PLENARY PRESENTATIONS

Tom Markvart from the University of Southampton, UK, used thermodynamics to explain the operation of a solar cell and the way the chemical potential of emitted photons is recovered through photon recycling. Recognising that a significant fraction of the incident energy is lost to carrier thermalisation, Tom continued to outline a thermoelectric approach for the implementation of a hot carrier solar cell, in which SQ efficiency could be surpassed.

David Cahen from the Weizmann Institute presented a comprehensive survey of halide perovskite materials and their application to photovoltaics. He highlighted that perovskite materials have a number of unusual properties, chiefly that they represent a rare instance of a soft inorganic semiconductor. They also have remarkably low defect densities and in common with CIGS, they have a self-healing ability but with a much shorter time constant, 10 minutes as opposed to 10 years for...
CIGS. He concluded with some recent device results noting that the highest efficiency for a perovskite/silicon tandem cell is 28%, held by Oxford Photovoltaics.

Uwe Rau from Fz. Julich showed how losses in a solar cell can be determined by either performing a detailed bottom up analysis, or by using reciprocity relationships between absorption and emission it is possible to use top-down methods such as luminescent imaging to extract surprisingly rich data from a solar cell.
Regular Sessions

In Area 2 “CIGSe Alkali Treatments and Other Interface Phenomena” an extensive study of alkali post-deposition treatments on (AgCu)(InGa)Se$_2$ films and solar cells by M. Edoff showed that low Voc deficit of 0.4 V could be attained with KF, K, RbF, and Rb treatments but the Rb treated cells required light soaking for maximum performance. Using Raman Spectroscopy, S. Soltanmohammad showed that Cu-poor ACIGS showed lower Voc losses than Cu-rich ACIGS after light soaking. N. Valdes showed XPS data that revealed Ga-containing ACIGS has larger decreases in surface Cu and Ag than ACIS after KF post deposition treatment. Also unlike for CIGS, Voc decreases occur in Ag-containing alloys after KF post deposition treatment.

In Area 2: “Advanced Characterization and Simulation of CdTe” A. Phillips introduced the concept of a back buffer layer and a new composite parameter IFLO which rolls up the effects of doping and band offset of the back buffer layer. High doping in the TCO emitter and positive valence band offset at back interface are critical to minimize effects of interface recombination and improve Voc. Thomas Fiducia of Loughborough University, UK presented work titled ”3D imaging of selenium distributions in high efficiency selenium-graded cadmium telluride solar cells”. Thomas combined beautiful high resolution cathodoluminescence images with elemental distributions to show how selenium was distributed through high-performance CdTe cells, with a deficit at grain boundaries in the regions with high selenium concentrations near the cell top surface and a surplus in bulk regions, induced by the diffusion processes during CdCl$_2$ treatment of CdSeTe/CdTe bilayers. This implies that the conduction and valence band edges vary differently from grain to grain boundary in the front and back of the cell, leading to much improved cell performance. This is part of a recent emerging trend in thin film PV recognising that the composition and electronic structure of grain boundaries are heterogeneous not just with crystallography but also with depth in the cells as results of processing. Lastly in this session, work from UI Chicago and Argonne pioneered the use of machine learning to predict the properties of defects in random alloys of semiconductors, which is a notorious challenge for ab-initio calculations.

In Area 4 “Silicon Material: Substrate Formation and Preparation” C. Nguyen presented a fast new microparticle-based c-Si texturing method suitable for thin silicon wafers demonstrated. P. Guimera Coll presented a method for producing ultrathin c-Si wafers by spalling with very low surface roughness through suppressed wave technology. K. Bittkau presented an advanced light trapping structure in which light is selectively scattered into internal optical modes and achieves light-trapping beyond the Lambertian limit.

Areas 3 & 6 combined for a joint session on “Hybrid Tandems - Battle Royale”. S. Fan et al. reported on a 20% MBE-grown GaAsP/Si tandem solar cell. They demonstrated high bottom cell current and implemented a thermally stable tunnel junction in their device. Tyler Grassman reported on improvements over his group's 2018 record 20.1% epitaxially grown GaAsP/Si tandem cell. By improving the current of the Si cell, improving the GaP nucleation, and reoptimizing the top cell and buffer layer, they showed a path to a 30% efficient device. To date an unconfirmed efficiency of 21.8%. Marko Jost presented how the employment of a thin NiO$_x$ layer between the CIGS bottom cell and perovskite top cells can be optimized to reach a 21.6% efficient cell on a 0.78cm$^2$ device area. Zhaoning Song et al. developed a low bandgap Sn-Pb based perovskite solar cell for the bottom cell of the all perovskite tandem cell using Cl for improved passivation. The two subcells are connected via an all vacuum processed ultrathin Ag/MoOx/ITO layer. San Theingi discussed the optimization of a Si bottom cell for a luminescent solar concentrator tandem. She showed a 15.4% Si cell with a Voc over 700mV underneath a filter and wave-guide structure, a promising result for the future of this type of tandem device. Zhengshan Yu et al. employ additives in their perovskite absorber film to increase the grain size and efficiency. Under consideration of improved light management from optical modelling and optimized contacts the perovskite solar cell is integrated in a perovskite/Si tandem cell with 25.4% power conversion efficiency.

