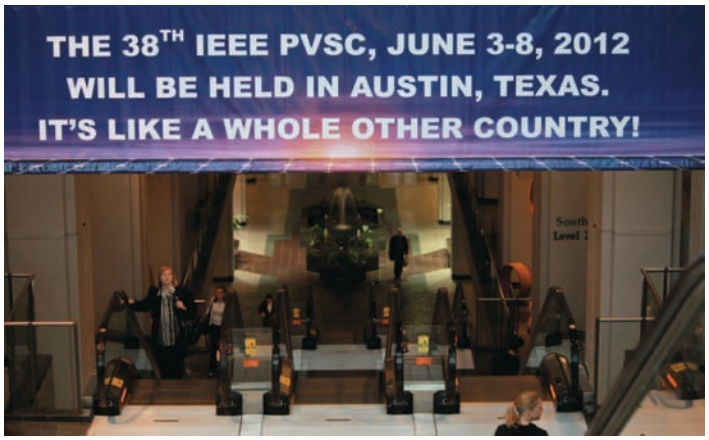
The IEEE PVSC has come to a close with another very successful conference. The week was filled with outstanding talks, excellent networking opportunities, and a great chance to see the latest in instruments and technologies at the exhibit. Congratulations to the organizers for another great PVSC. If you did not make it to this year's meeting, remember that next year the 38th IEEE PVSC will be held in Austin Texas.



Today in the **Area 1** talks, Chris Bailey from the Rochester Institute of Technology had a great presentation on InAs/GaAs quantum dot solar cells. By adding InAs quantum dots the spectral response of the cell was be extended to longer wavelengths. However, typically this also leads to a decrease in open circuit voltage due to increased dark current. Bailey's latest work, though, describes the use of reduced InAs coverage, which resulted in a 0.5% absolute improvement in efficiency using 40x dot layers over their baseline p-i-n GaAs cell.

Evidence for two photon absorption in QD solar cells was described based on photocurrent evidence from Shoji (U. Tokyo) and Fourier transform infrared (FTIR) measurements of absorption by Ban (ASU). Effective nanowire passivation using a-Si was also demonstrated by Dan (Harvard).

Goldschmidt showed how a resonant effect using white light can provide up-conversion above expectation from measurements using monochromatic excitation. An enhancement factor of three is predicted based on electromagnetic modeling of near field effects. Overall, significant advances toward practical applications were demonstrated.

In **Area 2**, Hironori Katagiri presented a talk on the development of rare-metal-free CZTS solar cells. Best performances were with a Zn/Sn ratio near 1.2 and Cu/(Zn+Sn) in the range 0.85-0.9. There was some sulfurization of the Mo back contact. The initial films were produced by sputtering from a single target with post-deposition sulfurization. As sputtered films have a very strong preferred orientation but do not produce active devices as deposited so the anneal is necessary.

Qijie Guo (Purdue) presented a talk on device production from solution-based nanocrystal inks. The nanocrystals, dispersed in alkanethiol, were printed using a doctor blade. Performances were discussed for a variety of process conditions. The process was robust with a 7.2% efficient device achieved.

Tokio Nakada (Aoyama Gakuin University) described three-stage-evaporation-deposited CIGS films and studied the effect of Sb incorporation in the films. With a 30 nm thick Sb layer on the substrate the grain size was significantly enhanced and the resistivity decreased. Cell performances were in the range of 15-16% with improvements noted in V_{oc}

and J_{sc} for a 10 nm thick Sb deposition on the Mo back contact. Decreases in performance were noted for thicker Sb layers. A similar study with Bi on the Mo showed some diffusion of the Bi into the CIGS and reduction of Na incorporation into the CIGS. In general Bi did not improve device performance except in the absence of Na, where benefits were modest. There were benefits to Bi addition when no Na barrier layer was used on the substrate. Benefits of addition of Sb and Bi are larger when low deposition temperatures were used.

