PVE300
Photovoltaic EQE & IQE solutions

Light. Measurement. Excellence.

Quantum Design EUROPE

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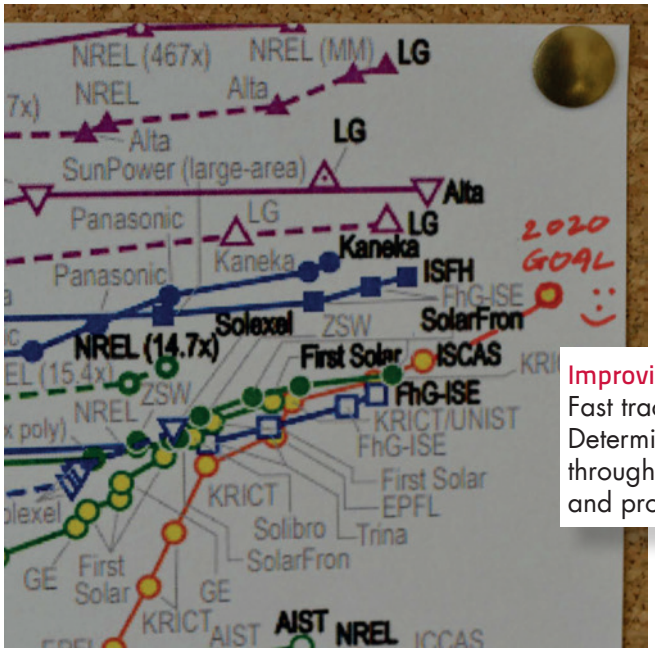
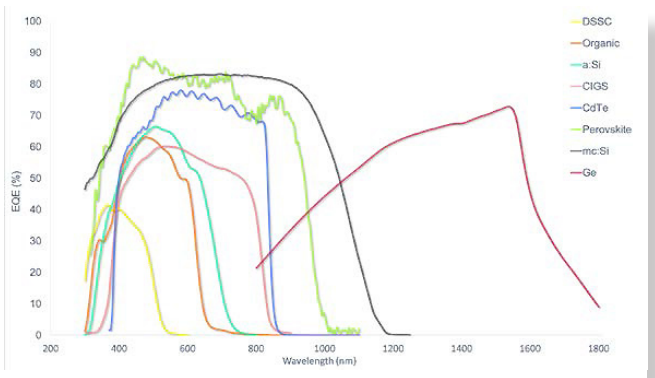


Improving efficiency, breaking records
Fast track your PV research with EQE testing. Determine where your device wins and loses throughout the spectrum to drive design, material and process optimisation.

EQE testing of photovoltaic devices allows you to determine where your device wins and loses throughout the spectrum and gives you an insight into the physical processes that drive and limit current generation.

The PVE300 is primed and ready to fast track your PV research by enabling the accurate measurement of:

- EQE (IPCE)
- IQE
- Reflectance
- Transmittance
- Predicted J_{sc}



Measure all device types
Compatible with all types of photovoltaic devices and architectures: c:Si, mc:Si, a:Si, µ:Si, CdTe, CIGS, CIS, CZTS, Ge, dye-sensitised, organic, polymer, multi-junction (2-, 3-, 4– junctions and more), quantum well, quantum dot and perovskites.

Wide spectral range
Adaptable to your research interests, the standard spectral range of 300-1100nm may be extended down to 250nm and up to 3000nm and beyond.

Simple to operate
Fully automated through the USB interface and controlled by the Benwin+ application, the PVE300 directly reports measurement results including spectral response, EQE, IQE and predicted Jsc.

Accuracy and traceability
Have confidence in your results thanks to the superlative wavelength, photocurrent and beam power measurement accuracy of the PVE300.

