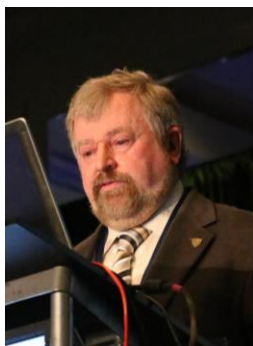
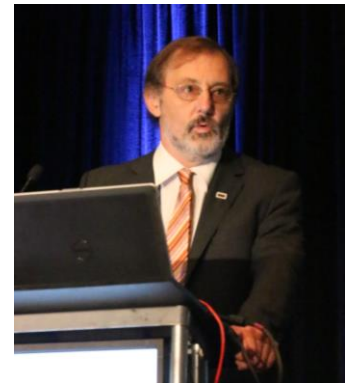




PVSC42 kicked off on Monday 15<sup>th</sup> June with a brief welcome from Steve Ringel and Alex Freundlich with some of the days anticipated highlights being pointed out to attendees. Dahlma Novak, President of IEEE Photonics Society, presented the key role of photonics in the shared advancement of PV, and in particular J-PV, covering the International Year of Light as a great success in this shared venture and reiterated the strong support of the Photonics Society to PVSC.

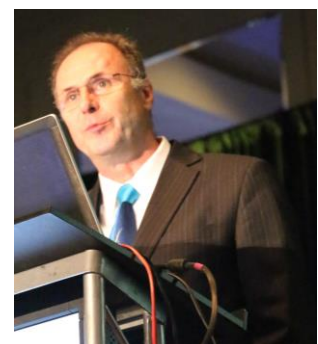
It was then on to plenary talks in Areas 3, 2, and 9, looking at concentrator PV, probing of polycrystalline Silicon for PV, and large scale production of high performance solar cells and modules, respectively.

Andreas Bett from Fraunhofer ISE, using his experience in both CPV research and being founder of Concentrix Solar, presented an excellent snapshot of the CPV industry in which he emphasized the rapidly improving technology in this area that is leading to significant lowering of cost. Highlighting the differences in module make-up and cost structure due to considerations such as larger cooling requirements and the need for tracking the importance of efficiency was emphasized. The recent improvements seen in efficiency of CPV devices are being adopted to industry in a typically 3 year timeframe helping CPV deliver competitive leveled cost of electricity produced. Along with more field data becoming available that show CPV performance not degrading or losing availability up to 6 years in the field the bankability of CPV has improved greatly in recent years.



Robert Collins from the University of Toledo presented on polarization probing of polycrystalline PV. Focusing on CdTe and CIGS the use of spectroscopic ellipsometry was shown to be a powerful in-line real time tool for CdTe and CIGS thin film production. The challenges in analyzing growth on rough substrates were discussed and the impressive abilities of these approaches to analyze multi layers and to even be used for monitoring of the growth process, allowing for optimization. Future directions identified included the adoption of these techniques to roll to roll production.

Pierre Verlinden of Trina Solar, took the audience through some of the advantages and challenges of taking high efficiency solar cell designs through to industrial production. A key point stressed by Pierre is that implementing high efficiency in production is not just about the design, but many of the other costs involved in manufacturing. The current position of manufacturers in terms of the high efficiency road map was highlighted with some impressive recent achievements that have been translated to production being



highlighted including PERC and IBC structures, proving the viability of these approaches. Moving beyond the cell level and to the module was also stressed as a key consideration for lowering the LCOE to make these approaches cost competitive.

After a round of delicious beignets and coffee, Conference Chair, Steve Ringel, gave a warm welcome to all attending the conference in 2015. The global diversity of participants at PVSC is reflected in a bumper program with 1029 presentations from 46 countries, with 56% of these coming from groups outside the US.

Keynote talks touched on the continuing move of PV into the commercial energy mainstream. Raffi Garabedian, CTO of First Solar Inc., challenged listeners as to why they are in PV and gave his own perspective of being part of an industry with purpose. He identified driving down utility scale cost to build on the gains made by PV in utility scale generation as crucial to the future of PV. He also showed how the market had shifted dramatically in the US from being rooftop driven to utility driven since 2010. However the size of PV capacity to the total energy needs is still  $< 1\%$ , which is a huge opportunity for the industry as 1TW of generation is targeted in the future. Rafi also reported an impressive CdTe Module efficiency of 18.6% - a new world record!



