,-2.168375E+11
Sheet Res. (Ohm/cm2) ,2.163989E+07
Type of Carriers ,electrons

Appendix B

Kurt J. Lesker Company

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SALES: 1-800-245-1656
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Fax: 412-233-4275

Friday, February 27, 1998

Fisk University
Department of Physics
1000 17th Ave. N.
Nashville, TN 37208

Attn. Rixiang Mu

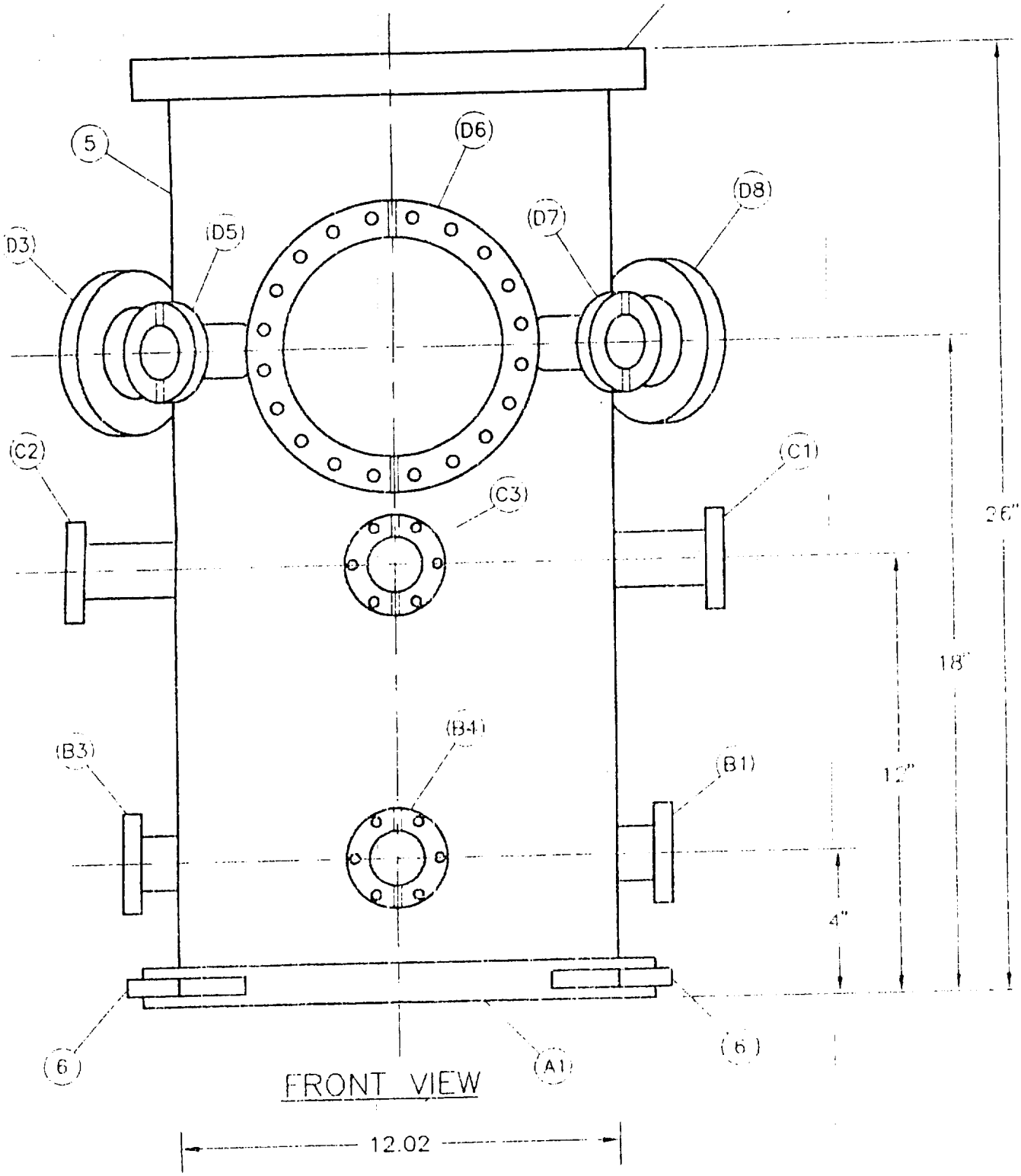
Dear Rixiang,

Attached, please find rev 3 of your drawing with port lengths of B1, B3 & B4 changed to 1.5". Please initial the drawing with your approval and return to me.