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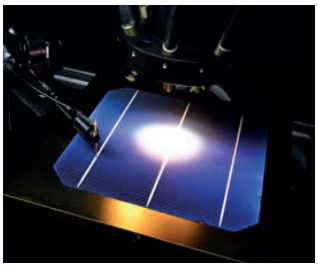
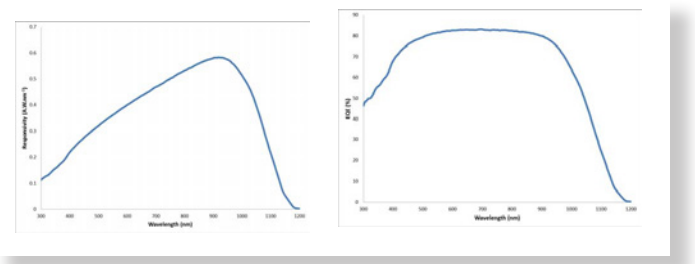
We know that you are busy with your research. That is why we have designed the PVE300 to be easy to use, ever ready and most importantly, accurate. Spectrally characterise your PV devices in confidence with the PVE300.

1. Measurement of EQE (IPCE)/ spectral response

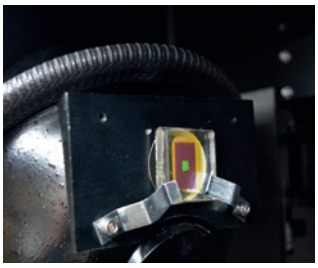
A range of configurations of tuneable light source and sample mount are offered to ensure measurement of all device types and architectures.

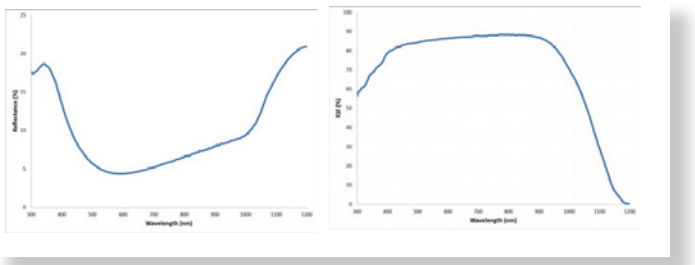


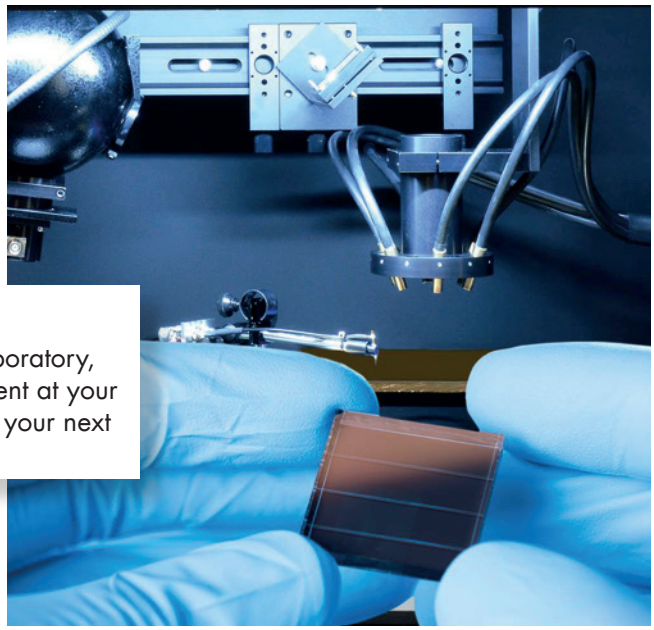


2. Measurement of total reflectance and transmittance (convert EQE to IQE)

An integrating sphere based spectrophotometer mode allows characterisation of reflectance and transmittance of PV devices and their components.







Fast track your PV research

With the PVE300 in your laboratory, benefit from EQE measurement at your fingertips, ready to evaluate your next device.

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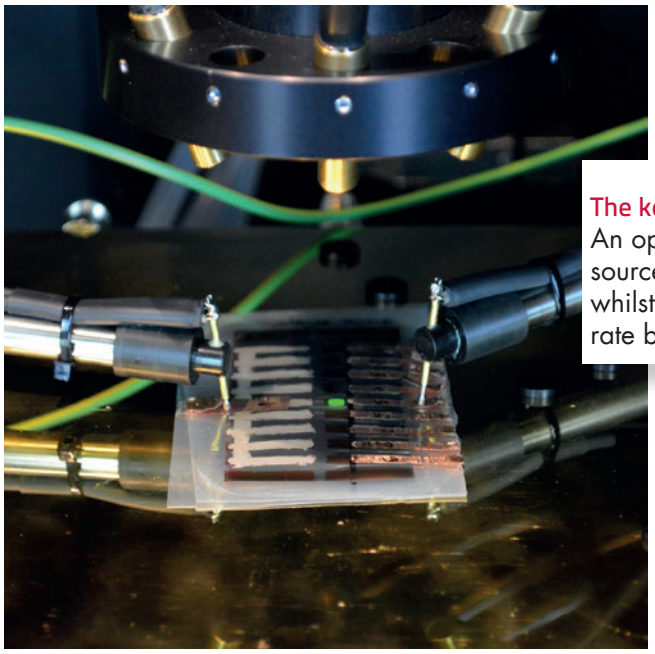
Monochromatic probe

