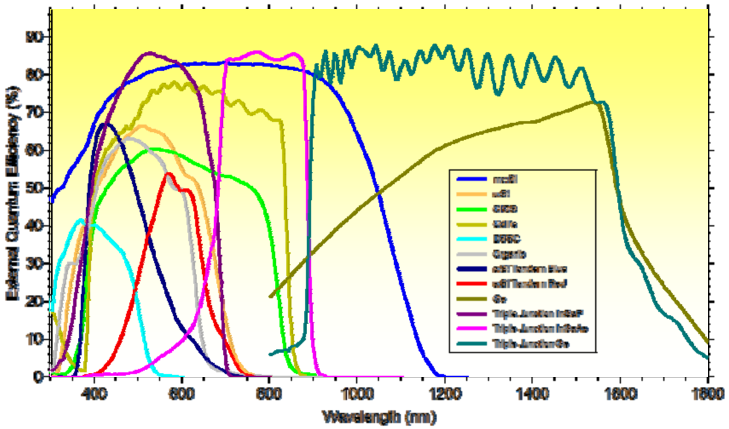
BENTHAM

PVE300

Photovoltaic Spectral Response

EQE (IPCE), IQE

The PVE300 system is a monolithic, turnkey solution for photovoltaic material and device spectral characterisation; a key component in research, or as part of a production-line quality process.



Quick and Accurate

Using a monochromatic probe (any shape up to 6x6mm) and NMI traceable calibrated reference diodes, the PVE300 permits the quick and accurate determination of solar cell spectral response/ EQE (IPCE). The additional measurement of cell transmittance and reflectance allows the determination of IQE.

Measure all Device Types

Compatible with all types of photovoltaic devices, from silicon to 3rd generation devices: c:Si, mc:Si, a:Si, µ:Si, CdTe, CIGS, CIS, Ge, dye-sensitised, organic/polymer, tandem, multi-junction, quantum well, quantum dots etc...

Electrical Interface

A full range of detection electronics are available to accommodate the requirements of all device types, including AC or DC operation, transformer, pre-amplifiers and lock-in amplifier with device operation in short circuit or voltage biased.

Wide Spectral Range

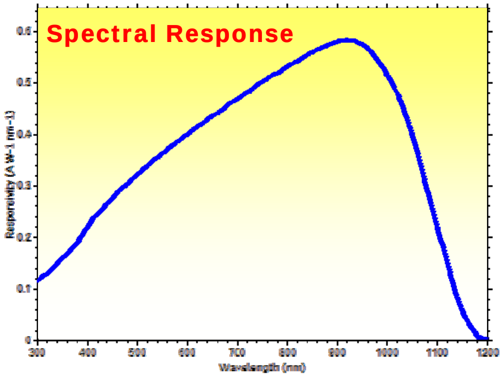
The standard spectral range of 300-1100nm, may easily be extended to 1800nm and beyond.

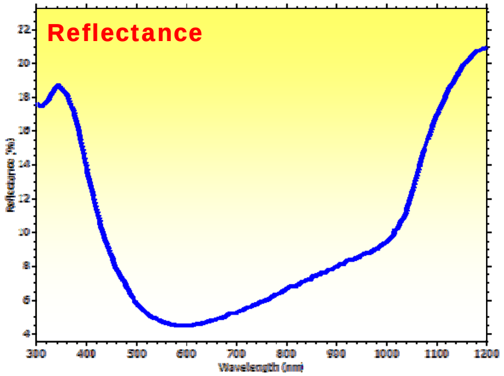
Let the PVE300 do the Measurements for You

Fully automated through the USB interface and controlled by the Benwin+ windows software, the PVE300 directly reports measurement results including spectral response, EQE, IQE and AM1.5 J_{sc}.

