Characterisation of Photovoltaic Materials and Cells

Standard Measurement Services and Prices

No.	Measurement	Description	Reference	Price as of 1 Nov 2018 (US Dollars)
1	Large area, 0.3-sun bias spectral response	Wavelength measurement range: 300 – 1200 nm; Beam power monitoring and compensation; Measurement cell size: Up to 160 x 160 mm^2; Repeatability: Within 0.4% in integrated I_{sc}; Probe beam spatial uniformity: ≤ 5%; Bias light spatial uniformity: ≤ 2%; Stage temperature control range: 20-60°C (±0.5°C); We welcome customers to have cells preconditioned by light soaking at SERIS at a low cost (see item 5).	IEC 60904-8	1st cell: $300; 2nd cell onwards: $180
2	Determination of linearity of spectral response with respect to irradiance	Spectral response at 1%, 5%, 10%, 30%, 100% of 1-sun bias; Specifications of spectral response analyser as per Item 1.	IEC 60904-8 IEC 60904-10	1st cell: $500; 2nd cell onwards: $450
3	Xenon lamp based I-V characterization under AM1.5G with spectral mismatch correction	Class AAA steady-state solar simulator; Measurement cell size: Typically up to 160 x 160 mm^2 (please enquire about other sizes); 0.3-sun bias spectral response (See Item 1); Spectral match to AM1.5G spectrum: ±12.5%; Spatial non-uniformity: ≤ 2%; Stage temperature control range: 15-70°C (±0.5°C); Area measurement included (refer to Item 6); We welcome customers to have cells preconditioned by light soaking at SERIS at a low cost (see item 5).	IEC 60904-1 IEC 60904-7 IEC 60904-9	1st cell: $350; 2nd cell onwards: - $210 (with SR for every cell) or - $80 (SR only for 1st cell, spectral mismatch correction based on 1st cell)

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NUS National University of Singapore

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No.	Measurement	Description	Reference	Price as of 1 Nov 2018 (US Dollars)
4	LED light based I-V characterization under AM1.5G or arbitrary spectrum conditions with spectral mismatch correction	Class AAA steady-state solar simulator; 0.3-sun bias spectral response (See Item 1); Set of 21 LED wavelengths tunable to compose arbitrary spectra as defined by customer; Measurement cell size: Up to 160 x 160 mm^2; Spatial non-uniformity: ≤ 2%; Stage temperature control range: 20-60°C (±0.5°C); Area measurement included (refer to Item 6); We welcome customized requests for measurement under more than one spectrum.	IEC 60904-1 IEC 60904-7 IEC 60904-9	1st cell: $350; 2nd cell onwards: - $210 (with SR for every cell) or - $80 (SR only for 1st cell, spectral mismatch correction based on 1st cell)
5	Plasma lamp based light soaking	Total illumination area: 70 x 70 cm^2; Acceptable sample height: 10 mm; Spectrum: IEC Class A; Nominal light intensity: 1000 W/m^2 ± 2%; Irradiance homogeneity: ±5%; Temporal instability: ±5% over 24 hours; Stage temperature control range: 25-60°C (±2°C); LED based light soaking also available, please inquire. We welcome customized requests for light-induced degradation studies.		$300 per batch (up to 16 x 6” wafers) for 24 hours
6	Area measurement of cell	High-precision topology measurement tool. Measuring range: (i) 300 mm (x-axis), (ii) 200 mm (y-axis), (iii) 200 mm (z-axis); Accuracy (@20°C ± 1°C): 3 + 4L/1000 μm (xy-axis)		$120 per sample