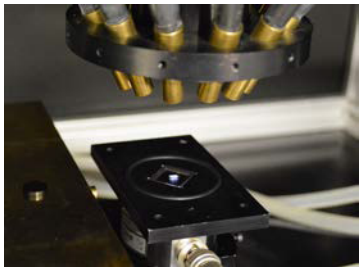


The key to EQE testing

An optimised tuneable monochromatic light source provides wide spectral range operation whilst calibrated reference diodes ensure accurate beam power measurement.

The tuneable monochromatic light source is the key to the spectral characteristics of photovoltaic devices. Precise optical probing of the sample and accurate beam power measurement is the cornerstone of EQE results you can rely on.

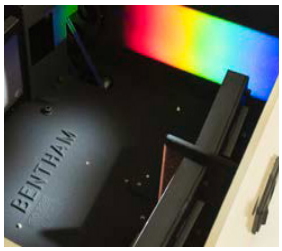
Accurate beam power measurement

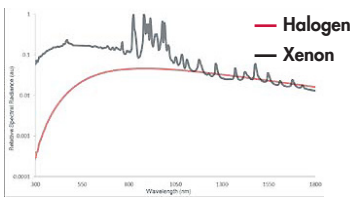


The optical power of the monochromatic probe is characterised using reference detectors with traceable calibration to national metrology institute (NMI) . This step is crucial in the establishment of a traceable EQE measurement, the foundation of measurement confidence.

Precise optical probing

A dual xenon- halogen light source and triple grating monochromator provides a wavelength agile, power optimised monochromatic probe across the spectral range of interest. A reflective optic relays an image of the monochromator exit port onto the sample plane, providing a probe of any shape up to 6x6 mm.





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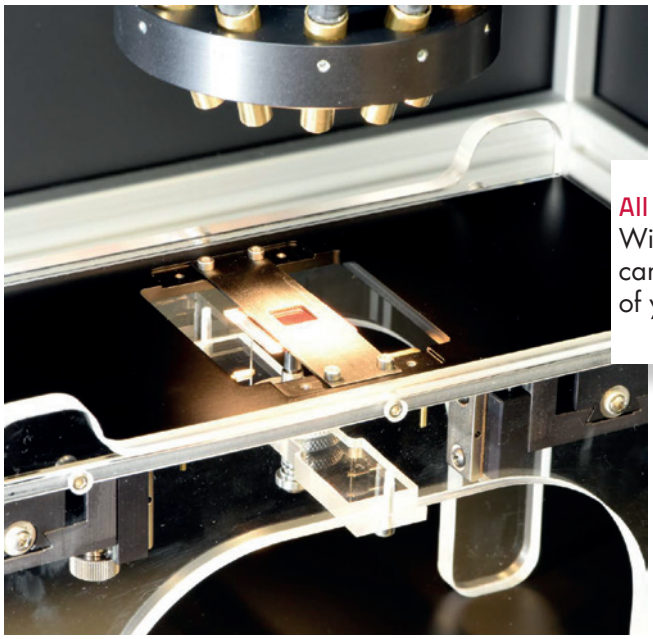
Sample mounts & probes



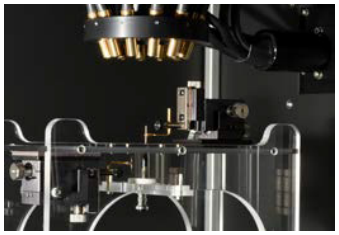
All devices, all architectures
With the PVE300, be confident that you can easily mount, contact and measure all of your devices.

