Wednesday, June 11th at the PVSC began bright and early for some of our colleagues who competed in the annual Sun Run. Led by Larry Kazmerski, over 70 PVSC specialists hit the road and traversed 3.1 miles, running alongside the beautiful Cherry Creek, in which gold was first discovered in 1858. Congratulations to the men's and women's group winners, Daniel Derkacs and Kristine Drew!

Following the morning run, the usual conference activities began with plenary lectures given by PV experts, speaking on recent developments in thin film silicon, PV modules and manufacturing, and chalcogenide thin film solar cells.

In Area 5, Jun Lin from Tokyo Electron (TEL) gave an overview over recent achievements in the field of thin film silicon based devices. He presented three new certified world record efficiencies that were reported during the last year, showing that this relatively mature technology makes still impressive progress. The AIST laboratory in Japan could demonstrate new single junction world record efficiencies for stabilized amorphous silicon of 10.1% and 11.0% for microcrystalline silicon solar cells. Combining the two materials in advanced tandem cells, EPFL in Switzerland achieved a stabilized efficiency of 12.6%. Likewise, the talk summarized impressive progress on devices based on thin crystallized silicon-films. Work at UNSW in Australia and at HZB in Germany underline the importance of barrier layers that serve as dopant source, window layer, and nucleation template, the latter functionality being particularly important for the recent advances towards higher open circuit voltage beyond 650 mV. The speaker continued by reporting on recent progress achieved by TEL who concentrated novel anti-reflection layers, and a hydrogen treatment of the zinc-oxide electrodes. Paired with improved deposition regimes for the silicon films, TEL obtained a certified efficiency of 11.7% for their latest stabilized module and they expect more than 12% in the near future. Further progress is expected with their nano-imprinted texture for light scattering which they demonstrated for the first time on full Gen5 area.

The Area 9 plenary was given by Steve Ransome from SRCL who presented an overview of the methods used to model and predict PV module and system performance. He indicated that there is still considerable disagreement between module performance models. Temperature coefficient uncertainty of up to /- 5% is explained by differences in the way modules are heated to control the temperature. Industry standards for measuring temperature coefficients are needed.

Ayodhya Tiwari of EMPA and Flisom (picture to left) delivered the Area 2 plenary, talking about progress in research breakthroughs and industrial developments within thin film chalcogenide PV. Ayodhya shared how the efficiency of thin film cells has overcome the efficiency of multi crystalline Si, even with flexible cells, and as such presents a formidable technology. He shared new TCOs with good properties for PV deposited at room temperature, and shared that most of the recent progress in CIGS efficiency is due to the incorporation of potassium.

In the joint Area 2 & 8 session, Pyuck Choi presented on his use of atom probe tomography to investigate CIGS grain boundaries (GB) and interfaces. The results indicate fast impurity diffusion of Na and O along GBs. GB chemistry depends on the grain boundary character. Laurent Lombez described how micro metric imaging indicates bulk dominates micro cell performance rather than edge properties. Bill Stanberry reported on electroluminescence of CIGS modules to extract changes in recombination and carrier collection. The influence of absorber thickness and Ga gradient in the near surface region was analyzed in detail. Puja Pradhan shared her work using real time spectroscopic ellipsometry to analyze surface roughness, composition, void formation in the first stage of CIGS, the conversion to CIGS and the formation of Cu_xSe in second stage, and the reconsumption of Cu_xSe in the third stage. Different thicknesses have been analyzed in real time using this approach. Hannes Hempel shared a technique to measure intra grain mobility on thin film solar cells in direction of the current flow. CIS have extremely high intra grain mobilities that are comparable to single crystals. Cu poor samples have reduced mobilities, due to potential fluctuations.

In the joint Area 10 & 11 session on system grid integration, Daniel Cormode discussed the contentious topic of optimal curtailment strategies to meet ramp rate requirements by bulk power systems. Bryan Palmintier discussed new statistical clustering methods for feeder modeling based on methods that have been "hidden" in the statistical space for years. Tess Williams presented on new methods to utilize PHIL (power hardware in the loop) systems and communications to understand advanced inverters and

their interaction with each other and the grid. Muesli Baggu presented on advanced feeder modeling techniques used to evaluate feeders with high penetration in the Arizona Public Service Company territory. John Seuss presented results from advance modeling of advanced inverters with reactive power control capabilities. Yingying Tang presented a modeling and analysis overview of the feeder under study at Arizona Public Service Company. The focus of the research was the coordination of the protection system which includes utility system fuses and breakers.

In Area 3, Daniel Biro (Fraunhofer ISE) presented a MWT silicon solar cell for low concentration PV applications, which was tested and well performing with efficiency above 20%. Different cell areas can be realized from the same wafer due to the modular design. Alex Freundlich described how these MWT Si cells are integrated into a receiver operating at approximately ten sun concentration. Kyusang Lee (picture to right), a best student presentation award finalist, gave a presentation on his work developing cost-effective high efficiency GaAs solar cells using a lift-off process to recycle the substrate. These cells are to be used in a plastic mini-compound parabolic concentrator.