Flexible

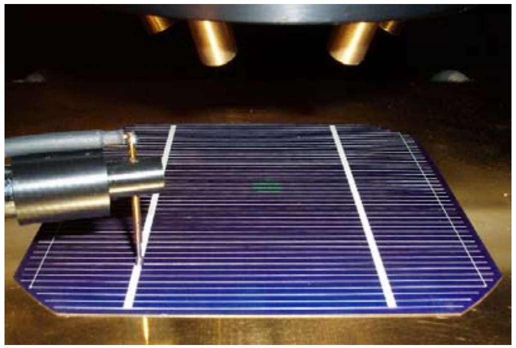
A wide range of options include temperature-controlled vacuum mounts for substrate, superstrate or packaged devices, integrating sphere accessory for measurements of total reflectance and transmittance, a choice of single or multiple channel bias sources, including an AM1.5 matched bias source and a motorised XY stage for device mapping.

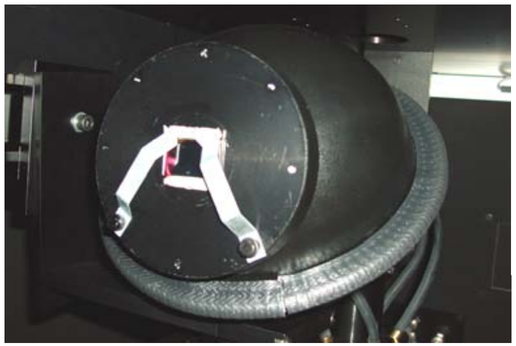


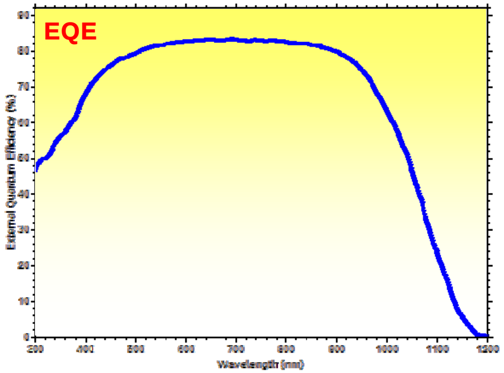


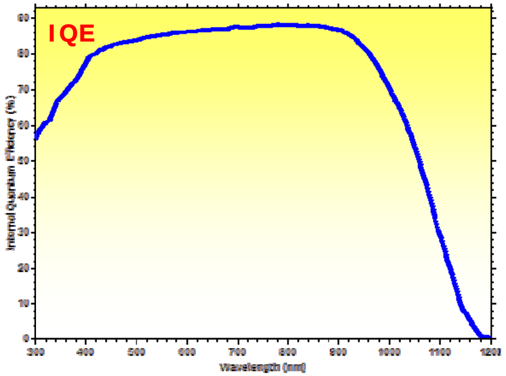
Determination of spectral response (SR, A W^{-1}) & external quantum efficiency (EQE / IPCE, %)

Determination of total reflectance / transmittance (R / T), to modify EQE to yield internal quantum efficiency (IQE, %)









Overview of Operation

The sample under test is mounted horizontally on a temperature controlled vacuum mount for thermal stability. A monochromatic probe is made to be incident upon the sample under test; at each wavelength is measured the photocurrent generated by the device. Having measured the beam power with a detector of known responsivity, spectral response and EQE can be directly obtained. The manner in which the device photocurrent is measured, and the conditions under which this test is performed, depends upon the type of device under test, described overleaf.

In many instances it is desirable to operate the cell in the presence of a bias of one sun (1000 W m^{-2}) to simulate use conditions; indeed the use of such, with appropriate filtering, is essential in the measurement of multiple junction cells to ensure that the subcell under test be current limiting. In the case of multiple junction and thin film devices, a voltage bias may also be required.

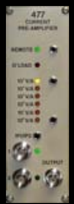
Intervening a divert mirror in the beam relays the monochromatic probe to a 6” diameter integrating sphere, mounted on an optical rail to the upper of the PVE300 chamber, for the measurement of device total reflectance and total transmittance (where required). The EQE may be modified by these latter measurements to determine the more fundamental parameter of IQE.