From research idea to production ready device- across material systems and device architectures- device size, and location of the electrodes can vary significantly. Benefit from a range of standard sample mounts and probes to ensure compatibility with your devices.

Front/ front and front/ rear contact devices

A temperature controlled vaccum mount (sample area 200x200 mm) provides flexible electrical probing, using the gold coated mount as rear contact. The sample temperature can be controlled to counter the effect of sample heating under light bias and explore performance with temperature (15-65°). Where device mapping is required a motorised XY stage option enables automated measurement over large sample areas.

Rear contact devices



A superstrate mount (sample area 60x60 mm) offers flexible electrical probing using magnetic-based micro-positioning probes. For samples including multiple rear contact devices, a customisable multi-probe mount enables the simultaneous electrical probing of all devices, whilst an XY stage moves the sample under the monochromatic beam.

Electrical probes

Two types of electrical probe are offered according to the available contact area. For larger contact pads, robust spring probes are recommended. For smaller contact pads, needle probes with an XYZ micro-positioning feature facilitates probing.

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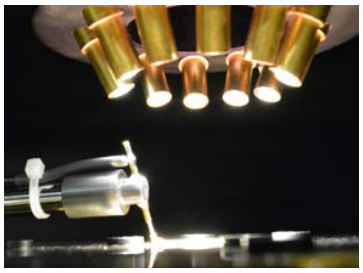
Testing conditions

The ultimate goal
Ensure your results are transferable from your laboratory to the real world.

Light biasing. Voltage biasing. Set up your device for testing- and explore its behaviour- to understand the physical processes that drive and limit current generation With the PVE300, tailor testing conditions to the requirements of your PV technology.

Light biasing



The EQE measurement is performed in the presence of a steady-state light bias to study device performance under high carrier injection level (differential spectral responsivity (DSR) method). Halogen and xenon light bias sources are offered to enable testing under variable irradiance up to 1000 W.m-2. Since the light bias is used only to set up measurement conditions, it need not spectrally match AM1.5. This allows the use of halogen as light source, the superior stability of which offers the best signal to noise performance in the EQE measurement. The PVE300 light bias sources are complemented by a range of filters to modify the light bias spectrum, used in the testing of multi-junction devices and exploring material systems exhibiting light bias dependent behaviour.

Voltage biasing

Whilst EQE testing is generally performed under short circuit conditions, some devices, such as thin film solar cells, may have a voltage dependent EQE. In such cases, testing under a defined reverse voltage bias is therefore crucial. With the PVE300, reliable voltage biasing is delivered by an industry standard Keithley source measure unit.

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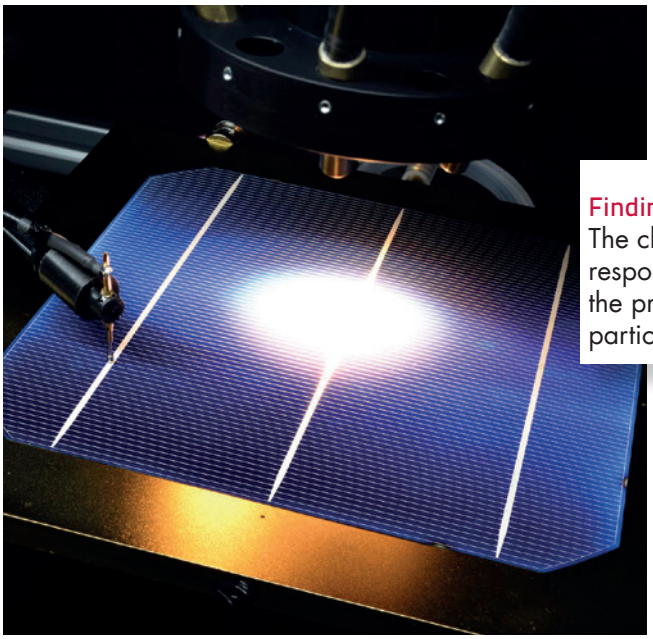
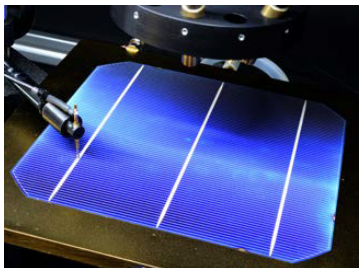
Photocurrent measurement



Finding a needle in a haystack
The challenge of measuring the photocurrent response to the monochromatic optical probe in the presence of one sun light biasing is particular to EQE testing.