Jeremy Leggett, founder of SolarCentury, gave a rousing address telling all that the traditional energy industry is in panic mode as the ‘terrordome’ of lowering PV costs rapidly transforms the energy industry. He identified three megatrends of lowered insurgency costs, incumbency costs rising, and carbon action as driving this transformation. Not only has the industry achieved remarkable cost reductions, but at the same time traditional energy costs have ramped up. In parallel the political landscape is transforming with commitments to 70% carbon emission reductions further strengthening PVs hand. As more than 100 countries commit to zero net emissions by 2050 our industry will have an increasingly large role to play.

Sarah Kurtz then presented Christiana Honsberg with the 2015 Cherry Award in recognition of Professor Honsberg’s contributions to the advancement of PV across a number of areas.

Professor Honsberg used the Cherry address to explore some of the implications for society of the energy transition underway. Using the previous transportation transition as an example the interaction of peoples desires was explored, asking the question what do people actually want? All of this was examined with a thermodynamics bent. Some of the reasons given for PV to not succeed were taken head on, with energy payback dismissed in short time and the duck curve was shown to not be simply a technical issue, but mostly social and economic. Some more



technical issues were then addressed with pathways for improving silicon solar cell efficiencies were earmarked, pathways not excluded by thermodynamics. The discovery of novel processes and harnessing these in new designs were highlighted as key drivers for PV in the future. Finally, the applications for the electricity generated by PV were explored with key examples such as CO<sub>2</sub> mitigation and water desalination illustrating PVs power to transform society, as previous energy transformations have.

After lunch, Oral sessions for Areas 1,2,3,9, as well as joint sessions for 4 & 6, and 6 & 1 took us through to 3:00 pm.

**Area 1** saw an emphasis on the use of nanostructures for spectral manipulation. Several talks proposed application of colloidal QDs for upconversion and IBSC s and MEG. The potential for Solid state quantum structures for upconversion were also proposed. The ability to use band alignment for recombination rate manipulation was proposed.

**Area 2** reported on the progress being made in CdTe technology. Wyatt Metzger of NREL discussed how CdTe device efficiency can be advanced beyond current levels by increasing both the net carrier concentration and minority carrier lifetime. Open circuit voltages over 1.0 Volt were measured for single crystalline CdTe devices with grain boundaries play an important role in determining the effective minority carrier lifetime. Naba Paudel of the University of Toledo described how alloying of CdTe with CdSe can lead to improved photo-currents in CdTe solar cells. John Walls of the University of Loughborough discussed the effects of CdCl<sub>2</sub> annealing on CdTe solar cells investigated with TEM. The CdCl<sub>2</sub> anneal removed most of the stacking faults; only twin boundaries remained. Jonathan Majors presented work on ZnO nanowire-based radial CdTe cells. He noted that, although difficult to achieve high performance, nanowires provide some anti-reflection effect

**Area 3** gave updates on metamorphic multijunctions. Ryan France of National Renewable Energy Laboratory presented impressive results for a 4 junction inverted metamorphic device with an efficiency of 45.7% under 234 suns, the highest efficiency for such a device. Introducing an InAsP grade to the conventional InGaP graded buffer layers enabled access to a 0.7 eV bottom cell. In doing so, the low energy absorption is extended, adding 1.2 mA/cm<sup>2</sup> to the device Jsc. Drew Cardwell (The Ohio State University) and Michelle Vaisman (Yale University) both presented exploratory results regarding metamorphic, wide-Eg (>2.0 eV), Al-containing solar cells for multi-junction top cell applications.

**Area 9** started off with contributions on the materials, manufacturing and production of solar cell modules. Zhang from Trina Solar showed how all aspects of module interface to optimize module efficiency, delivering a record 335W panel. Buehler of First Solar showed how to use a technology readiness level approach to address reliability. Abbott described how PV Lighthouse has released a free cloud-based virtual silicon module production tool (PV Factory) for teachers. Soderstrom reported on



Meyer Burger developing manufacturing turnkey systems for bifacial modules and reduced silver usage. Schulte-Huxel of ISFH explained about replacing conventional soldering and conductive adhesives with Al-based Mechanical and Electrical Laser Interconnection.