PVE300 System Components

The PVE300 reunites the probe and bias sources at the sample plane where the temperature-controlled vacuum mount is situated. A diverting mirror is inserted to relay the probe to an integrating sphere for the measurement of transmittance and reflectance.

Detection Electronics
The 417 unit houses the detection electronics of the PVE300 system. The detection electronics employed depends on the nature of the device under test, discussed in detail overleaf.

474– Transformer/ low noise amplifier
• Front-end for lock-in amplifier
• Transformer couples only AC signal
• Cell operated in short circuit conditions or under voltage bias
• Transformer followed by low-noise amplifier



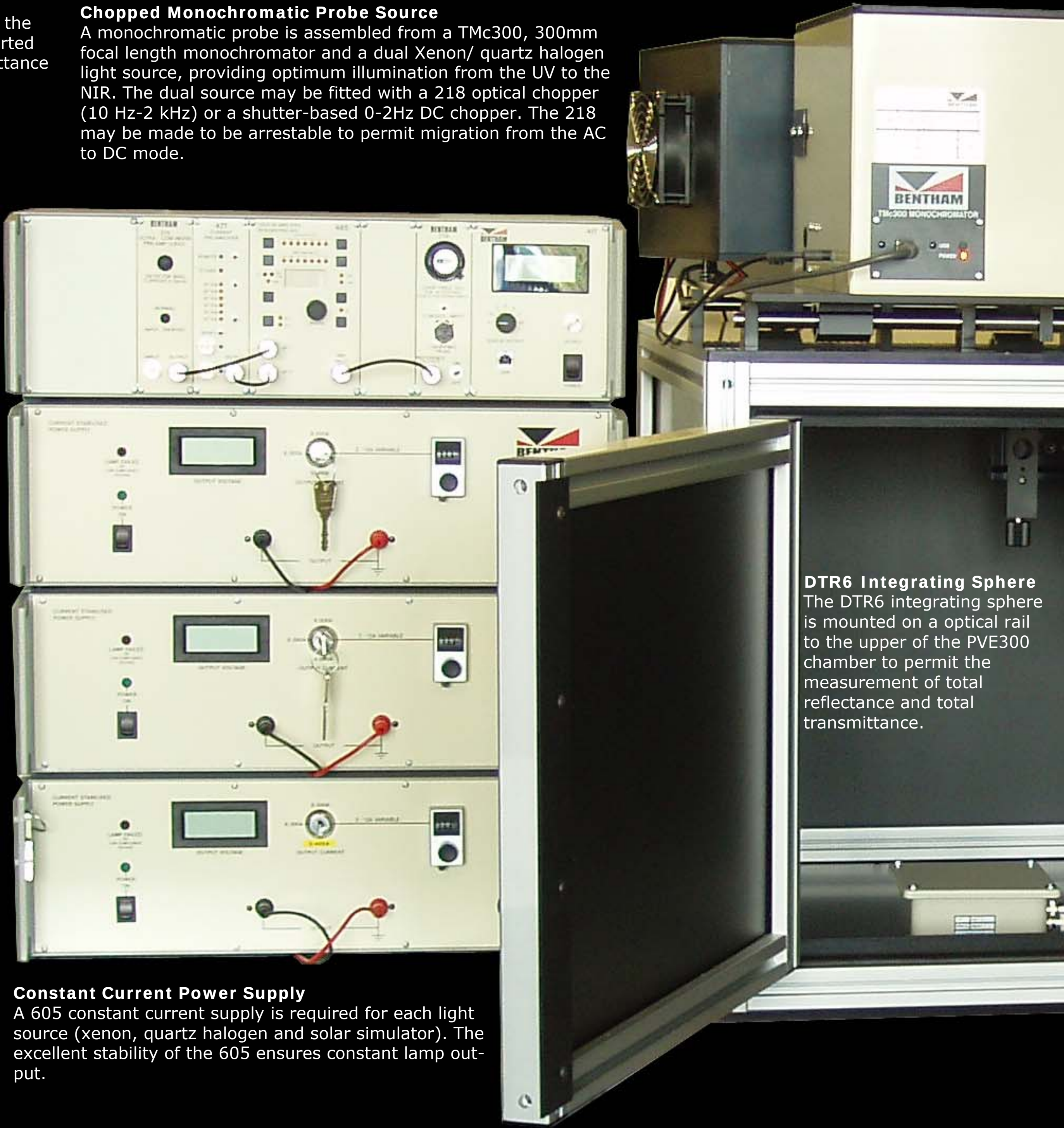
477– AC trans-impedance pre-amplifier
• Front-end for lock-in amplifier
• Six decades of gain
• Cell operated in short circuit conditions
• Useful in measuring experimental devices and cell reflectance/ transmittance