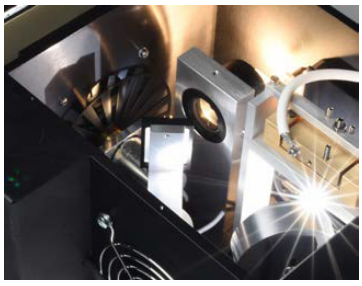
The challenge of measuring the photocurrent response to the monochromatic optical probe in the presence of one sun light biasing is particular to EQE testing. With the PVE300, problems solved with a range of device specific photocurrent measurement routes.

Silicon, chalcogenides, III-V, organic, quantum dot, conjugated polymers and perovskites



In EQE testing, we are interested in the device response to the monochromatic probe and not the light bias. Optically chopping the monochromatic probe and passing the measured photocurrent through a transformer allows optimal lock-in amplifier signal recovery of the monochromatic probe response, the best light- biased EQE measurement under one sun.

DSSC



The electron transport mechanisms at play in DSSC devices are too slow for an optically chopped measurement, only DC measurement can give an accurate result. A unique DC chopper mode enables measurement of DSSC response in presence of small levels of light bias.

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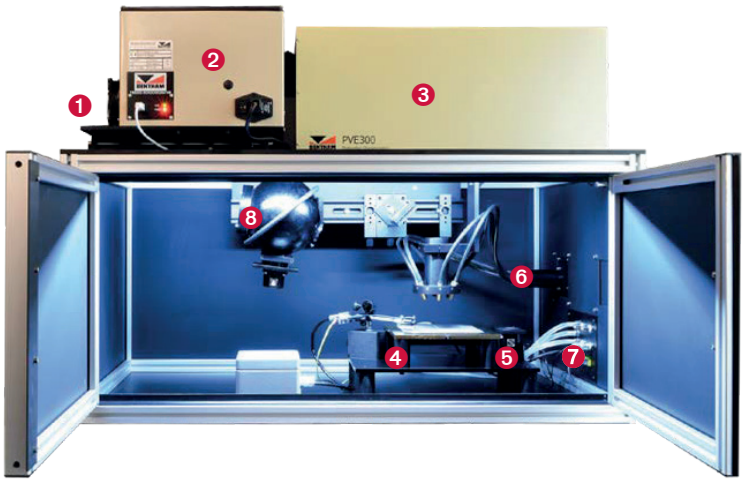
System components
The PVE300 brings together a monochromatic probe and light bias at the plane of the sample for the measurement of EQE. A divert mirror relays the probe to an integrating sphere for the measurement of transmittance and reflectance.

❶ Light source
A dual xenon- halogen source with automated source selection and constant current operation ensures high beam irradiance and excellent stability.

❷ Monochromator
A narrow bandwidth monochromatic probe, continuous wavelength tuning and high throughput is provided by a 300 mm focal length, triple grating monochromator.

❸ Relay optic
A reflective optic relays an image of a monochromator exit port aperture onto the sample plane, providing a probe of any shape up to 6x6 mm.

❹ Sample mount & probes
A range of sample mounts and probes ensure positioning of your sample at the beam focus and reliable electrical probing.



❺ Reference detectors
The optical power of the monochromatic probe is characterised using reference detectors with traceable calibration to national metrology institute (NMI): silicon (300-1100 nm) and germanium (800-1800 nm).

❻ Light bias
Up to two variable-irradiance halogen or xenon light bias sources with computer-controlled shutter are mounted to the side wall of the PVE300 chamber. Light is transported via six-branch fibre to ensure uniform illumination in the sample plane.

❼ Photocurrent measurement
Optimal signal recovery of all but DSSC PV devices is achieved with a transformer followed by a DSP lock-in amplifier to decouple the device response. Best results under the sun with no user intervention. The unique DC chop mode allows EQE testing of DSSC under low-level light biasing.

❽DTR6 integrating sphere
The DTR6 integrating sphere is mounted on an optical rail to the upper of the PVE300 chamber, allowing the measurement of total reflectance and total transmittance.