If you have any questions, feel free to contact me.

Sincerely,

Joey Keller



FRONT VIEW

Appendix C

Optical Properties of Metallic Nanocrystals Confined in Dielectric Media: Effects of Shape and Interface

R. Mu, A. Ueda, M.H. Wu and D.O. Henderson
Chemical Physics Laboratory, Department of Physics, Fisk University, Nashville, TN 37208

K. Malone and G. Mills
Department of Chemistry, Auburn University, Auburn, Alabama 36849

It is known that both linear and nonlinear optical properties and electron dynamics of nanocrystals embedded in dielectric media can be strongly related to their size, shape and host-guest interface. Although the effect of physical size on optical properties is fairly well-understood, it has been difficult to exclusively demonstrate how the shape and the interface modify the optical response of nanocrystals, such as surface plasmon resonance (SPR). Recently, we have shown that classical effective medium theories (EMT) are inadequate in predicting the SPR of metal particles when interfacial effects between the nanocrystal and host material are significant. In particular, we have shown this for the case of Au colloids embedded in MgO host.[1]

In order to illustrate the fundamental mechanisms of how the shape and the interface change the SPR frequency and line shape of the Au nanocrystals, a new approach has been developed that uses porous Vycor glass with a well controlled pore size (~4 nm) as the host material. Au colloids are formed by spontaneous reduction of $AuCl_4^-$ ions in basic methanol.[2] The reduction processes are accomplished both thermally and photochemically. The former reduction is done by placing the impregnated Vycor sample in 100°C oven for 1 hr which are subsequently immersed in pure methanol to extract any unreduced Au(III). The pore volume filling fraction is estimated to be 0.1%. Photochemical reduction is carried out by irradiating the samples with 350 nm light. This procedure yields a volume filling fraction of ~1%. The thermally prepared Au in Vycor appears red-blue, while the photochemically reduced Vycor sample is dark blue. The optical spectra are illustrated in figure 1. For the photochemically generated sample, the surface plasmon absorption is centered at ~ 615 nm and has a FWHH >200 nm , while the thermally reduced sample has surface plasmon absorption at 535 nm and a FWHH of ~100 nm broad. When the samples were thermally annealed under reducing atmosphere (H_2+Ar) up to 400°C, a 60 nm blue-shift is observed from 615 nm to 555 nm for the photochemically reduced sample and a 11 nm blueshift is observed for the thermally reduced sample from 535 nm to 524 nm.

It is noteworthy that the linewidth of the SPR for Au colloids formed in densified fused silica is considerably smaller than that of the Au colloids in porous Vycor. This difference is expected to originate from the very nature of the porous Vycor network that serves as confining medium to restrict the colloid shape and degree of aggregation at low volume filling fractions. Under the condition of low volume filling fraction in porous Vycor glass, it would then be expected that the samples prepared by thermal treatment would be principally spherical in shape. However, the colloids formed by photochemical reduction may be templated by the porous network of the glass rendering a more cylindrical particle shape. The aspect ratio of the axis to the to the radius of the cylinder of the colloids formed by photochemical and thermal reduction can in principal account for the linewidth variations observed in figure 1.

The changes observed in the SPR line shape for the two samples prepared by thermal and photochemical reduction after annealing are most likely due to changes in the effective dielectric constant of the medium and not to thermal effects. This follows from the reasoning that the there is no appreciable melting or diffusion of the Au in the pores at temperatures up to 400°C. Consequently, the shifts in the SPR for the annealed samples are attributed to the removal of residual solvent (MeOH and H_2O) used in the synthesis of Au colloids. This is supported by the observation that immersing the samples in pentanol (n=1.408) causes a redshift in the SPR for the samples prepared through both chemical routes.

