**DegradationLab: Infrastructure description**

The DegradationLab is a new laboratory at the University of Cyprus aimed at testing degradation and failures in new and emerging solar cells. It is co-financed by the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation, under the programme 'New Strategic Infrastructure Units – Young Scientists'. The DegradationLab project has a total budget of 999,460 Euro and is coordinated by the University of Cyprus (Coordinator: Dr. Maria Hadjipanayi).

One of the foci of the DegradationLab will be the accurate characterization of perovskite solar cells (single-junction and multi-junctions) which are considered excellent candidates for the realization of very low-cost, flexible, industry-scalable PV technology, potentially well-suited for integration in the urban environment. This technology currently exhibits high conversion efficiencies (for solar cells) as well as desirable and tunable optoelectronic properties (for other novel applications), however, there remains a key challenge to overcome in order to reach commercialization status and this is related to its reliability and long-term stability.

Essentially, the main aim of the newly developed research unit is to test degradation and failures (from fundamental level to devices) in new and emerging solar cells through the use of advanced optoelectronic, spectroscopic, and structural techniques for testing indoors (laboratory conditions) and outdoors (real operating conditions). These include the combination of measurements such as performance and spectral response, light beam induced current (LBIC), illuminated and dark lock-in thermography, electroluminescence, photoluminescence, ultrafast and Raman measurements, as well as analytical electron microscopy (TEM, SEM, EDX, etc.). An important aspect of this project is also the development of accurate measurement protocols and standards for novel cell evaluation which currently do not exist for perovskites thus hindering the development and full potential of the field.

For the successful implementation of the DegradationLab project and establishment of the new research unit, the DegradationLab brings together three advanced laboratories from the University of Cyprus (the Photovoltaic Technology Laboratory, the Laboratory of Molecular Spectroscopy, and the Laboratory of Ultrafast Science) with three excellent European research organizations, namely IMEC (Belgium), the AIT Austrian Institute of Technology (Austria), and the Max Planck Institute for the Science of Light (Germany).

**Infrastructure details:**

1) Steady-state solar simulator:
The steady state solar simulator will be used to test performance of all types of solar cells under AM1.5 spectrum. The Solar simulator is certified to IEC 60904-9 Edition 2 (2007), JIS C 8912, and ASTM E 927-10 standards for Spectral Match, Non-Uniformity of Irradiance, and Temporal Instability of Irradiance.
Manufacturer: Oriel, Newport
Model: Sol3A Class AAA Solar Simulator

2) **Spectral response and External Quantum efficiency set-up**
A high-resolution spectral response (SR) set-up was designed to measure small dimensions' organic and inorganic solar cells. The spectral response of a cell can be measured with or without encapsulation by using a solar simulator and measuring the short-circuit current output of a cell under different wavelengths of light.
The SR set-up consists of a light source, a monochromator, chopper, lenses and lock-in amplifiers. A 100 W Quartz Tungsten Halogen lamp provides the light source that is divided by the monochromator in order to produce the monochromatic light input which is then chopped at 75 Hz superimposed on the continuous bias light and measured by digital lock-in amplifiers. The monochromatic light is separated by a beam splitter and allows simultaneous measurement of a small size monitor device and a reference cell of known absolute SR. The monochromatic light is focused on the surface of the cells with a circular spot of 1.5 mm in

diameter. The temperature of the cell is kept stable at 25°C. In the case of multi-junction solar cells light bias is required in order to saturate the non-measured junctions and subsequently achieve current limitation by the junction of interest.
The spectral response measurements follow the IEC standard 60904-8.

3) Electroluminescence and Photoluminescence setup:

The Electroluminescence and Photoluminescence (EL/PL) turn-key solution system can conduct spatially-resolved Electroluminescence and Photoluminescence measurements of single and multi-junction solar cells (encapsulated and non-encapsulated) with dimensions from 0.5 x 0.5 $cm^2$ up to 15 x 15 $cm^2$ to image micro-cracks, shunts, regions of low lifetime, inhomogeneities, hot spots and other cell failures.

