Unique Features of SPD Lab PV Power Analyzers

The SPD Laboratory, Inc. has developed its first generation PV Power Analyzer VK-PA-25 (currently discontinued) with built-in Maximum Power Point Tracking (MPPT) function in 2015, and then delivered to Prof. Segawa Group at the RCAST, University of Tokyo. By utilizing this, Prof. Satoshi Uchida has patiently continued his research on perovskite solar cell (PSC) hysteresis and used MPPT technique to evaluate the PSC performance for the first time (PSC0-2015, Sep. 25, EPFL; Chem. Lett. 2015, 44, 1750-1752). The announcement was new to everyone's memory. In particular, it was significant to clarify that the hysteresis of a stacked PSC was caused by its capacitance component inside and to make the skeptical researchers mostly from Europe acknowledge its existence. Also, the MPPT has been gradually used in the real evaluation of solar cell performance, different from the conventional I-V curve method, where all of the SPD Lab's power analyzers have built-in advanced MPPT algorithms driven in firmware level by maintaining the cell at the maximum output conditions.



SPD Laboratory, Inc.

Hamamatsu, 432-8011, JAPAN Tel: +81-53-474-7901 Fax: +81-53-401-7080 Email: <u>ing@spd-lab.com</u> Web: <u>http://www.spdlab.com</u>

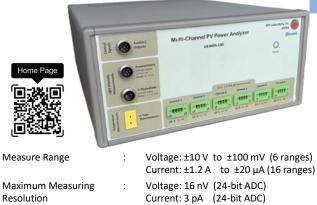
VK-PA-100

VK-MPA-100





Measure Range	:	Voltage: ± 10 V to ± 30 mV Current: ± 1 A to ± 6 μ A
Maximum Measuring Resolution	:	Voltage: 2 μV (16-bit ADC) Current: 14 nA (16-bit ADC)
Communication	:	Bluetooth
Functions	:	I-V Tracer, MPPT, Potentiostat /Galvanostat, 4 Quadrant I-V, 4 Probe Ω Automatic Light intensity measurement
For More Details	:	http://www.spdlab.com/English/VK-PA- 100.html



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:	6 (PV), 4 (Light Intensity), 1 (Temperature)
:	Bluetooth
:	I-V Tracer with automatic curve fitting,
	MPPT, Programmable electronic load,
	Continuous plotting of light intensity and
	temperature graphs
:	http://www.spdlab.com/English/VK-MPA-
	:

100.html

VK-PA-300





VK-PA-8000



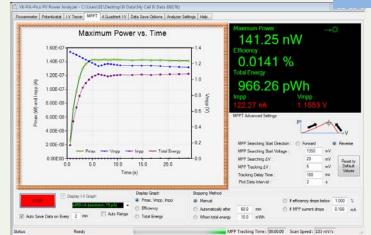
VK-PA-Pico



(1) True Maximum Power Point Tracking (MPPT) Function:

- Determination of true conversion efficiency of a solar cell is impossible with the I-V curve when it shows hysteresis effect.
- MPPT is the way to extract true maximum output power and efficiency of solar cell with time.
- Taking series of I-V curves with a given time interval and then plotting the calculated P_{max} against time will NOT solve the issue. Because of all I-V curves have two different P_{max} values for forward and reverse I-V.
- Our VK-PA series analyzers have built-in advanced MPPT algorithm driven in firmware level which can continuously maintain the cell at maximum output conditions.

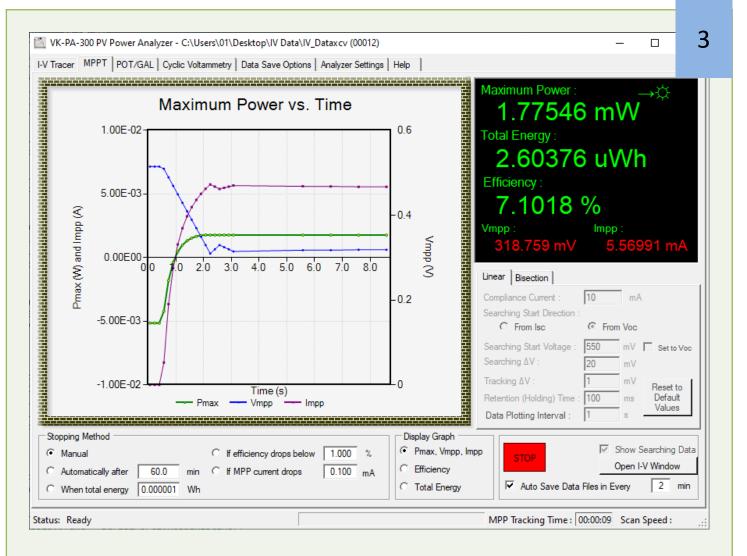
MPPT Advanced Se	ttings F		+ N	C
MPP Searching S MPP Searching S MPP Searching Δ MPP Tracking Δ Tracking Delay Ti Plot Data Interva	tart Voltage : V : / : me :) Forward 650 20 3 100 3	Reverse MV MV MV Reset to Default Values s	
	Stopping Meth Manual Automatic When tota	ally after	60.0 min 0.000001 Wh	
Linear Bisection Compliance Cur Searching Start	rent : 10. Direction :	000 mA From Voc	N.	
Searching Start Searching ∆V : Tracking ∆V : Retention (Hold Data Plotting In	20 [1 ing) Time : [100) mV mV mV	Set to Voc Reset to Default Values	



