



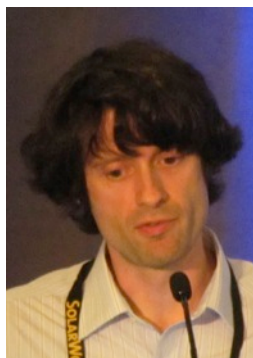
## Tuesday Highlights

Tuesday at the 43<sup>rd</sup> PVSC more technical sessions with many high quality results being reported. The Morning plenary session consisted of excellent presentations in Areas 3, 2, and 11.

In Area 3, Geoffrey Kinsey from the Department of Energy gave an excellent overview of many of the challenges faced by concentrator PV and the shake-out that affected the industry. Looking at whether the next decade will be zombie or superhero, the impacts of conventional silicon PV on the CPV market and some of the funding induced features of the CPV manufacturing space it was concluded that it could be a superhero as large scale PV takes hold.



For Area 2, Ingrid Repins spoke on some of the challenges for Chalcogenide solar cell design related to band-edge effects, and how these rules are changing as efficiencies improve. CIGS, CdTe, CZTSe, and new materials were discussed. The impact of increased diffusion lengths was shown to mean a move away from grain boundary mediated collection. Different requirements for both the front and rear grading, and minimization of band-edge fluctuations, are needed if the impressive results in this material system area are to be improved upon.



Jan Kleissl in Area 11 gave a very accessible overview of the current status of solar forecasting showing the considerable progress that has been made in the last six years. The improvement of forecasting models over different timescales and the move from deterministic to probabilistic models was highlighted. The question of what the appropriate metrics are for measuring the accuracy of solar forecasting was also tackled and some highly illustrative real world examples were shown to make clear the huge monetary losses that occur when solar forecasting is not accurate.

# Photovoltaics



## International

It was then time for the first poster session, with presentations in Areas 1, 2, 3, 6, 9, and 11. Some excellent work was on display and below are the winners of the poster prizes in each Area.

### **Area 1 - Light Management and Avant Guard Concepts**

Absorption Enhancement in III-V MQW Photovoltaic by Incoherent Back Reflector, **Wei Wang<sup>1,2</sup> & Alex Freundlich<sup>1,2</sup>**, <sup>1</sup>*Center for Advanced Materials, Houston, TX, United States*, <sup>2</sup>*Physics Department, Houston, TX, United States*

### **Area 2 - Absorber Preparation and material properties**

Effect of Varying Deposition Source and Substrate Temperature on CSS CdTe Thin-film Photovoltaics, **Amit Harenkumar Munshi<sup>1</sup>, Jason M Kephart<sup>1</sup>, Ali Abbas<sup>2</sup>, Kurt L Barth<sup>1</sup>, John M Walls<sup>2</sup>, Walajabad S Sampath<sup>1</sup>**, <sup>1</sup>*Colorado State University, Fort Collins, CO, United States*, <sup>2</sup>*CREST (Center for Renewable Energy Systems Technology), Loughborough, United Kingdom*

### **Area 3 - CPV Systems**

Next Environment-friendly Cars: Application of Solar Power as Automobile Energy Source, **Taizo Masuda<sup>1,2</sup>, Kenji Araki<sup>2</sup>, Kenichi Okumura<sup>1</sup>, Shinichi Urabe<sup>1</sup>, Yuki Kudo<sup>1</sup>, Kazutaka Kimura<sup>1</sup>, Takashi Nakado<sup>1</sup>, Akinori Satou<sup>1</sup>, Masafumi Yamaguchi<sup>2</sup>**, <sup>1</sup>*Toyota Motor Corporation, Susono Shizuoka, Japan*, <sup>2</sup>*Toyota Technological Institute, Nagoya Aichi, Japan*

### **Area 4 - Silicon Material Technology and Analysis**

Hydrogenation effect on low temperature internal gettering in multicrystalline silicon, **Mohammad Al-Amin & John D. Murphy**, *University of Warwick, Coventry, United Kingdom*

### **Area 6 - Perovskite Photovoltaics**

Evaluation of New Materials for Electron and Hole Transport Layers in Perovskite-Based Solar Cells Through SCAPS-1D Simulations, **Puruswottam Aryal & Shubhra Bansal**, *Department of Mechanical Engineering, University of Nevada-Las Vegas, Las Vegas, NV, United States*

## Area 9 - Reliability of Cells and Modules

Assessing Field Performance of Flexible PV Modules for Moisture Induced Degradation from Accelerated Testing, **Kedar Y. Hardikar**, **Todd Krajewski**, **Kristopher Toivola**, *Miasolé Hi-Tech, Santa Clara, CA, United States*.