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No.	Measurement	Description	Reference	Price as of 1 Nov 2018 (US Dollars)
7	Determination of temperature coefficient - T dependent I-V - With spectral mismatch correction	Measured using Xenon lamp based I-V tester (Item 3); Temperature dependent I-V characterization (at 15, 25, 30, 40, 50, 60°C); Spectral mismatch correction using 0.3-sun biased spectral response (Item 1) at Option (i) 25°, or (ii) respective temperatures of I-V characterization.		$700 per sample for Option (i) $1400 per sample for Option (ii)
8	Single point, solar cell active area external quantum efficiency / total reflectance	Bentham/IVT PVE300 spectral response system; Measurement of external quantum efficiency (EQE) and total reflectance (R) at small localized area; Measurement wavelength range: 300-1700 nm; Motorized X-Y stage with 200 x 200 mm travel; Small typical beam size ~ 1 x 9 mm; For solar cell metal finger pitch > 1.5 mm, beam lies completely within active area of solar cell between fingers; Excellent repeatability of < 0.2% in integrated I_{sc}.		1st cell: $220 (EQE or R only), $300 (EQE and R); 2nd cell onwards: $100 (EQE or R only), $150 (EQE and R) Mapping option at $50 per additional point (EQE or R), $80 (EQE and R)
9	Total reflectance / transmittance	Agilent Cary 7000 UMS; Measurement wavelength range: 200-2500 nm; White reflectance standard; Automatic wavelength calibration; Wavelength accuracy: (i) UV-VIS (200-900nm): ± 0.08 nm (ii) NIR (760-2500nm): ± 0.4 nm		1st sample: $150; 2nd sample onwards: $80

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Other Measurement Services (Inquire for further details)

No.	Measurement	Description
10	Angular resolved reflectance	Agilent Cary 7000 UMS; Measurement wavelength range: 200-2500 nm; Automatic wavelength calibration; Wavelength accuracy: (i) UV-VIS (200-900nm): ± 0.08 nm (ii) NIR (760-2500nm): ± 0.4 nm
11	μPCD point measurement / mapping	Semilab PV-2000; Measures injection-dependent differential lifetime in Si by measuring the rate of change in carrier density with step changes in illumination conditions.
12	Corona voltage measurement / mapping	Semilab PV-2000; Employs incremental corona charging of dielectrics and subsequent measuring of the surface potential with a vibrating capacitive electrode (Kelvin probe), to achieve non-contact mapping/measurement of (i) Surface barrier height (V_{sb}) (range: -800 to 800 mV, resolution: 1 mV), (ii) Flat band voltage (V_{fb}) (range: -60 to 60 V, resolution: 0.001 V), (iii) Dielectric total charge (Q_{tot}) (range: 5 x 10^9 to 5 x 10^{13} cm^{-2}, resolution: 5 x $10^9/cm^2$) (iv) Interface trap density (D_{it}) (10^{10} to 10^{13} cm^{-2}, resolution: 10^{10} cm^{-2}) Suitable for mapping square wafers up to 156 x 156 mm^2.
13	Surface photovoltage (SPV) sheet resistance mapping	Semilab PV-2000; SPV-based technique for mapping of sheet resistance.
14	Four point probe mapping	AIT Instruments CMT-SR2000-PV with Jandel probes; Allows mapping / checking of spatial uniformity of square wafers up to 160 mm x 160 mm and round wafers up to 230 mm diameter, with maximum thickness of 6mm; Measuring range: 1 mΩ/sq – 2 MΩ/sq (sheet resistance) or 10.0 mΩ.cm - 200.0 kΩ.cm (resistivity)

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Other Measurement Services (Inquire for further details)

No.	Measurement	Description
15	Fourier transform infrared (FTIR) spectroscopy	Thermo Scientific Nicolet iS50 FT-IR; FTIR spectroscopy over spectral range of 400 – 4000 cm^{-1}; Total / diffused reflectance and transmittance using integrating sphere with MCT detector accessory; Surface analysis of materials using single bounce Ge attenuated total reflection (ATR) accessory; High wavenumber resolution of ~0.1 cm^{-1}.
16	Raman spectroscopy	Renishaw inVia Reflex; 514 nm Ar ion excitation laser (50 mW); Measures Raman spectrum from 100 cm^{-1} to 4000 cm^{-1}; Raman peak positions allow material and phase identification (e.g. amorphous vs crystalline silicon); Raman relative peak intensities and peak shifts provide further information on material and strain; Research grade Leica microscope (5x, 20x, 50x objectives) with binocular head and color video camera.
17	3D profile microscope	Zeta Instruments Zeta-300; Non-contact optical profiler; High sensitivity for low reflectance surfaces such as anti-reflection coated, rough surfaces; Optically image large areas and provide accurate 3D topography information; Enables measurement of roughness parameters, lateral dimensions, step heights, wall angles, etc; Z resolution: <10 nm; 5x, 20x, 50x, 100x, 150x objective; Motorized XY stage with 200 x 200 mm travel and automated Z stage.
18	Stylus profiling	Veeco Dektak 150 Surface Profiler; Measures surface steps, variation and roughness as a function of position by monitoring the displacement of a stylus moved in contact on the sample surface; Vertical resolution: 1Å max; Vertical range: 524 mm; Scan length range: 55 mm

