UCEP

University Center of Excellence in Photovoltaics Research and Education

Georgia Institute of Technology
School of Electrical and Computer Engineering

Creating a New Energy Source

Dominant conventional energy sources-oil, coal, natural gas, and nuclear power-are accompanied by problems of air and water pollution, resource depletion, and the greenhouse effect, all of which are becoming increasingly unacceptable and unaffordable. In the 21st century, photovoltaics (PV)-direct conversion of sunlight into electricity-can potentially meet the rapidly growing demand for electricity with minimal environmental consequence. The real challenge lies in reducing the cost of solar cells while raising their efficiencies. Research and education on advanced PV materials and devices will play a major role in accelerating the development of cost-effective PV.

To address these issues, the Department of Energy established a University Center of Excellence for Photovoltaics Research and Education (UCEP) at the Georgia Institute of Technology, one of two such centers in the United States. The Center under the direction of Dr. Ajeet Rohatgi, reports to the Dean of Engineering at Georgia Tech.

Mission

- To improve the science and technology of advanced photovoltaic (PV) devices
- To reduce the cost of PV generated electricity
- To design and fabricate record high efficiency solar cells
- To develop low-cost materials and rapid thermal processes for next generation silicon solar cells
- To provide training and enrich the educational experience of students
- To maintain a leadership position and give the United States a competitive edge in PV through high quality research and education

Educational Accomplishments

- Teach two courses on solar cells each year
- Provide hands-on training to students in the area of modeling and fabrication of solar cells
- 20 Ph.D students graduated and 10 current Ph.D. students
- Train undergraduate students, including students from historically black colleges/universities
- Participate in graduate student exchange program with ISFH and Fraunhofer Institute
- Published 156 refereed journal papers, 137 refereed proceeding papers, and presented 65 invited presentations
- Awarded 10 United States patents
- Received Georgia Tech's best Thesis Award on the thesis pertaining to "Rapid Thermal Processing (RTP) of Silicon Solar Cells"
- Received SIAC Best Paper Award on the research on "Fundamental Understanding and Development of Screen Printed RTP Al BSF"
- Received Best Poster Paper Award – 1995 Nice, France, EUPVSC
- Received Best Poster Paper Award – 2000 New Orleans, LA, PVSC
- Received Best Special Paper Award – 1999 Japan, PVSEC

Research Accomplishments

- Design, install, maintain and monitor 342 kW rooftop grid-connected PV system on the Georgia Tech Aquatic Center roof, which has produced more than one *billion* watt hours of electrical energy
- Pioneered the field of RTP which reduces the cell processing time from 16 hours to 2 hours

DEVELOPED

- novel "STAR" technology for simultaneous front and back diffusion and oxidation in a single furnace step
- novel high throughput phosphoric acid spray technology for forming n^+-p junctions for silicon solar cells
- novel and very effective RTO/SiN stack for passivating silicon surfaces which reduces the surface recombination velocity to less than 20 cm/s, and can also withstand screen printing firing
- rapid Al BSF which reduces back surface recombination velocity to 200 cm/s on 2 ohm-cm cells
- screen printing process that can produce very high fill factors of 0.795 on monocrystalline silicon
- SP process to achieve 0.76-0.77 FF on multicrystalline silicon cells
- and optimized manufacturable gettering and passivation techniques, including Al-enhanced hydrogen passivation, to achieve >25 μs lifetime in most commercial substrates

FABRICATION (percent efficiency)

- (22%) 4 cm^2 FZ cells by inverted pyramids and CFP/PL
- (20%) 4 cm^2 FZ cells and (18.5%) CZ planar cells by CFP/PL
- (18.1%) 42 cm^2 planar CFP/PL CZ cells
- (18.6%) planar multicrystalline CFP/PL silicon solar cell*
- (16%) EFG sheet silicon CFP/PL cell*
- (16.2) 4 cm^2 string ribbon CFP/PL cell*
- (20%) efficient FZ and (19.1%) CZ "STAR" cell

*** Record High Efficiency**

Research Accomplishments
Fabrication (cont.)

FABRICATION (percent efficiency)

- (19.3%) rapidly processed RTP/PL FZ silicon cells, and (18.5%-19%) CZ and MCZ cells*
- (17.3%) 4cm² dendritic web RTP/PL cell*
- (17.6%) 4cm² low-cost screen printed planar silicon solar cells*
- (11-13%) screen printed bifacial cells with rear illumination efficiency*
- (17%) 4cm² monocrystalline silicon cells by a low-cost manufacturable process using screen printing, beltline diffusion and PECVD SiN
- (14.9%) 4 cm² belt-line screen printed manufacturable cell on string ribbon silicon
- (14.3%) 4 cm² manufacturable n-type phostop, and (14.2%) p-type BLP/PECVD/SP cells on dendritic web silicon
- (15.1%) 100 cm² belt-line/RTP/SP cell on EFG silicon
- (15.9%) screen printed cell on silicon ribbon*
- (15.3%) screen printed solar cells with porous silicon antireflection coating*
- (16.4%) 4 cm² SBLC on string ribbon*
- (15.9%) 4 cm² screen printed on EFG silicon ribbon*
- (15%) 49 cm² screen printed cell on string ribbon silicon*
- (15.9%) 4 cm² screen printed on HEM multicrystalline silicon (flat + single layer AR)*