Manufacturer: Greateyes
Model: LumiSolarCell

4) Lock- in Thermography (Dark and Illuminated):

A turn-key solution for the Dark Lock-In Thermography and Illuminated Lock-In Thermography spatially resolved measurements of multi-junction solar cells with dimensions from 0.5 x 0.5 $cm^2$ to 20 x 20 $cm^2$. The PV-Shunt Inspection System is able to detect shunts, defects and inhomogeneities in the solar cell devices.

The system includes a high-speed thermography camera for the detection of infrared radiation during the dark lock-in thermography and illuminated lock-in thermography of multi-junction solar cells with the abovementioned. The camera allows precise, fast and remotely controlled motorized focusing. With the indoor system, there is also a tripod for outdoor thermographic measurements using the same camera.

Manufacturer: Infratec

Model: PV-LIT Inspection system DLIT + ILIT (with ImageIR 8325)

5) Light beam induced current (LBIC):

The Light Beam Induced Current (LBIC) automated system enables fast high-resolution spatial mapping of the photovoltaic response of multi-junction solar cells with dimensions from 0.5 x 0.5 $cm^2$ to 30 x 30 $cm^2$. It is ideal for the quality control and identification of defects and shunts, poor or inactive regions. The system is a turn-key solution and can also provide External Quantum Efficiency (EQE) spatial mapping of the solar cells.

Manufacturer: InfinityPV

Model: LBIC Economy

6) Nitrogen generator and dessicator

Adjustable shelf storage desiccator cabinets with two doors (model: 1500-2-L) and a membrane Nitrogen Generator with 11 SCFH flow rate at 99% nitrogen purity (model: 1700-1-A).

Manufacturer: CLEATECH

**7) Outdoor cell/mini-module level performance infrastructure**

In addition to the development of the indoor laboratory, work took place on developing appropriate **outdoor test setups** in order to enable successful performance measurements on perovskite-based photovoltaic devices. Currently, a current-voltage (I-V) characterization system controlled by Labview software can collect and analyze the electrical characteristics of the cells under study.

A **maximum power point (MPP) system for prototype cells/modules** has been developed and introduced into an existing outdoor test bench at the PV Technology Laboratory and LabVIEW software is being used to perform automated current-voltage sweeps using a Keithley sourcemeter. The electrical parameters of the photovoltaic configuration such as short-circuit current, open circuit voltage, fill factor and efficiency are to be continuously monitored alongside the respective environmental conditions. The measurement system is composed of a number of sensors and a central data logging measurement system that can acquire data at a rate of one sample every 5 seconds or more. With this setup an array of modules can be tested sequentially for their I-V

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characteristics in different I-V sweep conditions i.e. varying voltage scan rates, keeping at open circuit or MPP operating conditions, performing forward or reverse bias scans and varying the scan order.

As concerns testing perovskite cells outdoors, we are in the process of developing new solutions to enable I-V measurements to be undertaken.

The DegradationLab infrastructure developed currently has the capabilities to test new and emerging photovoltaic technologies including the following perovskites and perovskite tandems, chalcopyrite solar cells, chalcogenite solar cells, and organic and dye-sensitized solar cells. Overall a 'portfolio' of techniques will be utilized between the partner labs of our project to cross-investigate the degradation mechanisms in novel solar devices developed by IMEC. The main ones are the following:

- Current voltage (I-V) measurements
- External Quantum Efficiency (EQE) measurements
- Capacitance – Voltage (CV) measurements
- Light Beam Induced Current (LBIC) imaging
- Spatially-resolved Electroluminescence (EL) measurements
- Spatially-resolved Photoluminescence (PL) measurements
- Dark Lock-in Thermography (DLIT) and Illuminated Lock-in Thermography (ILIT)
- Ultrafast spectroscopy & time-resolved PL
- Resonant Raman spectroscopy
- Structural microscopy: TEM, SEM, XRD, EDX, etc.
- Field performance testing

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