497– DC/AC trans-impedance pre-amplifier & ADC
• Front-end for lock-in amplifier or main detection electronics in DC mode
• Six decades of gain
• > 14 bit ADC
• Cell operated in short circuit conditions

495– Phase insensitive lock-in amplifier
• Recover optically chopped signal
• Operation 10-2000Hz
• Measures two orthogonal phases to return vector sum
 > 14 bit ADC

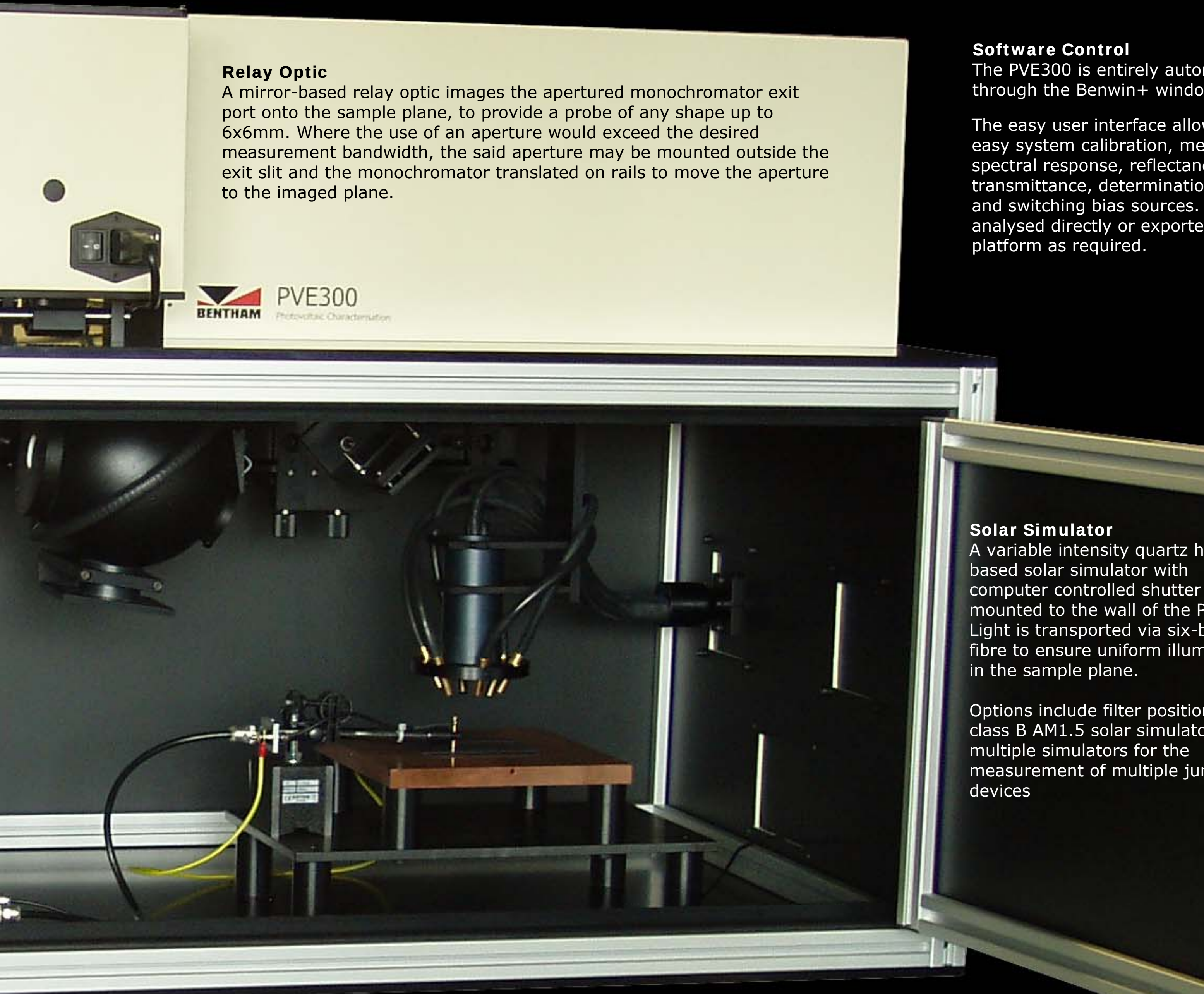
218– Optical Chopper Controller
• Controller for optical chopper housed in dual source
• Reference output for lock-in amplifier

