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ENERGY FOCUS

14th International Conference on Hybrid and Organic Photovoltaics

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In-person conferences are restarting after 2 years of online events. One of the first live conferences in the field of hybrid and organic photovoltaics was the 14th International Conference on Hybrid and Organic Photovoltaics (HOPV22), of which this report presents a subjective summary.

The research field of hybrid and organic photovoltaics has a history spanning back several decades. However, in the past decade the field has changed dramatically. With the advent of metal halide perovskite semiconductors, many groups have shifted their focus to these materials. At the same time, the success of perovskite solar cells (PSCs) has put pressure on existing technologies like organic PV, quantum dot solar cells, and dye-sensitized solar cells (DSSCs) to remain competitive. The efficiency of PSCs is approaching that of silicon solar cells (>25%). Organic and quantum dot solar cells have seen an equally impressive rise in their efficiency, now reaching almost 20%, while maintaining their advantages like non-toxicity (organic PV) and wide tunability (quantum dot PV). DSSCs remain an excellent testbed for new dye molecules and can be very efficient in harvesting light for indoor applications. It is thus fair to say that these changes have enriched the field and have increased its dynamics. In addition, in the past decade, commercialization of these new kinds of solar cells has become a realistic prospect, and serious effort and funding is poured into up-scaling.

During the pandemic of the past 2 years, the field kept its dynamic nature, but would researchers still remember how to exchange ideas during a real-life conference? HOPV22, taking place in Valencia, Spain, May 23–25, 2022, after an online-only portion May 19–20, 2022, was clear proof that we do. Starting in 2009 with its first conference in Benidorm, Spain, HOPV, organized by nanoGe, has been at the heart of the field. In the beginning, the conferences focused on organic (bulk heterojunction) PV and DSSCs. Perovskites were first mentioned as part of the program in 2014. After two online editions in 2020 and 2021, the conference resumed with a hybrid event this year. The organizers, Eva Unger (Helmholtz-Zentrum Berlin), Elizabeth Gibson (University of Newcastle), and Pablo Docampo (University of Glasgow), made a choice early on to run the event as a hybrid conference, to make sure that everyone could attend despite possible travel restrictions. Eva Unger said, “I think hybrid events are there to last as this provides some very valuable alternative means for academics to speak about their work if resources or personal circumstances make frequent international conference travel difficult.” As one of the first live conferences after the travel bans, the organizers had to be flexible. “We did unfortunately receive a very large number of last-minute cancellations and I think this is unavoidable in the current uncertain climate with regards to international travel,” Pablo Docampo remarked. Still, fears that participants might have forgotten how to participate in a live event did not materialize. More than 300 live participants enjoyed a very open, interactive, and informative conference. The conference started with group singing, celebrating the birthday of the organizer Elizabeth Gibson, and numerous participants noted how much they missed traveling to conferences (see Figure 1). At the same time, the online part (segmented into an “online-only” event and a livestream of the in-person presentations) was attended by almost 70 people, showing the value of the hybrid format.

The research presentations were centered around four general topics: manufacturing, structure, new materials, and characterization. Organizing the content along these lines resulted in new and interesting combinations of topics. Below are a few examples.

Manufacturing. Manufacturing a PSC such that it withstands hard irradiation requires protection, much like perovskite devices that are immersed in water for light-driven water oxidation. Francesca Brunetti (Tor Vergata University of Rome) showed that a P3HT derivative can effectively protect PSCs from high-energy neutron irradiation, even on large-area substrates. For water immersion, a thick carbon electrode effectively protects the device, such that even a $CsPbBr_3$ solar cell operates under water at various pH levels, as presented by Petra Cameron (University of Bath).

A large part of the optimization efforts is, of course, driven by the aim to reach higher efficiency and stability. Ted Sargent (University of Toronto/Northwestern University) showed that the 2D/3D strategy often employed to stabilize n-i-p solar cells also works for p-i-n cells when the 2D layer is applied on the buried contact. It does require careful consideration of the energetics and distribution of the different thicknesses of the 2D phases. These phases presumably use steric hindrance to

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Figure 1. (a) Birthday cake for the organizer Elizabeth Gibson at the beginning of the HOPV conference. (b) Presentation by Juan Bisquert. Images courtesy Fundació Scito.

avoid degradation and energetic passivation of defects at the interface. Mingzhen Liu (University of Electronic Science and Technology of China) showed that molecular passivation with ammonium formate can also passivate the buried contact, leading to very efficient flexible PSCs.

