REAP

Renewable Energy Academic Partnerships

August 8, 2005

REAP Student Summer Research Program Review Meeting

Vail, Colorado

NREL/BK-520-38594

Minority University Research Associates 2005

National Renewable Energy Laboratory
Golden, Colorado

2005 NREL-MURA Summer Research Associates

Bryan Taliaferro, North Carolina A&T State University
Dawit Jowhar, Fisk University
Juana Amieva, University of Texas at Brownsville
Clarisse Steans, North Carolina Central University
Luis Romo, University of Texas at El Paso
Jamal Thompson, Howard University

Conference and Review Meeting Description

Program Overview

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

Because of this program's successes, the program has been expanded to include additional minority-serving colleges and universities and all solar energy technologies. Each university will conduct research in 1-3 areas: Basic Research, Photovoltaic Panel Measurement and Testing, and Solar Radiation Profile Study. This expansion will include Tribal Colleges-Universities, Hispanic, Alaska Native, and Hawaiian Native serving college and university students to be included along with the Historically Black Colleges and Universities. Expansion to other solar energy technologies such as wind, bioenergy, and geothermal, will provide additional solar energy project opportunities and internships. Students involved in research excel in the classroom learning experience and are committed to contribute to the development of renewable energy technologies in order to create a sustainable environment.

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

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

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

The DOE/NREL Renewable Energy Academic Partnership (REAP) Conference and Review Meeting, which was established to review progress of the DOE/NREL/MURA-funded research projects at the eight universities, was hosted by the Florida Solar Energy Center (FSEC), Cocoa, Florida, in August 2004. The annual meeting for 2005 was cancelled due to funding constraints.

This year, the REAP Student Summer Research Program Review Meeting (REAP-SSRM) marks the first student organized and operated meeting. Held as part of the 15^{th} Workshop on Crystalline Solar Cells and Modules in Vail, Colorado, the REAP Student Summer Research Research Program Review Meeting presents students with a unique opportunity to be involved in the organization and management of a conference. Additionally, this meeting will provide students the opportunity to network and be mentored by professional scientists and engineers, which would not generally be afforded to them.

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

Fifteenth Annual Workshop on Crystalline Silicon Solar Cells & Modules: Materials and Processes of the DOE-NREL
August 7-10, 2005

Vail Cascade Resort & Spa
Vail, Colorado

Monday, August 8, 2005

1:00–1:15 p.m. *Welcome*- **Fannie Posey-Eddy and Syl Morgan Smith**

1:15-5:15p.m. ***Technical Presentations***
***Moderators*: Bryan Taliaferro,** North Carolina A&T State University
Dawit Jowhar, Fisk University

1:15-1:30 p.m. ***Fabrication and Characterization of ZnO Nanostructure for Innovative Nano-PV Cells***
Dionicia O'Berry, Fisk University

1:30–1:45 p.m. ***Optical and Electrical Characterization of CdSe-nanocrystal/MEH-PPV Composite on ZnO Electrode for Solution-processible Solar Cells***
Roberto S. Aga, Fisk University

1:45-2:00 p.m. ***Fabrication of Ordered Gold Nanoparticle Arrays for Metal Oxide Nanowire Growth***
Tam'ra Kay Francis, Fisk University

2:00-2:15 p.m. ***Fabrication, Characterization, and Simulation of Solar Cells***
Dr. Gregory Lush, University of Texas at El Paso

2:15-2:30 p.m. ***Design and Construction of a Solar Energy Charging Station at Central State University***
Clark Fuller and Carl Eloi, Central State University

2:30-2:45 p.m.	***Current Status of the Tonatiuh Software Development Project*** Juana Amieva, University of Texas at Brownsville (MURA)
2:45-3:00 p.m.	***Optical Processing Furnace Software Improvement*** Luis Romo, University of Texas at El Paso (MURA)
3:00-3:20 p.m.	***……. Break …….***
3:20-3:35 p.m.	***Characterization of Thin Films On Absorbing Substrates*** Juana Amieva, University of Texas at Brownsville (MURA)
3:35-3:50 p.m.	***Iron Detection Using SPV and QSSPCD Spectroscopy*** Dawit Jowhar, Fisk University (MURA)
3:50-4:05 p.m.	***Cost Analysis of a Concentrator Photovoltaic Hydrogen Production System*** Jamal Thompson, Howard University (MURA)
4:05–4:20 p.m.	***Wafer Bonding and Related Processing Issues for the Inverted Mismatched Solar Cell*** Clarisse Steans, North Carolina Central University (MURA)
4:20–4:35 p.m.	***Solar Thermal Concentration Verification for Concentrator Photovoltaic Electrolysis*** Jamal Thompson, Howard University (MURA)
4:35-4:50 p.m.	***Polishing Single and Multi-Crystalline Silicon for Defect Etching*** Bryan Taliaferro, North Carolina A&T State University (MURA)
4:50-5:10 p.m.	***……. Break …….***
5:10-5:40 p.m.	***Special Presentation*** MURA- Juana Amieva, Dawit Jowhar, Luis Romo, Clarisse Steans, Bryan Taliaferro, Jamal Thompson

