Kiwa Cermet Italia

TECHNICAL REPORT

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Measurement of photovoltaic devices

The following measurements have been carried out at the Department of Information Engineering, University of Padova. The measured DUT samples come from two different batches: i) Multijunction PV device with an expected efficiency of 30 %, in the following MJ30, and ii) Multijunction PV device with an expected efficiency of 40 %, in the following MJ40.
Required characterization comprise:

- IV Dark measurement
- IV Light measurement
- External Quantum Efficiency

The response of a photovoltaic device strongly depends on the irradiation spectrum used to measure the device characteristics. In a single junction solar cell a simulated spectrum can be used to measure the performance of a photovoltaic device for example by adjusting the intensity to reach the rated short circuit current. Two terminal multijunction solar cell, instead, require all the junctions to be correctly illuminated to generate the same amount of current, any current generation unbalance, will cause the reduction of the cell efficiency. Due to the nature of the multijunction devices several measurement spectrums have then been tested to assess the characteristics of the devices: a) a state of the art solar simulator, class AAA, b) an halogen structure with a full infrared spectrum, c) the natural radiation of the sun.

DUT characteristics:

Active area	10 mm x 10 mm
Contact area	2 top contacts: 1 mm x 10 mm each
Total Area	12 mm x 10 mm

DUT pictures:

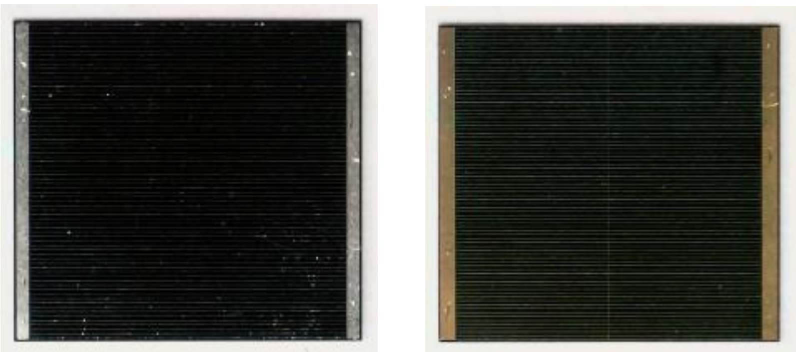

Figure 1: Picture of the DUT (MJ30 on left, MJ40 on the right)

IV Dark measurement

Instrument	Instrument manufacturer and model	Notes
Light Source	none	
Electrical measurement unit	Keithley SourceMeter 2651A	4 wire connection
Automation system	National Instruments Labview Custom program	Standard current vs voltage characterization
Connection system – top contact	MPI MP40 micropositioner with DC arm and tip	Dual tip used on the two busbars of the cell
Connection system – bottom contact	Curamik substrate	Dual spring contact to achieve force and sense connection on the substrate