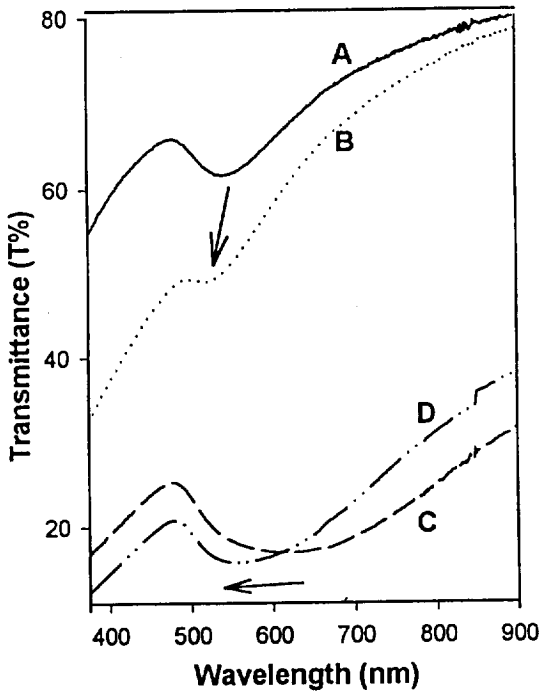


Figure 1 Optical transmission spectra of Au colloids in porous Vycor glass. A & B are the spectra of thermally reduced Au colloids before and after thermal annealing and C & D are the spectra of photochemically reduced sample before and after thermal annealing.

Reference

1. A. Ueda, R. Mu Y-S. Tung, M.H. Wu, W.E. Collins, D.O. Henderson, C.W. White, R.A. Zuhr, J.D. Budai and A. Meldrum, Nucl. Inst. Methods B (in print, 1998).

2. M. Quinn and G. Mills, J. Phys. Chem. **98**, 9840 (1994).

Optical Properties of Silicon Nanocrystals Formed by Ion Implantation

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C. W. White, R. A. Zuhr and A. Meldrum
Solid State Div., Oak Ridge National Laboratory
Oak Ridge, TN

The optical properties of quantum confined semiconductors have attracted much interest due to potential device applications and due to basic physical questions concerning the effects of confinement. Silicon nanocrystals (NCs), in particular, are of great interest following the observation of efficient luminescence in the visible region.[1] Conflicting theories concerning the origin of the red luminescence from Si NCs have been presented. Two possible mechanisms have been suggested: radiative recombination of excitons within the Si NCs, and carrier tunneling to a "radiative center" outside the NC followed by emission from the radiative center.[2] Studies of the optical properties of Si NCs created by ion implantation of Si into a variety of dielectric hosts have been performed to shed more light on this subject.

Silicon and other semiconductor NCs have been successfully fabricated in a number of dielectric hosts by ion implantation followed by thermal annealing. White and co-workers have shown that the mean size of the NCs formed by ion implantation into SiO_2 substrates can be controlled by varying the ion energy and the post - implantation thermal annealing conditions.[3] Photo-luminescence (PL) measurements on these samples and a number of studies on Si NCs formed in thermally grown SiO_2 layers on Si substrates have conclusively shown that PL in the red region (650nm - 900 nm) appears only after the formation of NCs.[4] To distinguish between the two possible mechanisms that cause the red PL, comparisons were made between ion dose dependent PL and excitation energy dependent PL on samples with a given dose. While both methods allow for size selectivity, variation of the excitation energy for a single sample removes the dependence on the type or density of defects which can act as radiative centers.

The NCs used in the current are identical to those used by White, et. al. Si^+ ions were implanted into SiO_2 at energies selected to achieve planar concentration profiles. Ion densities of 1×10^{21} , 2×10^{21}, 5×10^{21} and 1×10^{22} ions/cm^3 were studied. All samples were annealed a reducing atmosphere (Ar and H_2) for one hour. Transmission electron microscopy revealed nanocrystals which ranged in size from < 2 nm (lowest concentration) to 4 nm (highest concentration). Time resolved PL measurements were performed using the output of an optical parametric generator/amplifier pumped by the third harmonic of a Nd:YAG laser (30ps pulse width). The pump energy was limited to 2 microjoules to avoid nonlinear effects. The PL was focused into a ¼ m monochromator and measured with a photomultiplier tube. Spectra were taken using a boxcar averaging system, and time resolved PL was measured with a digitizing oscilloscope.

The linear absorption spectra of these samples, as reported previously by White and co-authors,[3] give some initial indications that the PL is not due to excitonic recombination within the Si NCs. They reported that, while the optical absorption edge shifts dramatically with particle size (absorption edges ranging from 2 eV to >3 eV), small shifts (~ 0.17 eV) are observed in the position of the peak of the PL spectra.

The measurements described above have been complemented by monitoring the PL from a selected sample (2×10^{21} ions/cm^3) while the excitation photon energy was varied from 2.0 eV to 2.8 eV. The results are shown in Fig. 1. Neither the peak positions nor the peak shapes show any significant variation with excitation energy. This indicates that the (0.17 eV) shifts described above are not due strictly due to changing NC size.