Tokio Nakada gives his talk in Area 2

Angel Aquino (Illinois) described PL results on (Cu,Ag)$InSe_2$. Defect states were identified as a function of alloy composition that showed consistent behavior for a wide range of compositions. It was proposed that there was a "sweet spot" for Ag content. For Ag contents between 20 and 60% Ag on the group I site where the energy gap was modified but where there was not a large tail of defect states such as was observed for pure $AgInSe_2$.

Jonathan Major (Liverpool) presented results on novel CdTe device processing. The process yields Cd rich surfaces and blocks Cl diffusion into the material. This resulted in a 5x increase in doping. In the best cells, the devices were limited by the series resistance in the TCO.

After a break, Lorelle Mansfield described the use of Mo:Na as a substrate material as compared to standard methods such as Na supply from the soda-lime glass substrates and NaF precursor depositions. The results showed that the Mo:Na back contact yielded better performance issues. Some adhesion issues were observed. A brief selenization step for the MoNa before deposition of the CIGS improved adhesion. Better adhesion was obtained when a simple Mo layer was deposited on the Mo:Na layer.

Negar Neghavi (CNRS) presented results on ultrathin CIGS solar cells with absorber thicknesses between 0.5 and 0.25 microns. Performances were maintained down to 0.5 microns. The primary focus was on optical techniques to maintain current as thickness is lowered. Thin cells were produced by finishing the device as a standard substrate configuration and then removal of the device from the Mo back contact by adhesion on a new superstrate and peel-off of the device. A new back contact based on Au was applied to

Negar Neghavi describing her work on thin CIGS solar cells.

improve the back surface reflection and improve the ohmic contact resistance.

John Perkins of NREL reported on the use of InZnO (IZO) for the transparent-conductor contact. This material has been shown to be highly conductive, transparent, smooth, and easy to deposit. Equally important, the a-IZO is extremely robust in the presence of water. Ian Carbone from UC Santa Cruz discussed the use of organic down-conversion films to improve the short wavelength response of CdTe cells. The films used were supplied by Nitto Denko, and the most effective film used was extremely stable (over 7000 hours) and improved the relative CdTe efficiency by 8.5%. Noriyuki Sakai from Solar Frontier reported of the use of Zn-based buffer layers for CZTS cells, and made direct comparisons with Cd-based cells. Best cells to date with the Zn-based buffer have shown an efficiency of 5.8%.

Richard King (Operations Chair) and Angele Reinders (Area 9 Chair)

For **Area 3**, Geoffrey Kinsey of Amonix described their work to install 0.5 MW/day of devices. A 20 percent variation in energy output between cell vendors was a challenge. Designs for most desert locations are essentially the same, which makes these exceptionally easy locations for standard engineering of devices. 29% efficient modules have been demonstrated in the field. CPV and tracked PV generated essentially the same energy output for each year. This was stated to be better than fixed plate devices. Higher concentration and temperature favors CPV over other options. It was found that there was a five to seven percent difference between clean and dirty panels. 70% failures occured in trackers. ISFOC is working on tracker standards. Wiring and switch gear failures are second to tracker problems. Cells are the most reliable components. SolFocus determined that a 20% degradation over 25 years and 0.37% degradation per year was a reasonable warranted performance. Mini-panels were tested in environmental chambers for accelerated testing of tracker reliability. A low concentration system with a 10° acceptance angle from Ohio Optical showed that efficiency can dominate cell performance if carefully accounted for. Taking a single sun cell for concentration requires consideration of series resistance. Screen printed pastes have improved both in ability to increase aspect ratio and reduced resistivity.

Under **Area 4**, presentations focused on metallization aspects of c-Si solar cells. An elegant characterization methodology was presented for the series resistance components of PERC solar cells using photoluminescence imaging. Nicolas Grant (ANU) reported a 12 cm/sec surface recombination velocity on a chemically grown silicon oxide annealed at 400 C. The process was based on alternating current electrochemical oxidation. A lower duty cycle for oxidation was reported to be superior to shorter cycles. Interface character-

ization was done with capacitance voltage measurements. Michael Rauer from ISE Fraunhofer reported addition of silicon content in the range 6-24% in the aluminum paste to optimizing the properties of local contacts. This provided improved understanding for the local contact formation.