**Area 11** looked at reliability of system and balance of system components. Ahmed Elasser discussed adapting reliability requirements in distributed power electronics (array, string, module) by compromising the number of minor failures permitted while maintaining overall reliability. Patrick Chapman discussed reliability analyses and verification testing of module-level electronics, concluding that non-component reliability concerns can dominate the component-level reliability analysis. Jack Flicker discussed PV array isolation monitoring requirements, concluding that the range of conditions that an inverter may be exposed to is too wide to allow a one-size-fits all criterion. Jay Johnson spoke about PV array arc fault detection in an effort to provide material to improve the draft UL1699B AFCI test standard so that it can pass ballot. Eric Schindelholz discussed characterization of PV connector degradation by lab testing and outdoor exposure, identifying considerably higher levels of connector degradation induced by outdoor exposure in the high desert area of New Mexico. George Kelly presented current status of the IEC Renewable Energy Conformity Assessment program for verifying designs, commissioning and operation according to established standards.

The **Joint Areas 4 & 8** session looked at the characterization of silicon PV. Dr. Hameiri showed how to extract effective lifetime curves from PL images providing a path to spatially resolved defect maps. Dr. Johnston from NREL presented an innovative way of measuring EL from individual cells in full modules in a contactless way. The results showed striking accuracy and resemblance to typical EL and PL measurements. Markus Lenz from Aachen University presented some interesting results in the applicability of THz pulses to characterize dopant segregation after phosphorous diffusion, simultaneously with sheet resistance. This capability shows potential for spatial mapping and in-line testing. Thomas Missbach from Fraunhofer ISE showed how to use a DDM by an original and clever design using the Texas Instruments Micro-mirror for frequency multiplexing. Johnson Wong quantified cell losses in specific regions such as edge and contact recombination by modeling the solar cell as interconnected diodes.

The **Joint Areas 6 & 1** session reported on efforts in hybrid materials and devices. Susanna Thon showed that, using nanophotonic and plasmonic enhancements, CQD cells could have increased current by 35%. Mailoa showed that the major efficiency loss was parasitic absorption in the hole transport layer. Tucci reported on very good efficiencies of 14.% for tandem perovskite/c-Si cells using mechanical stacking. Qin showed that a tandem architecture of perovskite and a-Si has greater stability than perovskite by itself. Paetzold showed that significant optical losses in perovskite cells can be reduced significantly by implementing nano-patterning of the front electrodes.

After a rejuvenating break it was on to the late afternoon Oral sessions.

**Area 2** continued with contributions to advances in buffer layers, and interface and back contact engineering. Hiroki Sugimoto discussed the impact of the buffer on kesterite solar cells, including materials costs and performance. Riedel discussed thinner devices, with light absorption enhanced by addition of nanorods to the back contact. He reported on Cu rich domains and the comparison of CdS with and without oxygen. Bugot discussed comparisons between near-junction diffusion in CdTe and CIGS, also demonstrating that annealing ZnOS buffer layer is possible and that the efficiency follows the

behavior of FF. Kim looked at depth profiling of ZnS layer properties on CuZnSnSSe devices using Kelvin probe scanning.

**Area 3** looked at high concentration PV Systems. Ghosal gave an interesting description of recent Sempruis field test results on modules and some highly reproducible flash test measurements. Sempruis have improved their commercial product to give 34.9% average efficiency. M. Yamaguchi described recent results from a Japanese-EU CPV consortium called NGCPV, designed to accelerate higher performance and lower cost. E. Loetscher described an interesting approach to reducing tracker costs using low cost concrete mirrors with an Al foil reflector. Ottawa showed results and simulations of the acceptance angle of three different commercial CPV systems using the SunLab tracking system. Eisler presented modeling and experimental results describing polyhedral spectrum splitters. This approach can lead to efficiencies in excess of 37%. Tatsiankou reviewed very impressive results for a new solar spectrum irradiance monitor. This detector offers a cost effective and reliable solution for spectral monitoring and showed calibration and reliability data.