Measurement details	
Ambient temperature	25 °C

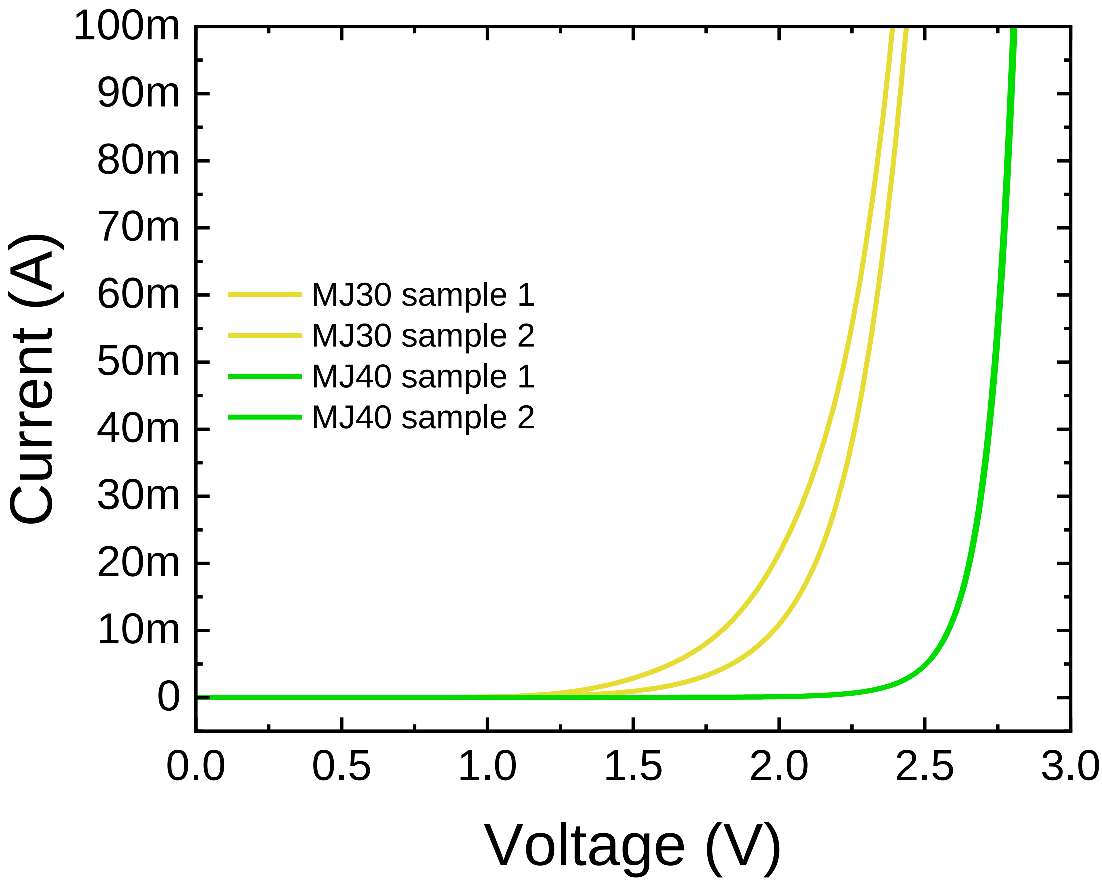

Figure 2: IV dark - linear scale

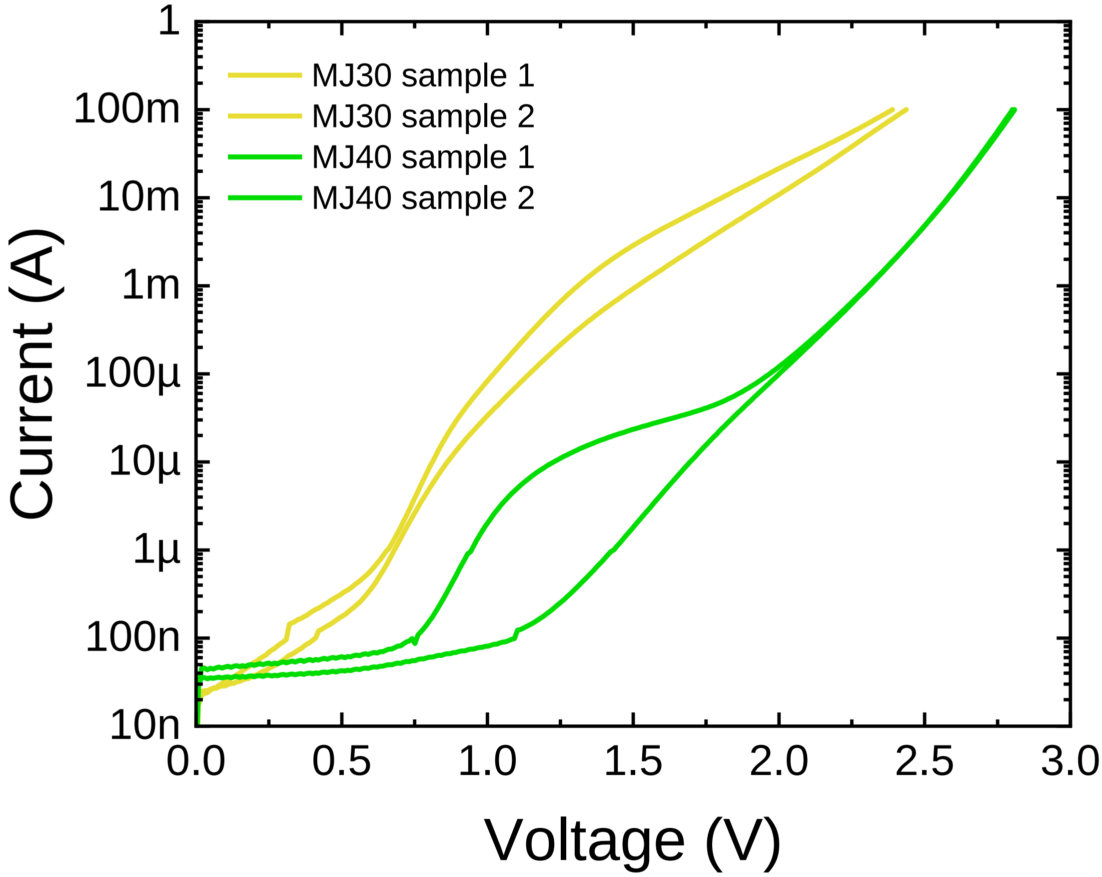

Figure 3: IV dark – semilog scale

IV Light measurement: Solar Simulator

Instrument	Instrument manufacturer and model	Notes
Light Source	Arc Lamp Solar Simulator: Newport Sol 3A 94063A	Class AAA 6 inches x 6 inches
Electrical measurement unit	Keithley SourceMeter 2651A	4 wire connection
Automation system	National Instruments Labview Custom program	1. Measurement of Voc 2. IV with voltage in 100 steps between Voc and 0 V
Irradiance reference	Calibrated Refernece Si Solar Cell Newport 91150V	2 cm x 2 cm area Maximum reading: 3.5 sun
Multiplication lens	PMMA Fresnel Lens	Size: 300 mm x 300 mm Focal length: 330 mm
Connection system – top contact	MPI MP40 micropositioner with DC arm and tip	Dual tip used on the two busbars of the cell
Connection system – bottom contact	Curamik substrate	Dual spring contact to achieve force and sense connection on the substrate

Measurement details	
Irradiance – 1 sun	No lens used Distance of DUT from Solar Simulator lens: 180 mm Attenuator completely open Irradiance confirmed by reference cell
Irradiance – 2 sun	Attenuator regulated at 50% output Lens used 10mm below Solar Simulator optic Distance of DUT from Solar Simulator lens: 180 mm Irradiance confirmed by reference cell (center of the beam)
Irradiance – 4 sun	Lens position and distance of DUT from Solar Simulator unchanged Attenuator completely open
Ambient temperature	25 °C
Measurement duration	Completed in less than 5 seconds after the solar simulator shutter is opened