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Optional extras

The PVE300 has been designed to be compatible with all types of photovoltaic device and architectures. The following extras are included to meet with specific device requirements.

1. Multiple light bias sources

In the measurement of four (or more) junction devices, the flexibility of two light bias sources assists in generating the tailored light bias required to isolate the EQE of the middle sub-cells.

2. Double monochromator

Exploring sub-band gap requires the stray light performance of a double monochromator. Extend the dynamic range of the PVE300 by replacing the TMc300 monochromator with the DTMc300.

3. Custom sample mount

Whilst the electrical and thermal connection of substrate devices is relatively trivial, the same cannot be said of superstrate or packaged devices. With an in-house design service, Bentham can design a mount suitable for your application.

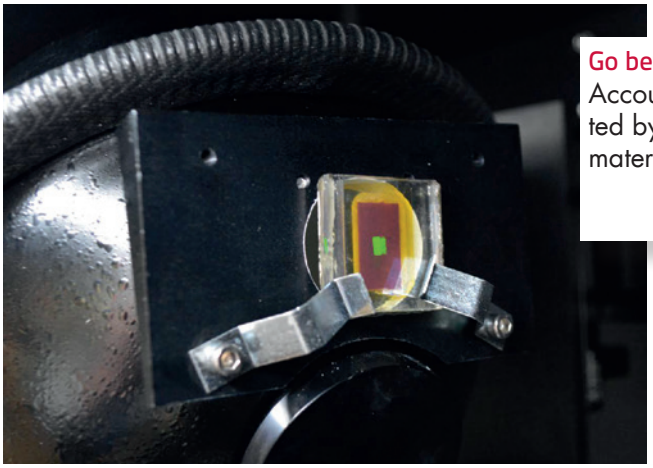
4. High irradiance monochromatic bias source

For ultimate flexibility in the measurement of multiple junction cells, a high irradiance monochromatic source, assembled from a 450 W xenon lamp and 300 mm focal length monochromator provides a tuneable source 300-1100 nm.

5. Temperature sensor

Where accurate knowledge of the temperature of a device under test is required, a non-contact infrared temperature sensor is available. Mounted to the top of the PVE300 chamber, the sensor is directed to the vicinity of the sample illuminated by the monochromatic probe.

Reflectance and transmittance

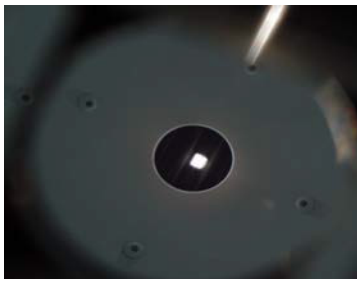


Go beyond the device level

Accounting for the light reflected and transmitted by your device allows characterisation at the material level and the computation of IQE.

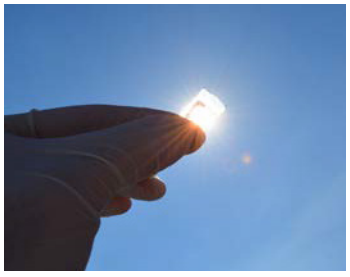
Accounting for the light reflected and transmitted by your device allows characterisation at the material level and the computation of IQE. Using an integrating sphere, components of the device, including absorber layers and transparent electrodes may also be characterised.

Reflectance



Light incident on a PV device is reflected both specularly and diffusely. In order to collect both components, the sample is illuminated at an angle of incidence of 8° and the total reflected light collected by an integrating sphere. A simple 0°/0° specular reflectance measurement is incorrect. It is unable to estimate the diffusely reflected component.

Transmittance



Whilst limited to the characterisation of transparent materials at the device level, at the component level, the transmittance measurement gives crucial information on the layers that make up a PV device, including absorber layers and transparent electrodes.

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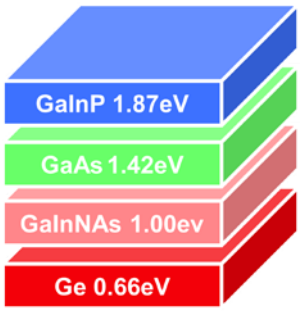
Multi-junction devices

Seeing through multi-junction devices
Access the EQE of multi-junction device sub-cells with tailored conditions for both light and voltage biasing with the PVE300.

