

PVSC 50 Daily Highlights Monday June 12, 2023

Welcome to the first day of the 50th IEEE Photovoltaic Specialists Conference in beautiful San Juan, Puerto Rico!

Plenary Sessions:

Area 8 Plenary: Colin Sillerud from CSV Labs presented the first Plenary of this year's conference on challenges with PV module reliability testing. Colin showed how extended stress testing could help to early identify problems with module designs and bill of material combinations. This is of special importance for new technologies like HJT, TOPCon, and IBC to secure project financing, risk mitigation, or justification of high quality panels. As modules have become larger, the smaller frames and thinner glass may cause a significant increase in failures, which manifest in interesting ways. While glass/backsheet combinations may survive hail better but cells may suffer internal damage, while glass/glass arrangements don't tend to break cells as long as the glass doesn't crack. Considerations for extended reliability testing were discussed including UV testing, encapsulant type and formulation, temperature, humidity, and UVID. He concluded with some suggestions for the future of testing specifications such as hail components and improved UV testing.

Area 7 Plenary: Mauro Pravettoni from SERIS at the National University of Singapore highlighted different challenges and opportunities of conventional vs floating PV. He highlighted the appeal of FPV for densely populated island nations, but challenges with harsh, dynamic environments which can cause structural collapse or torsional module breakage. This presentation overviewed many of the alternative concerns, including the constant presence of water, salt and other chemicals, sea life and rodents, sand, vibration and sinusoidal motion. New tests were developed to test unique challenges such as thermal shock from the sudden impact of water, water impact/immersion, biological impact, and torsion tests. Testing demonstrated that PID salt causes significant damage on older modules subjected to PID, as well as torsional mechanical testing. Future includes investigating cold/night conditions, propagation of cracks in this dynamic environment, and accelerated testing.

Area 9 Plenary: Unfortunately the speaker was not able to attend, and the session was ended early.

Opening Session

General Chair Mariana Bertoni officially opened the conference, thanking the Organizing Committee for their hard work and welcoming everyone with a brief history of the PVSC (and a hint to take notes for Quiz Night later in the week). Highlights included the first PVSC at NASA HQ 1961, the first session on terrestrial applications in 1970 (8th PVSC), the first multi-day conference in 1976 (12th PVSC), the first Cherry Award presented in 1980 (to Dr. Paul Rappaport), the first Sun Run in 1982 (16th PVSC), the emergence in the 1990s of Kaz Solar designs on ties and scarves, and the first female chair Shelia Bailey in 1998 (27th PVSC).

This year we have presentations from 39 countries, with 64% of those from the US. There are many great events this week outside of the Technical Program including the Minority Carrier Lunch, Women in PV lunch, Sun Run, Jobs Fair, Quiz Night, and the Middle & High School Competition. Finally, the 19 intrepid GSAs were thanked for their services helping things run smoothly this week.

Program Chair Jeremiah McNatt thanked the Program Committee Area Chairs, Sub-Area Chairs, Reviewers (over 2900 total reviews performed!), and Session Chairs for delivering a strong technical portion of the conference. With topics spanning early concepts, materials, cells, modules, systems, decommissioning, and policy, the PVSC has grown significantly from early days and now addresses all aspects of photovoltaic technology and integration. This year's Keynote will be given by Gabriela Bunea, and Plenary presentations will be given throughout the week. There are two Special Sessions: Renewable Initiatives in Puerto Rico; and 100% Renewable Energy, moderated by Ron Sinton.

This year's IEEE Stuart R. Wenham Young Professional Award Winner is Yifeng Chen, who will give an invited talk on Thursday in Area 7.



Image: (left to right) Conference Chair Mariana Bertoni, IEEE EDS President Ravi Todi, IEEE Stuart R. Wenham Young Professional Award Winner Yifeng Chen, and Program Chair Jeremiah McNatt.