*** Record High Efficiency**

Fabrication Capabilities

- Class 100 Clean Room and Cleaning Hoods
- Phosphorus Diffusion Furnaces (P_20_5 and POCI)
- Boron Diffusion Furnace (BBr_3)
- Al Drive-in Furnaces
- Oxidation Furnaces
- Forming Gas Annealing Furnaces
- RTC Belt Furnace with Tungsten-Halogen Lamps
- Custom made RTC Belt Furnace with UV and Tungsten Halogen Lamps
- Belt Dryer
- Plasma Enhanced Chemical Vapor Deposition of SiN and SiO Films
- Rapid Thermal Annealer (RTA) (3)
- Metal Evaporators (Ti, Pd, Ag, Au, Al)
- Dielectric Evaporators for AR Coatings
- Silver Plating
- Photolithography (Spinners, Ovens, Mask Aligners for UV Exposure)
- Surface Texturing
- Wafer Thinning
- Lapping and Polishing
- Reactive Ion Etcher
- Screen Printer (Ag, Al, P) (3)
- Dicing Saw
- Sandblaster

Materials and Device Characterization Facilties

EQUIPMENT	FUNCTION
Automated Dark & Light I-V	For determining solar cell parameters, cell efficiency
Spectral Response	For determining quantum efficiency a function of wavelength
Reflectivity Measurement	For determining reflectance as a function of wavelength
Spectroscopic Ellipsometer	For index, thickness and absorption in dielectric films for AR coatings
PCD and OCVD Lifetime	For determining the minority carrier lifetime J_{01}, J_{02}, and R_{sh}
DLTS	For detecting deep energy levels due to impurities and defects.
LBIC	To map defects and diffusion length in semiconductor materials and devices
EBIC	For determining electrical activity of defects
FTIR	For epitaxial thickness, detection of impurities such as O, C, B, Al and H in Si and Si_xN_y
SIMS	For doping and impurity profiles
Electrochemical Doping Profiler	For doping concentration profile
Hall Measurements	For carrier mobility, dopant concentration and energy levels, and conductivity type
Photoluminescence	For shallow levels, bandgap, and stress, and optical properties
TEM, SEM, X-ray Topography	For defect and microstructural evaluation
Auger and ESCA	For chemical analysis
C-V, C-t	For interface state density, insulator charges and generation lifetime in MOS capacitors
Four Point Probe	For measuring conductivity type, resistivity, and sheet residence
Curve Tracer	For analyzing IV characteristics of Silicon devices
I-V-T Tester	For determining carrier transport mechanism defect centers responsible for leakage current.
Positron Annihilation (PAS)	Defects in Semiconductors

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Modelling and Analysis Capabilities

MODELS	ANALYSIS
PC1D	Program to solve semiconductor transport equations and model solar cell performance
Dessis	Two and three dimensional modeling of semiconductor devices
PV Optics	Ray tracing programs to model light trapping on textured surfaces
Arcoat	Anti-reflectance coating design and characterization
S-model	Computes internal recombination velocity in any region of a cell
Hydro	Multidimensional solutions to the semiconductor equations
Tau Model	Calculates SRH and lifetime in bulk silicon
Grid Model	Design and optimization of front contact for rectangular geometry with a tapered bus bar
SRV	Computers effective surface recombination velocity for varying passivation conditions
IQE	Computation and analysis of internal quantum efficiency from spectral response and reflection measurements
J_0	Computes reverse saturation current from data obtained from photo-conductive decay measurements
PCD	Computes SRH lifetime, ambipolar Auger coefficient, and band-to-band radiative coefficient from PCD measurements
Sizing	Design and modeling of PV system
PV Form	Design and performance of PV systems
PC Cad	Design and performance of PV systems
Size PV	Design of PV systems
PV Design Pro	Design and modeling of PV systems

External Collaboration

US UNIVERSITIES

Arizona State University
Clarkston University
Clemson University
Indiana University of Pennsylvania
New Mexico State University
North Carolina State University
Purdue University
Texas Tech
University of South Florida

US NATIONAL LABS

NASA
NREL
Sandia National Labs
Oakridge National Labs

SOLAR INDUSTRY

ASE America
Advanced Energy Systems
AstroPower
Bayer
BP Solar
Crystal System
Dupont
Ebara Solar
Evergreen Solar
Eurosolare
Ferro Corporation
GT Solar Inc.
Iset
MEMC Inc.
MV Systems
Shi-Etsu Handotai
Siemens Solar
Solar Cell Inc.
Solarex Corporation
Spire Corporation

INTERNATIONAL

ECN, Netherlands
Fraunhofer Institute, Germany
IMEC, Belgium
NPL, India
RESPV, India
University of Konstanz, Germany
UNSW, Australia
ISFH, Germany
Euro Solare
ENEA, Italy

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