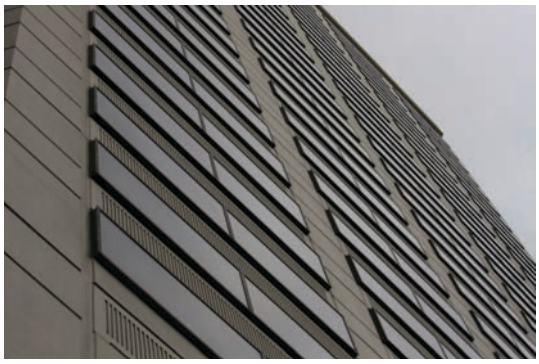
Thursday is a day when the conference starts to feel like it is winding down. Posters end in the morning because the exhibit is closing up. The day started rainy with clouds blanketing the city so it felt less cheerful than previous days. However, just like the history of the PV industry, the sun came out, the day cleared up, and we heard a lot of great talks to start the day. Everyone is feeling hopeful and excited for the future. Just like the future of the PV industry, the talks and posters have lived up to our expectations and it has been a great day at the PVSC.



Is this the façade of the Sheraton or a PV array? The BIPV community surely looks up at this building and dreams that every window would be producing power.

There are no plenary talks on Thursday so we jumped right into normal oral sessions. In Area 1, I-Kang Ding presented on behalf of M. McGehee and highlighted importance and improvement in die sensitized solar cell (DSSC) performance with pore filling. The cells utilize plasmonic back reflectors to boost J_{sc} and efficiency in these devices. A 5.93% efficient device was reported. Increased efficiency with fill fraction was observed experimentally. Sushoban Avasthi presented results on Si : P3HT hybrid organic/inorganic solar cells with 10% efficiency. A key advantage of this technology is that all processing is performed near room temperature. Ching-Fuh Lin and Rotem Har-Lavan presented a talk on PDOT:PSS-semiconductor devices showing the importance of chemical passivation and band bending in these hybrid organic/inorganic devices.

Steve Ringel, conference program chair, gives instructions to the session chairs and presenters at breakfast.

In the Area 2 session Roland Scheer of the University of Halle discussed the importance of the band offsets at the buffer-window-interface for controlling the major recombination path in CIGS solar cells, as well as the fact that in very high efficiency cells a better mobility might be actually detrimental. He went on to note that similar effects may limit CZTS devices. It may be necessary to re-engineer the transparent conductor in addition to the emitter for CZTS.

Byungha Shin of IBM presented results for their latest CZTS devices. One small area CZTS device showed high performance (8.4% efficiency) with good carrier collection. The primary shortfall was in voltage. Bias-dependent quantum efficiency data shows no change in the results under reverse bias (-1V), with peak QEs in the range of 90%. Minority carrier lifetimes in the 8 nsec range were determined by time-resolved photoluminescence. Based on an assumed 5 cm^2/V-sec

mobility they estimate a 350 nm minimum minority carrier diffusion length. UPS indicates a 0.41 eV band offset with CdS and DLCP suggests 10^{16} cm^{-3} carrier concentration. Temperature-dependent photovoltage suggests low voltage at 0K, indicating interface recombination. A very nice cross-sectional TEM image shows large single grains passing through the whole CZTS film with some ZnS at the Mo-CZTS interface along with formation of MoS_2 and drive in of Cu into the back contact. All of the second phases are localized at the back interface.

Roland Scheer presents his invited talk.

Area 3 had an excellent session. Cherry Award winner Jerry Olson presented his group's work on measuring the band offset at heterobarriers of GaInP and GaAs. He showed the importance of doping level and doping gradient in the back surface field layer of a multijunction III-V solar cell. It influences the sharpness of the band-offset at the junction and has a strong influence on the fill factor of the solar cell. Pairing simulation with experiment, they demonstrated a method for measuring this heterobarrier by doing current-voltage sweeps at high irradiance. For example, they demonstrated a 300 meV offset for GaInP/GaAs. Surprisingly, they also measured about a 300 meV offset for an AlGaInP/GaAs heterobarrier, while expecting something about 100meV higher. Olson suggested the difference may be due to grading at the interface.

There were also two interesting papers on the measurement of temperature coefficients of multijunction cells. Philip Chiu spoke on InGaP/GaAs/InGaAs made by bifacial epitaxial growth: showing that the temperature coefficient was dominated by the strongly negative behavior for I_{sc} of the bottom InGaAs layer. The solution was to grow on a substrate with a different miscut angle.