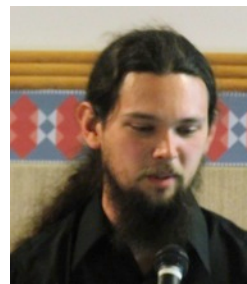
## Area 11 - Solar Resource for PV and Forecasting

Evaluating a Model to Estimate GHI, DNI, & DHI from POA Irradiance, **Michael Gostein**<sup>1</sup>, **Bill Stueve**<sup>1</sup>, **Kendra Passow**<sup>2</sup>, **Alex Panchula**<sup>2</sup>, <sup>1</sup>*Atonometrics, Inc., Austin, TX, United States*, <sup>2</sup>*First Solar, Inc., San Francisco, CA, United States*

Following the lunch break there was another set of oral sessions; some of the highlights from the 1.30-3.00 pm session are included below.

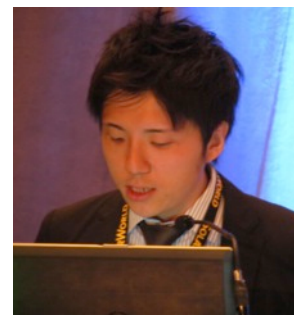
## Area 1 – Concepts in Hot Carrier and Thermophotovoltaics

The session started with **Gregg Scranton** (pictured) presenting work on designing a new type of TPV device, with a robust discussion ensuing on TPV background and promising future prospects, in particular, light management for high efficiency. This was followed by **Olivier Dupré** highlighting the importance of including thermal balance on evaluating optimal TPV parameters. The audience was notably animated on the subject of TPV with many questions. This session also featured an early result reported by **Pelz et al.** of a far IR rectenna demonstrating energy diode behavior in a bow tie/traveling-wave design. The session then featured **Gibelli and Guillemole's** hot-carrier simulation study using a novel non-equilibrium Planck method to calculate efficiencies in non-systemic material systems. The concluding talk continued with hot-carriers, with **Dimmock and co-workers** showing the effect of temperature variation on a metal/semiconductor hot-carrier device.



## Area 2 – Worldwide Industry Advances

**Bayman** reported on MiaSolé Hi Tech's flexible CIGS products that have been in production since 2013. Using stainless steel foil substrate and a single sputter deposition tool without vacuum break and a one hour total time from substrate entry to cell completion, 17% efficiency for best cells with narrow range for production cells has been demonstrated. **Hariskios et al.**, have demonstrated improved growth rate of chemical bath Zn(O,S) by changing from thiourea based bath to thioacetamide based bath. Also allows strong reduction of materials



consumption in bath. Achieved efficiency = 19.1. **Hiroi** (pictured) reported on Cu(InGa)S<sub>2</sub> absorber layer deposited by rapid thermal anneal process. Using a ZnMgO buffer layer deposited by ALD, gave high Voc = 973 mV, with efficiency = 13.1%, and Voc = 983 mV with efficiency = 10.1 %

#### **Area 4 – Silicon Materials Analysis**

Alternatives for fast dissolution of oxygen precipitates have been reported by **Bushan Sopori**. A better understanding of degradation in mc-Si and especially PERC solar cells have been reported by several authors. **Catherine Chan** from UNSW reported on the impact of firing temperature and conditions to the extent of degradation in mc-Si. She also showed two possible solutions to the degradation by extra firing step and laser processing condition. She also showed that in particular conditions near removal of the carrier injection degradation in p-type mc-Si is possible. **Simone Berandini** from ASU gave a very clear and comprehensive presentation on his work on mc-Si metal impurity distribution in GBs after different cell process steps and analyzed the impurity decoration of such.

#### **Area 6 – Organic Photovoltaics**

**Wallace Choy** from University of Hong Kong showed broadband plasmonic absorption enhancement from mixtures of metal nanoparticles of different shapes blended into OPV active layers. Dual plasmonic systems showed >9.5% efficiency. **Byeongseop Song** gave a very nice talk on molecular dynamics to explain non-intuitive optimization of D-A blending. **Wade Braunecker** described heavy fluorination of organic donors to complement fluorinated acceptors and conductivity optimization using characterization by time resolved microwave conductivity.

#### **Area 9 - Cell Reliability**

The relationship between PID shunt and Na accumulation was discussed by **Harvey et al.** Mechanisms for PID and LID were also discussed by numerous authors and it was shown how the leakage current may be used as the indicator of PID. **Tanahashi et al.**, reported on their study of the mechanism for hygrothermal stress by direct exposure to acetic acid vapor.

