



Thursday at PVSC44 saw some very entertaining sessions and the conference banquet in a legendary setting. Attendees found a second wind to keep themselves going, with more outstanding talks and technical results presented.

Area 3 plenary speaker, Stefan Myrskog (VP of Control Systems at Morgan Solar), gave a nice talk about Morgan Solar's innovative thin-plate high- and low-X concentrator modules (and lighting products) that leverage concepts from the optical communications field. Using a highly standard bill of materials based on Si module manufacturing, Morgan is able to produce cost effective HCPV (and LCPV) systems with a range of applications, from utility scale to building-integrated.



The Area 10 plenary saw Thomas Bialek (San Diego Gas and Electric) first describe the current challenges of high penetration PV integration, including the variability issues of PV generation and the lack of high-temporal resolution visibility that utilities have traditionally used to operate their systems. Tom went on to discuss how advanced PV inverter capabilities can mitigate many of the undesirable impacts by managing reactive power in the grid and building in bulk system support in distribution-connected PV to maintain overall system reliability.



In Area 9, John Trout (Dupont) summarized the use of field data and accelerated testing data to better understand materials durability. Data from 200 systems including 2 million modules showed 7.5% observation of problems with back sheets and 11% problems related to cells. The accelerated test sequence correlating best with field data included damp heat, UV, and thermal cycling and found 1000 h of damp heat exposure for backsheets and 2000 h for cell corrosion.



Today wrapped up the end of the Poster Sessions for PVSC 44. Throughout the 4 days, over 600 posters were presented which included traditional printed posters and the new digital format. Today's session included work in Areas 1, 2, 3, 4, 5, 9, 10. A complete list of winning posters can be seen in the registration area and will be posted to the PVSC website.

Women in PV Luncheon

During the lunch break it was on to the Women in PV luncheon. Guest speaker Dr. Lynnette Madsen spoke to an energetic crowd about her recent book, *Successful Women Ceramic and Glass Scientists and Engineers: 100 Inspirational Profiles*. It was a unique insight into the lives of many successful women in diverse careers, including scientists, astronauts, and policy makers, who hailed from countries all over the world. Dr. Madsen distilled some recurring themes of advice into 20 "pearls of wisdom" from which we can all learn and benefit, shared statistics and observations about the evolving nature of women in science and engineering, and highlighted the importance of fostering a supportive social and intellectual environment starting with children, and maintaining that support through adulthood. As always, an engaging and enlightening discussion session followed!



After lunch it was back in for a series of oral sessions in Areas 4, 5, 8, 9, 10, 12, and a joint session on Si-based Tandems dubbed Battle Royale! Highlights provided by area session chairs are presented below.

Area 5 - Advanced Characterization Methods

Lilei Hu from University of Toronto developed a method to acquire high-frequency HeLIC images of QD solar cells to identify carrier transport parameters, including lifetime, with mm spatial resolution. Andreas Buchler, from Fraunhofer Institute, presented a correlation between micro-Raman and micro-LBIC to map and understand the origin of shunt resistance in solar cells, as the material degrades, induced by mechanical stress. Julia Deitz, from The Ohio State University, gave an outstanding presentation on how EELS can be realized to measure and understand deep level defects in CIGS. She found that trap states were revealed by

EELS maps in good agreement with measurements by DLTS. The method can be extended to other systems. Jason Baxter, from Drexel University, showed time-resolved reflectance and transmission THz spectroscopy as an alternative to TR-PL for probing carrier dynamics on the ps timescale. By varying injection level, the approach can separate surface, SRH, Auger, and radiative recombination. John Moseley, from NREL, used quantitative cathodoluminescence with absolute intensities to obtain large statistical collection of grain properties to separate grain boundary, bulk, and surface recombination. 3D carrier dynamics modeling was used to extract SRV and lifetimes. Pierpaolo Spinelli, from ECN, discussed THz scanning characterization of Si surfaces to identify quantitative sheet resistance with 10 um resolution (subwavelength). Deconvolution techniques should improve resolution further. THz processing can assist characterization of dielectric opening, selective emitters, and more.

Area 8 - Measurement, Analysis and Rating of System Performance

Bruce King, Sandia National Labs, presented on the degradation of 6 CIGS modules typologies, modules presented either high degradation in Pmp > 2%/year or very stable with < 0.5%/y (degradation accompanied by degradation in fill factor). Katherine Klise, Sandia, presented running IEC 61724 with PecosReview and tested new IEC 61724 standards via analysis of Regional Test Center data using Sandia's open-source Pecos and PVLIB (code will be made available with new features). This work filters out edge-of-day effects via a sun position algorithm instead of low light filter. Panagiotis Moraitis, University of Utrecht, reported on the use of ground meteorological data available from Royal Dutch Agency to transpose to POA and calculate PR. PV systems in the Netherlands are divided in urban, sub/urban, rural categories. PR in rural area is clearly higher than in urban area when irradiance is unshaded (this difference is minimal during summer seasons). The difference in hourly PR decreases strongly as solar elevation increases, especially above 20 degrees (winter and morning/afternoon). The urban morphology (shading) is the cause of lower PR given unshaded POA. Andre Nobre, Cleantech Solar, highlighted that soiling is a significant problem in the high humidity tropics. Soiling of the irradiance sensors makes the calculation of PR particularly challenging. Satellite irradiance may have higher uncertainties due to lack of accurate aerosol (including AOD) data, given the high levels of atmospheric contamination (pollution). Satellite irradiance appears to predict higher irradiance during times of highest aerosols (winter). It was reported that a 0.5-1% PR degradation per day soiling rate has been observed in India and other countries in Asia. This requires frequent cleaning which is partially mitigated by lower labor rates and thus costs. Sandy Rodrigues, Madeira Interactive Tech Institute, spoke about organizing machine learning techniques into 5 tribes. Sandy conducted a literature review of all PV papers employing machine learning and categorized them as 1 of the 5 tribes to generate informative histograms about the most common use cases for the different ML approaches. Sandy also gave indications which techniques need more investigation in each "tribe". Genetic