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Other Measurement Services (Inquire for further details)

No.	Measurement	Description
19	Scanning electron microscope (SEM)	Zeiss Auriga field emission scanning electron microscope (FESEM); Characterization of sample's surface topography, structure and electrical properties; Schottky type field emission system; Resolution: 1.0 nm at 15 kV and 1.9 nm at 1 kV; Accelerating voltage: 100V to 30 kV ; Beam current: up to 20 nA
20	Electron beam induced current (SEM-EBIC)	Kammrath & Weiss EBIC capability; Extension to Zeiss Auriga FESEM; Allows study of electronic quality of p-n junctions with SEM resolution.
21	Electron backscattered diffraction (SEM-EBSD)	Bruker e-Flash1000 attachment to Zeiss Auriga FESEM; Mapping of crystal orientation of crystalline semiconductor films; Native resolution: 640 x 480 pixels
22	Electron dispersive X-ray spectroscopy (SEM-EDX)	Oxford Instruments, Aztec Energy Advancd (plus IE350) with X-Max^N 80; Resolution better than 127 eV with 80mm^2 Silicon Drift Detector (SDD) (liquid N_2 free, Peltier cooling); Elemental detection and mapping from beryllium (Be) to californium (Cf).
23	Electrochemical capacitance voltage (ECV) profiling	WEP Wafer Profiler CPV21; Measurement of concentration of active dopants in semiconductors; E.g. Bulk doping density or doping profile of Si, Ge, GaAs, InP, GaN, etc; Concentration resolution: < 10^{12} cm^{-3} to > 10^{21} cm^{-3}; Depth resolution (depending on material): up to 1 nm
24	Solar cell metal line and contact resistance measurement	Custom built tool Measurement of metal-semiconductor contact resistance via transmission line method (TLM); Measurement of metallization grid resistance via busbar-to-busbar resistance and line resistance techniques.

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Other Measurement Services (Inquire for further details)

No.	Measurement	Description
25	Photoconductance based Si wafer lifetime measurement	Sinton Instruments WCT-120; Measures effective lifetime of Si (e.g. in quasi-steady state or transient modes); Measures implied V_{oc} and emitter saturation current density J_0; Sensor area: 40 mm diameter; Lifetime measurement range: 1 μs to 10 ms; Typical calibrated injection range: 10^{13} to 10^{16} cm^{-3}; Sample size diameter: 40 to 210 mm
26	Temperature & injection dependent lifetime spectroscopy	Sinton Instruments WCT-120TS with temperature controlled chuck; Similar to Item 25 but with temperature range from room temperature to 200°C.
27	PL imaging of raw Si wafers	BT Imaging LIS-R2; PL based method of mapping defect distribution (e.g. handling marks, material defects, process quality & homogeneity, iron concentration, etc) High power 915 nm infrared laser with illumination intensity up to 3.6 suns Si back illuminated deep depletion CCD camera (high sensitivity over wavelength 800 to 1100 nm) Image size: up to 1024 x 1024 pixels; Wafer size: up to 160 x 160 mm^2
28	PL/EL of cells with R_s and efficiency maps	BT Imaging LIS-R2; Combination of luminescence images at different operating points of a finished solar cell to construct maps of R_s and efficiency Advanced solar cell analysis options are available (please enquire).
29	Time-resolved fluorescence spectroscopy	PicoQuant FluoTime 300; Measures (1) fluorescence/photoluminescence spectrum, and (2) fluorescence/photoluminescence time decay of luminescence samples. Time-correlated single photon counting (TCSPC) or multi-channel scaling (MCS) is employed.