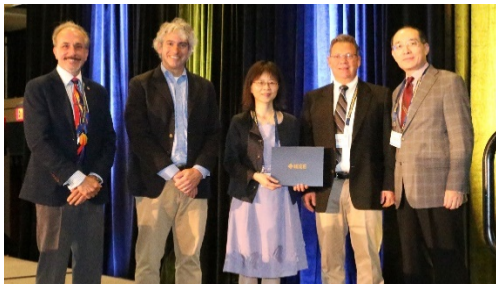




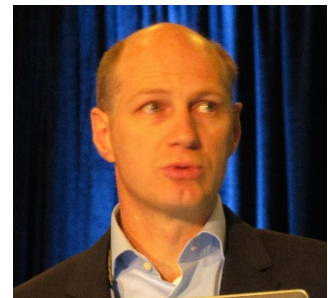
Tuesday at PVSC42 kicked off with this year's PV past year distinctions, honors and awards. The 2014 Cherry Award recipient Ron Sinton was recognized as well as the 22<sup>nd</sup> Becquerel prize winner Stefan Glunz of Fraunhofer ISE. 6<sup>th</sup> WCPEC award was received by Prof Masafumi Yamaguchi of Toyota Technology Institute and the PVSEC award winner was Dr Tatsuya Takamoto of Sharp Corporation.



Congratulations to Harry Atwater of Caltech and Supratik Guha of IBM on their election to the National Academy of Engineering. They join the illustrious colleagues Stephen Forrest, Larry Kazmerski, Mark S. Lundstrom, Thomas F. Kuech, and James S. Harris as elected members. Congratulations also to our colleagues Ray Hua Horng of Chung Hsing University, Taiwan, Yong Hang Zhang of Arizona State University, and Roger Malik of First Solar, on becoming IEEE Fellows (all pictured to the left).

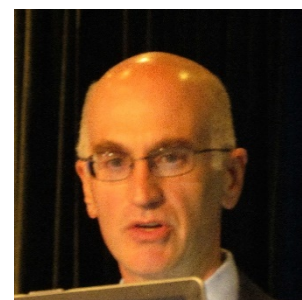
Following this it was on to plenary talk in Areas 5, 4, and 10.

In **Area 5**, Edward Hamers from HyET Solar presented the potential of thin film silicon photovoltaics as a flexible product. He stressed that thin film silicon flexible PV products have various unique selling points, such as high power density per mass, mass per nominal power, price per mass price per area. The thin film PV product allows low cost encapsulation materials and the lightweight character allows various unique building integrated PV applications. A 10% module efficiency for an a-Si:H/nc-Si:H device was presented as well as the progress in research on single- and multi-junction thin film silicon on a lab scale.



In **Area 4**, Andres Cuevas presented on the advances of new approaches to surface passivation and how incorporating carrier selectivity to this layer can produce high efficiency cells. He presented on results using an MIS type of structure achieving 21% cells and also using MSIS structure showing extremely low  $J_0$ . He also noted that it is early days with this approach and that many more materials will be used in the future to achieve these outcomes.

In **Area 10**, Robert Margolis presented on the future of PV in the US with future costs of PV expected to continuing declining. The main challenge cited is to increase efficiency of modules at low cost. Future growth requires a



combination of rooftop and utility PV as well as CSP to reach the Sunshot goal. Many of the benefits for PV in the US, including job creations, and environmental and economic benefits were highlighted. Many of the challenges including transmission, siting, environmental and land-use issues, as well as grid-integration were also discussed.

Following the coffee break the first poster session got under way with Areas 2, 3, 4, 5, 9, 10 and the Joint 1,3, 4 and 7 session. There was a lot of lively discussions with a very high standard of work being presented. The following posters received awards in their respective areas:

### Poster Award Winners

**Area 2:** J. Major et al., Structural and electrical characterisation of MgCl<sub>2</sub> treated CdTe solar cells. Paper 101

**Area 3:** R. Horng et al., High Separation Rate of Epitaxial Lift-Off Using Hydrophilic Solvent for III-V Solar Cell and Reusable. Paper 120

**Area 4:** T. Mueller et al., Interface investigations of hydrogen plasma etched silicon surfaces for heterojunction silicon solar cell applications. Paper 147

**Area 5:** P. Aryal et al., Quantum Efficiency Simulations with Inputs from Spectroscopic Ellipsometry for Evaluation of Carrier Collection in a-Si:H Solar Cells. Paper 163

**Area 9:** A. Carr et al., Tessera: Scalable, Shade Robust Module. Paper 188

**Area 10:** R. Fu et al., Economic Competitiveness of U.S. Utility-Scale Photovoltaics Systems: Regional Cost Modeling of Installed Cost (\$/W) and LCOE (\$/kWh). Paper 222

**Joint Area 1,3,4,7:** A. Tamboli et al., Indium Zinc Oxide Mediated Wafer Bonding for III-V/Si Tandem Solar Cells. Paper 255

After lunch 7 more oral sessions got under way.

