Si PHOTOVOLTAICS TECHNOLOGY & MANUFACTURING

The 3-day course covers silicon semiconductor photovoltaics technology and fabrication processes through the major topic areas listed below.

Day 1

1. Motivation: Global Warming, Greenhouse Effect
2. Characteristics of Solar Radiation: properties of sunlight, the energy and photon flux spectra, direct and diffuse radiation, air mass, sun-hour equivalents.
3. Semiconductor Material Properties: bandgaps, intrinsic material, doping, behavior of holes and electrons, absorption of light, generation/recombination, diffusion length, comparison of n and p-type, drift & diffusion, diode equation.
4. Solar Cell Structure: principle of cell operation, collection probability, photocurrent, surface recombination, effective carrier lifetime, lifetime measurement, separation of recombination components, quantum efficiency, inverse IQE, spectral response, photo-voltage, IV curve, Isc, Voc, FF, efficiency, components of series resistance, shunt resistance, 2-diode model, dark IV curve fitting, effect of temperature on Voc, effect of light intensity, ideality factor.
5. Measurement of Solar Cell Efficiency: Standard test conditions, illumination sources, spectral mismatch calculations, measurement electronics, Suns-V_{OC} , numerical device simulators.

Day 2

6. Design of Si Cells: optical losses, reflection, AR coatings, surface texturing, light-trapping, effect of recombination losses on current & voltage, back-surface field, calculating components of series resistance, front gridline optimization.
7. Manufacturing Si Cells: polysilicon feedstock creation process, multi vs. single crystalline Si, Cz Si growth, FZ Si growth, mc-Si growth, wafer slicing, cost components of Si wafer formation, dopant diffusion, screen-printing metals, low-cost mc-Si cell production line.
8. High Efficiency Designs: design principles, buried contact cells, PERC and PERL cells, back-junction back-contact cells, minimizing losses in IBC cells, EWT cells, HIT cells.
9. Cost-Effective Solar Cell Design: ideal cell properties, cost vs. efficiency tradeoffs, effect of cell efficiency on LCOE cost, benefits of high efficiency, module cost components, examples from my own cell research.

Day 3

10. Module Manufacture: cell testing and sorting, interconnecting and packaging, module material properties, soil repellents, module glass reflectance, module AR coatings, module backsheets and encapsulants.
11. Module Circuit Design: cell mismatch losses, shaded cells, hot-spot heating, bypass diodes, dissipated power, mismatch effects in arrays, blocking diodes.
12. Heat Generation in PV Modules: module cooling mechanisms, cell operating temperature, module temperature dependence, meteorological data and predicted energy output, trackers vs. fixed tilt, LCOE determination.

13. Module Degradation and Failure Modes: Thermal expansion mismatch, electrical insulation and PID, water vapor ingress, increases in series resistance, open circuits, short circuits, glass breakage, delamination, diode failures, system failure rate data.
14. Failure analysis: Lock-in thermography, Electroluminescence, quality control methodologies, module certification testing.

Instructor Profile

Douglas Ruby, Ph.D.

Douglas Ruby is a consultant to the Photovoltaics Industry. He initiated and successfully conducted direct industry joint experiments with most major US Si solar cell manufacturers, resulting in numerous publications and several process improvements adopted by industry into manufacturing production lines. Doug received a Bachelor of Science in Physics from MIT and an M.S. and Ph.D. in Physics from the University of Illinois.

Doug worked for Sandia National Laboratories in Albuquerque, New Mexico for over 22 years. He served as the Team Leader of PV Cell Development Team and $2M/year semiconductor fabrication facility. He directed 7 team members, authored the annual operating plan, and directed all PV cell research projects. Doug also served as the Director of the Crystalline Silicon Research Cooperative, a government/industry consortium for mutually beneficial research consisting of representatives from the entire US Si-PV manufacturing and research communities. He worked as a contract monitor and advisor for several R&D contracts at Georgia Tech and in the DOE Concentrator Initiative Program in the 1990s, and was closely involved with and provided technical feedback to manufacturers developing silicon and concentrator Photovoltaics systems.

Doug served as an area chairman of the IEEE PV Specialists Conference in Silicon Cell Processing and has authored and co-authored numerous technical papers on photovoltaic technologies. He has now been a Consultant to the Photovoltaics Industry for 5 years, and as such has helped many PV manufacturers improve the performance and reduce the cost of their PV products.