Title	*Field monitoring of perovskite modules: experiences and learning curves*
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Abstract *(max 350 words)*

It is widely accepted that the determining factor for any photovoltaic (PV) technology to 'succeed' in penetrating the solar PV market it needs to 'prove' its long-term stability and reliability under real operating conditions. Market leaders such as crystalline silicon, a-Si, CIS, CIGS, etc. have underwent (and still undergo) extensive, continuous, and systematic studies following international measurement standards to establish a good understanding of their long-term performance, reliability, and failures in the field. On the contrary, for emerging PV technologies such as perovskites until now there exists only limited experience in long-term field monitoring under real operating conditions with no international standards yet in place for accurate and reliable test procedures for this technology.

This paper addresses work performed on outdoor monitoring of perovskite-based mini-modules highlighting the overall difficulties in measuring and assessing the outdoor performance of such devices compared to monitoring more robust and stable PV technologies. Some of the challenges faced were the hysteretic I-V behavior, diurnal performance variation, and reversible degradation which make the development of perovskite-appropriate' test protocols quite challenging. It should be noted that as emerging technologies are not at the stage of large installation long-term monitoring, the PV monitoring aspects presented focus only on research-based monitoring at outdoor test laboratories. In this work, a number of different architecture perovskite mini-modules were monitored outdoors in terms of their performance. The devices were tested indoors prior to mounting outdoors where their current-voltage characteristics were recorded at regular intervals over the set test periods ranging from days to several months. Alongside electrical parameters, the ambient environmental conditions and irradiance levels were also monitored in order to determine their effect on device lifetimes. In addition, various loading and voltage sweeping strategies were employed to test their impact on the measured performance. Some of the aged devices exposed outdoors were tested indoors using imaging techniques (Electroluminescence, photoluminescence and Dark Lock-in thermography) in order to investigate failure development and evolution.

Overall, the measurement campaigns yielded useful insights regarding outdoor lifetime assessment of perovskite modules and appropriate outdoor measurement tactics and test parameters for perovskite PV monitoring.

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Figure 1: Perovskite mini-modules mounted outdoors on a tracker at the University of Cyprus site

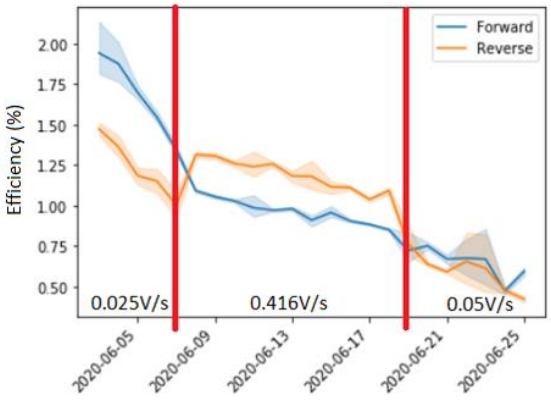

Figure 2: The impact of I-V sweep conditions (here: sweep rate and direction) on the efficiency recorded from a perovskite mini-modules. The module was kept at MPP loading.

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Bio

Dr. Hadjipanayi is a research scientist at the Photovoltaic Technology group in the Department of Electrical and Computer Engineering of the University of Cyprus working on the investigation of the optoelectronic characteristics and photovoltaic performance of novel solar cell devices and her latest work focuses on the characterization of perovskite-based PV and measurement protocol development.

She has received her BSc in Physics (2001) from the University of Cyprus and her DPhil (PhD) in Condensed Matter Physics (2006) from the University of Oxford. Her employment record includes a Post-Doctoral Research Associate position at the Quantum Information Processing Interdisciplinary Research Collaboration (QIP IRC), Department of Physics, University of Oxford (2006-2009) and an Associate Research Scientist post at the Energy, Environment and Water Research Centre of the Cyprus Institute (2009-2012). Her research interests lie within the area of fundamental and applied physics of novel materials which are promising for future energy-efficient technological applications, especially in the field of solar energy. More specifically and more recently, these include: Investigation of optoelectronic properties and degradation mechanisms of novel solar cell devices including multi-junction solar cells, nanostructured silicon cells, perovskites; Development of accurate standardized and non-standardised testing protocols for new solar cell technologies.

Maria has over 10 years' experience in national and European research projects (full project life-cycle involvement: from initiation to implementation, monitoring and reporting). She is currently the principal investigator in a strategic infrastructure development project at the University of Cyprus (DegradationLab) focusing on the development of an advanced centre for accurate characterization of new and emerging solar cells such as perovskites and tandems.

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