Next to the transport layers, the active perovskite layer can be manufactured in different ways. Spin-coating is still the most prevalent on a research scale but is impractical for up-scaling. Henk Bolink (University of Valencia) showed efficient evaporated PSCs that are stabilized against oxidation with a layer of alumina. Evaporation also enables fabrication of semi-transparent devices for tandem applications. One way to use solution processing on large areas is slot-dye/blade coating, with the prospect of high throughput. Maria Antonietta Loi (University of Groningen) showed that a blade-coated 2D PEA_2PbI_4 perovskite, which shows good crystallinity, can be used as a template for conversion into highly crystalline 3D Pb- and Sn/Pb-based perovskites. 2D perovskites are beneficial to device performance and stability, and Giulia Grancini (University of Pavia) showed that 2D materials provide many advances simultaneously, by increasing the V_{OC} by passivation (both surface and bulk), helping charge extraction, and trapping ions.

Passivation can also work on lower-dimensional structures. Qing Shen (The University of Electro-Communications, Japan) showed that Na^+ doping of $CsSn_{0.6}Pb_{0.4}I_3$ perovskite quantum dots reduces the defect density and hence the photoluminescence quantum yield (PLQY) by almost 2 orders of magnitude by occupying the interstitial defect site on the surface. In perovskite nanoplatelets, the thickness can be carefully controlled, so that their interesting exciton fine structure and transport can be studied, as demonstrated by Alexander Urban (LMU Munich). With the selection of well-passivating ligands, these platelets achieve very high PLQY close to 100%.

Structure. Junctions play a key role in the operation of any practical solar cell reported to date. In particular, the heterojunction in organic solar cells has been a subject of decades of discussions. An energy offset between the singlet exciton and the charge-transfer (CT) state energy has been thought to be necessary for dissociating the strongly bound exciton. Jenny Nelson (Imperial College London) showed that this energy offset decreased steadily with the advent of non-fullerene acceptors. Reducing the offset is directly linked to reducing voltage losses, and in some of the most efficient devices the offset is so small that the singlet state and the CT state are mixed. There is an active debate as to how much, or if at all, these devices need an energetic offset to work efficiently. An entirely new type of heterojunction was presented by Yana Vaynzof (TU Dresden). They grew γ-phase $CsPbI_3$ perovskites on top of a β-phase version of the same material to passivate the β-phase. This passivation reduces the recombination and increases the solar cell performance. This is a rare example where different perovskite phases benefit device performance. Most often the performance is hampered in heterophase samples, for example, when the material phase-segregates under illumination. Udo Bach (Monash University) showed microscopically resolved measurements of mixed-halide perovskites under illumination. Polarons that form upon illumination cause a strain gradient which attracts iodide ions. These then attract more iodide, forming an iodide-rich phase. At high intensity above the Mott transition, where polarons overlap, the phases remix because the polaron-induced strain gradient is absent.

Many of the unusual structural properties of the perovskites originate from their soft nature. David Egger (Technical University Munich) showed that the vibrational motions are so strong that a harmonic description is insufficient to describe the atomic motion. Similarly, the atoms rarely visit their average structure. As a result, the dynamic disorder is correlated only on very short length scales.

New Materials. While lead-free perovskites or perovskites with reduced lead content are not, strictly speaking, new materials, they receive far less attention than leaded perovskites and require new interface materials to avoid tin oxidation. Antonio Abate (Helmholtz-Zentrum Berlin) showed that DMSO in the precursor solution leads to tin oxidation by releasing water into the system when the environment is slightly acidic. After screening many solvents, they found about 15 suitable solvents and managed to produce more stable tin-based PSCs. Filippo De Angelis (CNR-SCITEC) used first-principles calculations to show that the tin-based perovskite $MASnI_3$ is p-doped by tin-induced defects.

The use of new materials for transport layers can have dramatic effects on device stability and efficiency. For example, doped Spiro-OMeTAD, used as a transport layer, induces degradation of the solar cells. Feng Gao (Linköping University) described the use of Spiro-OMeTAD combined with a radical (Spiro-OMeTAD^{2+}(TFSI$^-$)$_2$) and a pyridinum salt (TBMP$^+$TFSI$^-$), which is equally efficient as traditionally doped Spiro mixtures but about 4 times more stable. Self-assembled molecular layers, presented by Emilio Palomares

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(ICIQ-BIST), can even replace the polymer transport layers in p-i-n PSCs. Even though these layers are close to a molecular monolayer in thickness, the solar cells and LEDs work as well as devices with poly(triarylamine) as the hole transport layer but are more stable.

