Tuesday morning welcomed attendees with Plenary Talks in Areas 1, 6, and 11. The morning session kicked off with a presentation in Area 1 given by Jean-Francois Guillemoles of the IRDEP at CNRS, who spoke about hot carrier solar cell and some of the illusions surrounding them. After first presenting an excellent overview of hot carrier effects in semiconductors, he then described the hyperspectral photoluminescence imaging technique that allows the carrier temperature and electrochemical potential of electrons and holes to be determined unambiguously. Insights on hot carrier solar cell design included not simply requiring slowed cooling, but control of all of the processes, as well as the selective energy contact operation.

In Area 6, Michael McGehee of Stanford University delivered an excellent overview on recent progress and development of perovskite solar cells. He showed promising thermal cycling results for addressing the big challenges to perovskites with stability results indicating the potential for long term performance. The focus of his group’s work is on improving stability and lowering costs and their work on a perovskite-silicon tandem devices was highlighted. As result of this work a world-record efficiency of 23.6% for 1 square centimeter monolithic perovskite Si tandem solar cell was demonstrated.

Area 11 saw Steven Steffel of Pepco Holdings Inc. give a broad overview of some of the challenges faced when integrating renewables into the electricity grid and some of the opportunities for PV in particular to play a vital role on the grid of the future. He showed how the grid of the future will need advanced monitoring and secure communications for existing infrastructure, advanced modelling for geolocating generators, as well as smart algorithms in order to balance load and distributed generation. The importance of PV in terms of ancillary services such as voltage regulation will also continue to grow in the future.
Following this session, attendees were able to recharge with some coffee before checking out the second poster session, covering Areas 1, 2, 3, 4, 6, 8, and 11. All of the poster winners will be listed on the PVSC44 website and you can check out the winning posters near the registration area.

After grabbing some lunch at some of the local eateries it was back into technical sessions with a full afternoon of oral presentations. In the early afternoon session there were talks across Areas 1, 2, 3, 4, 6, 8, and 9, with some of the highlights provided by the session chairs summarized below.

**Area 1 - Light Management and Spectral Splitting**

This well attended session included significant discussion around the talks on epitaxial lift off with light management techniques. Gabriel Cossio of UT Arlington presented new results on omnidirectional anti-reflective coatings manufactured on large area over 20cm$^2$. The talk from Natasha Hjerrild (UNSW) stirred the interest of the audience regarding incorporation of nanofluidic thermal harvesting. The author stated the possibility of greater than 30% combined efficiency. The last two talks of the session from Seth Hubbard (RIT) and Federica Cappelluti (Politecnico di Torino) gave good summaries of light trapping for absorption enhancement of nanostructures, with the first focusing on the effects of various backside patterns, while the last looked at the problem holistically.

**Area 2 - Advances in CdTe I**

Wyatt Metzger discussed doping in CdTe and the importance of simultaneously achieving high doping and minority carrier lifetimes. Their work demonstrated p-type doping $>10^{16}$, and also demonstrated compatibility of group V dopants with the CdCl$_2$ heat-treatment. Sachit Grover discussed As doping work at First Solar. They achieved p-type doping $>10^{16}$ cm$^{-3}$, however, with only a few % activation due to compensation. Brian McCandless discussed p-type group V doping of CdTe deposited by Vapor Transport. They demonstrated p-type doping above $10^{16}$ cm$^{-2}$, with As and Sb doping efficiency on the order of 10%. Mahisha Amarasinghe discussed the effects of CdCl$_2$ recrystallization on grain size, GB recombination, and intra-grain recombination. Amit Munshi discussed new efficiency records achieved for a CdSeTe/CdTe solar cell. They demonstrated efficiency $>19.0\%$ as a result of very high Jsc that was measured to be $>28.0$ mA/cm$^2$. 
Area 3 - III-V PV: Materials and Multijunctions

John Geisz presented the results of component development for a 6-junction inverted metamorphic device. Low-sheet-resistance 2.1-eV top cells with reverse heterojunctions were developed, as well as transparent tunnel junctions, high quality 1.7-eV material, and various methods of integrating high quality lattice-mismatched low bandgap junctions. Initial results of component integration showed promising results, with a realistic target over 50% efficiency. Daniel Friedman analyzed the influence of high temperature (400°C) operation on the performance of multijunction cells. Cells receive a greater boost in voltage with concentration due to the elevated temperature, and tandems are less sensitive to current-mismatch, making them less spectrally sensitive. Ignacia Rey-Stolle studied the effect of recently-developed TCOs for III-V multijunction cells. CdO:In is a potential candidate to be integrated within the anti-reflection coating while enabling lower sheet resistance with minimal absorption loss. Initial experimental results showed that the absorption followed expected modelled behavior, but a non-ohmic resistance appeared between the AlInP window and TCO, potentially due to the sputtering process or TCO reaction. Ivan Garcia systematically studied the effects of component integration and annealing during fabrication of a 4-junction lattice-matched GaInNAs cell. A large Voc drop was observed in the GaInNAs cell as well as the Ge subcell, pointing out areas for research and realistic pathways to device improvement. Aymeric Maros investigated the influence of bismuth surfactant on the growth and quality of a GaAsNSb solar cell, potentially useful for integration into lattice-matched multijunction cells. While bismuth surfactants previously had a positive influence on GaInNAs cells, for GaAsNSb the bismuth surfactant altered N and Sb incorporation, decreased PL intensity and increased carbon and oxygen incorporation.