The decay of the photoluminescence as a function of ion dose and excitation energy has also been examined. For the measurements performed as ion dose was varied, the excitation photon energy was 2.75 eV and the detected photon energy was 1.72 eV. The decay for the three highest concentration samples can be fit well by a stretched exponential function ($I(t) = I_o \exp(-(t/\tau)^{\beta})$), which is often used to describe dynamics in inhomogeneous systems. The lifetimes extracted from these data decrease as the ion dose is increased, ranging from 50 microseconds for the 2×10^{21} ions/cm^3 sample to 19 microseconds for the 1×10^{22} ions/cm^3 sample. The decay for the sample with the lowest ion concentration could only be fit with a sum of stretched exponentials with two decay times, with a shorter time on the order of the system resolution (10ns) and the longer decay time of 70 microseconds.

The time resolved PL measurements described above can be compared to measurements, shown in Fig. 2, performed on a single sample (2×10^{21} ions/cm^3) while the excitation energy is varied. The lifetime of the PL dervied from fits to stretched exponential functions varies only slightly as the excitation energy is varied from 2.78 eV to 2.30 eV. The measured lifetimes show no definite trend and range only from 44 microsecond to 54 microseconds. This contrasts greatly with the dose dependent lifetime data, which show much greater differences between samples.

The two comparisons between size selection by ion dose and by excitation energy clearly show that there is a much greater variation in the PL spectra and decay when the dose, rather than the excitation energy, is varied. This means that the systematic decrease of the PL lifetime as the ion dose is increased must be due to factors other than the particle size. Increasing the ion dose affects the type and increases the density of defects which may serve as radiative centers. Since these radiative centers serve as sites for emission from carriers produced within the NCs, it is reasonable to expect that the lifetime would decrease as ion dose increases.

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[1] L. T. Canham, *Appl. Phys. Lett.* **57**, 1046 (1990).

[2] See, for example, P. F. Trwoga, A. J. Kenyon and C. W. Pitt, *J. Appl. Phys.*, **83**, 3789 (1998) and J. C. Vial, A. Bsiesy, F. Gaspard, R. Herino, M. Ligeon, F. Muller, R. M. Macfarlane and R. Romestain, *Phys. Rev. B* **45**, 14171 (1992).

[3] C. W. White, S. P. Withrow, A. Meldrum, J. D. Budai, D. M. Hembree, J. G. Zhu, D. O. Henderson and S. Prawer, *Mat. Res. Soc. Symp. Proc.*, to be published.

[4] See, for example, H. Z. Song and X. M. Bao, *Phys. Rev. B* **55**, 6988 (1997) and references therein.

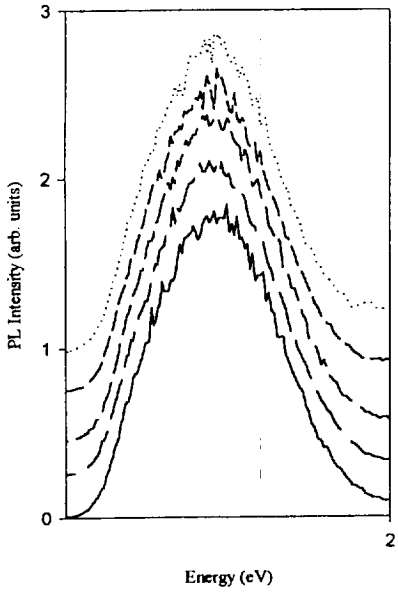

Fig. 1. Excitation energy dependence of PL spectra. The spectra have been normalized and displaced vertically for clarity. From bottom to top traces represent excitation photon energies of : 2.78 eV, 2.66 eV, 2.55 eV, 2.45 eV and 2.30 eV.

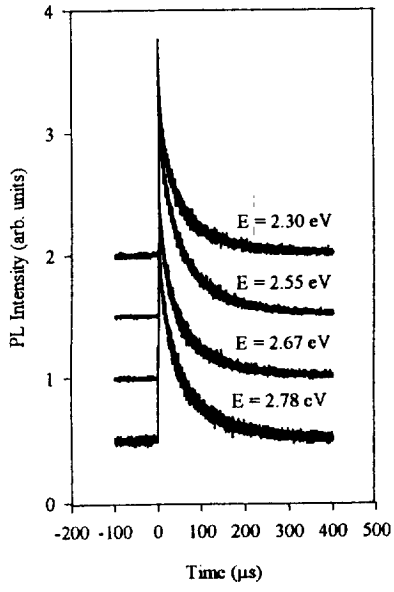

Fig. 2. Excitation energy dependence of PL decay. The spectra have been normalized and displaced vertically for clarity.

