Emerging Thin-Film Photovoltaics: Stabilize or Perish

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We are pleased to present this special issue focused on current developments and new insights in stability and lifetime for emerging photovoltaic (PV) technologies. The issue is composed of invited contributions from Symposium E “Materials design and processing concepts for efficient and stable organic, hybrid, perovskite and dye solar cells” from the Spring Meeting of the European Material Research Society (EMRS) that took place in May 2015, in Lille, France. The aim of the symposium was to address specific prerequisites for reaching commercially viable next generation PVs, including novel materials and architectures, stable devices, and energy efficient and overall sustainable fabrication. An important focus was placed on lessons learned from developing reliable testing protocols for specific PV technologies and how these can be adapted as a framework for defining general lifetime and stability metrics for other emerging technologies. Over the last years incredible advances have been made in the field of emerging PV. New materials and device architectures have led to rapid increases in power conversion efficiency over a very short period of time. In contrast to conventional PV, the design concept of organic and organic-inorganic hybrid solar cells, i.e., dye sensitized solar cells (DSSCs), organic photovoltaics (OPV) and metalhalide-organic perovskites, inherently relies on the assembly of a large range of different materials and interfaces with specific functionality. This allows for high flexibility in device engineering so that the efficiency of each step in the photovoltaic energy conversion process – light absorption, charge separation and transport, and charge collection – can be increased by selectively optimizing specific materials and interface properties for relevant processes. This approach has allowed for breakthroughs in solar cell efficiencies. Improvements in PV performance are directly correlated with research efforts to increase and deepen fundamental insights into the solar energy conversion in these systems and translate these into dedicated material and solar cell design. The drawback to emerging thin film photovoltaics, i.e., those based on ultrathin films and multiple material interfaces, is that there are a plethora of degradation pathways reducing long term performance. These pathways generally have a complex interdependence, resulting from a combination of both intrinsic chemical, electrical, and structural instabilities as well as environmental stress factors. For this reason, developments in the field of emerging thin film photovoltaics are ubiquitously accompanied by challenges related to elucidating the physical origins for degradation, and correlating these with device failure. The result is a need for detailed stability studies, from the microscopic to device scale, for key physical processes occurring in femtoseconds to seconds, to device degradation and failure occurring over minutes, days, months, and years, and as the result of different stress conditions. Very recently metal-halide-organic hybrid perovskite solar cells have taken the photovoltaic scene by storm. Thin films composed of methylammonium lead halide perovskites combine good optical absorption with high carrier mobility, making them highly interesting candidates for PV applications. Power conversion efficiencies of these devices have increased at unprecedented rates. The pioneering study in 2009 reported efficiencies of 3.8% for the application of perovskites to a classical DSSC architecture, and a few years later a breakthrough was reached leading to efficiencies exceeding 10%.

In only five years, efficiencies of over 20% have been reported for perovskite solar cells. For comparison, recorded efficiencies of DSSCs have now reached 14%, and for single junction organic solar cells recorded efficiencies have surpassed 10%. The remarkable pace at which performance increases in perovskite photovoltaics have been reported, combined with deeper intriguing scientific questions related to the properties of this class of materials, has resulted in a rapid fusion of the DSSC and OPV communities. A large number of researchers who previously worked on either DSSCs or OPVs have now combined their efforts in the field of perovskite PV resulting in an explosion of publications on the topic. Interestingly, what is currently emerging from these studies is the impression that perovskite PV unifies both the advantages and disadvantages of DSSC and OPV technologies. On the one hand, superior photovoltaic performances have been achieved based on innovations in material processing and device architectures borrowed from OPV and DSSC. On the other hand, issues related to material and device stability are currently so acute that providing reliable assessments of solar cell parameters remains a challenge. Factors such as anomalous electrical hysteresis during current-voltage measurements have made it clear that a focus on efficiency is not enough for the further development of perovskite PVs for real applications. The result has been an increasing number of studies focused on understanding fundamental material and device properties, including ionic reorganization and migration, instability of the active layer in the presence of moisture and polarization of the electrodes. Now, about five years after the first pioneering study, the need to define reliable testing procedures, and identify issues which limit stability and lifetime have quickly emerged as central topics in the fi eld. Lessons learned from the OPV and DSSC communities in this direction are enormously useful for tackling these issues. Over the past several years the OPV community has been particularly active in channelling collective efforts towards elucidating underlying physical mechanisms that limit material and device stability, defining established testing protocols for extracting performance and lifetime metrics and generating awareness for the need to increase the comparability of results between laboratories. Defining a framework for performance and lifetime testing is a challenge which requires an integrated and holistic approach, from fundamental studies to device engineering. This wide spectrum is reflected in this issue which includes reports on the design and synthesis of materials for increased OPV stability (Ma et al., DOI: 10.1002/aenm.201501282, and Lin and Zhan, DOI: 10.1002/ aenm.201501063), identifying key environ mental stress factors limiting device lifetime (Züfle et al., DOI: 10.1002/aenm.201500835) and studying failure mechanisms which are relevant under operational conditions (Adams et al., DOI: 10.1002/aenm.201501065). The progress report by Roesch et al. (DOI: 10.1002/aenm.201501407) examines protocols which have been developed over the last years in the OPV community, their relevance to existing protocols for safety and market standards for commercial thin fi lm PV, and the extension of this work to newly emerging PV technologies. It is notable that despite the intense activity in the OPV community dedicated to stability and lifetime testing, the majority of contributions in this special issue are focused on instability and degradation mechanisms afflicting perovskite solar cells.

This highlights the urgency to address stability in this field, as discussed in the review by Rong et al., (DOI: 10.1002/aenm.201501066) and the progress report by Leijtens et al., (DOI: 10.1002/aenm.201500963). The contributions cover a spectrum of topics, from controlling current-voltage hysteresis (Deng et al., DOI: 10.1002/ aenm.201500721, and Hou et al., DOI: 10.1002/aenm.201501056), to understanding (Leijtens et al., DOI: 10.1002/ aenm.201500962) and improving environmental stability with material design (Lee et al., DOI: 10.1002/aenm.201501310) to the control of device interfaces for the realization of highly efficient perovskite solar cells (Seo et al., DOI: 10.1002/ aenm.201501320). Finally the environmental and economic ramifications of applying lead versus tin in the hybrid perovskite active layer are examined under considerations of life-cycle analysis (Serrano-Lujan et al., DOI: 10.1002/ aenm.201501119). Despite promising advances in performance, the future of emerging thin film PV is at the crossroads. While the power conversion efficiencies of DSSC, OPV and metal-organic perovskites have all surpassed the traditional performance benchmarks for new PV technologies, strong burn-in effects, considerable long term degradation, sudden death and other crippling ailments are still major hurdles to be overcome towards real applications. Before these issues are resolved, it will be a challenge to accurately estimate factors which are decisive for feasibility, such as energy pay-back time and environmental impact. Low production costs and reduced material usage simply cannot balance the expense of short and unpredictable solar cell lifetimes. For this reason continued, concerted efforts on reconciling efficiency with stability in emerging PV are required. The merging of a large number of researchers from the OPV and DSSC sub-communities towards the topic of metal-halide-organic perovskites has shown a unique synergy in redirecting research momentum towards this common goal. Recent research trends in emerging thin fi lm PV demonstrate that lessons learned about the complex relationship between efficiency and stability, and awareness of the need for accurate and reproducible characterization, can be valuable drivers for marketization and application.