How to make perovskite photovoltaic devices stable under reverse bias

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One of the main issues hindering the commercialization of perovskite photovoltaics (PV) is device stability. A myriad of various strategies to stabilize the perovskite layer against degradation under continuous illumination has been demonstrated in perovskite community, such as perovskite passivation with 2D perovskites, organic hydrophobic layers, ionic liquids, as well as the deployment of robust inorganic charge transport layers. However, for commercially established PV technologies, the most detrimental degradation occurs in fact under reverse bias. A cell in a module can be placed under reverse bias due to significant current mismatch between series-interconnected cells, which typically happens under operational conditions when shading takes place. Such situation causes the non-shaded solar cells to act as a reverse-bias voltage source on the shaded cell, causing it to operate at high negative voltages, dissipating its energy as heat producing a so-called This phenomenon is commonly known as “hot-spot” degradation and is considered to be one of the most severe degradation mechanisms even in crystalline silicon PV. Concomitantly, only few studies on the reverse bias degradation in perovskite PV devices have been published, revealing that this is a severe source of degradation. Thus, reverse bias degradation presents one of the most fundamental challenges for commercializing not only single-junction perovskite PV modules, but also the ones with tandem configurations.

In this work, we demonstrate that perovskite PV devices with mesoscopic scaffold and carbon-based electrode have outstanding resilience against reverse bias degradation and are able to withstand negative voltages up to -9V. The presence of chemically inert carbon electrode, utilization of single-halide mixed-dimensional 2D/3D perovskite and robust inorganic charge transport layers helps to avoid commonly-occurring issues in state-of-the-art cells, like localized -melting of metal electrodes, ion diffusion and halide segregation. Looking more in-depth at the nature of reverse bias degradation in PSCs we demonstrate that the issue of iodine loss still prevails even in such stable devices. Low activation energy of I- vacancies causes an accumulation of charges at the interfaces, resulting in significant bend bending at the interfaces between perovskite and charge-transport layer. Under reverse bias the bending increases until the so-called “breakdown voltage” is reached beyond which holes are able to tunnel through to the valence band of perovskite. This hole-tunneling oxidizes incorporated iodine to create iodine vacancies and thermodynamically favorable iodine compounds, which decompose perovskite structure. Thus, iodine loss can cause device degradation, if it is exposed to reverse-bias for long time durations. For reverse bias voltages exceeding -9V, via thermographic imaging we overserved *in-operando* formation of hotspots and thermal degradation of perovskite into PbI2.

To demonstrate that modules with carbon electrodes would be able to withstand hot-spot conditions, we manufactured modules with carbon back electrodes of 10x10cm^2 size and 11.1% power conversion efficiency and subjected them to requirements of IEC61215 hot-spot test at an accredited laboratory Fraunhofer ISE PV Modules Testlab, which has never been done before according to our knowledge. Finally, the modules were able to pass the conditions of the IEC tests for c-Si and thin-film technologies confirming that mesoscopic scaffold and carbon electrodes provide effective stabilization strategy for perovskite PV devices against reverse-bias degradation. (Bogachuk et al. 2021) This work for the first time demonstrates that perovskite-based modules with carbon-based modules can withstand severe reverse bias, which is an essential attribute of this emerging technology on its path towards commercialization.

Literaturverzeichnis

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