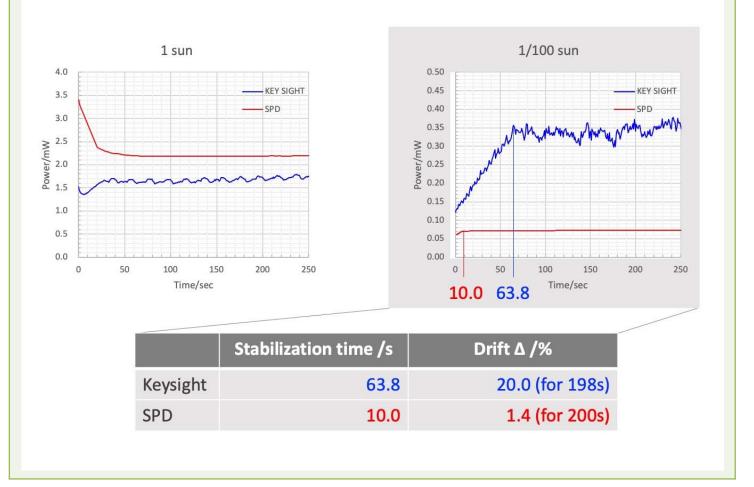
- Our user-friendly software interface offers maximum flexibility to set searching and tracking parameters.
- Measured power conversion efficiency, maximum output power, voltage, current, and total energy are plotted against time on an auto-scaling graph. Users can view I vs. V plot on a separate graph during MPPT.
- Optimized two step MPPT algorithm (initial searching and tracking) used in our analyzers capable of quickly reaching and keep tracking MPP without oscillatory behavior.
- Four different conditions can be conveniently used to automatically stop the tracking process when condition satisfied.

min Wh	 ○ If efficiency drops below 1.000 % ○ If MPP current drops 0.100 mA 	
1	Linear Bisection	
	Compliance Current :	10.000 mA
	Numerical differentiation ΔV :	5 mV
Voc	Tolerance (ε) :	1 mV
	Retention (Holding) Time :	100 ms
to It s	Data Plotting Interval :	3 s

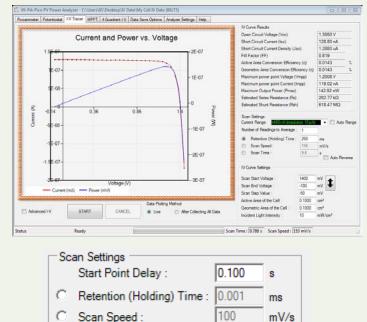
- Our VK-PA-300 and VK-PA-8000 analyzers offer two different maximum power point searching methods.
- "Linear" tab for "Hill climbing algorithm" to find the maximum power point.
- "Bisection" tab for "Bisection algorithm" to find the maximum power point.



Results of independent measurement on MPPT performed by Prof. Satoshi Uchida's group at RCAST, University of Tokyo shows the comparison between SPD Lab VK-PA-Pico and Keysight + add-in-software measuring systems.



All of our PV Analyzers offer conventional I-V tracing function with following capabilities.