IEEE EDS President Ravi Todi announced the winner of this year's IEEE William Cherry Award, Jenny Nelson, as well as the election of Pierre Verlinden to IEEE EDS Fellow for leadership in high performance silicon solar cell and photovoltaics technology and commercialization. Following the announcements, Christiana Honsberg formally introduced Jenny Nelson, with salient moments of her career noted from the calculation of missing plutonium from UK energy production and the resulting Nature paper, to early development of quantum well solar cells, and the distinction of having the almost the highest rated book on the physics of solar cells on Amazon, second only, somehow, to Green Eggs and Ham.



Image: (left to right) Conference Chair Mariana Bertoni, IEEE EDS President Ravi Todi, IEEE William Cherry Award winner Jenny Nelson, Christiana Honsberg, and Program Chair Jeremiah McNatt.

Jenny Nelson delivered her Cherry Award acceptance talk, discussing the need to use all the tools at our disposal to continue the proliferation of photovoltaic deployment, which includes: silicon, silicon + X, multijunctions, low cost solution process; PV + X integration to meet the needs of decarbonizing with solar. This extends to all enabling technologies including transmission, distribution, storage, buildings, transport, agriculture, water, and fuels. She then discussed some of her own career highlights, including getting hired 33 years ago hired as a postdoc by Keith Barnham to figure out how quantum wells affect voltage in III-V devices. She moved on the low cost dye sensitized solar cells, modeling charge transfer. Next, conjugated polymers and understanding function of OPV from absorption of a photon to carrier extraction. Material development on selective contacts, thicknesses, microstructure, etc. has led to an

increase in OPV efficiency from 2.5% in 2001 to > 19% in 2022. Using reciprocity of emission versus absorption, non-radiative recombination was examined and used to modeling limits and non-idealities to determine a realistic efficiency limit. Adding the chemistry into the physics of drift diffusion plus kinetics at the interface, the whole story of the system is modeled, which allows targeting properties for improvements. She concluded discussing what lies beyond bulk heterojunction devices and improved control of the interface. At a higher level, she notes it is important to look at if we do X, what difference will it make, and what is the energy cost.

Technical Sessions:

Area 3 - Advancing III-V Single and Multijunction Devices

III-V PV is alive and well! Lots of nice results on optimizing results for space and lightweight applications. Robert McCarthy (MicroLink Devices) gave an invited talk showing thinning of middle cells and using DBRs allows better power retention than existing designs. Kenneth Schmieder (NRL) showed tunnel junction designs on InP requires tuning of many growth parameters including hydrogenation, and must be tested in-device to get an accurate idea of performance. Improved design using C:InAlAs Si:InP allowed operation at over 370 suns. Rao Tatavarti (MicroLink Devices) showed combining quantum wells and DBRs gives improved efficiency with improved EOL efficiency performance after 1 MeV $1e15$ e-/cm² from 18.5% (control) to 19.6% (MQW). Seth Hubbard (RIT) showed dual junction design incorporating QWs provide a 3.6% absolute AM0 efficiency improvement with minimal loss in Voc, but radiation results indicate significant J02 reduction, limiting voltage at EOL. With improvements, dual junction devices could outperform triple junctions at the end of life due to higher radiation tolerance and lower operating temperature from IR rejection. Mijung Kim (UIUC; Best Student Presentation Award Finalist) presented on metamorphic rear heterojunction InGaP for high temperature operation that outperformed lattice matched and front junction InGaP by suppression of thermionic emission.

Area 4 - Thin Silicon, Light Management, Device physics and characterization

Karsten Bothe (ISFH) showed that decreasing doping density and wafer thickness of the silicon substrate can lead to open circuit voltage (Voc) over 750 mV and fill factor (FF) around 89.2%. This session included presentations by three Best Student Presentation Award Finalists: Anh Huy Tuan Le (UNSW) on Temperature-dependent performance of ultra-thin silicon heterojunction solar cells for space applications, Chirag Mule (Mines, NREL) on Electron paramagnetic resonance investigation of the defect responsible for light- and elevated-temperature-induced degradation in Ga-doped Czochralski Si, and Jorge Ochoa (ASU) on The Temperature Dependence of Auger Recombination in Silicon.