DSSCs have been around for decades, but new materials and processing methods still push the field forward. Claudia Barolo (University of Turin) showed new polymethine dyes that can be tuned to absorb in the near-IR spectral region. This IR absorption leads to practically transparent solar cells in the visible region. Another way to benefit from the tunability of the absorption spectrum of the dyes is to match them to the spectrum of typical indoor light sources. By also optimizing the surface passivation by better TiO_2 surface coverage, and adapting the electrolyte, Marina Freitag (Newcastle University) showed that DSSCs can be very efficient indoor light-harvesting solutions, harvesting up to 40% of the energy of indoor light sources. Peter Holliman (Swansea University) demonstrated how far modeling of dye assemblies has come, leading to a new understanding of how to improve the coverage of molecules, for example by co-sensitization. He also showed the need for greener solvents and cheaper synthesis (for example, for Spiro-OMeTAD) when scaling up DSSCs and presumably other solution-processed solar cells.

Characterization. Materials used in hybrid and organic photovoltaics are rich in properties and hence require advanced characterization to understand the mechanistic origin of performance losses, degradation, and structure–property relationships. Sam Stranks (University of Cambridge) demonstrated that sometimes a new look at simple characterization techniques can be quite powerful. By using simple intensity-dependent PLQY and transient PL measurements, one can extract radiative, non-radiative, and Auger coefficients of recombination.

Stranks also showed that understanding degradation is key to stabilizing perovskite devices. They use scanning electron diffraction to spatially resolve the crystal structure. Degradation starts at phase impurities, which also act as trap sites. Many forms of degradation require ion migration, and several contributions investigated the role of ion migration on device performance. For example, Piers Barnes (Imperial College London) showed that one needs at least a mobile ion density of 10^{17} cm^{-3} to make a difference in device operation and that the ions then screen the electric field inside the PSCs. The way ions affect hysteresis was also discussed in his presentation, and further during the talk by Juan Bisquert (Universitat Jaume I), who showed that a set of equations developed to describe biological neurons can be used to describe the hysteretic effect induced by ions, even in the extreme case where perovskite devices become memristors. He also showed that light-intensity-modulated impedance spectroscopy can be used to investigate electronic diffusion, in contrast to electrical impedance, which only probes ionic diffusion. The author of this Energy Focus related ion migration to strain in perovskites and showed that compressive strain and other means of changing the steric freedom can be used to control ion migration.

Many of the techniques for characterizing ion migration require an estimate of the electronic charge density. Yet, the background charge or defect density in perovskites is still a field of active debate. Thomas Kirchartz (Forschungszentrum Jülich) showed that the minimum charge density accessible by capacitance-based measurements is limited by the perovskite thickness, and often the values reported are thus not those of the bulk but rather the surface charge densities. Kirchartz further investigated the mystery of why transient photoluminescence measurements often show a faster decay than transient photovoltage measurements, even though they both should measure recombination lifetimes. When a capacitive term is added to the equations for decay rates, the two measurements are consistent with each other.

The presented work described in the above summary is a selection and by no means extensive or complete. There were many more contributions on 2D perovskites, the perovskite structure and fabrication, organic solar cells, quantum dots, phase segregation, plasmonics, interactions of active solar cell materials with water, upscaling, defects, interfaces, tandem solar cells, modeling, and much more, presented during the plenary and parallel sessions and in the poster presentations. Some of that work can be found in the conference proceedings (https://www.nanoge.org/nanoge-conference-proceedings). Clearly, scientific progress has not been standing still during the break from in-person conferences.

A Diverse Program. The conference showed a diverse set of scientific topics, bringing together scientists from theory and experiment in different fields (organic, perovskite, DSSCss, catalysis, etc.), online and live participants, and spanned fundamental to applied research (Figure 2). But there was diversity on other levels as well, and that was no coincidence. Organizer Eva Unger explains, "We tried to set up an as balanced program as possible with respect to topics (PSC, OPV, DSC, QSC) and diversity (male/female, emerging/established, country of origin/affiliation). ... We also tried to make room for some emerging topics." Pablo Docampo confirms: "I think I can speak for the three of us [the organizers] when I say that we are proud to have managed to produce such a diverse program and demonstrate that this leads to excellent talks and excellent science." While the scientific content was of course very insightful, maybe the most important lesson from the HOPV conference is that diversity along many directions improves the conference experience for all participants.

Figure 2. Participants enjoying a guided walk through the historic city of Valencia. Image courtesy Fundació Scito.

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Notes

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