#### **Joint Areas 10, 11 – Solar Resource Forecasting for Grid Integration of PV**

Temporal down-sampling of low frequency irradiance data can result in 4-second data with widespread geographic coverage for grid integration and tap-change cycling studies. Multiple probabilistic and numerical techniques are used to predict daily accumulated irradiance PDF's in Singapore. A combination of Bayesian model averaging and Ensemble Model output techniques provide the greatest accuracy, particularly with the inclusion of numerical weather prediction models. Spatial averaging over larger

geographic regions will result in 3x reduction in day-ahead forecast errors and 3x reduction in level of curtailment or cost of storage batteries. This can be of particular value to ISO-wide day ahead grid dispatch orders. A combination of PV forecast and load forecast based on meteorological forecast data in Colorado can produce a gridded net load forecast for regional utility forecasts. Solar deployment is now to the point that you can no longer neglect PV production in utility demand forecasts. But tools are available that work, at comparable uncertainty to existing demand forecasts.

### **Joint Areas 1, 3, 4, 7 – Low Cost III-V**

**Schmieder** reported on GaAs cell with high efficiency (23.8%) at a grow rate of 1um/min and the use of higher temperatures at high growth rates to improve performance. **Jain** spoke about HVPE of InGaAsP growth with good composition uniformity. **Shervin** then showed interesting results for Al induced crystallization of Ge with crystalline/poly 220 Ge obtained, with PL of Rhombic Ge observed. **Scheiman et al.** reported on solar for UAV under 10,000 ft.

In the late afternoon sessions there were the following highlights submitted by Session Chairs:

### **Area 2 - Progress in CIGS Technology**

**Lorelle Mansfield** from NREL showed how statistical approach to experimental design could be used to quickly get to a higher efficiency level for CIGS with an Sb flux.

### **Area 4 – Surface Passivation**

**Sivaramakrishnan Rad** and co-workers from IMEC reported on 22% efficiency cells with a layer transferred interdigitated all back contact. Stable amorphous silicon carbide for heterojunction solar cells, was presented by **Boccard** of ASU.

### **Area 6 - Scaled Production and Reliability Studies on Perovskite PV**

**Hillhouse et al.**, gave a very insightful fundamental understanding on perovskite solar cells and generated lots of questions. **Bertoni** provided a very impressive elemental analysis of the cells using synchrotron X-ray. The information is particularly important to understanding the working mechanism of perovskite solar cells. **Xiao** (pictured) presented work on the potential profiling measured by Kelvin probe in the cross-section of perovskite solar cell using SnO<sub>2</sub> as a hole blocking layer. **Song** described the possible reasons of degradation and used laser induced current to study the degradation mechanisms.



### **Joint Area Session - Joint Session (9, 10): System Safety and Reliability**

**Felix Eger** presented his research on arc-fault noise from in-field measurements. It was found that the arcing signature for different fault cases produced different temporal results. He also showed the possibility to use a replay technique and the utility of a new arc-fault generation method (ball and ring).

**Jack Flicker** presented his work on module-level power electronics (MLPE) accelerated lifetime testing. He discussed the DOE PREDICTs program effort to create and exercise a qualification testing protocol for MLPE, including thermal cycling, damp heat, high temperatures, and grid transients/current pulses.

**Hamidreza Jafarian** presented a PV inverter robustness technique called the Smart Inverter Robustness Index (SIRI). SIRI is designed to take Latin Hypercube Samples for different inverter parameters to determine the impact on various inverter operations. **Narendra Shiradkar** presented accelerated testing for bypass diodes and junction boxes. Temperatures for multiple regions (3 climatic zones) were compared to standard testing procedures for electronics. It was found that in extreme climates the standard test is not conservative enough to predict lifetime for the parts. **George Kelly** presented his work on the IECRE, an IEC conformity assessment for renewable energy systems. This collection of certificates was designed to certify components installed at a specific site.

### **Area 11 - Solar Resource Near-Term Forecast Model Advancements**

Contrasting methods for quantifying solar variability in the day-ahead forecasting time frame were explored by a number of authors. Both methods exhibited promising skill in their ability to statistically assign probabilistic bands around day-ahead NWP forecasts. A notable audience feedback was the use of abbreviations and acronyms by authors.

Following these sessions after a brief break was the Cherry Award reception, where the recipient, Pierre Verlinden, got another chance to thank those who have helped him over the years and for the PV community to show their appreciation of the great work he has done over so many years.

That wraps Tuesday of the 43<sup>rd</sup> IEEE PVSC conference! Make sure you have got your tickets for this year's Conference Banquet, which will be held at Providence Park on Thursday evening. Ask at the conference registration desk if you haven't done so.

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PVSC ATTENDEES**

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