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IV Scan Time :

Auto Reverse

1.000

s

"Auto Reverse" option allow user to plot forward and reverse I-V on same graph and analyze

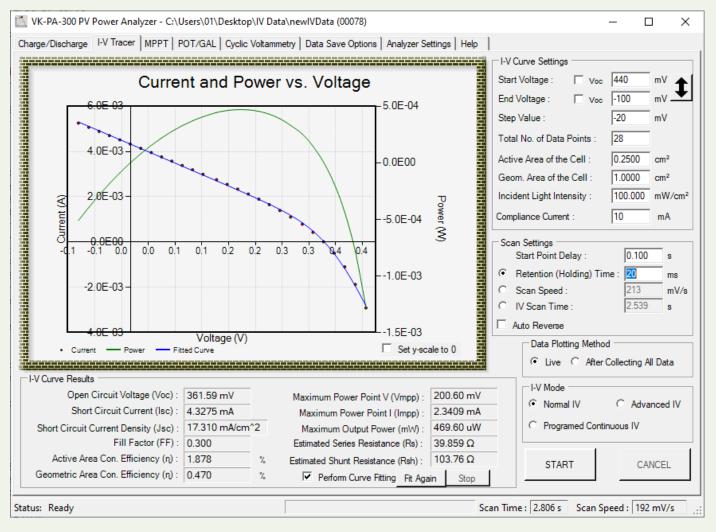
hysteresis effects

-I-V Curve Settings		
Start Voltage : 📃 Voc	600	mV 🛧
End Voltage : 📃 Voc	-100	mV 💌
Step Value :	-20	mV
Total No. of Data Points :	36	
Active Area of the Cell :	0.2500	Cm ²
Geom. Area of the Cell :	1.0000	Cm ²
Incident Light Intensity :	100.000	mW/cm ²
Current Limit :	10.0	mA

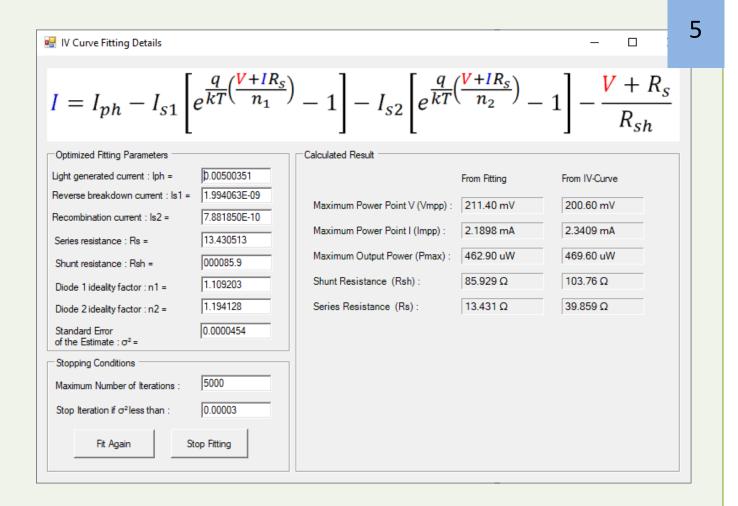
User can set start, stop, step and select one of three different scan methods.

-I-V	Mode		
œ	Normal IV	0	Advanced IV
0	Programed Continu	Jous	IV

Advanced I-V and "Programmed Continuous I-V" options are available.



Automatic curve fitting function is applicable to fit the I-V data with two diode model and calculate various parameters.

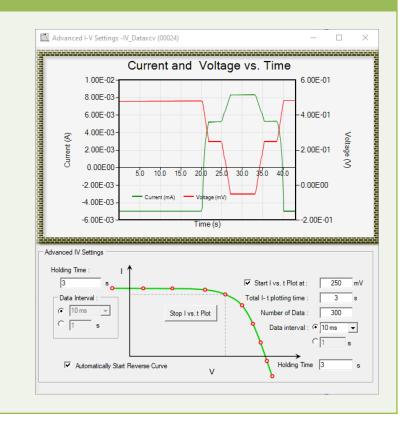


Calculated fitting parameters. This will show the difference of parameters calculated form the fitted curve and direct I-V data.

(This function is available on VK-PA-300 and VK-PA-8000)

(3) Advanced I-V Tracing Function:

- This function allows user to change the following settings during I-V tracing and observe transient behavior of the cell.
 - 1. Start point holding time
 - 2. End point holding time
 - 3. Current vs. time plot (I-t) for each data point
 - 4. I-t plot for given fixed voltage in the middle of I-V curve.



(4) **Pico Ammeter Function:**

- Pico ammeter function allow user to measure true short circuit current of PV device with 0 V voltage drop across the PV device.
- Analyzer uses trans-impedance amplifier with less than 4 μV offset and 0.015 μV/C° offset drift to perform this operation.
- VK-PA-Pico can reach the maximum measurement resolution of 17 fA.



Two automatic calibration functions allow user to null the thermoelectric current generated from dissimilar metal contacts in the circuit and measure only the photo current.