Design and Construction of a Solar Energy Charging Station at Central State University

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Abstract

Undergraduate renewable energy research at Central State University (CSU) focuses on two themes: (1) economic development challenges in developing countries, and (2) renewable energy technology applications for the transportation industry. One student research associate project involves the design and construction of a solar energy charging station on CSU's campus. While still in progress, the project attempts to incorporate components of both themes. And although the research topic is primarily related to renewable energy in transportation, aspects of the project directly relate to energy projects that CSU directs in some locations in West Africa.

The solar charging station project involves designing, assembling, and constructing a battery-centric, solar energy charging station to be mounted on a solar tracker rail and pole assembly on campus. The objective is to provide student research associates with a problem-solving challenge, while providing the university with an alternative energy charging source for the eight to ten electrical logistics support vehicles (ELSVs) used by CSU's maintenance and facilities division. In the design process, the electrical energy generated by the solar charging station will be stored in six deep-cycle battery banks, and used when needed. The goal of the 72 volt-series or 12 volt-parallel solar charging system is to charge the ELSVs as needed and as dictated by varying voltage needs. Because a solar charging station has multiple applications, the principle is being examined by research associates for applicability to conventional electricity needs in rural areas of West Africa.

Fisk University

Fabrication of Ordered Gold Nanoparticle Arrays for Metal Oxide Nanowire Growth

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Abstract

To develop high-efficiency third-generation solar cells, an innovative nanocomposite structure using metal oxide nanowires as an effective electron-conducting electrode has been proposed. Achieving the device's optimal energy conversion efficiency, it is important to understand how the photo-generated charge carriers are separated and transported. Therefore, there is the need to fabricate spatially ordered nanowires on a chosen substrate. By controlling the wire diameter, length, and spatial density, it is possible to find sets of fabrication parameters for device optimization. Nanosphere lithography is an inexpensive and scalable technique that allows us to fabricate spatially ordered nanoparticle catalyst on substrate surface. In this poster presentation, we will provide examples of highly ordered Au nanoparticles fabricated on substrates, along with the related experimental approaches to modify substrate wettability, such as silica sol nanocoating.

Optical and Electrical Characterization of CdSe-Nanocrystal/MEH-PPV Composite on ZnO Electrode for Solution-Processible Solar Cells

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Abstract

Solution-processed hybrid solar cells may provide an inexpensive technology with high photovoltaic efficiency. A crucial component in this type of device is the active layer composed of an interpenetrating network of electron-donor and electron-acceptor materials. In this work, we study a CdSe-nanocrystal/MEH-PPV composite as a possible active layer for a ZnO electrode. Our samples were prepared using composite solutions with different concentrations of the polymer and CdSe. Solution was spin coated on glass substrate and ZnO electrodes to create a uniform film. Results from optical absorption and photoconductivity measurements of our samples will be presented.

Fabrication and Characterization of ZnO Nanostructure for Innovative Nano-PV Cells

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Abstract

One of the most critical issues related to quantum dot – organic nanocomposite solar cell is charge separation and transport. The innovative approach has been sought to use metal oxide (*i.e.*, ZnO, SnO_2, and TiO_2) nanostructure as the quantum dot supporting matrix for effective charge separation and electron conducting network. A series of experiments has been conducted under various conditions to grow ZnO nanowire-based 3D networks with the physical vapor transport technique. In our poster presentation, we will present our most recently obtained results, along with discussion related to the growth mechanisms.

University of Texas at Brownsville

Current Status of the Tonatiuh Software Development Project

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Abstract

As a consequence of the oil crisis of the mid-1970s, important resources were committed in the United States, Germany, Spain, and other countries to develop computer programs that simulate the optical behavior of solar concentrating systems.

Those computer programs provided much aid in the design and evaluation of the first generation of solar thermal power plants. Because relatively little effort has been devoted to update those programs, most have become obsolete and are no longer suited to address the challenges faced by the designers of modern solar concentrating systems.

The Tonatiuh project, that is under way at the University of Texas at Brownsville under the DOE-NREL Minority University Research Associate (MURA) Program Subcontract, intends to contribute to the increase of the cost-effectiveness of solar energy technologies by advancing the state-of-the-art of the simulation tools available for the design and analysis of solar concentrating systems.

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

This paper presents an overview of the Tonatiuh Software Development Project, emphasizing the current status of the project.

