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Editorial: Solutions to Scaling and Reliability of Metal Halide Perovskites: Materials and Manufacturing Innovation at the Inflection Point of Solar Energy

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Editorial on the Research Topic

Solutions to Scaling and Reliability of Metal Halide Perovskites: Materials and Manufacturing Innovation at the Inflection Point of Solar Energy

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Metal halide perovskites are earth-abundant solar absorbers with intrinsic optoelectronic potential for driving high-efficiency single junction and tandem photovoltaics. Their explosive recent development could mark an inflection point in renewable energy technologies if fundamental challenges related to scaling and stability are addressed. Cost models for perovskites PV hinge not only on module-level efficiency, but on the assumed service lifetime (Song et al., 2017), a point which demands the utmost attention ahead of continued investment in this technology. Groups the world over have realized that scale-up of perovskites is a non-trivial undertaking, demanding unprecedented control of material synthesis, solution-deposition, and annealing processes over large areas, bounded by unique perovskite material constraints such as its thermal and moisture sensitivity. One result of these challenges that we highlight is the gap between the performance of rigid and flexible cells (Altinkaya et al., 2021), particularly for large area modules. These challenges demand careful consideration of whether high efficiency sub-cm-scale device architectures can satisfy demands for uniformity at the meter-scale and the module-level (Li et al., 2018).

In this Research Topic, we assemble three articles addressing these essential topics for upscaling metal halide perovskite photovoltaics. This collection covers two modes of rapid processing—spray-plasma processing and photonic curing—considering how each can be integrated to fabricate not just perovskite absorber films, but entire device stacks consisting of transport layers and transparent electrodes. A key finding highlighted by Rolston et al. is that using large area and high speed plasma processing can allow for integration of each of the relevant layers of perovskite solar modules, improving efficiency while also bolstering thermomechanical reliability. For example, a primary design consideration they offer for perovskite modules is to minimize perovskite film stress to support long-term device stability and thermomechanical reliability. This work addresses both functional cell layers and encapsulating barrier layers—key for obtaining a stack that has exceptional long term stability. To account for the impact of these high throughput methods, this work also considers the cost models (Rolston et al.) that appropriately describe upscaling from MW to GW production based on the experimentally demonstrated speeds of these new methods (Rolston et al., 2020). These cost models show the need for the continued elimination of vacuum-processing steps in charge transport layers and for printable inks for the metal electrodes.

A common theme in this collection is the development of scalable processing methods that use high instantaneous energy inputs to drive rapid film conversion. Piper et al. demonstrate how photonic curing at the millisecond time scale can eliminate a barrier to processing inorganic inverted perovskite architectures at high speeds Piper et al. This work specifically links together rapid curing processes of perovskites absorbers and inorganic NiO_x charge transport layers known to provide significant benefits to stability. Pulsed photonic annealing can support high web speeds (26 m/min), replacing the need for long thermal annealing treatments of these layers. Piper et al. also show how it is possible to utilize flexible glass substrates to capture the benefits of R2R processing but integrate more robust inorganic materials. These results connect rapid processing with the materials chemistry of inorganic film conversion and the optoelectronic requirements for demonstrating high efficiency.

To put these upscaling and material design works in context of their stability, Futscher and Milić provide a mini review of mixed conductivity of hybrid halide perovskites (Futscher and Milić), discussing opportunities to mitigate as well as exploit these ionic effects in future devices. Building off of the theory of mixed conductivity and mobile ion diffusion which determines the motion of halide species (I^-), Futscher and Milić describe the impact of ETL and HTL interfacial engineering and strain on ion migration to guide design of module architectures with improved long term stability. One interesting note is how low-dimensional perovskites (e.g., 2D) have become a suitable strategy to block halide migration due to the effectiveness of the organic spacer layers (AkritiShi et al., 2021). Finally, this work describes how new perovskite based semiconductor devices such as resistive switches can leverage ionic migration for neuromorphic computing. Unraveling the physics of these new devices promises to deepen our understanding of the interplay between light and electric field modulation of the ion migration.

Collectively, these works highlight the potential as well as a few of the grand challenges for upscaling and commercialization of perovskites. For example, Rolston et al. highlight the need to improve intrinsic perovskite material stability and extrinsic encapsulated device stability through device-integrated barriers. Towards this end, Piper, et al. provide a photonic curing route to rapidly synthesize robust inorganic NiO hole transport layers that are known to have higher mechanical reliability (Scheideler et al., 2019). Finally, to improve intrinsic perovskite material stability, Futscher and Milić, show us that there is a need for deeper understanding and control of ion migration, particularly under the synergistic aging effects of light, heat, and electric field.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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