Under concentration, cell temperatures may rise to 70-100C. Thus, measuring cell characteristics at these high temperatures is important. Temperature dependent measurements on multijunction solar cells may seem relatively straight-forward, but Myles Steiner from NREL discussed the importance of adjusting the input spectrum based on changes in the EQE of subcells at various temperatures. His paper outlines a reliable procedure for making temperature-dependent measurements on inverted metamorphic and multijunction solar cells. The paper showed that cells optimized for real operating temperature (75°C instead of standard 25°C) show a lower temperature coefficient and a higher power output at the nominal operating temperature.

Among multijunction cell developers, lattice mismatched approaches are becoming more common due to the desire to optimize subcell band gaps for the solar spectrum. However, common wisdom suggests that the addition of threading dislocations through metamorphic growth will ultimately degrade performance and can affect optimal band

gap combinations. Alvin Chan from Imperial College discussed this very topic and showed that this inherent degradation in material quality will certainly affect optimal band gaps of cells developed for 1 sun conditions (by hundreds of millivolts), but not for high concentration (500x) due to the dominance of radiative processes at the higher biases.

Sebastian Bruechner described fundamental aspects of surface science for obtaining high-quality III-V epitaxy on Si and Ge substrates using surface analysis techniques such as STM, RAS, LEED, XRF.

Kicking off Area 4, Paul Basore presented a very versatile and easy to use 2D simulation tool, PC2D, a two-dimensional improved version of the classic PC1D simulation tool. Kevin Pollock showed a comprehensive comparison of different surface passivation techniques for characterization purposes - an important study for everybody who is analyzing carrier lifetime. John Allen presented a simulation of an interdigitated back "HIT" type contact and showed the effect of defect levels and rear intrinsic layer on fill factor. Victor Prajapati compared three passivation dielectrics to study the illumination dependence of cell parameters. The dense dielectric showed the most dependence compared to fresh materials. Raffaele De Rose modeled the selective emitter design of solar cells to show the effect of contact alignment tolerance on cell efficiency. The larger the alignment width, the lower the selective-emitter benefit.

Paul Basore speaking in the Area 4 session.

Jeff Yang of UniSolar

In Area 5, Jeff Yang of Unisolar announced the introduction of a new product in 2011: a 10%-efficient module, which is considerable progress relative to the present 8.2% efficient product. A dual function n-type layer enhances the current from the middle cell of the triple junction structure. Other speakers in this session, among which were two of the best student finalist presentations, showed great progress in the optical functions of SiO_x and ZnO layers at specific locations in thin film Si solar cells.

Area 9 focused on PV System Interaction with the Utility Grid. Joao Fonseca (AIST) presented a talk on power production forecasting. The regression methodology makes use of two hour weather data and 25 hour weather data preceding the time of the energy output forecast. The results showed that the shorter forecast horizon gave improved accuracy. The Japanese utilities are interested in these results but are looking for tighter accuracy. Mike Ropp (Northern Plains Power

Technologies) described a methodology for testing the grid for "readiness" for connection of a PV system to the grid. The objective of the methodology is to prevent "islanding," which is necessary when there is a high penetration percentage of PV on the grid. The session then held a discussion forum on reactive power control strategies, which included audience questions and answers. Michael Behnke (BEW) presented a talk on modeling of photovoltaic systems in grid planning, which gave an overview and status of PV system modeling for the Western Electricity Coordinating Council. This is a consortium of utilities in the western US overseeing the quality control of what gets hooked up to the grid. Michael Coddington presented a high penetration case study. No voltage control or distribution upgrades were needed for a project incorporating a 5.2 MW PV system on a utility feeder with a 9 MW peak load. The penetration in this case is high but has a low impact on the grid operation because the feeder is large, or stiff, with high current capacity conductors. Michael discussed new definitions of "high" penetration because of the site specific parameters that determine whether there are issues or not.

Listening to talks.

In the afternoon oral sessions resumed as there were no poster presentations.