In **Area 1**, hot carrier solar cells were the topic. Louise Hirst from NRL gave an informative review of the status of hot carrier research and the fundamental basis of operation. An InP lattice matched superlattice approach to energy selective contacts was modelled and experimental result were presented showing a

The logo for Photovoltaics International features the word "Photovoltaics" in a large, bold, sans-serif font. The "Photo" part is in orange, and "voltaics" is in black. Below this, the word "International" is written in a smaller, grey, sans-serif font. To the left of "International" are five colored squares: red, orange, green, blue, and purple.

lowered heat conductivity of carriers in the InGaAsP/InAlAs system. Jeffrey Chou of MIT showed efforts for a photoelectric water splitting device using hot carriers generated in metal and collected through a Schottky contact. A photonic crystal is included to help with absorption. Simon Chung from UNSW introduced HfN as a potential hot carrier absorber material. Sputtered samples showed interesting results

with extended thermalization times suggested. Jingfeng Tang from University of Oklahoma spoke about some encouraging results in InAs/AlAsSb quantum wells showing heightened carrier temperatures. Jianfeng Yang spoke about modelling results for plasmon enhanced optical extraction with results suggesting transferral of hot carriers to a PV device is promising.

In **Area 2**, chalcogenide solar cells was the topic. Schorr gave a complete description of compositions in CZTS kesterite that can be tolerated without having secondary phase segregation. The different compositional domains were described in terms of the defect composition. Liu showed that a double heterostructure reveals CdTe can achieve lifetimes greater than 1 microsecond. Surface recombination scales with barrier height and thickness. Lovelett developed a stochastic model based on single phase elements and events for selenization sulfurization processes to predict Ga profiling. Broussillou of Nexcis showed 17.3 % cell efficiency (made by cutting out of large plate) for small area cell and 14 % efficiency for full scale module. Also new design of transparent modules for building integration. Langhorst discussed how to reduce roughness in two-stage processes by adjusting the temperature profile during selenization and the impact on TCO uniformity.

In **Area 4**, advanced silicon cell structures was the theme. Christophe Ballif presented a 22.2% result on an innovative silicon heterojunction technology with MoOx and copper plated contacts and 10% efficient "White" PV modules for building integrated PV modules. Weiwei Deng presented a record efficiency for multi-crystalline silicon cells of 20.8% (243 sq. cm) and a module efficiency of 19.2% (aperture area) with average cell efficiencies of 20%.

In **Area 5**, it was thin film silicon materials and solar cells. Amkreutz of Helmholtz Zentrum Berlin showed comparable Voc to multicrystalline Si cells for liquid phase crystallized Si solar cells: 649mV at PCE of 12.2%. A new IBC concept for liquid phase crystallized Si solar cells was presented exploiting improved front side passivation. Richter showed nanocrystalline silicon oxide PCE of 20.4% in heterojunction Si solar cell with nc-SiOx at both contacts. Podrazatrac tracked, in-situ, the evolution of amorphous to nanocrystalline Si with real time spectral ellipsometry, correlating crystallinity evolution and electrical performance. Gaucher from CNRS PCE spoke of 6.5% efficiency for ultrathin c-Si solar cell with thickness below 5um using nanoscale pyramids. Meier from FZJ used in-situ Raman to measure and control the crystalline fraction for a constant fraction throughout the entire bulk. The efficiency of the single junction cell is improved considerably, demonstrating power of the technique.

In **Area 9**, solar resource measurement and modelling was on the menu. Perez presented on improvements in the V4 of the satellite to irradiance model including injection of now-casts, enhanced dynamic range, and better aerosol optical depths. Westbrook presented on sky diffuse irradiance modeling using the Brunger radiance model and numerical integration over the sky hemisphere. Results show similar or better performance as established Hay and Davies or Perez transposition models. Duck presented on the impact of spectrum on measured power output of various PV technologies in Newcastle, Australia. The Sandia and CREST models were found to have overall and daily offsets. Mutiara presented an evaluation of spectral distribution in the Netherlands, noting that the average spectra in summer and winter was different from the standard AM1.5 spectrum. Ivan Garcia presented on the binning of spectra for solar cell design and energy yield calculations, finding that binning by a spectral content parameter can yield a



low uncertainty with 3 bins corresponding to 3 representative spectra. Nguyen (pictured right) presented on the use of sky imagery to predict PV performance in the context of a utility feeder with a large PV source. The variability due to clouds can cause voltage deviations limiting the effective penetration on a feeder.

In **Area 10**, Trends in PV deployment was the subject. Barbose of LBNL showed that addition of PV has a greater impact on ROE than utility rates; utility PV ownership shows promise to reduce negative rate and ROE impacts of added PV. Yamaya outlined how, in Japan, regulatory agencies are needing to mandate PV curtailment as grid hosting capacity is not sufficient for the amount of approved PV applications for interconnection. Guerrero-Lemus showed that for island grids, storage is cost effective solution to avoiding transmission build out and upgrades.