Area 5 - Advanced Optoelectronic Characterization Techniques

David Jacob (Maxeon) showed a fast (1 minute/cell) camera-based absolute TRPL technique on finished and unfinished cells, used every day in production and R&D to extract different components of

recombination with a spatial resolution of 0.3 mm/pixel. Calvin Fai (UF; Best Student Presentation Award Finalist) showed how an adaptive and physics-driven Bayesian approach can handle the complexities TRPL parameter extraction. Used metropolis monte carlo sampling method to cut optoelectronic simulations numbers to a manageable number. Steve Johnston (NREL) studied larger than expected voltage degradation in Si HIT modules by EL, PL and DLTS, and observed a series of majority (electron) traps. Mason Mahaffey (ASU; Best Student Presentation Award Finalist) showed us how to utilize Quasi steady state photoluminescence to probe lifetimes and external radiative efficiency of thin film devices such as CdTe and perovskites It can measure doping concentration as well using this method and get good agreement with the model without the need for a capacitive structure. Chun-Sheng Jiang (NREL) presented that grain boundaries are positively charged based on SKPM images, with potential fluctuations mainly arising from the grain boundaries. Nikos Kopidakis (NREL) discussed the effects of spectrum adjustment on overdriving the current in one junction or another in multijunction devices, which can further affect the FF. Poor spectral adjustment is large source of systematic error in multijunction solar cells.

Area 6 - Single Junction and Tandem Halide Perovskite Solar Cells - 1

Bin Chen (Northwestern, Toronto) reported a study of losses in all-perovskite tandem solar cells and found that they could achieve 90% of the detailed balance voltage limit by reducing surface recombination between the perovskite/electron transport layer Chongwen Li (Toronto, Toledo) addressed stability mismatch issues between Si and perovskite and found that they can improve the NiO/perovskite interface by incorporating P3CT-N for surface passivation. Jinsong Huang (Chapel Hill) worked on optimizing bifacial modules and reported on addressing challenges with increased resistance loss from rear side transparent layer, reducing moisture damage from the atomic layer deposition process by incorporating TPFB additive in the hole transport layer and improving red and NIR light absorption by using embedded SiO₂, resulting in a bifacial mini-module that retained 97% of the initial PCE after light soaking for 6000 hours (at 50C in Voc condition). Kai Zhu (NREL) summarized three recent studies at NREL, focused on improving operational stability of high-efficiency inverted perovskite solar cells. Jinhui Tong's Nature Energy paper looked at 2D additive engineering to improve 1.25 eV Sn-Pb mixed perovskite cells, Qi Wang's Nature Energy paper studied reactive surface engineering to improve 1.53 eV perovskite cells by using a surface treatment that reduces surface potential variations, and Qi Wang's Science paper investigated a gas quenching fabrication technique which allows improved control of material growth to suppress defects, leading to reduced ion migration and enhanced phase stability, resulting in efficiency optimization of 1.75 eV cell for perovskite-perovskite tandem top cells.

Area 7 - Novel Applications and Integration of PV

Masafumi Yamaguchi (Toyota Technological Institute) showed a Toyota Prius built with 3-junction PV cells. They calculated the annual driving distance in Tokyo and across the globe under varying irradiation, temperature, wind speed, and insulation variables. Morning driving is more efficient due to lower temperatures. Leonardo Micheli (DIAEE) assessed the advantages (less land use challenge, using hydroelectric interconnection) and disadvantages (more angular losses due to low tilt angles for wind protection) to calculate the bankability of FPV. Labor costs for FPV were lower than standard land install,