In Area 5 “Advanced characterization for perovskite PV”, S. Wieghold discussed the effects of Pbl incorporation and the fact that thicker films not only had larger grains but less unreacted PbI$_2$ as determined by X-Ray synchrotron measurements. H. Nguyen
described a technique to determine losses in perovskite films using spatially filtered EL and PL. A. Bercegol described observation of photon diffusion in perovskite film and its effect of extracted diffusion length. C. Xiao presented a cross sectional analysis of perovskite solar cells showing the main interface occurs at perovskite/SPIRO interface but this junction switches to the TCO/perovskite after illumination and improving performance. X. Chen used Impedance spectroscopy to show two dynamic responses in perovskite solar cells that were attributed to dark and light recombination channels. These recombination processes are understood to be related to electron and ionic migration, respectively.

In Area 5 “Advanced characterization for Silicon PV,” the ability to measure voltage on the nanoscale to characterise individual PERC back contacts using photoconductive AFM tips was demonstrated by Bryan Huey. Spatially resolved measurement of the temperature coefficient of implied voltages was demonstrated on multi-crystalline wafers from different positions of the ingot by Shuai Nie.

In Area 6: “Applications of Perovskite PV: Tandems, Scale-up and Industrialization” Colin Bailie presented work from Tandem PV on the complexities of scaling up halide perovskite PV architectures from cells to mini-modules pointing out the relative advantages of laser versus mechanical methods for scribing through the various layers. Valerio Zardetto described Solliance’s progress on scalable fabrication of 100 cm² area, semi-transparent halide perovskite PV modules using primarily slot-die coating and S2S ALD. Y. Huang employed a model to study the diffusion of mobile ions in perovskite solar cells and reproduce key characteristics such as hysteresis, etc. He applied ‘Big data’ analyses to determine key degradation mechanisms and sort them by significance (moisture, inclusion of oxygen, heat, type of CTL etc.)

S. Lee reported on attempts to deposited perovskite top solar cell on textured Si bottom solar cell by a dry two-step process. The perovskite layers grown on textured Si solar cells show good conformal layers, proven by partial LBIC and spatial PL. S. Manzoor investigates performed optical modelling of all perovskite tandem PV cells. For the first time conclusive set of the optical constants of low- and wide bandgap perovskites are provided.

In Area 8 “System Optimization and Performance”, A. Le Henaff presented a cost optimisation of desalination systems, showing that curtailing PV consumption and cutting out battery systems can reduce CAPEX of a community scale installation. Kendra Passow of First Solar analysed mis-tracking related losses, which had large implications on a daily basis. She demonstrated that a lot of these problems can be remedied at a cost. Allison Perna discussed the idea of optimising PV plants not for kWh but secondary use, showing the value of dual land usage.

In Area 9 “Global Perspective on PV Degradation”, Jordan, French, Karin, and Golive all spoke about the influence of climate and mounting and, in particular, how those factors can play together. Perez gave us a high-level view of how we can look at system performance with capacity factor, and showed variations across the
Another theme we heard in the session is that operations and data quality are critical to getting clear answers about degradation and the factors that influence it.

In Area 9 “PV Degradation Assessment Methods,” the presentations focused on degradation rates and showed tremendous variability between different parts of the world. There are important differences between module degradation rates and system or plant degradation rates. Understanding system degradation rates requires knowledge of recoverable losses like soiling, inverter or tracker failures, and other O&M events. Module losses can also be affected by soiling or front surface damage, along with additional degradation modes expected, like hot spots due to cracked cells, backsheet failures, and interconnect damage.

In Area 10 “Grid Integration, High-penetration PV and Energy Storage” the session covered a variety of modelling, analysis, control, simulation, and testing approaches for networks with high levels of PV integration. Papers covered broad topics spanning timescales (real-time control to longer-term optimization) and applications (distribution- to transmission-level systems).

