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
• 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
• 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 cm² FZ cells by inverted pyramids and CFP/PL
• (20%) 4 cm² FZ cells and (18.5%) CZ planar cells by CFP/PL
• (18.1%) 42 cm² planar CFP/PL CZ cells
• (18.6%) planar multicrystalline CFP/PL silicon solar cell*
• (16%) EFG sheet silicon CFP/PL cell*
• (16.2) 4 cm² string ribbon CFP/PL cell*
• (20%) efficient FZ and (19.1%) CZ “STAR” cell

* Record High Efficiency
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 ($P_2O_5$ 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
<table>
<thead>
<tr>
<th><strong>EQUIPMENT</strong></th>
<th><strong>FUNCTION</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated Dark &amp; Light I-V</td>
<td>For determining solar cell parameters, cell efficiency</td>
</tr>
<tr>
<td>Spectral Response</td>
<td>For determining quantum efficiency a function of wavelength</td>
</tr>
<tr>
<td>Reflectivity Measurement</td>
<td>For determining reflectance as a function of wavelength</td>
</tr>
<tr>
<td>Spectroscopic Ellipsometer</td>
<td>For index, thickness and absorption in dielectric films for AR coatings</td>
</tr>
<tr>
<td>PCD and OCVD Lifetime</td>
<td>For determining the minority carrier lifetime $J_{01}, J_{02}$, and $R_{sh}$</td>
</tr>
<tr>
<td>DLTS</td>
<td>For detecting deep energy levels due to impurities and defects.</td>
</tr>
<tr>
<td>LBIC</td>
<td>To map defects and diffusion length in semiconductor materials and devices</td>
</tr>
<tr>
<td>EBIC</td>
<td>For determining electrical activity of defects</td>
</tr>
<tr>
<td>FTIR</td>
<td>For epitaxial thickness, detection of impurities such as O, C, B, Al and H in Si and SixNy</td>
</tr>
<tr>
<td>SIMS</td>
<td>For doping and impurity profiles</td>
</tr>
<tr>
<td>Electrochemical Doping Profiler</td>
<td>For doping concentration profile</td>
</tr>
<tr>
<td>Hall Measurements</td>
<td>For carrier mobility, dopant concentration and energy levels, and conductivity type</td>
</tr>
<tr>
<td>Photoluminescence</td>
<td>For shallow levels, bandgap, and stress, and optical properties</td>
</tr>
<tr>
<td>TEM, SEM, X-ray Topography</td>
<td>For defect and microstructural evaluation</td>
</tr>
<tr>
<td>Auger and ESCA</td>
<td>For chemical analysis</td>
</tr>
<tr>
<td>C-V, C-t</td>
<td>For interface state density, insulator charges and generation lifetime in MOS capacitors</td>
</tr>
<tr>
<td>Four Point Probe</td>
<td>For measuring conductivity type, resistivity, and sheet residence</td>
</tr>
<tr>
<td>Curve Tracer</td>
<td>For analyzing IV characteristics of Silicon devices</td>
</tr>
<tr>
<td>I-V-T Tester</td>
<td>For determining carrier transport mechanism defect centers responsible for leakage current.</td>
</tr>
<tr>
<td>Positron Annihilation (PAS)</td>
<td>Defects in Semiconductors</td>
</tr>
</tbody>
</table>
# Modelling and Analysis Capabilities

## Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1D</td>
<td>Program to solve semiconductor transport equations and model solar cell performance</td>
</tr>
<tr>
<td>Dessis</td>
<td>Two and three dimensional modeling of semiconductor devices</td>
</tr>
<tr>
<td>PV Optics</td>
<td>Ray tracing programs to model light trapping on textured surfaces</td>
</tr>
<tr>
<td>Arcoat</td>
<td>Anti-reflectance coating design and characterization</td>
</tr>
<tr>
<td>S-model</td>
<td>Computes internal recombination velocity in any region of a cell</td>
</tr>
<tr>
<td>Hydro</td>
<td>Multidimensional solutions to the semiconductor equations</td>
</tr>
<tr>
<td>Tau Model</td>
<td>Calculates SRH and lifetime in bulk silicon</td>
</tr>
<tr>
<td>Grid Model</td>
<td>Design and optimization of front contact for rectangular geometry with a tapered bus bar</td>
</tr>
<tr>
<td>SRV</td>
<td>Computes effective surface recombination velocity for varying passivation conditions</td>
</tr>
<tr>
<td>IQE</td>
<td>Computation and analysis of internal quantum efficiency from spectral response and reflection measurements</td>
</tr>
<tr>
<td>J₀</td>
<td>Computes reverse saturation current from data obtained from photo-conductive decay measurements</td>
</tr>
<tr>
<td>PCD</td>
<td>Computes SRH lifetime, ambipolar Auger coefficient, and band-to-band radiative coefficient from PCD measurements</td>
</tr>
<tr>
<td>Sizing</td>
<td>Design and modeling of PV system</td>
</tr>
<tr>
<td>PV Form</td>
<td>Design and performance of PV systems</td>
</tr>
<tr>
<td>PC Cad</td>
<td>Design and performance of PV systems</td>
</tr>
<tr>
<td>Size PV</td>
<td>Design of PV systems</td>
</tr>
<tr>
<td>PV Design Pro</td>
<td>Design and modeling of PV systems</td>
</tr>
</tbody>
</table>
External Collaboration

US UNIVERSITIES

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

US NATIONAL LABS

NASA  NREL  Oakridge National Labs
Sandia National Labs

SOLAR INDUSTRY

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

INTERNATIONAL

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