although structural costs were higher. LCOE is already competitive with fossil fuels, particularly for sunny European countries closer to the equator. In Italy, Greece, Turkey, and Spain, FPV is already cheaper than standard electricity generation practices. Eli Shirazi (Twente) presented the top designs of integrating LSCs in the built environment, including unique dynamic lanterns, shading for public spaces, blinds for the indoor environment, and bus stops. Brian Mirletz (NREL) used SAM and REopt Energy Planning Platform to assess a hypothetical hospital which assumed the battery system must assume 24hr outage with 50% critical load to most economically size PV and battery capacity. Lewis Tamuno-Ibuomi (Caledonian; Best Student Presentation Award Finalist) identified low packing density as one issue with BILCPV and addressed it with a polygonal structure, which was first mathematically modeled, optically modeled with varying angles of incidence, and developed a PMMA prototype. Silvana Ovatt (NREL) presented, as part of the InSPIRE Project, on the bifacial radiance ray tracing model, including with spatial albedo, and albedo optimization for throughout the year. She presented on 10 rows of installed AgriPV system at NREL, with 9 crops, where all 8/9 crops did better under partial shade of PV vs control.

POSTER SESSION AWARD NOMINEES AND **WINNERS**:

AREA 4: PASSIVATED, CARRIER-SELECTIVE, AND HETEROJUNCTION CONTACTS

Sagnik Dasgupta – Winner (Patterning the Front Polysilicon Contact for Silicon Solar Cells using Laser Oxidation)

Tasnim Kamal Mouri (~20% efficient Si PERC solar cell with emitter surface passivated by H₂S reaction)

48 - Maria Angelica M Garcia (20%-Efficient TOPCon Solar Cell with a Silicon Oxide Layer Deposited by Aerosol Impaction-Driven Assembly)

AREA 5: ADVANCED CHARACTERIZATION FOR PHOTOVOLTAIC MATERIALS AND DEVICES

Ekin Gunes Ozaktas – Winner (Effective and Equivalent Refractive Index Models for Patterned Solar Cell Films via a Robust Homogenization Method)

Joseph Chakar (Advanced Characterization and Degradation Analysis of Perovskite Solar Cells using Machine Learning and Bayesian Optimization)

Gaia Maria N. Javier (Decoupling open-circuit voltage and series resistance in electroluminescence images through deep learning)

AREA 7: PV MODULES, MANUFACTURING, SYSTEMS AND APPLICATIONS – 1

Luis E. Alanis – Winner (Analysis of Thermal Behavior and Reliability of Bare Die Diodes Embedded Within PV Modules as Bypass Devices)

Leonardo Micheli (Inverter clipping and its masking effect on PV soiling: truth or myth?)

Ryan J.E. Ruhle (Novel Module Architecture for Lower CapEx and Improved Recyclability for c-Si PV Modules)

AREA 8: PV MATERIALS, MODULE AND SYSTEM COMPONENTS DURABILITY

Yuhaun Meng – Winner (Chemical Reaction Kinetics of the Decomposition of Low Bandgap Tin-Lead Halide Perovskite Films and the Effect on the Ambipolar Diffusion Length)

Guy Beaucarne (Accelerated Aging Study of Backsheet Repair With Flowable Silicone Sealant)

Ian Slauch (Mapping Stress in PV Modules: The Influence of Soldering, Tapping, and Module Architecture)

AREA 10: SOLAR RESOURCE ASSESSMENT – 1

Joshua T Peterson – Winner (Modeling Reference Cell Performance Using Measured and Modeled Spectral Data)

Jabir Bin Jahangir (Can hierarchical physics-based machine learning de-anonymize solar farm locations?)

Anny Huaman Rivera (RESIDENTIAL ELECTRIC ENERGY STORAGE SYSTEM TO REDUCE VOLTAGE AND THERMAL VIOLATIONS IN DISTRIBUTION LINES AND INCREASE PV INTEGRATION)