In the **Joint 1,3,7 & 8** session characterization of multi-junction and concentrator cells was the subject. Deitz described a novel and very powerful SEM based technique (Electron Channeling Contrast Imaging) which provides much of the information traditionally found in TEM analysis, but much more quickly and easily. The technique was demonstrated on a variety of hetero structures and quantum dot materials. Dennis presented a novel solar simulator based on a super-continuum laser. The system allows the spectrum to be changed in an automated, programmable fashion and is capable of providing 1-sun power over 1cm<sup>2</sup> and up to 570x concentration.

In the late afternoon oral sessions were the following highlights:

**Area 1** – Quantum Well Devices. C. Bailey (Old Dominion University) gave an interesting extended oral regarding several physical effects related to quantum well solar cell performance and radiation hardness in the InAlGaAs/InGaAs on InP lattice-matched system. Toprasertpong (Univ. Tokyo) presented on time of flight measurements of the electron and hole velocity in quantum wells, with the results having important repercussions for optimum quantum well / barrier design for collection of both carrier types. Ichihashi (Univ. Nagoya) presented on novel work using visible-light photoemission spectroscopy to probe the conduction band structure of quantum well systems. This work elucidates effects critical for carrier transport in quantum well solar cells. Alex Freundlich (Univ. Houston) presented data showing great strides in his group to improve control of MBE growth for dilute nitride quantum wells, leading to a low band gap-open circuit voltage offset ( $V_{oc}$ ) of 0.4V. Chaffra Affouda (Naval Research Laboratory) presented on novel quantum well tunnel junction structures to interconnect sub-cells for InP-based solar cells. The inclusion of quantum wells increases tunneling probability whilst minimizing optical absorption.

**Area 2** – Progress in CZTS. Dennler reported consistent high efficiency (10.9 % max) CZTSSe by spray coating but high compensation was still an issue as well as a mid-gap defect at 0.51 eV. Adding water soluble Sn compound improved performance and eliminated 0.51 eV defect. Todorov presented on coevaporated CZTS on flexible ZrO<sub>2</sub> substrate for ultrafast annealing with up to 10% efficiency. Collard reported an investigation of Group I elements added to CZTSSe molecular inks. Li produced the best results with improved quasi-Fermi level spitting, better FF and  $V_{oc}$ , but also higher shunt resistance. Efficiency up to 11.3% reported. Wei reported AZTSe material ordering but became unstable above 400 C. Adding Cu to AZTSe resulted in little impact on device performance. Ag inclusion first lowered the

bandgap then increased the bandgap at higher compositions. Ernits showed that oxidation or ALD SnOx deposition on the surface of CZTS monograins resulted in improved Voc up to 810 mV. Best efficiency was 7.7%.

**Area 3** - High, Medium, & Low Concentration PV - Cells to Systems, Norton reported on first results from field investigation in Cyprus of new European Union Concentrated Photovoltaic project. With the notable exception of Cyprus, for the whole of the year no difference showing cell design tolerance. Raupp presented on a detailed study of the performance and reliability for 3 concentrated photovoltaic sites finding issues with off-axis tracking. Sharma spoke on performance of three multijunction cell within the same type of concentrator designs. Results of modelling show that for optimized systems a four junction cell can give you 3% efficiency boost. Videira presented on a concept for luminescent concentrators that can be used as a hybrid concentrated photovoltaic system and water splitting system, giving early details on the waveguide design required. Gu presented a novel concept for low-cost reflecting parabolic hexagonal concentrating system inspired by kirigami (origami where you can use scissors to create shapes) for a range of 5X to 9X with a flexible sheet actuated to perform one axis tracking.

**Area 6** - Device Stability, Scale-up and applications. Dr. Chittibabau, one of the special invited speakers for AREA 6, delivered an excellent overview for production of dye-sensitized solar cell using roll-to-roll process and integration of dye-sensitized solar cell for several consumer products. Jeffrey Tait (pictured right) of IMEC showed the in-depth investigation of the degradation mechanism of organic PV at Solliance. Davie Tanebaum of Pomona College showed the indoor and outdoor degradation of OPV devices from 8 different research group and showed degradation behavior all different OPV devices indoor and outdoor over 6 months. Finally, Jeffrey Tait of IMEC showed high efficiency >6%, blade-coated organic devices using environmentally friendly organic solvents.



**Area 9** - Models for Power and Energy Prediction. Riley presented a new predictive model for performance of AC modules that demonstrated small errors under 2% for power predictions. First Solar presented a new method for increasing the accuracy of PV performance modeling by including the effects of precipitable water in the representation of spectral shift effects. Hansen of Sandia National Laboratories showed that PV performance models can be accurately calibrated using fixed tilt IV curves, rapidly collected over a range of irradiance and temperature conditions.

**Joint Area 4, 5** – Contact formation. James Bullock of ANU, Canberra reported a greater than 20%-efficient p-type solar cell using a MoOx rear contact with 5% contact area based on the design concepts highlighted earlier in the day in the Cuevas plenary talk.

The day rounded off with two concurrent social events. The Cherry Award reception provided a nice high point to end the day with a great attendance and the PV Jobs Fair giving a great opportunity for those looking for new opportunities to establish links with those companies looking for good people. Following this most participants diffused into the surrounding areas in search of jazz, blues, and some good food.

That rounds out the highlights for Tuesday, there will be many more to come in the days ahead!

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