Chopped Monochromatic Probe Source
A monochromatic probe is assembled from a TMc300, 300mm focal length monochromator and a dual Xenon/ quartz halogen light source, providing optimum illumination from the UV to the NIR. The dual source may be fitted with a 218 optical chopper (10 Hz-2 kHz) or a shutter-based 0-2Hz DC chopper. The 218 may be made to be arrestable to permit migration from the AC to DC mode.



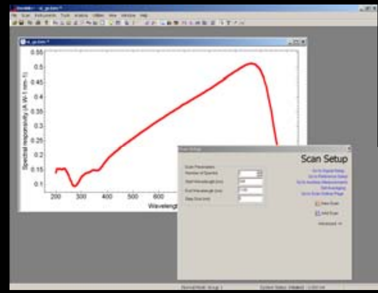
DTR6 Integrating Sphere
The DTR6 integrating sphere is mounted on a optical rail to the upper of the PVE300 chamber to permit the measurement of total reflectance and total transmittance.

Constant Current Power Supply
A 605 constant current supply is required for each light source (xenon, quartz halogen and solar simulator). The excellent stability of the 605 ensures constant lamp output.



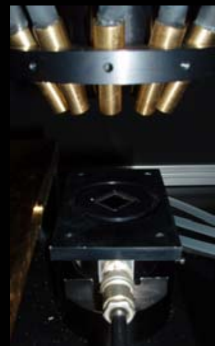
Relay Optic
A mirror-based relay optic images the apertured monochromator exit port onto the sample plane, to provide a probe of any shape up to 6x6mm. Where the use of an aperture would exceed the desired measurement bandwidth, the said aperture may be mounted outside the exit slit and the monochromator translated on rails to move the aperture to the imaged plane.

Software Control
The PVE300 is entirely automated through the USB interface and controlled through the Benwin+ windows application.



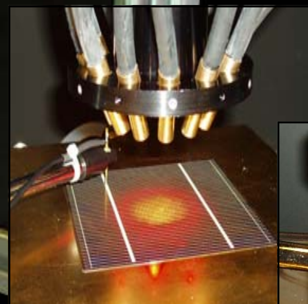
The easy user interface allows quick and easy system calibration, measurements of spectral response, reflectance and transmittance, determination of EQE/IQE and switching bias sources. Data may be analysed directly or exported to another platform as required.

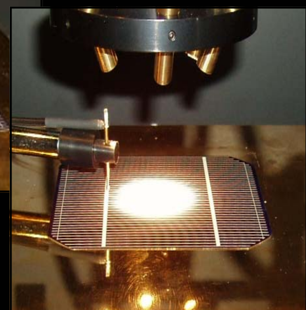
Reference Detectors
The system is calibrated with reference to NMI traceable calibrated photodiodes (silicon 300-1100nm; germanium 800-1800nm).