For **Area 5**, Youichirou Aya from Sanyo Electric presented the progress in high conversion efficiency amorphous-microcrystalline silicon tandem cells on generation-5.5 large-area glass substrates. The microcrystalline silicon is processed at high deposition rate of 2.4 nm/s using local plasma confinement CVD. Stable module efficiencies of 10.5% were obtained. Arindam Banerjee presented progress on high-efficiency multi-junction nc-Si:H-based solar cells deposited at 1 nm/s rates. Lab cells with a stabilized efficiency of 12.4 % (confirmed by NREL) were demonstrated. Modules of 400 cm^2 area with preliminary stable efficiencies of 11.4% achieved. Do Yun Kim introduced a new absorber material, a-SiGeC:H. Enhanced currents relative to a-Si:H cells were presented and initial efficiencies of 7.9% have been achieved. Fanny Meillaud from EPFL/IMT showed the latest progress in the micromorph cell development. Thick micromorph cells with a stable efficiencies of 11.5% and thin micromorph cells with a stable efficiencies of 11.3 % have been obtained.

Highlights from the Friday morning session in **Area 6** included a talk from Konarka which highlighted their recent announcement of 8.29% NREL-certified lab cells and indicated that OPV technologies can have a 20-55% improvement in total integrated power output per day for a given nameplate efficiency. This highlights the ability of OPV devices to outperform under lower intensity and off axis illumination. Recent results from the McGehee group at Stanford U. Indicate that OPV technologies can have lifetimes up to seven years under state of the art encapsulation.

BJ Stanbery, General Chair, 2011

In **Area 7** ESA presented an overview of missions in low solar intensity and high temperature environments, and challenges for solar arrays operating in these environments. Emphasis was placed on the importance of rigid substrates and proper fabrication process control. Also, proper solar cell construction to withstand high thermal and solar loads. Encore presented solar array design challenges for the closest mission to the sun thus far for a solar powered mission. The competing environmental and power requirements drive the design process to be highly iterative.

Despite the inherent difficulties in growing III-V's on Si, Gene Fitzgerald with 4Power gave this start-up's first public presentation on their work with III-V on Si solar cells. The ability to integrate Si microelectronics technology with III-V PV is a unique application that has many clear benefits. The approach utilizes microelectronics processing methods

to effectively build a "solar array on a chip". This is first time this has been presented at a PV conference. Spectrolab presented qualification and reliability testing of their new large area solar cells of 60 and 70 cm^2. Projected cost savings are up to 20%. In addition to mass savings, aged coupons passed electrostatic discharge tests successfully. Astrium presented current status of the testing of solar cells to be used on the Bepi Columbo mission, and the challenges of high solar intensity and high temperature 'HIHT' environments. A thorough materials investigation was presented to determine cause of some exhibited cell degradation. Spectrolab presented current status of the MISSE-7 flight experiment mounted for 18 months on the International Space Station, and recently returned to earth. The coupon included Spectrolab IMM3J solar cells, flown for the first time. On-orbit telemetry test data was presented, which showed good performance with the corrected data vs. ground test data.

Arno Smets, Area 5 Chair

Andreea Boca from Emcore discussed their work on designing the array for NASA's Solar Probe Plus flight to the sun. This program will be sending a satellite as close as ever to the sun. Their plans include designing for 20-30x concentration, 180°C operating temperature, but able to survive at 70x concentration and 250°C. One important step here is engineering the adhesives and kapton tape in such a way as to increase thermal conductivity between cell and substrate.

In the characterization session of **Area 8**, there was a clear demonstration of factors influencing energy yield. The discussions filled in for a lack of knowledge for spectral irradiance measurement of solar simulators. Talks showed deficiencies in measurement standards. New approaches and perspectives for quality assurance of PV modules were presented. Beate Roeder presented a really interesting talk in the use of fluorescence images to analyze and monitor aging in outdoor modules. The method allows detection of damage not visible by eye. At Sandia Labs there have been successes in DC arc fault testing at string levels by defining the frequency range of measurements. They have created a very interesting engine to simulate arcing at lab scale and have used it to characterize systems.