Annealing Atmosphere and Electron Irradiation Effects on Gold Nanocrystals Buried in MgO

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C.W.White, A. Meldrum, and R.A. Zuhr
Oak Ridge National Laboratory, Solid State Division, Oak Ridge, TN 37831

We have reported previously annealing effects on the surface plasmon (SP) of gold nanocrystals (NCs) formed by Au ion implantation in MgO. Annealing the samples after implantation promotes the diffusion of gold atoms, nucleation and growth of the NCs. The SP absorption for the Au/MgO system annealed in an oxidizing atmosphere (OA) is observed at ~560 nm, while annealing the same sample in a reducing atmosphere (RA) shifts the SP to ~524 nm. The process is entirely reversible and can be cycled hundreds of times. We propose that the SP shift originates from the creation of F_n-centers when the samples are annealed in a reducing atmosphere, while they are annihilated in an oxidizing atmosphere. The F_n center acts as an e^- donor to the Au NCs that causes a blue shift of the SP. Subsequent annealing in an OA annihilates the F_n centers and the SP shifts back to 560 nm. TEM studies on Au NCs in MgO indicate the crystals are cubic and are aligned along the <100> direction of the MgO lattice. Maxwell-Garnet effective medium theory was used to simulate the absorption spectra of the Au NCs formed in MgO under RA and OA. A good fit was obtained for sample annealed in an OA, but the fit for the annealed sample in a RA deviated from the experimental results. This is attributed to a change in the dielectric function of the Au NC that resulted from electron transfer from the F_n center. Electron beam irradiation of the Au/MgO samples was also investigated as an alternative method to study F_n center creation and their interaction with the gold NCs. The optical spectra in the SP region are presented for the electron irradiated Au/MgO samples and are compared to those annealed in a reducing atmosphere.

Banding of Gold Nanocrystals in Porous Vycor Glass

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Chemical Physics Laboratory, Physics Dept., Fisk University, Nashville, TN 37208

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Oak Ridge National Laboratory, Solid State Division, Oak Ridge, TN 37831

A. Hepp and E. Gordon
NASA Lewis Research Center, Cleveland, OH 44135

Porous Vycor glass (PVG) was implanted with Au at ion doses between $1x10^{16}$-$1x10^{17}$ ions/cm^2. Electronic and vibrational spectra were recorded before and after annealing the samples in a tube furnace at 900, 1000, 1100°C for 1 h in an atmosphere of 5% H_2+95% Ar. Peaks were observed at 2.34 eV and 1.4 eV after annealing and are assigned to the surface plasmon absorption of the Au nanocrystals (NCs). The vibrational spectra revealed an increase in the reflectivity of the LO, TO and Si-O-Si bending modes located at 1220, 1100, and 450 cm^{-1} for the as-implanted samples. The intensity increase is attributed to densification of the PVG that resulted from ion beam damage, i.e. the refractive index (n) of the glass becomes more silica-like as compared to the virgin PVG consisting of ~30% air with n=1 and silica n=1.4. Rutherford backscattering reveals a single peak located at ~0.5 μm below the surface for the as-implanted PVG. After annealing, additional peaks appear at greater depths below the surface indicating that the Au has segregated into isolated bands. This observation is supported by cross-sectional TEM studies that show well defined bands of Au NCs. The mechanism for the "banding" is expected to originate from the ion beam densification of the PVG. Au particles trapped in the densified region are less mobile than those residing in the porous region and this limits colloid growth. The particles in the porous region are comparatively more mobile allowing for diffusion and growth up the point where the annealing temperature (~1000°C) causes the porous glass network to densify. At this stage, further growth of the NCs is very small. Thus, as a consequence of ion beam and thermal densification of PVG, two distinct regions are defined that restrict NC formation which explains banding of the NCs.