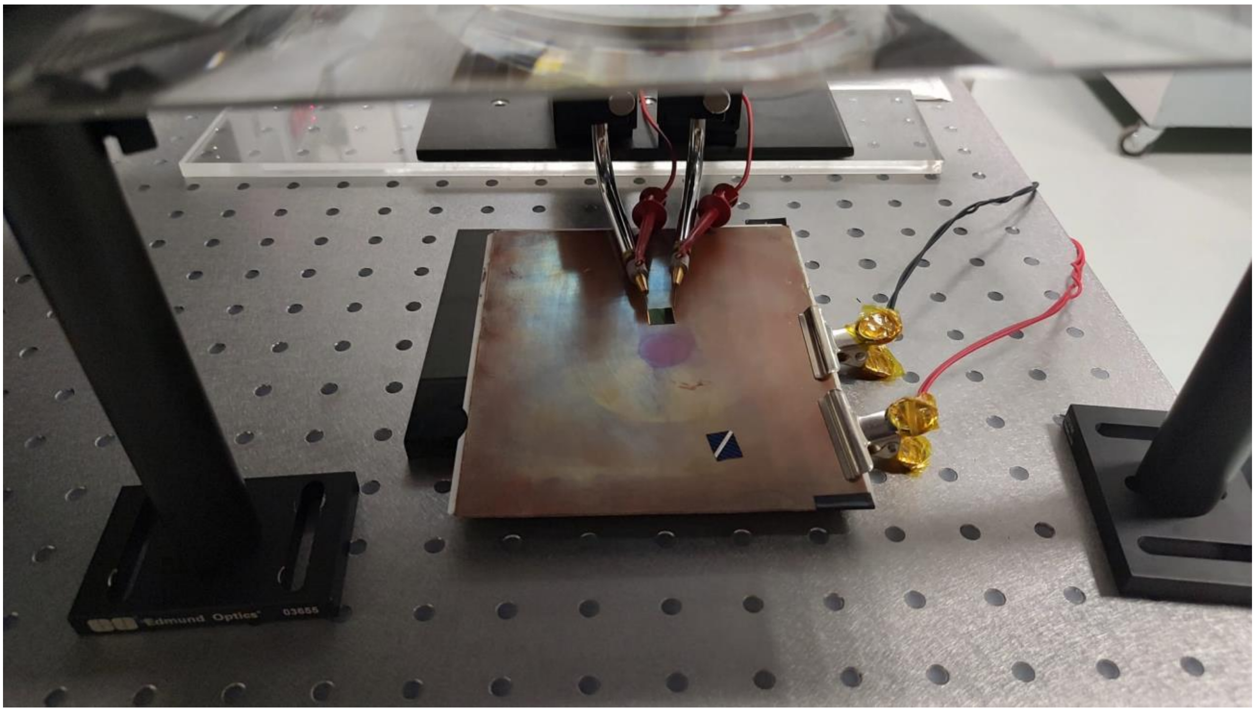

Figure 4: Picture of the measurement setup for the Solar Simulator

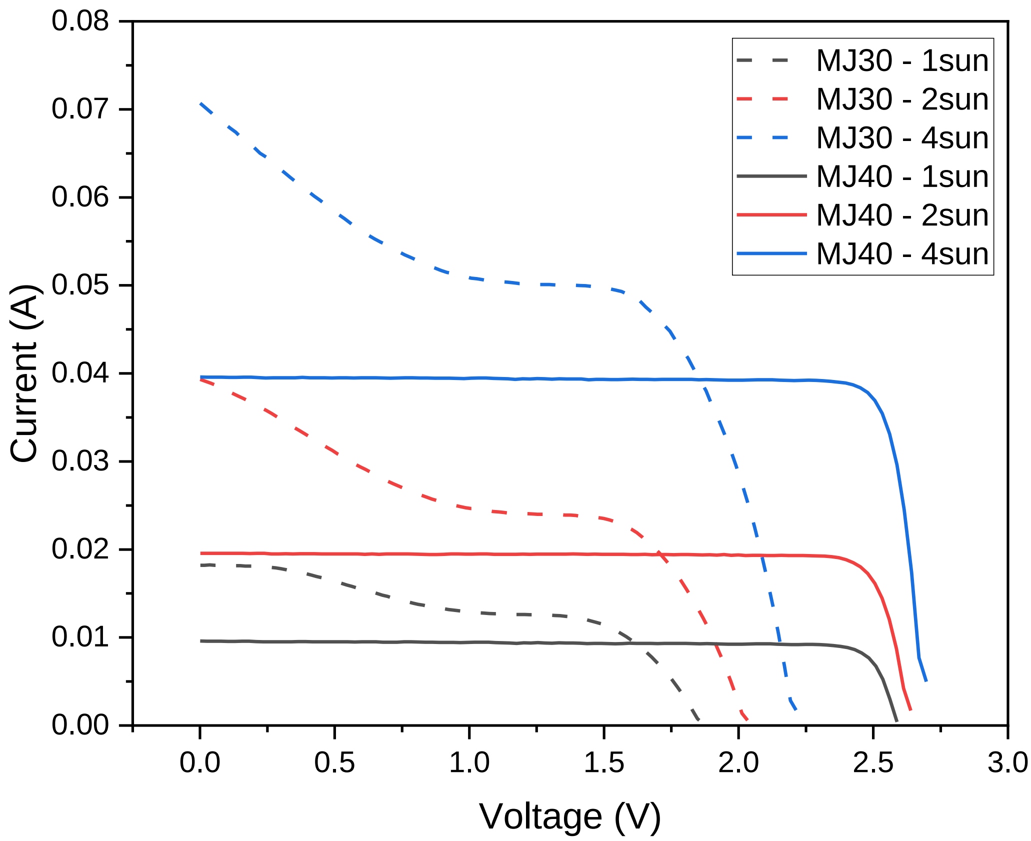

Figure 5: IV - Light - Solar Simulator

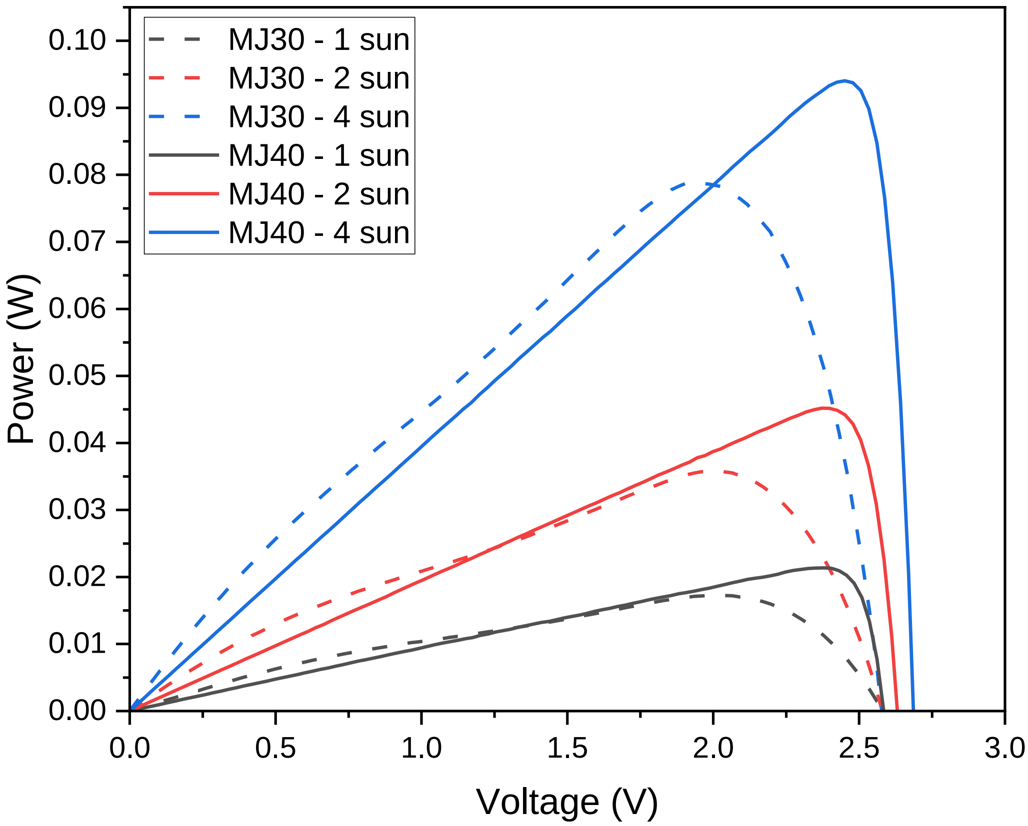

Figure 6: PV light, solar simulator

IV Light measurement: Halogen setup

Instrument	Instrument manufacturer and model	Notes
Light Source	Dual Halogen light source a - HALOSTAR OVEN 20 W 12 V G4 (with custom parabolic reflector) b - HLX OSRAM 150W 15V	The ratio between the two lamps has been adjusted to achieve a flat IV for the 30% solar cell
Electrical measurement unit	Keithley SourceMeter 2651A	4 wire connection
Automation system	National Instruments Labview Custom program	1. Measurement of Voc 2. IV with voltage in 100 steps between Voc and 0 V
Irradiance reference	Calibrated Refernece Si Solar Cell Newport 91150V	2 cm x 2 cm area Maximum reading: 3.5 sun
Stand	Kaiser RS 1	The distance between the light source and the DUT is set to change the irradiance. The irradiance of 1 sun is set on the basis of the Isc current of the cell, different values of irradiance are then calculated by means of the reference cell
Connection system – top contact	MPI MP40 micropositioner with DC arm and tip	Dual tip used on the two busbars of the cell
Connection system – bottom contact	Curamik substrate	Dual spring contact to achieve force and sense connection on the substrate

Measurement details	
Ambient temperature	25 °C
Measurement duration	Completed in less than 10 seconds after the lamps are switched on (5 seconds stabilization)