Fabrication, Characterization, and Simulation of Solar Cells

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Abstract

UTEP is working on the fabrication, characterization, and simulation of solar cells. For fabrication, this project is investigating an ordered nanofabrication technique to overcome problems inherent with random polycrystalline thin films. This technique could advance the state-of-the-art in conversion efficiencies of CdS/CdTe solar cells.

For characterization, we are applying unique techniques to study the spatial non-uniformities of CdTe material quality and device performance. Previous studies of CdTe/CdS solar cells found that it is the weakest region of the solar cell that may determine the overall performance of a thin-film cell. We are observing the electroluminescence of CdTe-based solar cells using a CCD camera and a thermal imaging system.

For simulation, we are developing an intelligent interface to a device simulator that allows one to ask more complex questions such as what is the best efficiency. Genetic algorithms are used to provide the "intelligence," and a sophisticated modeler will simulate the solar cells.

Polishing Single and Multi-Crystalline Silicon Wafers for Defect Etching

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Bhushan Supori
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Abstract

A good delineation of defects by chemical etching requires a well-polished surface produced by “damage-free” polishing. Damage-free polishing is a chemical-mechanical procedure, which works well for a single-crystal wafer. However, a multicrystalline-Si wafer has a grain-to-grain polishing rate variation, which cause variations in the surface profile of the polished wafer. A common variation noticed among certain multicrystalline wafers is the formation of small hills known as hillocks. These hillocks can be found within the polished regions of the multicrystalline wafers known as the grain boundaries that separate different areas. Without the help of telescopic imagery, these hillocks look merely like rough spots between the boundaries and apparently form during the polishing process. Through experimental procedures, different scenarios are tested to predict how exactly hillocks are formed and what similarities can be concluded from the data collected.

Wafer Bonding and Related Processing Issues for the Inverted Mismatched Solar Cell

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Abstract

The inverted, lattice-mismatched solar cell has great potential to emerge as an efficient and affordable technology for concentrator systems. Though this development has already set world efficiency records, it is relatively new and could use some fine-tuning. It is my goal to examine the flaws that currently exist in the processing methods, identify the nature of these flaws, and develop better methods that will aid in the performance of this cell. The primary issue right now with the processing of the inverted mismatched cell is the bonding of the handle-wafer. When I initially began this project, a liquid silver epoxy was being used to bond the materials. There is simply no way to consistently replicate this process. Each application yields a different thickness or smoothness. Additionally, the liquid epoxy generates air bubbles, which cause problems when the cell is placed under concentration. These air bubbles become hot spots, particularly under the metal grid lines, causing the cell to short out. My solutions involve finding ways to duplicate the application of the epoxy, as well as alternative methods such as using conductive film or solder foil. Because there are several aspects of processing, flaws may exist in some or all of these aspects. Therefore, solutions for identified problems may involve a single change in a procedure or a combination of changes.

Iron Detection using PCD Measurements through Minority Carrier Lifetime

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Chuan Li and Bhushan Sopori
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Abstract

Iron is an important impurity in the silicon industry. Its concentration affects the quality of the wafer. Interstitial iron (Fe_i) forms iron-boron (Fe-B) pairs with substitutional boron in *p*-type silicon at room temperature. By thermal or optical dissociation, Fe-B pairs can be dissolved and the presence of interstitial iron will reduce carrier lifetime. The lifetime is measured using the Quasi Steady State Photo Conductance Decay (QSSPCD) spectroscopy. The instrumentation allows lifetime measurements under different injection levels. The wafers are chemically passivated using a known concentration of iodine and ethanol before undergoing the lifetime measurements. One of the wafers is also doped with iron to detect the changes in the lifetime and also the concentration of iron. Through the diffusion lifetime measurements, iron concentration can be extracted before and after pair dissociation.

Cost Analysis of a Concentrator Photovoltaic Hydrogen Production System

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Abstract

The development of efficient, renewable methods of producing hydrogen are essential for the success of the hydrogen economy. Because the feedstock for electrolysis is water, there are no harmful pollutants emitted during the use of the fuel. Furthermore, it has become evident that concentrator photovoltaic (CPV) systems have a number of unique attributes that could shortcut the development process, and increase the efficiency of hydrogen production to a point where economics will then drive the commercial development to mass scale.

Concentrating solar energy to produce electricity can occur at quite high solar conversion efficiencies. The highest efficiency for solar concentrator cells, as measured at NREL, is now above 37%. Solar Systems P/L of Australia has exhibited a 40% boost in hydrogen production by separating the solar infrared radiation incident on concentrator solar cells and using it as the heat source for a solid-oxide electrolyzer cell operating above 1000º C. With today's solar cell technologies, it is therefore possible to achieve a 50% conversion efficiency of the solar energy to hydrogen through high-temperature electrolysis.