Solar Simulator
A variable intensity quartz halogen-based solar simulator with computer controlled shutter is mounted to the wall of the PVE300. Light is transported via six-branch fibre to ensure uniform illumination in the sample plane.

Options include filter positions, class B AM1.5 solar simulator and multiple simulators for the measurement of multiple junction devices





Temperature Controlled Vacuum Mount
This 200x200mm mount provides the user with a convenient manner of electrical probing and allows controlling sample temperature, by a quartet of Peltier devices, from 10-60°C , to counter the heating effects attendant to use of a solar simulator, or for material investigation. For superstrate or packaged devices, alternative mounting and probing schemes are available. An accompanying control unit houses the vacuum and water pumps and the bi-polar temperature control electronics.

The Choice of Correct Detection Electronics

In general, standard techniques require that the spectral response of solar cells be tested under light biasing at 1000 W m^{-2} to simulate use conditions†. This presents the problem of discriminating the photocurrent generated by the monochromatic probe from that generated by the solar simulator. In most cases, this situation may be circumvented by optically chopping the monochromatic probe and recovering the AC signal with a lock-in amplifier having either a transformer or trans-impedance amplifier front-end. Whilst the former input stage is preferred- since it does not pass the DC signal, the AC signal can be given maximum possible gain- it only functions at elevated frequency, incompatible with certain types of cell. Indeed, in the case of certain DSSC cells, with particularly slow electron transport, recourse is made to the use of a DC monochromatic probe and detection. The following are the recommended routes for testing the solar cells of today.

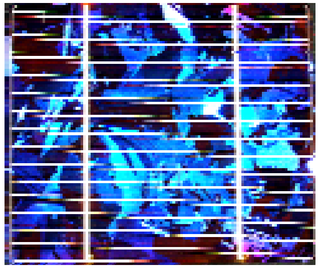
Semiconductor and Organic Solar Cells
474 Transformer & 495 Lock-in Amplifier

The fast electron transport mechanisms in most semiconductor and some organic cells permit exploitation of the preferred transformer coupling method.

The monochromatic probe beam is optically chopped at a frequency of 600 Hz and the cell under test illuminated with a one sun solar bias.

The solar cell output is coupled by the 474 transformer, which passes only the optically chopped signal. This signal is amplified and passed to the lock-in amplifier. The device is operated under short circuit conditions.

This technique is recommended for all semiconductor (c:Si, mc:Si, a:Si, µ:Si, CdTe, CIGS, CIS, Ge, tandem, multi-junction, quantum well, quantum dots) and some organic cells.



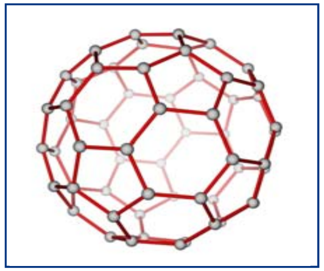
Organic and DSSC Solar Cells
477/497 Pre-amplifier & 495 Lock-In Amplifier

Where device response is slow, recourse is made in the first instance to reduced chopping frequency and the use of a trans-impedance amplifier front-end to the lock-in amplifier.

The monochromatic probe beam is optically chopped at a frequency of >10 Hz and the cell under test illuminated with one sun solar bias (or less to improve signal to noise).

The solar cell output is passed through the 477/497 trans-impedance amplifier prior to being passed to the lock-in amplifier. The device is operated under short circuit conditions.

This technique may be applied to organic and some DSSC cells.



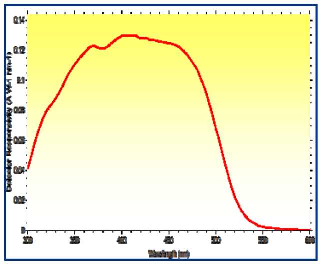
DSSC Solar Cells
497 and DC chopper

Due to carrier transport mechanisms at play in DSSC cells, it may be found necessary to operate these cells at much slower chopping frequencies or in the DC regime.