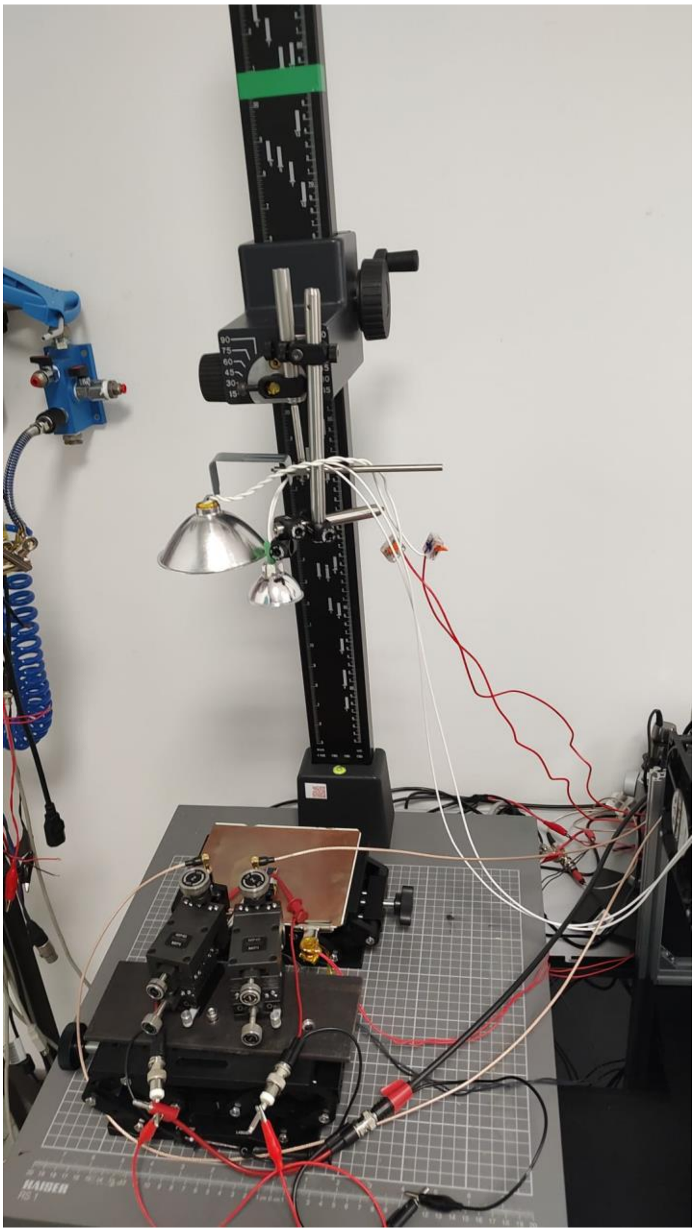

Figure 7: Picture of the measurement setup for the Halogen Illuminator

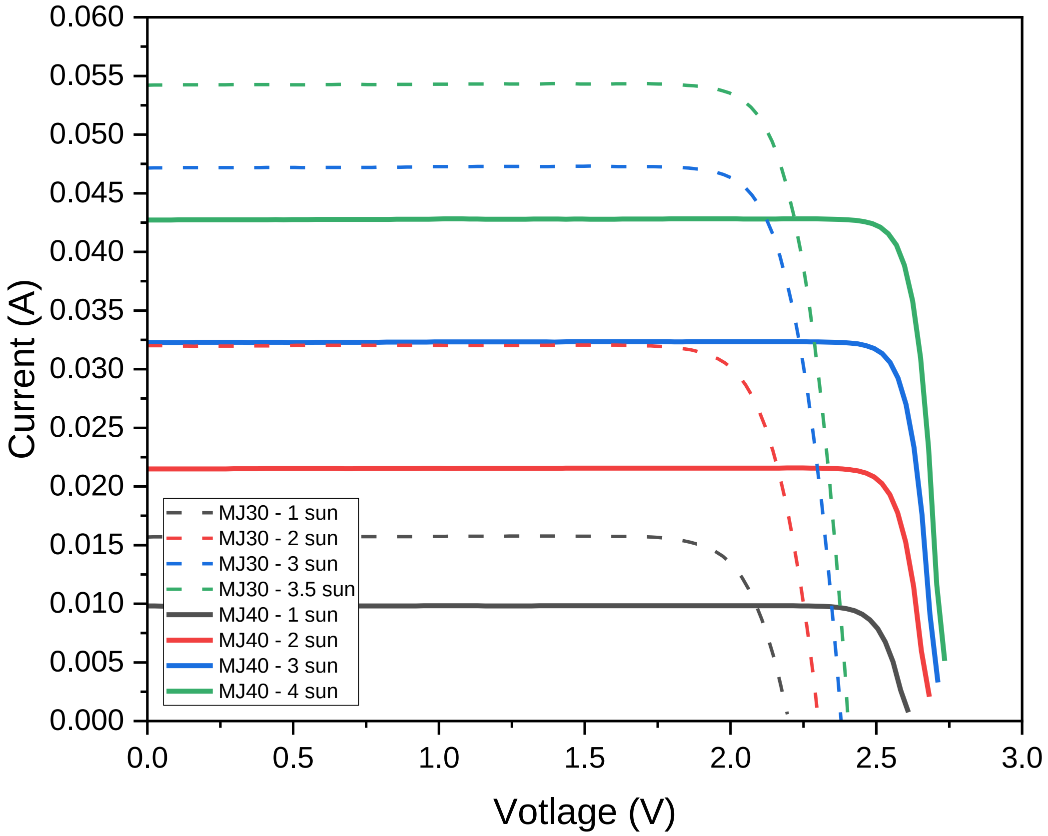

Figure 8: IV - Light – Halogen Illuminator

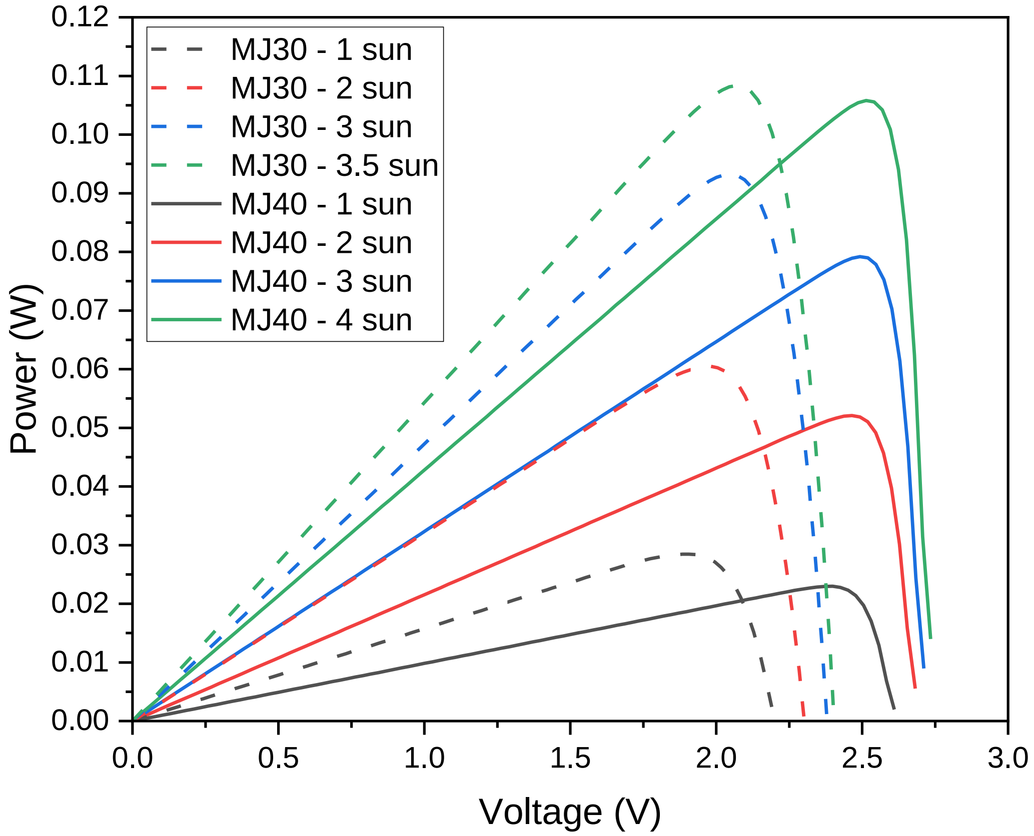

Figure 9: PV - Light – Halogen Illuminator

IV Light measurement: Outdoor measurement

Instrument	Instrument manufacturer and model	Notes
Light Source	Natural sun	Measurement carried out the 17/10/2023 at 11:30 AM in Padova, Italy Weather condition: clear sky Approx. irradiance on horizontal surface 0.59 suns
Electrical measurement unit	Keithley SourceMeter 2651A	4 wire connection
Automation system	National Instruments Labview Custom program	1. Measurement of Voc 2. IV with voltage in 100 steps between Voc and 0 V
Irradiance reference	Calibrated Refernece Si Solar Cell Newport 91150V	2 cm x 2 cm area Maximum reading: 3.5 sun
Multiplication lens	PMMA Fresnel Lens	Size: 300 mm x 300 mm Focal length: 330 mm
Connection system – top contact	MPI MP40 micropositioner with DC arm and tip	Dual tip used on the two busbars of the cell
Connection system – bottom contact	Curamik substrate	Dual spring contact to achieve force and sense connection on the substrate

Measurement details	
Horizontal irradiance	No lens used Irradiance confirmed by reference cell adjacent to the DUT
Horizontal irradiance + Fresnel lens horizontal	Lens positioned 170 mm above the DUT on the horizontal plane Irradiance measured by reference cell before the DUT measurement
Horizontal irradiance + Fresnel lens orthogonal to light path	Lens positioned above the DUT orthogonal to light path Irradiance calculated from the Isc of the DUT
Ambient temperature	19 °C
Measurement duration	The sun light on the DUT and reference cell has been covered between measurements, measurement completed in less than 10 seconds after the cover is removed