Indium Phosphide Nanocrystals formed by Sequential Ion Implantation into Fused Silica

D. O. Henderson, R. Mu, A. Ueda, M. H. Wu, and D. Denmark
Chemical Physics Laboratory, Physics Department, Fisk University, Nashville, TN 37208

C.W.White, A. Meldrum, and R.A. Zuhr
Oak Ridge National Laboratory, Solid State Division, Oak Ridge, TN 37831

Indium followed by phosphorous were implanted into optical grade fused silica at energies of 320 and 120 KeV, respectively and at doses ranging from $1x10^{16}$ ions/cm^2 to $1x10^{17}$ ions/cm^2. The the implanted substrates were annealed at 800°C for 1 h in a reducing atmosphere (5% H_2 +95% Ar). Vibrational and electronic spectra were recorded before and after annealing the samples. The vibrational spectra revealed a peak at ~320 cm^{-1} after annealing at 800°C. The intensity of this peak increased with ion dose and is assigned to the surface phonon of InP nanocrystals. XRD measurements confirmed the presence of crystalline InP and TEM showed particles with radii ranging from 4.6 to 11.6 nm. Electronic spectra of the annealed samples indicated the energy of the band edge absorption is well below the bulk value of 969 nm. The band gap energies increased with decreasing ion dose and is attributed to quantum confinement of the exciton. The quantum confinement of the exciton is supported by the TEM measurements which demonstrated that the nanocrytals are nearly equal to or smaller than the InP exciton radius of 10.7 nm.

Appendix D

1998 RENEWABLE ENERGY SUMMER ENRICHMENT PROGRAM JULY 12-JULY 17, 1998 CENTRAL STATE UNIVERSITY

RENEWABLE ENERGY SUMMERENRICHMENT PROGRAM

The Renewable Energy Summer Enrichment Program is a five (5) day program designed specifically for high school students. The aim of this program is to introduce college bound students (especially minorities) to the emerging field of renewable energy technology. Renewable energy technologies include the following areas: photovoltaics, wind energy, biomass, biogas, and hydropower.

CRITERIA FOR PARTICIPATION

To be eligible to participate in the Renewable Energy Summer Enrichment Program you must meet the following criteria:

- **demonstrate a strong interest in science, mathematics, and the environment;**
- **be in the 10th, 11th, or 12th grade during the 1998-99 school year;**
- **submit a completed application form and essay;**
- **submit a letter of recommendation from a teacher, principal, or counselor.**

DEADLINE

Students desiring to participate in the program should respond as early as possible. There are 30 slots allocated for students and they will be filled on a first-come, first-served basis. This application should be returned no later than May 1, 1998. After this date, applications will be reviewed and accepted on a space-available basis.

COST

Central State University will provide students with living accommodations, meals, and transportation for field trips during their six day stay. Students may want to bring a small amount of cash to purchase college apparel and the like. A stipend of $50 and a scientific calculator will be furnished to all students upon successful completion of the program. Students and parents are, however, responsible for transportation to and from Central State University.

ABOUT THE UNIVERSITY

Central State University is located in Wilberforce, Ohio, just outside of Xenia, Ohio. As Ohio's only public Historically Black University, Central State University academically prepares students for leadership and service in a rapidly changing world. As an open access institution, Central State University encourages academic excellence through a strong liberal arts foundation and majors in selected professional fields.

SUMMER WORKSHOP--CARET
"Consortium for the Advancement of Renewable Energy Technology"

Sunday, July 12, 1998

2:00 PM-4:00 PM	Registration and room assignments. Location: Jenkins Hall Auditorium
4:00 PM-5:00 PM	Welcoming ceremony and program orientation. (Parents welcome) Location: Jenkins Hall Auditorium
5:00 PM-6:00 PM	Dinner (parents welcome) Location: Mercer Cafeteria
6:00 PM-7:30 PM	Tour of Central State University.

Monday, July 13, 1998

8:00 AM-10:00 AM Introduction to Energy

Location: Banneker Hall, room 211
Instructor: Dr. Sam Laki, Water Resources Management
Topic Overview: Introduction to energy and definitions. Trends of energy use domestic and abroad will be explored. Energy use by sector (i.e., transportation, industry, municipality, and agriculture) will be compared and contrasted.

10:00 AM-12:00 PM Physics of Energy I

Location: Banneker Hall, room 211
Instructor: Dr. Sri Sritharan
Topic Overview: Measures of Energy and Power: Measures of mechanical, thermal and electrical energy will be discussed. The interrelationship between types of energy and energy conversion is investigated. The applications of mathematics in renewable energy physics is also discussed.

Solar Energy and the Environment: The nature of solar energy and the impact of solar energy on the environment (bodies of water, animals, humans) will be discussed. Factors affecting the amount of solar energy received on the earth's surface, the greenhouse effect, and measuring methods of solar energy will be discussed.