The monochromatic probe beam is either run DC or optically chopped up to 2Hz, and the cell illuminated with a reduced level of solar bias.

The solar cell output is passed through a trans-impedance amplifier and the cell response recorded as a shutter in the dual source switches on and off the monochromatic probe. The device is operated under short-circuit conditions.

This technique may be applied to DSSC technologies.



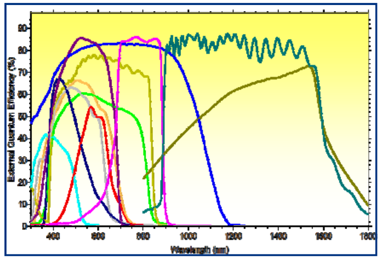
†IEC60904-8/ ASTM E1021 – 06/ ASTM E2236-05

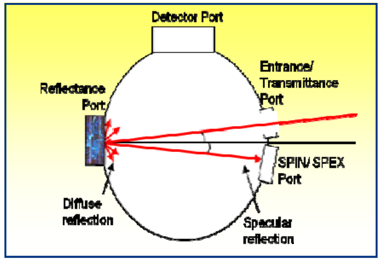
PVE300 System Options

This PVE300 has been designed as a modular and configurable system to adapt to the measurement requirements of the PV technology to be studied. The following provides a guide to the options available to enhance the functionality of the system.

Spectral Range

The TMc300 monochromator may be fitted with up to three diffraction gratings to allow measurement over wide spectral range in a single scan. The standard range of 300-1100nm may be extended to a maximum range of 250-2500nm.



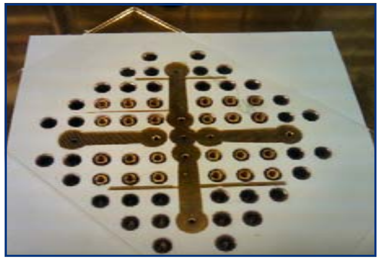


Integrating Sphere

The DTR6 integrating sphere is used to collect the total transmitted or reflected light from a sample (specular inclusive or exclusive), with which information may be modified the device EQE to determine the more fundamental parameter of IQE.

Temperature Controlled Vacuum 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.

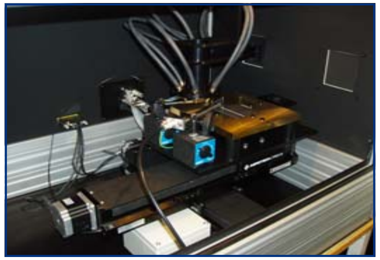


DC/ Chopped Monochromatic Probe

The monochromatic probe may be operated in the AC or DC regimes with either the 218 optical chopper (10 Hz-2 kHz) or a shutter-based 0-2Hz DC chopper. The 218 may be made to be arrestable to permit migration from the AC to DC mode.

Multiple Light Bias Sources

In the measurement of multi-junction devices, multiple solar simulators are required, one to bias the subcell under test at one sun, the other filtered simulator to ensure that the non– tested subcells are sufficiently illuminated that they do not current limit the tested subcell response.

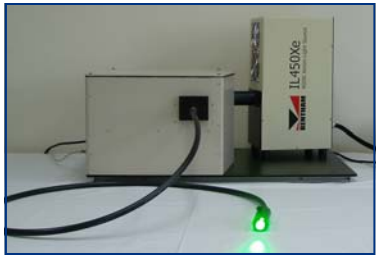


XY Stage

Device uniformity and IPCE mapping may be performed with the use of an XY stage, upon which is mounted the temperature-controlled vacuum chuck, and the PVE300 enclosure height extended. The sample position is scanned under the beam and entirely controlled through Benwin+.