In Area 1**,** Louise Hirst from Imperial College did a brilliant job of outlining the main ideas behind hot carrier solar cells. With around 30% solar radiation loss due to thermalization, the study of carrier dynamics in potential hot carrier solar cells is vital. Hirst's work on InGaAs quantum wells, strain-balanced by GaAsP barrier layers, exhibited slowed cooling of the carrier population, on the order of nanoseconds compared to ~500ps in bulk GaAs. In addition, she showed that carriers in deeper wells have higher temperature compared to shallow wells. Andenet Alemu (University of Houston) described his work using thermo-tunneling in dilute nitride multi-quantum well solar cells. Typically, photo-excited carriers in the well regions need about 8ns to make their way out of the well, but Alemu showed that proper design of energy states in successive quantum wells can reduce this escape time to 16ps, leading to reduced recombination and higher carrier collection. Tyler Grassman of *The* Ohio State University detailed a new understanding of metamorphic phosphide and arsenide phosphide growth on Si using higher growth temperatures to activate dislocation glide as well as to permit step flow growth. Gregory Kimball (Caltech) described careful investigations of the effects of Mg on the surface of Zn_3P_2. The results open up the possibility of using this material, identified decades ago as a possible absorber layer. The team transferred techniques from ion beam assisted deposition providing textured MgO to use for large area pseudo-single crystalline Ge substrates for III-V epitaxy. Adele Tamboli (Caltech) demonstrated the growth of large area Si wire arrays, which are then embedded in polymer and lifted off to reuse the Si substrates. This permits fabrication of nanostructured solar cell devices with lower costs. Yi Chen (Illinois) demonstrated a new

single step plasma chemical technique for forming angle-insensitive antireflective coatings on Si.

In area 2, Robert Collins descrbed very fast advanced spectroscopic ellipsometry tools available for online production monitoring of thickness, roughness, and reflectivity. Susan Murray discussed processing of CdTe/CdS solar cells in milliseconds on flexible substrate on existing web coating technology. Kurt Barth of Abound described recent progress in manufacturing. They are expecting to reach 170 MW production capacity by 2012 and are building a factory based on a Department of Energy loan guarantee. 120x60 cm, frameless modules are being produced. Deployment is coupled to a prefunded recycling program. He described unique aspects surrounding encapsulation technology including the encapsulation technology and the incorporation of dessication methods in module. The manufacturing includes all-automated processing. The projection for 2012-2014 is a major scale up in production and deployment of modules in increasingly large scale projects. They estimate that their cost per Watt can fall below $0.50/W in the near future.

Francilina Runai (Ulm/centrotherm) spoke about electroluminescence imaging and performance of CIGS thin film modules and how this can be correlated with performance. They are studying devices produced by sputtered precursors and selenization from solid sources of Se at atmospheric pressure.

Katy Hartman

An EPIR/NREL collaboration, described by Chollada Gilmore resulted in 15% efficient CdTe cells fabricated on commercial TEC10 glass. Lindsay Clark spoke of Dow's innovative, lower cost solutions for stringing and interconnects in their solar shingle technology. Rajiv from NREL showed a clear methodology to identify the mechanism of degradation of CIGS devices in damp heat. H. Sugimoto of Solar Frontier announced a new record efficiency of 17.2% for a CIGSS large-area device and a step by step process for improvement that Thayer made to get there.

In Area 3, Jim Ermer from Spectrolab discussed their newest cell offerings. The C3MJ+ is a lattice-matched triple junction with an average production efficiency of 39.3%. The C4MJ, the first production-scale metamorphic multijunction cell, is also coming out with average efficiency of 39.8%, with expectation for >40% soon. Extensive reliability testing on the C4MJ was conducted to ensure the metamorphic buffer region does not degrade the cell performance over time in real world conditions.

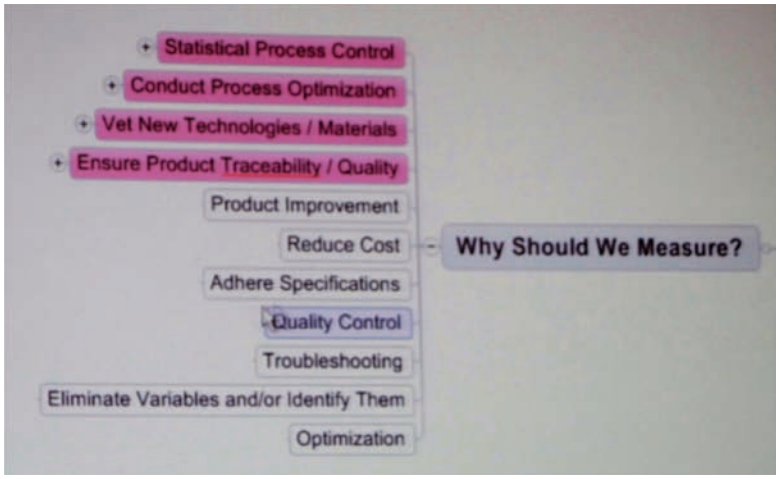
In Area 4 the topic was n-type substrates. Daniel Meyer described 18.5% phosphorous top cell rear Al-back-surface-field junction ion implanted front FSF was reported. A 19.1% front junction cell was achieved with a boron front implant and phosphorus rear