12:00 PM-1:00 PM LUNCH, Mercer Cafeteria

1:00 PM-3:00 PM Energy Sources

Location: Banneker Hall, room 211
Instructor: Dr. Sam Laki
Topic Overview: The instructor will explain the differences between renewable and non renewable energy sources. Non renewables include: fossil fuels and nuclear energy. Renewables include the following: solar energy, wind power, biomass, geothermal energy, and hydropower. An audio/visual presentation featuring "Mastering the Marketplace" will recap the discussion.

3:00 PM- 5:00 PM	Harnessing Wind for Power Production	
	Location:	Banneker Hall, room 211
	Instructor:	Dr. Samuel Okunade
	Topic Overview:	This session will deal with such climatic phenomena as pressure and its measurement, pressure as a factor closely tied to other weather phenomena, global pressure systems and related planetary wind systems, and basic definitions related to pressure. The advantages of wind energy are also highlighted. Lab Activities: Students will use laboratory instruments to obtain atmospheric pressure, examine and interpret zonal sea level pressure belts, and examine world pressure conditions at sea level in relation to the seasonal migration of the sun.
5:00 PM-6:00 PM	Dinner, Mercer Cafeteria	
6:00 PM-8:30 PM	Basketball with Upward Bound Program, Walker Gymnasium	

Tuesday, July 14, 1998

8:00 AM-10:00 AM — Natural Resources

Location: Banneker Hall, room 211
Instructor: Dr. Sam Laki
Topic Overview: Non Renewable Resources: Resources available in relatively large, finite amounts will be discussed. They include: fossil fuels, metallic minerals, and non metallic minerals. Perpetual Resources are resources that are ever present, they include: direct solar energy, winds, tides, and flowing water.

Potentially Renewable Resources: The following resources exhibit a high potential to be considered renewable resources: fresh air, freshwater, fertile soil, plants and animals (biodiversity).
A video entitled "Water Pollution" will highlight the sources and effects of pollution on the earth's fresh water supply.

10:00 AM-12:00 PM — Physics of Energy II

Location: Banneker Hall, room 211
Instructor: Dr. Sri Sritharan
Topic Overview: Wind Energy: Wind energy will be discussed in detail. The conversion of wind energy to electrical energy will be discussed along with factors that affect windmill performance, estimation of wind energy, and determination of wind velocity and direction.

Hydropower: Extraction of electrical power from dams and reservoirs will be explored. The student will gain an elementary understanding of how water rushing over turbines can create electricity. Exercises in water energy estimation will also be conducted.

12:00 PM-1:00 PM — LUNCH, Mercer Cafeteria

1:00 PM-3:00 PM — Field Lab

Location: Field sites on campus and McLin 150
Instructor: Dr. Sri Sritharan
Topic Overview: Measuring Wind Velocity: Using anemometers, students will obtain wind speeds and use the data to develop a wind velocity profile.
Measuring Net Solar Radiation: Students will obtain solar radiation measurements in the field and learn how to estimate cloud cover.

Hydraulic Turbines: Students will learn how to determine energy output from a hydraulic turbine and develop the corresponding relationship between water pressure and turbine velocity.

3:00 PM-5:00 PM Solar Energy: Temperature and Heat

Location: Banneker Hall, room 211
Instructor: Dr. Samuel Okunade
Topic Overview: The instructor will discuss the daily and annual cycles of temperatures, various controls of temperatures, and air temperature data in relation to isotherms. Lab Activities: Students will use laboratory instruments for accurate temperature measurement, learn the scientific difference between warm and cold air, investigate methods of heat transfer, use annual temperature data to determine heating and cooling degree days, and examine and interpret isothermal maps. This lab includes an outside assignment.

5:00 PM-6:00 PM Dinner, Mercer Cafeteria

6:00 PM-8:30 PM Basketball\board games\cards with Upward Bound Program participants.

Wednesday, July 15, 1998

8:00 AM-10:00 AM	Environmental Problems	
	Location:	Banneker Hall, room 211
	Instructor:	Dr. Sam Laki
	Topic Overview:	Pollution: The sources, effects, prevention, and clean up of pollution is discussed. In class information is reinforced with a videpresentationon of "Fragile Planet".
1:00 PM-5:00 PM	Location:	Dayton Wastewater Treatment Plant
	Instructor:	Dr. Sri Sritharan, Dr. Laki, Dr. Okunade
	Topic Overview:	Wastewater Treatment and Energy Production: Students will learn how wastewater is treated and how one of its by-products, methane, is used to generate energy. Students will observe most treatment processes from wastewater intake to discharge of treated water.
5:00 PM-6:00 PM	Dinner, Mercer Cafeteria	
6:00 PM-8:30 PM	Card Tournament in conjunction with Upward Bound Program participants.	