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

Solar Thermal Concentration Verification for Concentrator Photovoltaic Electrolysis

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Abstract

Hydrogen production by concentrator photovoltaic (CPV) electrolysis is an energy-intensive process. Solar concentrators naturally produce large amounts of heat that, if not rejected, can lead to degradation of the performance of the solar cell. CPV electrolysis presents a unique solution to this heat rejection by using the heat in a high-temperature solid-oxide electrolyzer cell (SOEC) to reduce the amount of electricity required to electrolyze water. This heat rejection is accomplished through spectral splitting of infrared energy from visible light. The results of using this heat are a more efficient and more productive electrolysis process.

The CPV electrolysis system, designed and patented by Solar Systems P/L (Australia), operates on the assumption that the infrared energy collected by the sun is capable of producing the heat necessary (1000°C) for the electrolysis process from a concentration of 300 suns. The tests discussed in this paper will prove that this energy is attainable from the concentration process. For this test, NREL's High-Flux Solar Furnace is used to generate the 300-sun (300 kW/m^2) flux. Metal plates are then placed at the focal point and used to measure this flux. These plates are modeled as grey bodies, and the analytical and theoretical results are compared to show that the 300-sun concentration is capable of producing the required heat. Results from this test will aid in the design of a concentrator test platform that would be used to determine the best type of optical filter to use for the spectral splitting required by the CPV electrolysis system.

Optical Processing Furnace Software Improvement and Surface Photovoltage Furnace Program

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Abstract

The National Renewable Energy Laboratory (NREL) has several optical processing furnaces (OPF) that use rapid thermal processing (RTP) technology for different solar cell manufacture processes. During RTP of semiconductor wafers, it is fundamental that the wafer temperature closely follows a pre-specified temperature trajectory and that the temperature profile across the wafer is almost uniform whenever the wafer is at high temperatures. These furnaces are controlled with computer software, where the temperature profile is input and shown in a temperature-time graph. The first part of the report presents the innovation made to OPF software, which consists in a graphical representation of temperature distribution along the wafer surface at all times, allowing the user to monitor the temperature profile through the RTP.

The second part of the report presents the surface photovoltage (SPV) furnace software, which calculates the minority-carrier diffusion length and the diffusion coefficient of a given wafer using the SPV measurements. SPV furnace performance consists in illuminating the wafer surface with monochromatic radiation with different wavelengths, creating electron-hole pairs that diffuse into the wafer surface, where they are separated by the electric field of the depletion region to produce surface photovoltage. Using feedback from the detector of the light source, reference voltages are obtained and input into equations that determine the diffusion length and diffusion coefficient, which is equal to the rate of diffusion.

Characterization of Thin Films on Absorbing Substrates

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Abstract

Thin films are used in many applications such as reflection/antireflection, material strengthening, and protection, as well for active devices, including those in solar cell fabrication. There are many techniques used in the industry and in research laboratories to characterize such films. Most of these apply only to nonabsorbent thin films with planar interfaces. Some ellipsometeric techniques can measure n, the refractive index, and k, the extinction coefficient, of weakly absorbing films. However, the currently developed techniques are difficult to implement to characterize the films used for photovoltaic applications. Such films include absorbing semiconductor films, absorbing films on metallic substrates and multilayer films. Furthermore, these composite films have rough or textured surfaces to promote optimal light-trapping. A suitable technique must be rapid, low cost, capable of measuring very large areas, and easy to use. In addition, it must be capable of measuring a number of thin-film parameters such as thickness and interface quality.

The applications of the GT-FabScan 6000 reflectometer, developed at NREL, are expanding to accomplish such measurements. The reflectometer uses spectroscopy and directional illumination to offer these necessary and useful features. This paper presents a preliminary study to show the basic principles of such measurements.

Acknowledgements

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

The 2005 MURA Summer Students would like to thank the mentors, *Larry Kazmerski*, *Bob McConnell, Martha Symko-Davies, Bhushan Sopori, Dan Friedman, and Helio Moutinho,* for working diligently with each of the summer students and for their continued support of the MURA Program.

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

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

This year's meeting would not have been possible without the assistance of the coordinators of the 15th Workshop on Crystalline Silicon Cells and Modules. Therefore, we would like to thank Bhushan Sopori and Sandy Padilla for supporting us in integrating our meeting into their workshop.

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

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
August 2005	Conference Proceedings	August 8, 2005

4. TITLE AND SUBTITLE
Renewable Energy Academic Partnerships (REAP) Student Summer Research Program Review Meeting, August 8, 2005 (Program and Abstracts)

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

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
F. Posey-Eddy

5d. PROJECT NUMBER
NREL/BK-520-38594

5e. TASK NUMBER
PVP42401

5f. WORK UNIT NUMBER

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

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/BK-520-38594

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

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

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

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

13. SUPPLEMENTARY NOTES

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

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

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