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Algorithm is stated as the method that can perform well in case of available is limited. Josh Stein, Sandia, reported on introducing a 3-year test program to measure outdoor bifacial module performance (module-, string-, and commercial-scale systems). High bifacial gains are inversely proportional to the amount of energy production produced. For example, higher gains may be observed at the edges of the day (morning/afternoon) as compared to solar noon. This may be advantageous in certain Time of Use utility rate configurations.

Area 9 - Panels and Materials Durability and Accelerated Testing

In this session, the characteristics of materials used in PV modules were discussed from the practical and basic view-points. For the solder bond damage caused by the viscoelasticity of encapsulant, the adequate selection-procedure of encapsulant was proposed, depending on the deploying climate. For the adhesion strength, by the analyses of veteran modules, the potential thresholds (front encapsulant- cell and backsheet-encapsulant) were proposed. One highlight was the presentation of threshold values for backsheet and encapsulation adhesion force/delamination energy. Modules over the threshold values showed no damage.

Area 10 - PV Power Electronic Design and Control

Mahesh Morjaria (First Solar Inc.) gave an invited talk presenting on the reducing cost of installed solar energy, flexibility and AGC capabilities of PV. Jason Galtieri (UIUC) investigated a method to reduce PV variability (and reserve requirements) using a control mode based on PV curtailment and battery. Yu Jiang (University of NSW) investigated placing an energy storage system in the junction boxes of PV systems to control PV ramp rates. Yu is adjusting battery manufacturing processes to provide this capability. Josh Stewart (Sandia National Labs) presented an approach to use medium voltage DC/DC converter to reduce plant losses. The SNL team also created and tested a prototype device. Jay Johnson (Sandia National Labs) discussed UL 1741 certification testing using a controller hardware-in-the-loop testbed and potential improvements to the standard.

Area 12 - PV Lifecycle Analysis and Applications

In his invited talk, Professor Vasilis Fthenakis, Columbia University, presented opportunities for clean water desalination and the role of photovoltaics. 75% of new desalination capacity is provided by reverse osmosis (RO) plants. RO requires constant power input. He discussed solutions in which PV, despite the intermittent nature, can provide a clean power source for RO.

The late afternoon segment was broken into three joint session breakout topics. All three areas were well attended and had vigorous discussions. Some of the highlights from these sessions are available below.

Joint Area Session - Si-Based Tandems: Battle Royale

This session pitted III-V vs. perovskite based Si tandems in a battle for the best. Old world records were “bodyslammed” into history, while new records took home the belt. Some records include a 32.3% 2-terminal III-V/Si cell by wafer bonding, presented by Frank Dimroth of Fraunhofer ISE and a 23.6% monolithic Perovskite/Silicon device presented by Jason Yu of Arizona State University. Additionally, Stephanie Essig presented her results on III-V/Si by mechanical stacking included 4-terminal devices with efficiency of 32.5% and 32.8%. Finally, Jeremie Werner from EPFL presented results on both 4-terminal and monolithic Perovskite/Silicon devices with over 20% efficiency.

Joint Area Session - Multi-national Collaboration on Photovoltaic Grid Integration

Six members of the International Energy Agency Photovoltaic Power System Programme Task 14 - High Penetrations of PV in Electricity Grids presented reports previously developed and under current development focusing on PV grid integration on the transmission and distribution levels, and PV inverter standards and communications/control. Kazuhiko Ogimoto reported that last May, during a holiday week in Japan, Kyushu was operated with 72% PV penetration on an instantaneous basis! A few days later a PV forecasting error caused a situation where four conventional power units were started in 15 minute intervals to manage the afternoon ramp in falling PV power production. This showed the difficulty of operating power systems with high penetrations of PV without accurate load and generation forecasts. Gerd Heilscher calculated that if Washington DC had as much PV per person as Ulm, Germany, DC would need 265 MW more of PV installed. Gerd went on to define the need for communications and control on PV inverters and stressed the needs also of the market for energy services, potentially desiring blockchain-based transactions and secure communications.

Joint Area Session - Thermophotovoltaic (TPV) Workshop

This well attended workshop saw Lewis Fraas give an overview of the cells and applications. Ivan Celanovic talked about ongoing work on portable TPV systems. Peter Bermel spoke about possibilities in solar TPV. Eli Yablonovitch talked about improvements that could be realized with good back reflectors, and applications to portable TPV. The workshop presentations wrapped up Seth Hubbard discussing ongoing work on GaSb solar cells by different growth methods. Following the presentations, the room was open for questions to all of the speakers.

With all of the technical talks completed for the day, attendees took some time to get ready for the conference banquet being held in the Smithsonian Air and Space Museum. Descending on the National Mall it was a return in some ways to PVs origins and a great opportunity to see an amazing museum. The flight simulators proved very popular and the chance to see such amazing displays without the big crowds was appreciated by all. Hopefully you got a chance to watch the planetarium show as well! The Air and Space Museum was truly a magical venue, with some good music and yummy food to make it a memorable night. Enough to get you dancing with delight.....



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