PHOTOVOLTAICS

Perovskite solar cells take a step forward

A new encapsulation technique helps move a photovoltaic toward commercialization

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Today's monocrystalline silicon solar cells have their throne on the roofs of our houses. In the past decade, however, perovskite solar cells (PSCs) show impressive advances with a high power conversion efficiency (PCE) of 25.2% (*1*) and low fabrication cost, which make this technology promising for further advances in decarbonization energy models (*2*). Yet the life cycle of PSCs needs to be increased for market integration. Poor stability is the main impediment to commercializing this technology. Thus, great effort has been focused on the causes and mechanisms of degradation, many of which can be mitigated or minimized with encapsulation. Various strategies have been proposed to increase PSCs' operational stability, which is affected by moisture, oxidation, heat, light, and other factors (*3*, *4*). On page 1328 of this issue, Shi *et al.* (*5*) report a successful encapsulation procedure for hybrid PSCs.

The standard test to assess the long-term operation of photovoltaic terrestrial flat-plate modules in open-air climates is referred to as IEC 61215:2016. The IEC 61215 standard was developed by the International Electrotechnical Commission (IEC) for working photovoltaic devices that incorporate robust inorganic light-harvesting materials such as silicon, cadmium telluride, copper indium selenide, and copper indium gallium selenide. The stability test must consider all components and encapsulating materials as a whole. Achieving a high score on a solar cell stress test has been challenging for organic-inorganic hybrid perovskite-based devices (*6*). The device developed by Shi *et al.* retained >95% of its initial efficiency after undergoing the harsh environmental conditions of the Damp Heat and Humidity Freeze tests. By doing so, their device exceeded the requirements of IEC 61215:2016.

The key strategy for the authors' success was the polymeric "blanket-cover" encapsulation that simultaneously prevented moisture/air ingress into the device and suppressed volatile organic gas release from the hybrid perovskite. The analysis of outgassing from several perovskite and precursor assemblies, monitored by coupled gas chromatography–mass spectrometry, was essential for determining and implementing the best encapsulation strategy. Beyond the simplicity of this encapsulation approach, the authors demonstrated the feasibility of developing low-cost packaging techniques for PSCs, in contrast with more technically challenging and expensive processes of forming a protective barrier, such as atomic layer deposition or chemical vapor deposition.

A reproducible high PCE (>20%) combined with the authors' demonstration that their PSC device can pass the harsh IEC 61215:2016 tests might suggest that PSCs are finally ready for commercialization. Unfortunately, each of these achievements, high efficiency and high stability, still has a downside. Deploying PCEs well above 20% is still problematic when scaling up the active area for these photovoltaics. This apparently is specific to PSCs, as it is practically nonexistent with wafer or other thin film–based photovoltaics. Moreover, the authors observed an enigmatic threshold temperature during the regular working condition for a solar cell under constant illumination, the so-called maximum power point test (MPPT). Once this temperature is exceeded, a prominent drop in efficiency initiates and drives the irreversible loss of the device. Shi *et al.* estimated this temperature threshold to be ~35° to 40°C despite their devices passing the IEC tests, which may require further specific thermal stability studies on PSCs.

> **"...vapors retained by encapsulation could regenerate perovskite during night hours..."**

This temperature threshold has been noted in a previous MPPT that successfully tested PSCs for 4000 hours of continuous illumination (*7*). Surprisingly, the threshold temperature for the earlier test was also ~40°C, even though nonmixed or pure methylammonium (MA) cation-type perovskite was used. This is in contrast to the mixed FAMA and CsFAMA perovskites [containing MA, FA (formamidinium), and cesium] used by Shi *et al.* A much higher temperature threshold would be expected for FAMA and CsFAMA because of their higher FA content. This analogous temperature threshold could be due to degradation factors such as MA content, diiodine sublimation, or disruptive ion migration. Determining this threshold in MA-free perovskites could provide insight, along with determining whether full inorganic halide perovskite-based devices are free of this threshold at MPPT conditions under 1-sun illumination. Standard stability tests are designed to stress all plausible weak points of the device and offer useful data for interlaboratory comparisons. Although considerable efforts to design specific stability stress tests for hybrid perovskites are under way (*8*, *9*), there is a lack of standardization in testing procedures, including specific active control of temperature during MPPT to find the fatal threshold temperature of the device.

Shi *et al.* provide further insight into the challenge of long-term stabilization for PSC devices by reporting the outgassing vapors generated above the ~35° to 40°C temperature threshold. The outgassing vapors retained by encapsulation could regenerate perovskite during night hours when the device cools down, but this is not possible if these vapors react irreversibly with other components of the device, such as selective contacts and metal electrodes. The chemistry of halide perovskite is quite different from the classic robust inorganic crystalline materials prepared at high temperature and used in commercial photovoltaics. Perovskite is an organic-inorganic hybrid semiconductor material, and this hybrid character can be assumed to be the clue to developing long-lasting PSCs for commercialization. ■

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ACKNOWLEDGMENTS

M.H. is supported by the MICIU (Spain) through a Ramon y Cajal Fellowship (grant RYC-2018-025222-I).

10.1126/science.abc5401

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