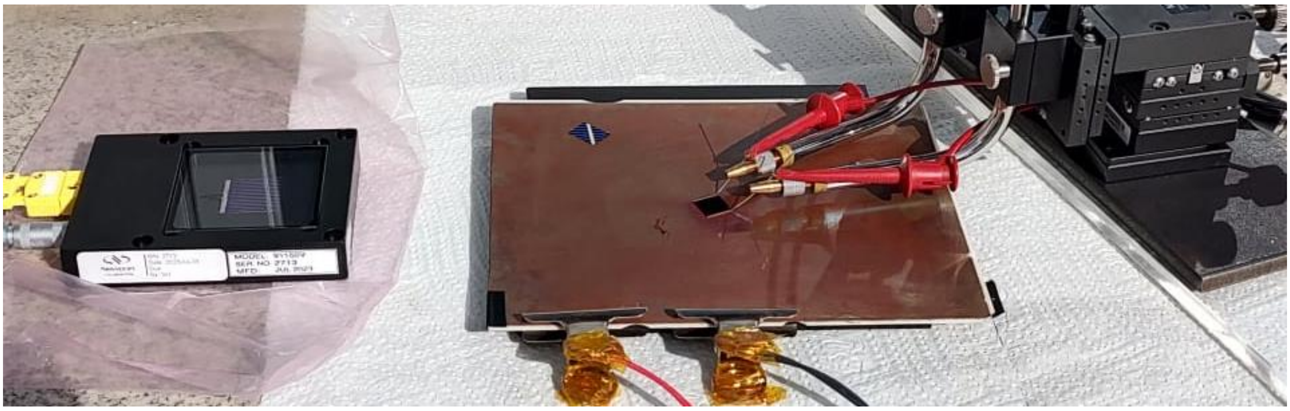

Figure 10: Outdoor measurement setup

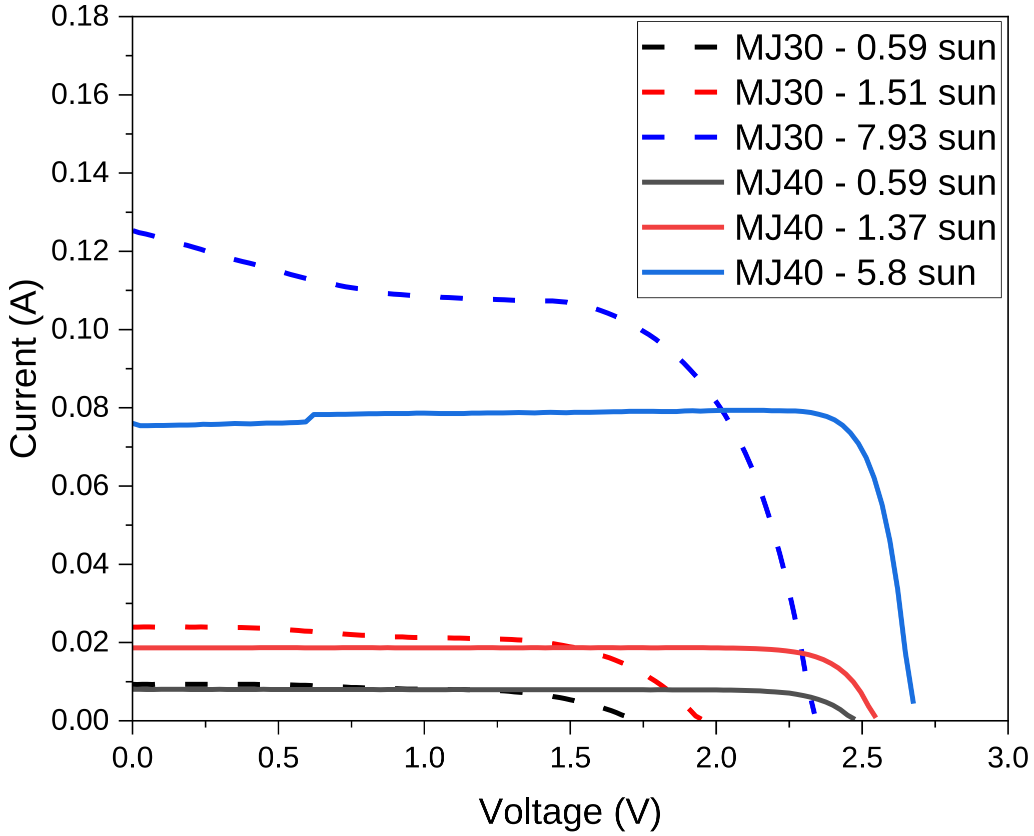

Figure 11: IV - Light – Outdoor measurement

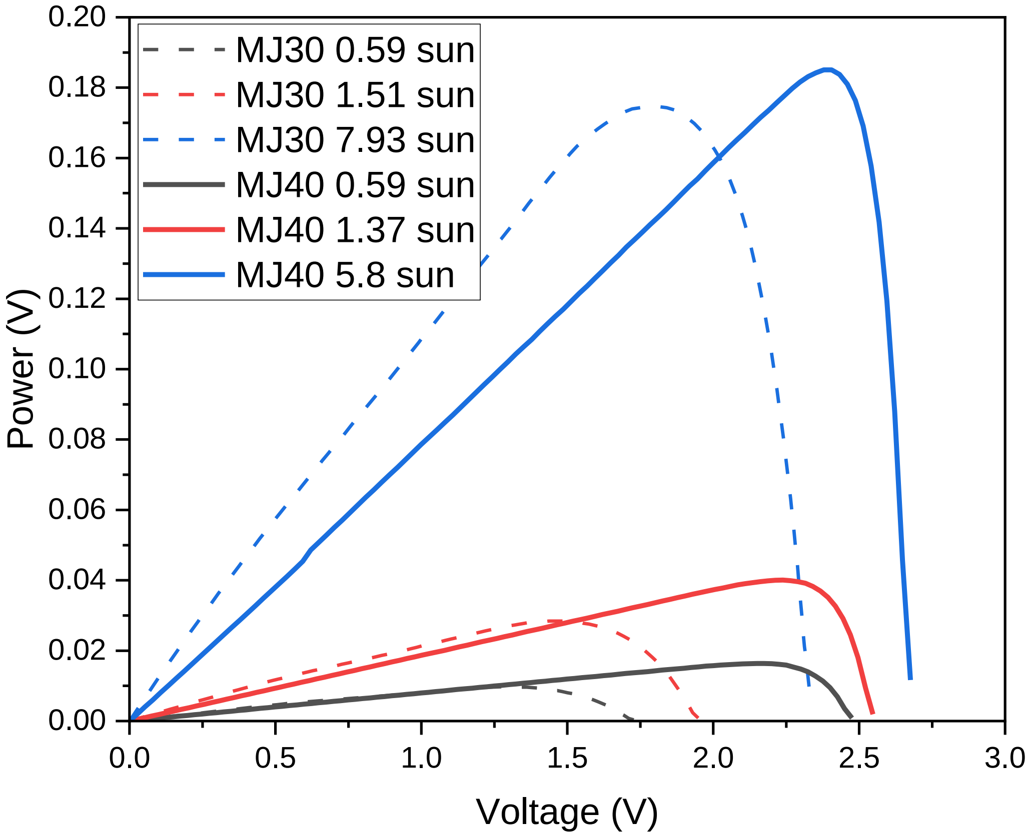

Figure 12: PV - Light – Outdoor measurement

Efficiency calculation

Efficiency of the devices has been calculated dividing the maximum power by the irradiance measured by the reference cell or calculated from the short circuit current.