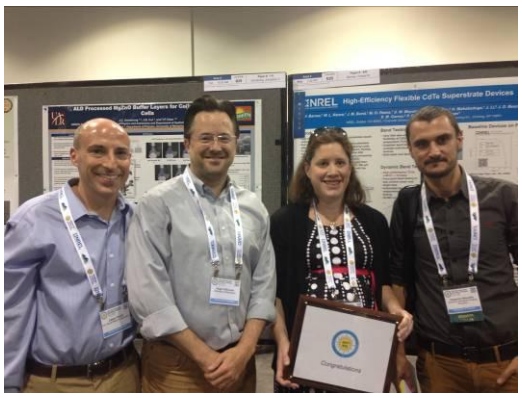
In Area 4, David Smith presented SunPower's 25% efficient industrially feasible large-area IBC cell. A detailed loss analysis shows the pathway to 26%. Paul Basore introduced a scheme for estimating the costs of new cell processes on module and system level. An app for this scheme is available from pvcolleagues.net.

Hans-Joachim Egelhaaf kicked off the Area 6 OPV stability session with his presentation on the intrinsic degradation of OPV under dry air exposure. He concluded with two focus points for improved lifetime of OPV, namely work on the environment by encapsulation and on the composition of the stack by modifying materials. Graham Morse made clear in his presentation that side chains can have an influence on the competing phenomena crystallization vs. PCBM dimerization which can be used to improve the device stability. Seunghyup Yoo presented the difference in OPV degradation behavior between an inverted and regular configuration with identical transport layers. His results show that even then, his inverted design is still more stable.

In Area 7, Ed Gaddy of the Applied Physics Lab presented on the complex power analysis of the solar probe plus mission, outlining in particular the considerations that go into predicting UV transmission loss at high temperature. Kazunori Shimazaki, JAXA, presented first flight results for the space solar sheet. I_{sc} degradation less than 1.5% was demonstrated after 251 days in orbit, even for the polymeric frontside coating. Ted Stern, Vanguard Space, outlined new automated methods of PVA manufacturing, making use of electronic industry manufacturing methods and a potential for considerable cost savings.

In Area 12, Bill Gambogi presented a study of field failures and accelerated testing of back sheets that showed that if a material has an asymmetry in its mechanical properties, it can lead to failures in the field from thermal stresses. Also, extruded materials had better abrasion resistance to sand than coated materials. Nicholas Wheeler

(picture to right), a best student presentation award finalist, shared his investigation of lifetime and degradation of PV technology systems. John Wohlgemuth, on behalf of David Miller, shared a comparison of indoor and outdoor testing of almost 500 junction box attachments. He found that hanging a small weight in indoor stress tests was successful in identifying the probability of outdoor failure. Yu-Tai Li presented on the use of a UV laser to cause EVA yellowing in a shorter time than using lower intensity UV sources. Lastly, John Wohlgemuth presented a comparative rating system for three climate zones (temperate, tropical, and desert) and two mounting configurations (open-rack and close-roof) was proposed, including a longer thermal cycling sequence and a multistep durability sequence for modules and additional materials testing.



In the afternoon poster sessions, Xiaohan Li won the best poster award in Area 1, presenting on integrated optical nanostructures for wide-angle antireflection and light trapping in III/V solar cells. Teresa Barnes and colleagues from NREL won the best poster award in Area 2 (Chalcogenide Thin Film Solar Cells) for their work on the development of flexible CdTe solar cells. (picture to right, Jesse Frantz, Hugh Hillhouse, Teresa Barnes (winner), and Edgardo Saucedo). The research effort focused on using flexible Dow Corning Willow glass in a superstrate configuration. They have made devices that are 16.4% efficient and perform well even after bending. Further improvement of the TCO layers is expected to lead to even higher device efficiencies. The Area 4 poster award went to Trevor Young for his design and characterization of an adhesion strength tester for evaluating metal contacts on silicon solar cells. Alexandre Nardes won the best poster award in Area 8 for his work studying the thermal annealing affects on vertical morphology, doping and defect density in BHJ OPV devices. Rhett Evans won the best poster award in Area 9 for his work data mining photovoltaic cell manufacturing data. Additional poster highlights from Area 9 include: a high voltage MWT module with improved shadow performance, HCPV Modules of SMALFOC design inversions for PV and PV/T operation; a proposed photovoltaic module form factor to reduce levelized cost of energy; and long-lasting anti-reflective coatings for PV module Glass. The Area 10 best poster award went to Eric Holton, for his cost and market analysis of integrative lightweight PV systems for low-slope commercial rooftops.

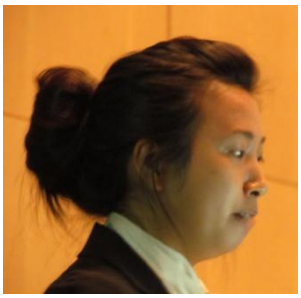
Following the afternoon coffee break, the afternoon sessions began. In Area 1, Dr. Newman reviewed metallic and dielectric light trapping structures over the past 5 years. She described how the dielectric nano particles are better than the metallic ones due to the elimination of parasitic absorption in metals. Using a surface conform lithography, she presented enhanced V_{oc}, high J_{sc} in a 1-um thick crystalline silicon solar cells (I-V characteristics by calculation), and enhanced blue wavelength response in polymer solar cells. Finally, she showed by restricting the photon emission angle, the limiting efficiency of a silicon cell can approach 30% with Auger recombination considered. Professor Steven Chou proposed a broadband blackbody concept based on plasmonic nano-cavities for organic solar cells, where the J_{sc} is

enhanced by 41%, FF by 6%, and efficiency by 52% (2.9->4.3%) with omni acceptance angles. The enabling top gold mesh electrode was fabricated by scale-up nano imprint technology.