implant. The Nicola Mingirulli of the HZB Berlin group reported a 20.2% efficient device using an a-Si emitter and base interdigitated back contact cell on float zone Si using photolithography. Arnam Das described the use of a spin-on B source combined with a SiO/SiN passivation provided the same performances on untextured 100 and 111 textured surfaces. Yannick Veschetti of INES described a 19.1% efficient device on 125x125 mm^2 wafers with screen printed contacts, a boron source based on BCl_3 diffusion, n-type doping from a $POCl_3$ diffusion source, and silica passivation. Results for the optimized process yielded results of 19.3% (best cell) 5) 21.6% on a Czochralski wafer (designated area) and for a larger area: 19.7%.

Ethan Good leading a discussion in Area 8

Yutaka Kishida of Nippon Steel described the 100MW production capacity of UMG Si from metallurgical grade Si by a combination of oxidation and vacuum and segregation treatments resulting in B concentrations of 0.1 - 0.2 ppm and P concentrations of 0.05 - 0.2 ppm by weight. William Imler reported purification times as low as 30 min to reduce B levels in solar grade silicon by 50% using a plasma arc treatment.

Area 5 discussed novel concepts and fundamental physics of thin silicon films and devices. Smets et al presented a consistent interpretation of the optical, structural, and defect properties in amorphous silicon based on an anisotropic disordered network theory. Stradins et al reported that the Staebler-Wronski effect in amorphous silicon layers can be reduced significantly by applying partially hydrogen-effusing thermal treatments.



The results of the discussion in Area 8 for the question "why should we measure?". Audience responses are in gray, previous responses from earlier discussions are in pink.

In Area 8 there were four nice papers including two invited talks. New characterization techniques (atom probe tomography, aberration-corrected scanning transmission electron microscopy, macro-Raman spectroscopy,coherence correlation interferometry) were introduced for understanding spatial variations ranging from the atomic scale to millimeter-sized regions. Such variations in length

scale allow detailed insights into the (in)homogeneity of photovoltaic materials. Sergio Molina showed outstanding images of III-V semiconductor nanostructures taking advantage of state of the art aberration corrected electron microscopes and obtaining angular-dark-field lattice images. He was able to identify the shape of nanometer-scale quantum dots through the Z-contrast afforded by angular dark field. Takuo Sasaki showed how reciprocal space mapping can be used in situ and in real time to understand strain relaxation during growth of compositionally graded InGaAs on GaAs. Alex Freundlich showed that RHEED can be used to monitor in real time the dimensions of growing quantum dots. Robert Collins showed how through the glass spectral elipsometry can give information on all layers in CdTe and a-Si cells and that large area maps up to 120x60 cm can be made. Veronica Bermudez illustrated that Raman spectroscopy is a fast and sensitive tool for assessment of alloy composition that can be applied in industry in real time. Liviu Stoicescu presented a fast method to simulate multi crystalline silicon cells with high spatial resolution in 2D.

Riding the monorail to the conference dinner.

The later afternoon Area 8 session ended with an interesting interactive discussion led by Ethan Good of Solar World with the audience that worked to identify why we measure, what we measure, and how we measure. The results of the discussion were compared to previous discussions on the same topics. As these discussions continue a list of answers to these topics is being accumulated.

Following a break many of the conference attendees gathered in the lobby of the Sheraton and/or made their way to the monorail a few blocks away. The monorail took them the few thousand meters to the site of the 1962 World's Fair. Everyone walked by the base of the Space Needle and gathered at the entrance of the Experience Music Project, whose acronym, EMP, strikes some those of us working on electronic devices as an uncomfortable reminder of electromagnetic pulses. We learned the difference when the doors opened and those attending the conference dinner enjoyed an evening experiencing the unique atmosphere of the EMP. Many of the attendees also took the opportunity to visit the observation deck on the Space Needle where there is an outstanding view of downtown Seattle and its harbor. It was a great way to wind down at the end of another successful day at the PVSC.

Dinner at the Experience Music Project