In Area 12 “Market, Policy, Financing and International Corporation” Izumi Kaizuka presented a summary on the freshly released annual report from IEA-PVPS on global PV markets. The global cumulative capacity has reached 500GW and heading towards the terawatt era. At present 2.58% of global electricity generation is derived from PV. A. Jaeger-Waldau summarized the New EU RE directive 2018/2001/EU, describing at least 32% RES share in the EU and allowing households and businesses to become clean energy producers. The EU PV market is recovering in many EU countries, possibly totalling around 15GW this year, yet falling short of reaching the 2030 target. An interesting talk was given by Harry Apostoleris of Khalifa University, Abu Dhabi, who discussed “The role of financing in achieving ultra-low electricity prices in the Middle East”, expanding upon a recent Nature Energy paper where he was lead author. He found that the low power purchase agreement prices being quoted were the result of several factors including high debt loads and low interest rates, a hybrid ownership model with the project partly owned by the developer and partly utility-owned and a large ownership stake by state-connected firms. He concluded that: “How do we pay?” is the wrong question. Instead we should be asking: “How do we identify which projects are viable?”; “How do we help viable projects get financed?”; “How do we reduce the cost of financing?”. Focus on financing will be the key to making the transition to unsubsidized solar.
Poster session
In Area 2 “Characterization and Modeling of Thin Film Photovoltaics”, Aanand Thiyagarajan won the poster prize for a poster titled “Analysis of the $\text{Mg}_{x}\text{Zn}_{1-x}\text{O}/\text{CdTe}$ interface in CdTe thin film solar cells using Density Functional Theory (DFT)”

In Area 3 “Hybrid Tandems, Cost Reduction, and Novel Concepts” Dan Lepkowski from the Ohio State University won the poster prize for his poster titled "The Critical Role of Window Design in Rear-Emitter Solar Cells." In it, he described the importance of taking Fermi level pinning of the window layer into account when designing rear-emitter GaAsP cells, a promising candidate for epitaxial III-V/Si tandems.

In Area 4 “Performance & Reliability” Pradeep Balaji won the poster prize for work on “Flexible silicon heterojunction solar cells on 40 µm thin substrates”

In Area 6 “Perovskite Materials and Devices” Jiadong Qian of ANU won the poster prize for work on an economic and experimental analysis of perovskite degradation and its impacts on tandem 2T and 4T perovskite-silicon tandems. Kyle Montiel of Case Western Reserve shared two-step PVD synthesis and device results of lead-free perovskite CsGeI$_3$, demonstrating a six-fold increase in Voc from previous reports on this potential emerging PV absorber.

In Area 8 “System Optimization, Performance and Models” Marília Braga won the poster prize for work on “Spectral Impacts on the Performance of mc-Si and New Generation CdTe Photovoltaics in the Brazilian Northeast”.

In Area 9 “System Performance and Degradation” Alan Curran won the poster prize for work on “Performance Loss Rate Consistency and Uncertainty Across Multiple Methods and Filtering Criteria”.
Professor Toshio Hirota from Waseda University and Mr. Keiichi Komoto from MHIR Japan gave an overview of the IEA PVPS Task 17 exploring the opportunity for integrating photovoltaic power generation into electric vehicles. An important, but not well studied element of this problem is the actual solar irradiance that a vehicle is likely to receive on a day to day basis. Dr Yasuyuki Ota explained his recent irradiance measurements taken from a vehicle rooftop while driving around the city of Miyazaki. Dr Bonna Newman from ECN-TNO explained that The Netherlands has one of the world’s highest number of electric vehicles on the road that in turn motivates the desire for partial charging from the sunlight that falls on the vehicle. ECN-TNO have developed an energy flow model accounting for charging rates from PV on curved vehicle surfaces. They find that for a regular commuting pattern of 10,000km per year in the Netherlands, the frequency of charging drops by almost one third, with almost no charging required at all during summer months. The Lightyear company in The Netherlands is building a high performance electric PV vehicle that will be powered using silicon IBC cells scheduled to be launched on June 25th. Jian Ding, CEO of Alta Devices outlined the many thin-film PV technologies that the Hanergy group are developing suitable for integrating into an EV, including highly efficient GaAs. Extensive modelling was presented considering the integration issues in vehicles while accommodating pedestrian safety; R&D proceeding in partnership with Audi. Simulation results confirmed that a PV equipped EV is charged 15x less frequently than a standard EV.