Series-connected multiple-junction devices require tailored measurement conditions for both light and voltage biasing to access the EQE of sub-cells. Easily see inside tandem, triple, four junction (or more) devices with the PVE300

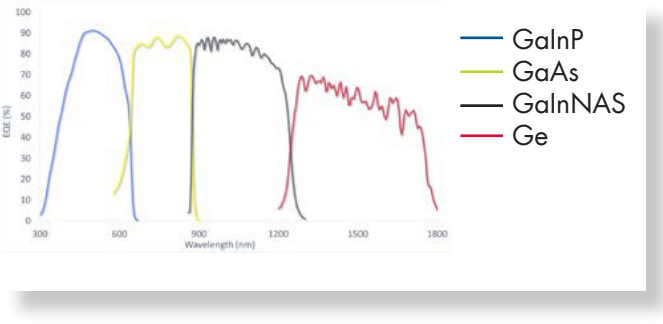
Light biasing



It is not possible to measure the EQE of the sub-cells of a monolithic multi-junction solar cell separately, since they are epitaxially grown on one substrate and interconnected by tunnel diodes. The EQE of a sub-cell is measured by illuminating the device with a light bias matched to the spectral response range of the other sub-cells. In this way, the non-tested sub-cells generate an excess photocurrent and the sub-cell under study is current limiting. The ability to tune the light bias is therefore essential. The PVE300 is offered with a range of standard filter sets for tandem and III-V triple and four junction solar cells.

Voltage biasing

A result of light biasing is to put tested sub-cells having low reverse breakdown voltage or low shunt resistance into forward bias which will lead to erroneous results. This is common with low band gap materials such as the germanium bottom cell of III-V MJ cells. Short circuit operation of the sub-cell in this case can be achieved by voltage biasing the entire multiple junction cell using a Keithley source measure unit.



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EQE measurement procedure
Accurate EQE testing in just a few steps

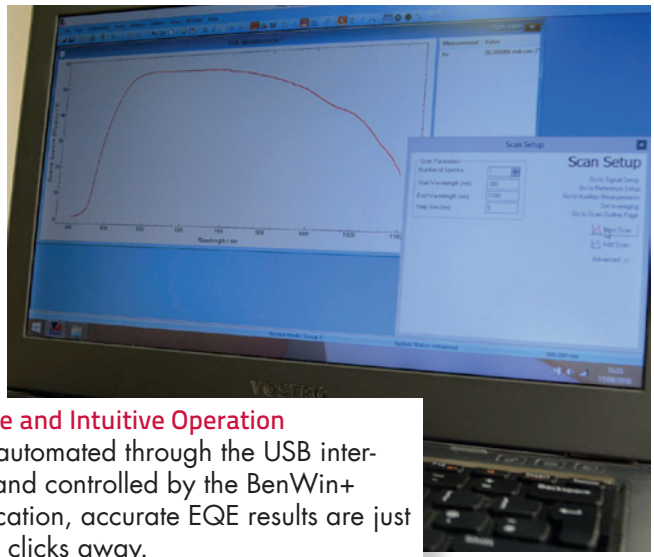
1. Power on the PVE300 and run Benwin+
- Get ready to launch a measurement over your spectral range of interest

2. Calibration, your link to national metrology standards
- Click the quick wavelength button to transmit visible light to facilitate alignment under the beam.
- Run a measurement to measure the power in the monochromatic beam over the spectral range of interest.
- It is recommended to calibrate once at the beginning of a measurement session to minimise measurement uncertainty.

3. Set up your device under the PVE300
- Click the quick wavelength button to transmit visible light to facilitate alignment under the beam.
- Position your device on the PVE300 mount, electrically probe for the photocurrent measurement.

4. Run a measurement
- Simply hit new scan to begin the measurement of your device, selecting whether or not to apply light bias.
- The EQE results will unfold on screen.

5. View results
- Inspect the EQE results, overlay measurements to compare.
- Directly view the reported value of predicted J_{sc}
- Export a measurement report or transfer the spectral data to your favourite platform.