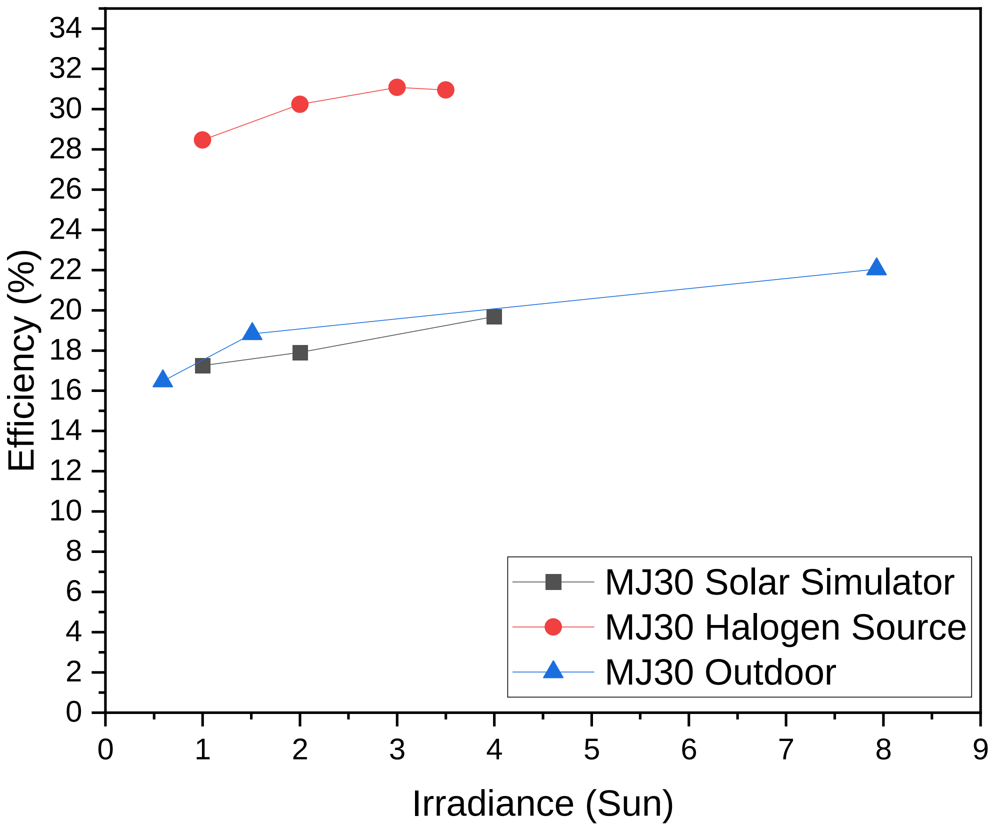

Figure 13: efficiency plot of the MJ30 devices

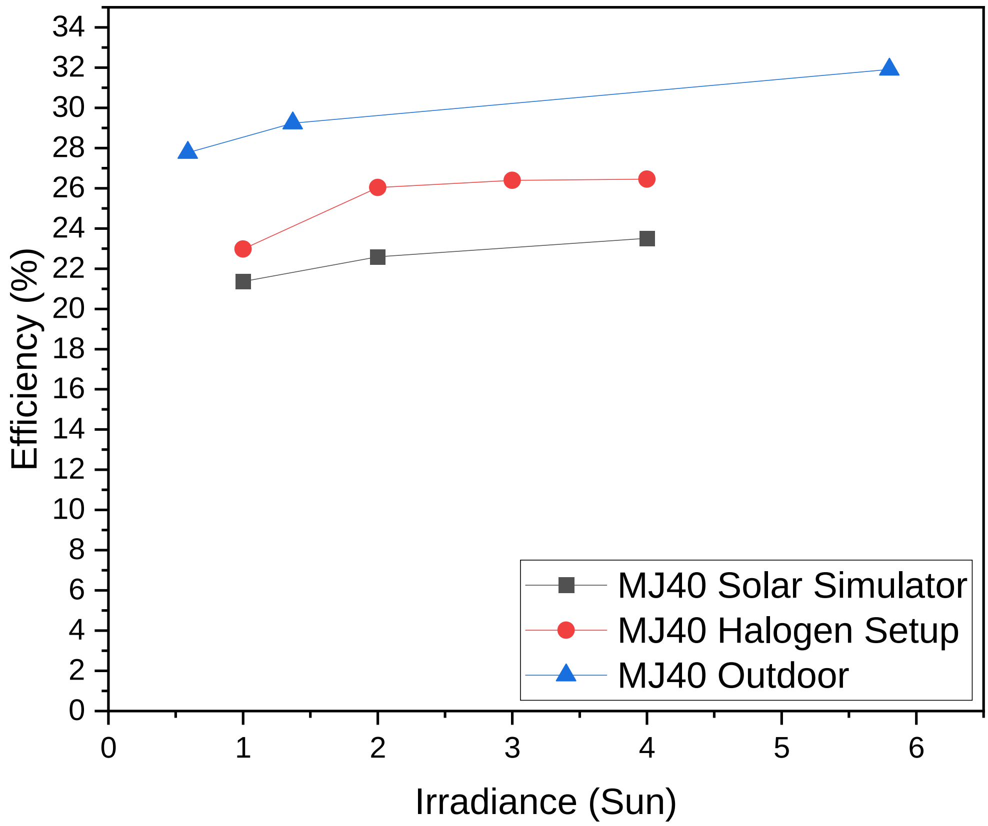

Figure 14: efficiency plot of the MJ40 devices

The extrapolation of the efficiency at different irradiance can be roughly estimated considering that:

- Short Circuit Current increases linearly with irradiance
- Open Circuit Voltage increases logarithmically with irradiance

The efficiency can then be considered also logarithmically related to the irradiance, if the Fill Factor of the cell does not change. Typically the fill factor decreases at high irradiances, but this effect cannot be estimated with the previous measurement. As a first approximation and for reference only the following graph reports the estimation of the efficiency based on a logarithmic fitting, without considering any Fill Factor variation.

