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Nanotechnology – Reliability assessment –
Part 2-1: Nano-enabled photovoltaic devices – Stability test

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FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62876-2-1, which is a Technical Specification, has been prepared by IEC technical committee113: Nanotechnology for electrotechnical products and systems.

The text of this Technical Specification is based on the following documents:

Enquiry draft	Report on voting
113/334/DTS	113/421/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- transformed into an International Standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Nano-enabled photovoltaics (NePV) is a novel format of photovoltaic technology that can be manufactured in large-area, flexible, thin sheets through solution processing or vapour deposition. Many of the materials involved are nanomaterials and organic semiconductors. They improve the conversion of sunlight into free electrons and support the extraction of the electrons out of the device. Furthermore, nanomaterials are used as boundary layers and act as protective coatings to increase the stability of the PV device. NePV has the potential to provide low-cost renewable energy due to relatively inexpensive, high-throughput manufacturing and low material costs, as a result of the use of low-cost flexible polymeric substrates and packaging films [1]. In addition, NePV is expected to enable new products due to its light weight, flexibility, ability to adapt and tune colour appearance and good efficiency at low light levels, which is conducive to indoor use. Due to these properties NePV is attracting more attention from a variety of groups with a view to improving the efficiency and stability, which has resulted in significant efficiency gains through achievements in materials engineering and process optimization. Concerning stability, however, improvements have not been evident and have not been demonstrated, since standardized testing methods do not exist. In order to commercialize NePV, its stability must be addressed and means for properly comparing stability need to be developed.

Within the scope of this document, NePV refers to photovoltaic devices made from nano-sized material entities, involving a combination of organic and inorganic components and hard and soft matter, sometimes including liquid electrolytes, which are combined using low-cost preparation methods mainly by low-temperature solution processing. The developments of these types of solar cells are primarily through four main directions: organic polymers or small molecules (OPV), dye sensitized solar cells (DSSC), organic/inorganic hybrid solar cells and quantum dot based solar cells. The procedures outlined in this document were designed for NePV, but may be extended to serve as a guideline for early stability assessment for new materials or processes for other photovoltaic technologies as well.

Stability assessment standards define the conditions for a set of stress tests, which address isolated stress factors that can lead to failure in a service environment, in order to allow developers to test under repeatable conditions and to quantitatively compare the stability of photovoltaic devices subjected to these conditions. Several such stability assessment protocols have been proposed by the International Summit on OPV Stability (ISOS) of the OPV community [2,3]. The test conditions defined in this document are based on the ISOS protocol by selecting and modifying the conditions so that they are applicable to a range of NePV devices. True reliability prediction and quantification, however, requires significantly more extensive testing and is not within the scope of this document.

The objectives of this document are to specify the requirements for a general stability assessment standard (SAS) for NePV intended to be used in but not limited to outdoor environments; give direction to developers and engineers developing NePV devices, to guide test laboratories on testing, and to allow for a quantitative stability comparison between different technologies. It is not intended that the requirements specified in this document are to be used for device-type approval or certification. This document simply provides a set of tests for stability assessment and establishes the minimum reporting requirements in order to guide the community through a process of technology improvement by achieving comparable measurements and allowing improvement in device stability to be measured in a qualified and comparable methodology. More specific test conditions for specific devices and/or for specific applications should be developed separately in the future.

The general procedure for the recommended stability testing procedure is to measure device performances before and at certain intervals after applying well defined stresses to NePV devices, in order to track the performance changes due to the applied stresses. Not all recommended tests or stress conditions need to be performed at all stages of development. In the early stages of development a subset of tests which are relatively easy to implement, e.g. dry-heat, damp-heat and light exposure, should be performed first to achieve a first information about the general stability of the tested system. As development of a particular technology progresses and the technology matures, it is recommended to add more sophisticated tests as deemed necessary. Retesting at later stages for regular process control and materials monitoring should also be considered to identify problems. The tests single out certain stress factors that are expected to frequently occur during outdoor exposure. In this document each of the tests is intended to be performed on a new set of devices in order to determine the most detrimental stress factors and aid in an optional failure mode analysis. Sequential tests in various conditions may be performed, but the results are expected to be difficult to interpret. To include the effect of multiple and varied stresses, a laboratory weathering test was adapted and included.