Thursday, July 16, 1998

8:00 AM-11:00 AM — Water Energy: Moisture in the Atmosphere

Location: Banneker Hall, room 211
Instructor: Dr. Samuel Okunade
Topic Overview: Students will gain a basic understanding if the hydrologic cycle. Topics to be discussed include: the processes and consequences of the hydrologic cycle, run off, groundwater, geothermal energy, humidity and cloud formation, phases of water in the atmosphere, and advantages of hydroelectric energy.

Lab Activities: Students will use laboratory instruments to measure humidity and precipitation, use diagrams to explain humidity, and observe cloud formations. An outside assignment is included.

Alternative Energy Sources--Oil Shale and Tar Sands Energy Crisis: During this lecture, students will be enlightened as to the environmental problems associated with oil shale production, processing petroleum, and synthetic fuel and biomass fuel as renewable resources.

Energy Conservation as a Mechanism for Reducing Environmental Problems: Energy conservation in the transportation , residential, industrial, and electric utility sectors are discussed.

11:00 AM-12:00 PM — Estimating Energy Consumption

Location: Banneker Hall, room 211
Instructor: Dr. Sri Sritharan
Topic Overview: Students will learn how to estimate energy use in regards to lighting, heating, cooking, and traveling.

1:00 PM-2:00 PM — Economic Development and Energy Consumption in Developing Countries

Location: Jenkins Hall Auditorium
Instructor: Mr. Clark Fuller, Office of Sponsored Research and International Affairs
Topic Overview: The challenges associated with economic development and the requirement for adequate domestic and industrial energy resources are explored in Africa, Asia, and Latin America. This session is supported with audio/visual presentations.

2:00 PM-3:00 PM	Case Study: Renewable Energy Solutions, a Case Study of the Northern Senegal Water Management Project, Senegal, West Africa

Location: Jenkins Hall Auditorium
Instructors: Mr. Gorgui Ndao/Mr. Hakim Evans
Office of Sponsored Research and International Affairs
Topic Overview: The Northern Senegal Water Management Project is an economic development and technology transfer program managed by Central State University in West Africa since 1990. This case study examines the project's impact on health, agriculture, and environment for Northern Senegal. This session is supported with audio/visual presentations.

3:00 PM-3:15 PM	Travel to renewable energy test site, CSU campus.
3:15 PM-5:00 PM	Hybrid wind/photovoltaic facility, demonstration and testing.

Location: Energy test site adjacent to CSU power plant.
Instructors: Mr. Clark Fuller, Mr. Gorgui Ndao, Dr. Samuel Okunade, Mr. Hakim Evans
Topic Overview: A combination of wind and photovoltaic water pumping mechanisms have been constructed at a field facility to demonstrate the applicability of mechanical and electrical devices for water resource needs in developing countries. The devices operate solely on renewable energy, and students will participate in hands-on demonstration and testing tasks.

5:00 PM-6:00 PM	Dinner, Mercer Cafeteria
6:00 PM-8:30 PM	Skating; recreational activity coordinated with Upward Bound Program.

Friday, July 17, 1998

8:00 AM-9:30 AM	Tour of Wilberforce University Campus
9:30 AM-10:30 AM	Applications of Renewable Energy Technologies Location: King, room 211 Instructor: Dr. Eric Lang, Why Not Corporation Topic Overview: An introduction into the practical aspects of the installation of renewable energy systems, specifically photovoltaic arrays and wind turbines.
10:30 AM-12:00 PM	Experiments in Solar Energy Location: King, room 103 Instructor: Dr. David Griffith, Dr. Tufeh Habash Topic Overview: Students will work in groups to prepare solar cells from silicone slabs. They will learn how to connect solar cells for the desired current and voltage.
12:00 PM-1:00 PM	LUNCH, Wilberforce University
1:15 PM-1:30 PM	Travel to Glen Helen Ecology Institute, Yellow Springs, OH
1:30 PM-4:00 PM	Location: Glen Helen Ecology Institute Instructor: Mr. Rick Flood Topic Overview: Students will be given a tour of the Glen Helen facility. A photovoltaic system partially powers the Trailside Museum at the Glen. Various topics concerning nature and energy conservation at the Glen will be explored.
4:30 PM-5:30 PM	Dinner and recognition ceremony and program wrap up. Parents are cordially invited.
5:30 PM-6:00 PM	Departure from the dormitories.