Area 9 - Field Reliability, Systems, and Safety

Area 9 included presentations in module performance and degradation of cells and modules from a perspective of safety and reliability. Highlights from the session include, Dirk Jordan presented an entertaining discussion estimation of degradation from field data using a "best thing since sliced bread" metaphor. Olga Lavrova showed that system size has little relevance to the safety of firefighters, so that
selection of personal protective equipment is much more effective at controlling risk posed by photovoltaic power systems. Arnaud Morlier presented a fast and cheap alternative for electroluminescence in the field for module inspection by ultraviolet fluorescence of EVA. After a short break to catch their breath and refuel on coffee, it was on to the later afternoon session, which talks in Areas 1, 2, 4, 6, 9, as well as two joint sessions. The joint sessions were focused on characterization techniques for modules and systems and on solar forecasting for grid integration of photovoltaics. Here are some of the highlights provided by session chairs.

**Area 1 - Nanowire Photovoltaics**

Lars Samuelson first reviewed the growth and applications of nanowire arrays in the early days, followed by the development of nanowire photovoltaics in nanophotonics. Topics include 15.3% record efficiency of GaAs NW in 2015, substrate reuse via NW thin film peel-off, and tandem junction NW cells. He also introduced the aerotaxy method of single crystalline NW synthesis as a low-cost means to the mass production of NWPV. Growth of working tunnel diodes was demonstrated in Xulu Zeng's talk and mechanism of different dopant species were investigated. Stephane Collin presented a contactless cathodoluminescence mapping method to determine the doping level of GaAs nanowires. Dopants were observed to broaden the CL signal considerably, although the energy gap was relatively unaffected. Kyle Robertson presented theoretical work to optimize nanowire design in terms of their optical properties. Careful design to the structure although preferential absorption in the NW, close to the p-n junction improving performance. Srinivas Vanka discussed work solar driven hydrogen production using Ga(In)N NWs grown by MBE. Hybrid Si-GaN solar cells were developed with PCE of 10% demonstrated.

**Area 2 - Advances in Characterization, Analysis, Theory, and Modeling**

In the invited talk by Paul Haney, SESAME grain boundary code was introduced for the general analytical calculation of the dark recombination current for different configurations of the degrain boundaries. Michael Stuckelberger, presented XBIV method for CIGS solar cells characterization. Measurements were presented at much higher resolution as well. Tao Song, on the other hand presented work on CdTe solar cells in which the back Schottky contact is replaced by a Te buffer layer. It was observed that Voc depends on Te thickness and addition of Cu improves effectiveness. Bandgap fluctuations by EL in CIGS were examined via a method presented by Matev Bokalic. Finally, C.S. Jiang presented methods and models for grain boundary characterization (Kelvin probe microscopy, EBIC and CL).
Area 4 - Light Management and Thin-Film Silicon
Area 4 included six presentations and a few highlights were provided. These include a nice demonstration from Fraunhofer by using the plasmonic effect of Ag nanoparticles to color modules. AIST showed a nice study that clearly demonstrates the relation between metastable light induced defects (LIDs) and the degradation in performance in solar cells.

Area 6 - Organic Photovoltaics
Invited speaker David Jones presented extensive work on the implementation of BTR and its analogs for improved organic solar cell device performance and stability. Benjamin Lipovsek discussed the potential performance enhancement to organic devices from light management foils, as determined through a combination of simulation and experimental results. Satvik Shah used FTIR to identify sources of degradation, and their causes, that can negatively affect organic solar cell device stability. Bryon Larson looked to the future of OPV, using key metrics and measurements to screen materials for implementation in the next generations of OPV devices and develop device processing best practices. Vivian Suru John presented work on the synthesis, characterization, and implementation of novel co-polymers for use as p-type semiconductors in OPV devices.

After a short break it was time for the Cherry Award reception, with this year’s event including a captivating performance by Stefan Blaak and Martijn Blaak, two renowned concert pianists, performing a diverse range of quatre-mains pieces in front of a healthy crowd in the main ballroom. From there it was drinks and some food to continue lively discussions on the day’s events and future breakthroughs in solar.

Just a reminder, if you don’t have tickets for this year’s Conference Banquet, which will be held at the amazing Smithsonian Air and Space Museum on Thursday evening, ask about them at the conference registration desk.

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