NePV will incorporate many polymeric materials such as binders for nano-materials, substrates, adhesives and packaging materials, which may have a strong interaction with the NePV photovoltaic active layers of the devices under test, and may therefore affect the stability of the device as a whole. To address this, the stability tests in this document are closely related to those used in artificial weathering for polymers. The stability tests outlined in this document could be a component of an exhaustive failure analysis in order to identify the causes of performance losses, which can be the result of many different issues. The procedures described in this document are focused but not limited to nano-enabled PV devices. The document outlines minimal equipment and procedural practices. Stability should always be regarded as a system property. As layers or materials in the system are changed (including in the packaging), retesting will be necessary to ensure that stability is not affected in a detrimental manner.

This document makes no specific recommendation about the materials and device structures to be tested, and can be applied to a wide variety of systems. A generic picture of a device under test is shown in Figure 1.

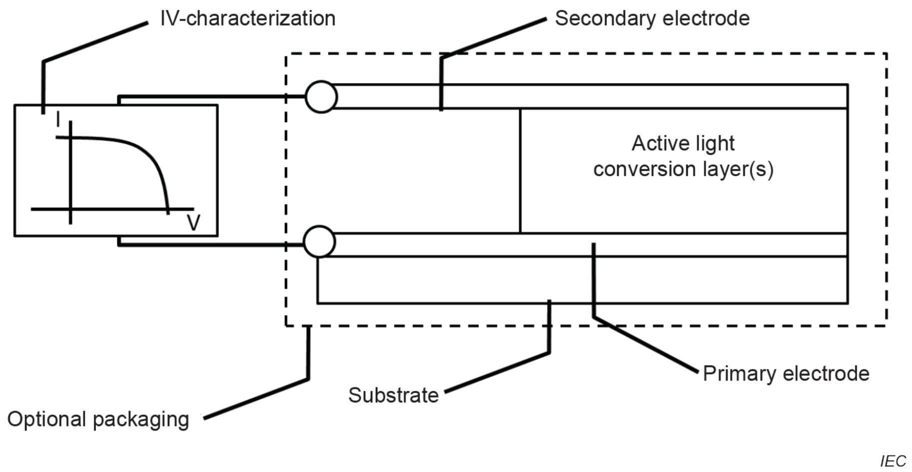

Figure 1 – Generic representation of a device under test during IV-characterization

This document is meant to be a general document that can be applied to all NePV devices. As such, it is not intended to be used as a standard for assembled photovoltaic modules. The stress tests are specific and explicitly defined to establish consistency of test procedures and reporting of reliability information.

NANOTECHNOLOGY – RELIABILITY ASSESSMENT –

Part 2-1: Nano-enabled photovoltaic devices – Stability test

1 Scope

This part of IEC 62876, which is a Technical Specification, establishes a general stability testing programme to verify the stability of the performance of nanomaterials and nano-enabled photovoltaic devices (NePV) devices. These devices are used as subassemblies for the fabrication of photovoltaic modules through a combination with other components. This testing programme defines standardized degradation conditions, methodologies and data assessment for technologies. The results of these tests define a stability under standardized degradation conditions for quantitative evaluation of the stability of a new technology. The procedures outlined in this document were designed for NePV, but can be extended to serve as a guideline for other photovoltaic technologies as well.

NOTE 1 The tests in this document are selected with outdoor use in mind, and as such represent isolated stress factors that devices will be exposed to in outdoor environments. For indoor environments, the stresses faced by the devices in operation are significantly less severe, and not all tests will be applicable. Despite this, the suggested tests provide a means of tracking stability improvements and can provide valuable data during device development.

NOTE 2 The performance of devices will be evaluated before and after the application of the stress tests. The efficiency characterization methods for NePV have not been fully established at present. In the text, notes are therefore added regarding the efficiency characterization. The notes particularly address issues to be discussed in the future for applications such as indoor use, or devices with a slow response or uncommon spectral responses such as tandem cells.

NOTE 3 The scope does not include photovoltaic modules, i.e. the final product. It is only intended to test the technology.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4892-1, *Plastics – Methods of exposure to laboratory light sources – Part 1: General guidance*

ISO 4892-2:2013, *Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps*

ISO 9370, *Plastics – Instrumental determination of radiant exposure in weathering tests – General guidance and basic test method*

ISO 877-1, *Plastics – Methods of exposure to solar radiation – Part 1: General guidance*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

IEC 60904-1, *Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics*

IEC 60904-9, *Photovoltaic devices – Part 9: Solar simulator performance requirements*

IEC 60068-2-2, *Environmental testing – Part 2-2: Tests – Test B: Dry heat*

IEC 60068-2-78, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*