**Area 4** got under way looking at surface passivation. Thomas Allen from ANU, Canberra, showed results on gallium oxide as surface passivation for c-Si. The passivation properties are similar to aluminium oxide, but are based on a doped semiconductor (not a dielectric). The first Ga<sub>2</sub>O<sub>3</sub>-based solar cells result was presented with efficiency above 19%

**Area 9** shifted emphasis to power electronics, storage and balance of systems. Chakraborty spoke on load rejection overvoltage testing results. T. Zhao presented on the new hybrid DC switch along with its advantages and accompanying test results. Fault protection and coordination scheme using these new switches was also discussed. Lars Norum spoke about a modular multi-level inverter. The new topology was discussed along with controller design. The results from simulation and hardware testing were shown in the presentation. K. Doubleday spoke on the performance of differential power processing sub-module DC-DC converters, shown to be beneficial in recovering inter-row shading losses. The last talk was given by R. Farswan on different PWM schemes for 3-level boost converter to reduce current stress on the DC link capacitors of NPC inverter.

**Area 10** started off by looking at sustainability of PV. Parikhit Sinha from First Solar showed that the risks of leaching from modules broken in the field is much lower than much of the traditional landfill leaching literature has presented. Kayla Collins, a student finalist calculated a reduced carbon footprint of 22% from US made solar panels compared to Chinese production. Lois Francke presented a full LCA analysis using specific data from Sunpower efficiency modules. The high efficiency modules have higher impact than comparable si modules due to specific materials use. Michele Bustamante showed risks to firms from commodity price volatility of byproduct materials tellurium and indium. The safety of QD nanoparticle production was evaluated by Bahareh Sadeghimakki using novel detection methods and toxicity essay. Finally a novel method was presented by Wolfram Palitzsch for recycling pv scrap that produces higher purity glass and active materials.

The **Joint Areas 2, 6, and 8** session looked at the characterization of thin film PV. Nikolas Podrazza (U. Toledo) presented spectroscopic ellipsometry data on hybrid perovskite materials showing evidence of formation of the compound and subsequent decomposition of the material near the substrate as the film became thicker. Carmen Ruiz (Univ. Aix-Marseille) reported photoluminescence and photoreflectance on hybrid perovskite materials. She showed that photoreflectance could measure the bandgap and these

values could be compared with the photoluminescence data, showing PL signal at a much lower energy than expected from the PR. There seems to be phase separation in the alloys into a material that is more iodide and bromide like rather than as mixed material. Andreas Vetter (ZAE Bayern in Erlangen) discussed results of illuminated lock-in thermography analysis of devices. An example was given for an OPV device with results simulated using a two-dimensional finite element tool to understand questions such as which defects control performance and does their distribution matter.

The **Joint Areas 1, 3, 4, and 7** session saw reports on the progress of III-V on Si via direct hetero-epitaxy. Tyler Grassman gave an exciting update on work on dual junction GaAsP/Si solar cells with recent work examining the effect of III-V growth on lifetimes in Si and lifetime recovery found by annealing under AsH<sub>3</sub> or PH<sub>3</sub>. Emily Warren, using a UHV MOCVD chamber with transfer (in vacuo) to STM, LEED, and Auger, presented evidence of the benefit of short, low temp anneals in AsH<sub>3</sub>. Surfaces resulted in single domain surfaces free of C and O contamination and no APDs or measurable misfit dislocations. Dan Chmielewski described worked on metamorphic tunnel junctions showing MOCVD grown junctions performed better than MBE grown junctions due to difference in dopants. MBE devices are expected to have Be diffusion problems and Si compensation. MOCVD results show C and Te dopants do not suffer from similar effects. Elisa Garcia-Tabares found that degraded lifetime observed in active Si cell (bottom cell) was result of hydrogen passivation during III-V growth, not related to P-gettering of defects or thermal effects, implying MOCVD growth is better suited for III-V / Si than MBE.

The exhibitors opening reception rounded off a busy first day for attendees, marking the opening of the exhibitors events with a good attendance making it a social highlight to end the day on. Exhibitors include materials and equipment suppliers, as well as national laboratories and others, all available to discuss their capabilities and how you might work with them on your next exciting research project. The exhibit is in Elite Hall for Tuesday 10am-6pm and Wednesday 10am-3.30pm if you haven't already paid a visit.

Finally, it goes without saying that N'Orleans is famous for its cuisine, and no doubt you have already sampled some of the many delights the city has to offer. So grab some old friends and some new ones and head out in to the Big Easy to find your next favorite food stop. The French Quarter is not that far, but perhaps minimize your time in Bourbon St!

A great start to the conference with more highlights to report in the coming days!

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