Voltage Biasing

In the case of multiple junction cells and some thin film device, testing under voltage bias is important. To this end, a Keithley 2400 Source Meter can be connected directly to the transformer primary coil, thereby biasing the device under test.



High Output Monochromatic Light Source

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

PVE300 Specifications

Monochromatic Probe	
Probe light source:	75W Xenon and 100W Quartz halogen
Monochromator configuration:	Triple grating, symmetric, single Czerny-Turner, 300mm focal length
Bandwidth:	Adjustable fixed slit, 1-10nm typical
Resolution:	0.3nm (1200g/mm); 0.6nm (600g/mm)
Dispersion:	2.7nm/mm (1200g/mm); 5.4nm/mm (600g/mm)
Wavelength Range:	300-1100nm (1200g/mm); 1100-2500nm (600g/mm)
Wavelength accuracy:	± 0.2nm (1200g/mm); ± 0.4nm (600g/mm)
Relay Optic:	Mirror-based, 1.2x magnification
Probe size:	Up to 6x6mm
Temperature-Controlled Vacuum Mount	
Temperature control:	4x70W Peltier-based heat pump, water-cooled hot side
Temperature range:	10-60°C
Temperature Feedback:	Centrally-positioned sensor situated 3mm below sample plane
Temperature stability:	± 1°C
Solar Simulator	
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 50mm square filter holders
Source Options:	Quartz halogen/ Xenon/ Class B AM1.5
Automation	
Software control:	BenWin+ Windows application
Interface:	USB

495 Phase Insensitive Lock-In Amplifier	
Frequency Range:	10Hz to 10kHz
Sensitivity:	1mV to 1V in decade steps
Input Impedance:	100MΩ/25pf, pseudo differential
Dynamic Reserve:	40dB
Gain Accuracy:	+1%
Gain Stability	200ppm/°C
Phase Control:	0.025° increments plus 90° increments
Output Stability:	5ppm/°C to 500ppm/°C depending on sensitivity
Time Constant:	10ms to 10s.
Phase Display:	3 digit LC display shows current phase setting
477/497 Specification	
Gain Ranges:	10^3-10^8 V/A
Maximum Input:	10mA
Input Impedance:	Virtual ground
Gain Accuracy:	+1%
Gain Stability:	200ppm/°C
Output Stability:	5ppm/°C to 500ppm/°C depending on gain range
495/497 ADC	
Resolution:	4 ½ digit BCD (0 to 19999) i.e. > 14 bit resolution
Conversion:	100ms
Input Range:	-0.2V to 9.8V
Linearity:	< 0.025% departure from linearity from zero to full scale

474 Specification	
Transformer DC resistance:	0.05Ω
Gain:	Trans. ~100x. Amp. 500x
Amplifier bandwidth:	5Hz to >100kHz
Amplifier short circuit input noise:	<1nV $Hz^{-1/2}$ at 1kHz
Amplifier Maximum Output:	10V
Frequency of Operation:	600Hz typical
Minimum responsivity:	0.03 A W^{-1} nm^{-1} 5nm BW, 2mm probe typ.
Optical Chopper	
218 frequency range:	10-2 kHz
DC chopper frequency range:	DC-2 Hz
Reference Diodes	
Diode & Range:	Silicon 300-1100nm; Germanium 800-1800nm
Traceability	NPL/ PTB
Voltage Bias (Keithley 2400)	
Voltage Range:	-20 to 20V
Current Limit:	1A
XY Stage	
Travel:	300mm in X & Y
Resolution:	0.1mm
DTR6 Integrating Sphere	
Port Size:	15mm Ø (5 &10mm Ø port reducers supplied)
Coating:	$BaSO_4$
Detector:	Silicon/ Germanium/ Silicon-InGaAs sandwich

Contact Us

Bentham Instruments Limited
2 Boulton Road
Reading
RG2 0NH
United Kingdom

Tel: 00 44 (0) 118 975 1355
Fax: 00 44 (0) 118 931 2971
Email: sales@bentham.co.uk
Web: www.bentham.co.uk