Area 1/3/4/7 shared a joint session on III-V on silicon solar cells which was well attended. Tyler Grassman from Ohio State University started with an invited talk. He presented developments regarding the use of Si solar cells as a bottom junction in a GaAsP/Si tandem configuration. Also tunnel diodes have been developed with good performance. Thomas Hannappel presented details of the atomic structure of silicon surfaces in the epitaxy environment. He further presented how the atomic configuration at the Si-GaP interface is influenced by the growth conditions. Finally, Santino D. Carnevale gave insight into a powerful characterization method of electron channeling contrast imaging (ECCI) where he could identify misfit dislocations in metamorphic materials. The method enabled the attainment of comparable results to plan-view TEM.

In the joint session between Area 2 & 9 Hiroki Sugimoto from Solar Frontier presented details of their world record 20.9% efficient CIGSSe cell fabricated using a metal stack selenization process. Dirk Herrmann from Solibro presented a coevaporated CIGS cell with a new world record efficiency of 21.0%. This cell used a single step process. Adam Burnton from M-Solv presented a new way to form module monolithic interconnects using inkjet printing to eliminate two of the three lasers typically used.

Benedicte Demaurex (picture to left), best student presentation award finalist, kicked off Area 4 presenting on ALD grown TCO layers used to prevent sputter damage on aSi emitters. The analysis showed interfacial oxide was the cause for the formation of a blocking contact. Fabian Kiefer presented a double printing technique to minimize contact recombination. Ned Western talked about an innovative technique of contact formation using dielectric breakdown. Pei Hsuan Doris Lu (picture to right) described the use of selective anodization as a new passivation method (including the possibility for laser doping and patterning). Kyumin Lee presented a 21.4% p-type Cz plated large area PERC solar cell. Liang Liang shared a peel force variation due to solder layer thickness variation, new in situ SEM strength test.



In Area 5, Isao Yoshida presented impressive results on up scaling from lab-scale results to gen5 deposition systems. J. C. Dornstetter explained the transition from amorphous to microcrystalline Si with a two-parameter model. Jimmy Melskens (picture to left) presented a detailed analysis of the degradation kinetics in amorphous silicon films and solar cells.

In Area 6, Yue Wu of Solarmer shared encouraging stability results of printed solar cell with a time to 80% initial power generation lifetime larger than 4 years. Jeffrey Tait presented the highest efficiency (6.4%) of a spray coated OPV device ever demonstrated; spray coating is as good as spin coating. Tamara Eggenhuisen described her

work developing an ink jet printing process for full digital fabrication of OPV, where all layers, including electrodes, were printed. She demonstrated a device with efficiency 75% higher than spin coated devices. Stephanie Dupont talked about top electrode adhesion issues and how to significantly improve the adhesion by thermal annealing.

In Area 9, Ken Sauer of Yingli Green Energy Americas outlined a method for calibrating the PVsyst software package, using measurements that correct for a frequently-observed bias in PVsyst projections at low irradiance. Aron Dobos of NREL showed that measurements obtained at the conditions specified in IEC 61853-1 can be used to not only calibrate a single diode performance model but also to discover modifications to the model that overcome model deficiencies. Brian Zaharatos of Colorado School of Mines presented a new attempt to extract parameters for a single diode equation from a measured IV characteristic, using Bayesian methods that also deliver rigorous uncertainty bounds on the extracted parameter values. Billy Hayes of First Solar demonstrated a validated time-dependent cell temperature model that more accurately predicts observed outdoor operating temperatures than the default temperature model in PVsyst. A new laboratory-based method for measuring EQE as a function of angle of incidence was presented by BG Potter of the University of Arizona; this method might open new capabilities to better understand and improve light management in module material choices. Finally, Carolyn Ulbrich described how the Kamalkar-Haneef model can be used to identify changes in system performance over time and can attribute performance changes to changes in series or shunt resistance with time.

Lastly, for all the CdTe fans out there, I leave you with a photograph by Larry Lee, taken at a theater near the Colorado Convention Center.

That wraps up day 4 at the 40th IEEE PVSC.

****

IEEE ELECTRON DEVICES SOCIETY - MEMBERSHIP PROMOTIONS FOR 40th PVSC ATTENDEES

Be sure to stop by the EDS membership booth, located in the registration area, to learn about the free EDS membership promotions available to PVSC attendees.

EDS members enjoy a host of important benefits including free, unlimited online access to the IEEE Journal of Photovoltaics. So stop by and see Joyce and Jean to learn more. Don't miss this opportunity to become part of the EDS community!

****