Martha Symko-Davies (Tutorials Chair) and Tim Anderson (Journal of Photovoltaics Editor in Chief)

In **Area 9**, Jerome Hastings covered the unique nature of the DC arc. All high voltage DC systems have a serious problem with arcing as

there is no zero-crossing to put out the arc. The power actually increases with an arc gap, which is important but not intuitive. DC arcs are very difficult to extinguish, and must be treated very seriously as they can burn for long times and start fires easily (until reaching local thermal equilibrium and finally being extinguished). Standard UL1699B addresses DC trip times. A 10 Amp arc can reach 5000 K at 50mm distance, which can ignite almost anything flammable. Flame retardant materials are very helpful for minimizing fire risks. Trip times are applicable to modules, connectors and wires. Jerome had both measured and modeled results, and showed a number of videos which demonstrated arc characteristics, ignition, and burn-through.

Louise Hirst receives her student research award.

Ron Vidano discussed results of the methods to implement accelerated inverter testing. Inverters are routinely subjected to a wide array of environmental conditions, often seeing hot, cold, dry and wet in one location. Dust, agricultural byproducts, and other chemical exposure can be detrimental to the life of inverters, even those located indoors. Accelerated fife testing (ALT) can identify weak components of any system. Manufacturers need to use ALT at the system and sub-system levels with a goal of developing improved system level testing. This can be complex and costly. In the presentation Vidano used a method that provided an acceleration factor that yielding additional confidence and lowers cost and time.

Robert Woehl receives his student research award

Michael Ropp discussed results from the SEGIS program, and in particular the results of the Advanced Energy systems work to develop a new test protocol that is simpler to implement than the Sandia or European models. The new protocol has shown to be useful and easier to apply. Sig Gonzales discussed testing and evaluation of inverters, with a particular focus on high penetration PV. Utility interconnection requirements were discussed with a focus on what the national standards require today. Many tests were performed with multiple Inverters in the circuit. Multiple-inverter tests revealed that different inverters behaved very differently, with at least one model that "hung on" longer than standards require for voltage "outage" tests. Power quality tests did not seem to be affected by the multiple-inverter configuration. Sai Alampoondi described a design qualification standard for inverters. Sai reviewed national standards which are germane to

PV system interconnection, as well as IEC standards which apply in other locales. The "missing links" for grid-connected PV inverters were discussed and are found in the associated paper. Some discussion of the IEEE surge-withstand tests C62.45 and C62.41.2 which were helpful.

At the closing session Dave Wilt gave a brief summary of the conference and turned the podium over to Steve Ringel who presented a detailed breakdown of attendance, papers submitted by area, the growth of the conference etc. Areas 1 and 8 were the largest areas of growth. There were papers submitted from many areas.

Cory Cress announced the student awards. The winners names are given in the table to the right.

Award Winner	Runner Up	Area
Louise C. Hirst	Christopher G. Bailey	1
Hamed Simchi	Adam Krysztopa	2
Ngai L. A. Chan		3
Robert Woehl	Jiun-Hong Lai	4
Mathieu Boccard	Sourabh Dongaonkar	5
Brian E. Lassiter		6
Zachary S. Bittner		7
Joel Weber		8
Ye Zhao		9

Alex Freundlich was awarded the Napkin Award for the greatest contribution to the technical quality of the conference. An Alaskan Cruise for two was awarded to one of the participants who stayed at a conference hotel.

Dave Wilt wrapped up the program by describing the results of the time capsule survey. This survey asked questions such as “what will be the cost of installed PV in 2061?” and “which country will have the largest installed PV capacity in 2061?”.

Several upcoming events were promoted. The 21st PVSEC will be held in Fukuoka Japan at the Hilton Sea Hawk hotel November 28 through December 2nd 2011. The 26th European PVSEC will be held in Hamburg this September 5th through the 9th 2011 in the conference center. The 38th PVSC will be June 2nd through the 9th 2012 at the Convention Center in Austin Texas.

So the conference comes to a close. We thank all of the speakers, attendees, staff of the convention center, the hotels, and organizers. We hope everyone has safe travels home and to Austin next year.