Simple and Intuitive Operation
Fully automated through the USB interface and controlled by the BenWin+ application, accurate EQE results are just a few clicks away.

PVE300 configuration
The instrumentation requirements to measure the EQE of PV devices depends on the material system and architecture. Configure the PVE300 your way.

The following options are required for the configuration of the PVE300.

1. Single point measurement or device mapping
- PVE300: Single point sample measurement.
- PVE300_XY: Includes motorised X-Y stage allowing the determination of device uniformity and IPCE.

2. Spectral range
- Monochromatic probe 300-1100 nm, Si reference diode
- Monochromatic probe 300-1800 nm, Si and Ge reference diodes
- Maximum range 250-3000 nm: Please enquire

3. Sample mount
- Temperature controlled vacuum mount: Measurement of front/ front and front/ rear contact devices with sample temperature control
- PV_SS6: Measurement of rear/ rear contact devices
- Custom requirements: Please enquire.

4. Monochromatic probe mode-AC/DC
- AC mode: Optical chopper (10 Hz-2 kHz) located in dual source
- AC/DC mode: Arrestable optical chopper located in dual source
- DC chopped mode: Stepping motor-based chopper located in dual source.

5. Detection Electronics
- Silicon, chalcogenides, III-V, organic, quantum dot, conjugated polymers and perovskites
- Dye-sensitised devices: 498 DC/AC trans-impedance amplifier/ADC

6. Measurement of reflectance/ transmittance
- Inclusion of DTR6 integrating sphere to measure total reflectance or transmittance of device.

7. Light bias source
- Inclusion of a variable irradiance halogen or xenon light bias with computer controlled shutter. Light transported via six-branch fibre to ensure uniform illumination in the sample plane.

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Specifications	
Tunable monochromatic probe (TMc300)	
Probe light source	75 W Xenon & 100 W Quartz halogen (QTH)
Monochromator configuration	Triple grating, symmetric, single Czerny-Turner, 300 mm focal length
Bandwidth	Adjustable fixed slit, 1-10 nm typical
Resolution	0.3 nm (1200 g/mm); 0.6 nm (600g/mm)
Dispersion	2.7 nm/mm (1200 g/mm); 5.4 nm/mm (600g/mm)
Wavelength range	300-1100 nm (1200 g/mm); 1100-2500 nm (600 g/mm)
Wavelength accuracy	± 0.2 nm (1200g/mm); ± 0.4 nm (600 g/mm)
Relay optic	Mirror-based, 1.2x magnification
Probe size	Up to 6x6 mm
Temperature-controlled vacuum mount	
Temperature control	4x70 W Peltier-based heat pump, water-cooled hot side
Temperature range	15-65 °C
Temperature feedback	Centrally-positioned sensor situated 3 mm below sample plane
Temperature stability	± 1°C
Light bias	
Transport to sample	Branched glass fibre bundle
Bias source irradiance	0-1.5 suns
Bias source uniformity	±1% over 1 cm^2
Filter option	Two 50 mm square filter holders
Source options	Quartz halogen/ Xenon/ Class B AM1.5
Reference diodes	
Diode & range	Silicon 300-1100 nm; Germanium 800-1800 nm
Traceability	PTB, Germany
Voltage bias (optional)	
Voltage range	-20 to 20 V
Current limit	1 A
XY stage (optional)	
Travel in x	in x: 250 mm in y: 200 mm
Positional accuracy	±16 µm
Bi-directional repeatability	±1 µm
Resolution	0.5 µm
Drive type	Stepper motor
Speed	15 mm/s

Integrating sphere	
Port size	15 mm Ø (5 &10 mm Ø port reducers supplied)
Coating	$BaSO_4$
Detector	Silicon/ Germanium/ Silicon-InGaAs sandwich
Micro-positioning probe	
Travel range (x, y, z axis)	12.7 mm
Screw resolution	508 µm per turn
Mounting	Magnetic based
Needle material	Tungsten
Needle dimensions	0.5 x 25.4 mm, 12.7 mm radius
General	
Interface	USB 2.0
Software control	BenWin+ Windows application
Operating system	Windows 7 or newer
Overall dimensions W x L x H	Requires minimum bench space 1500 x 500 x 1000 (mm)
Power	Mains input 110/220 V 50/60 Hz

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