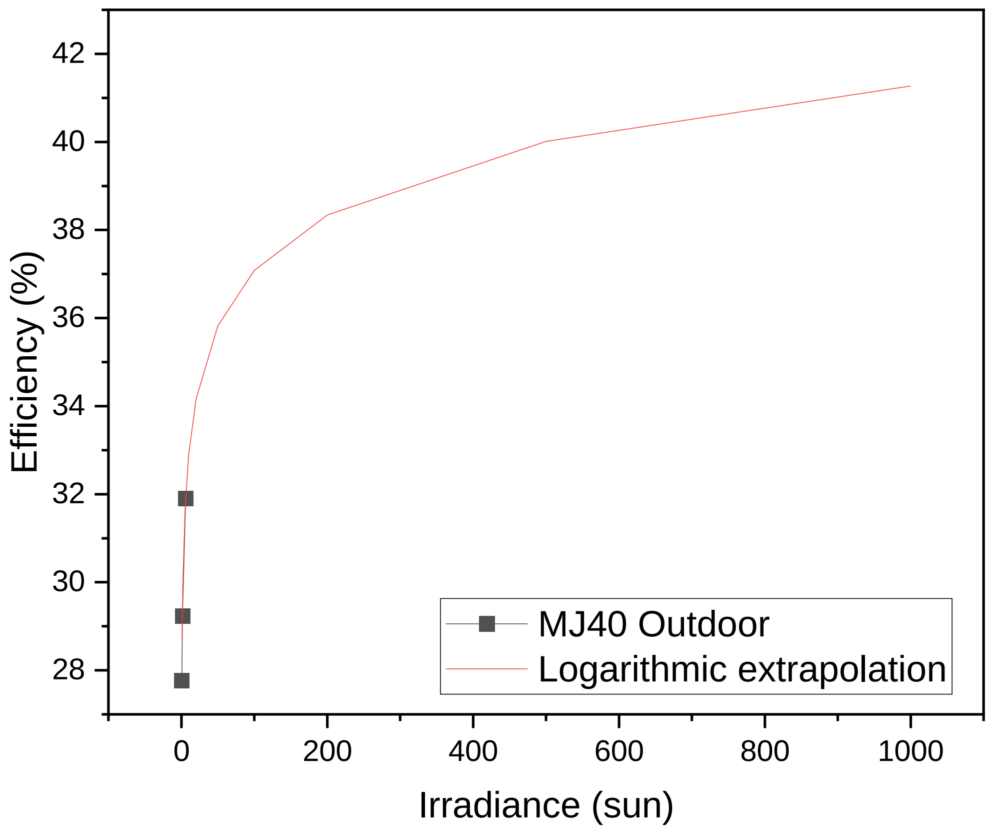

Figure 15: Efficiency estimation of the MJ40 device in outdoor condition

EQE measurement

Instrument	Instrument manufacturer and model	Notes
PV measurement system	Bentham PVE300 Photovoltaic EQE (IPCE) and IQE solution	EQE DC configuration no additional light bias Calibrated with reference Si cell and reference Ge cell Current amplifier Autorange ON
Connection system – top contact	MPI MP40 micropositioner with DC arm and tip	Dual tip used on the two busbars of the cell
Connection system – bottom contact	Curamik substrate	Dual spring contact

Measurement details

Ambient temperature	25 °C

It has not been possible to measure the EQE of the second and third junction, the EQE of only the first junction is then reported.

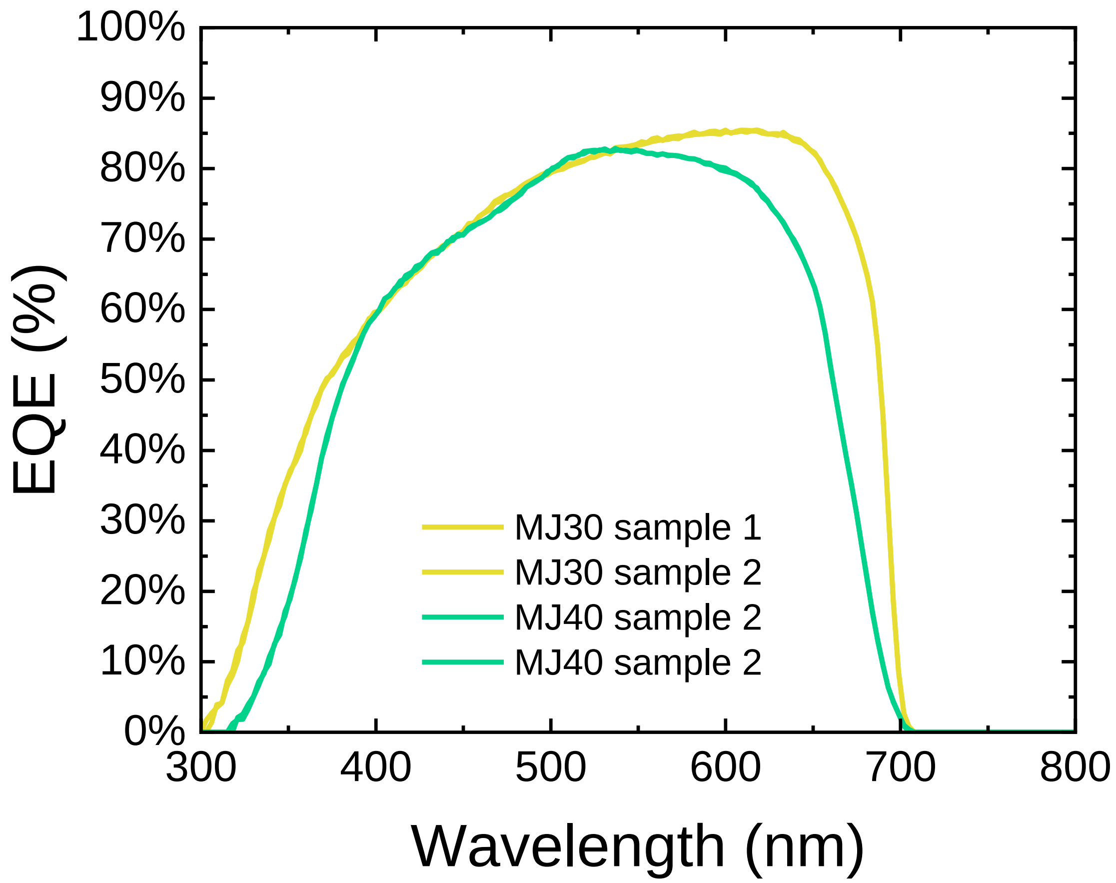

Figure 16: EQE measurement of the first junction of the MJ30 and MJ40 devices