CRAPHere M Rewrouted 14 Stack MMPT 4 Outstack I/V Data Stare Options Analysis File Picearment (bic) of the Solar Cell (Max S mA Min 1 pA) Picearment (bic) of the Solar Cell (Max S mA Min 1 pA)

(This function is available on VK-PA-Pico only)

(5) **Potentiostat /Galvanostat Function:**

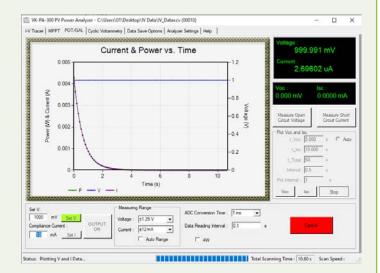
- Potentiostat function allow user to set the desired constant voltage across the sample and measure voltage current, resistance, and power.
- Galvanostat function (except VK-PA-Pico) allow user to set the desired constant current through the sample and measure voltage, current, resistance, and power.



User can plot voltage , current, and power with the time under the given set voltage or current.

Measure Open Circuit Voltage	Measure Short Circuit Current
Plot Voc and Isc	
t_Voc : 5.0	00 s C Auto
t_lsc : 10.	000 s
t_Total : 60	s
Interval : 0.0	01 s
Plot Interval : 1	s
Voc Isc	Stop

"Plot Voc and Isc" special function allows user to plot the behavior of solar cell when it switched from open circuit to the short circuit condition and backward condition intermittently.

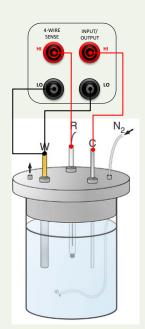


(6) Cyclic Voltammetry Function:

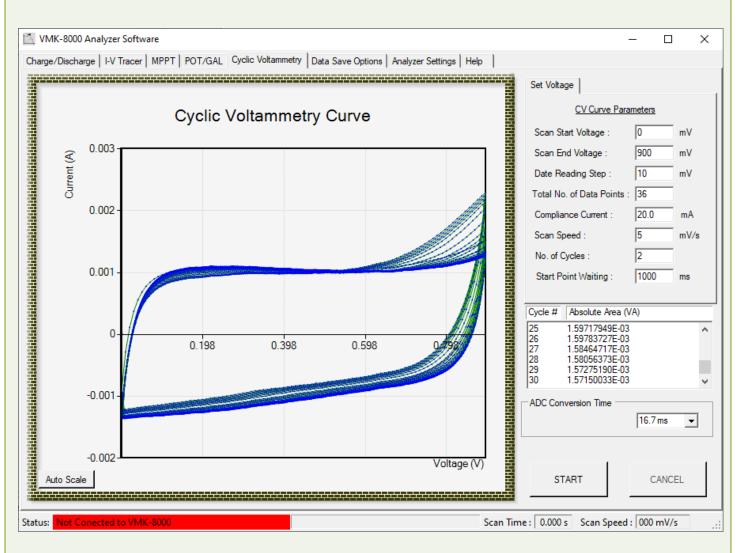
- This function allow user to plot CV curve of a sample.
- User can set the following parameters.

Set Voltage						
CV Curve Parameters						
Scan Start Voltage :	0	mV				
Scan End Voltage :	900	mV				
Date Reading Step :	10	mV				
Total No. of Data Points :	36					
Compliance Current :	20.0	mA				
Scan Speed :	5	mV/s				
No. of Cycles :	2					
Start Point Waiting :	1000	ms				

The inside area of each curve is automatically calculated by the anlyzer software.



User can use two or three electrode configuration to connect sample with the analyzer.



Screen shot of a Cyclic Voltammetry curve showing calculated absolute area inside each cycle

(7) Data Saving Options:

The control software of our PV analyzer can automatically generate fully formatted Microsoft Excel workbook with data and graph.

- Save as .txt file (This text file can be opened with Notepad or WordPad)
- $\hfill\square$ Save as .csv file (This comma separated values file can be open with Excel)
- □ Save as Microsoft Excel file with graphs
- Text file (.txt) and comma separated text (.csv) format file saving is also possible.

the second s		
Data File Saving Options VMK-8000 Analyzer Data Saving Folder		Jeer Settings
C:\Users\01\Desktop\VV Data	Brows	Save My Settings
Data File Name I Genarate Automatically	File name suffix	
IV_Data	(00000) Reset	1
		Load My Settings
Comment		
This is test comment line 1. Comments may have	maximum 5 lines	Save Current System Settings
	<u>w</u>	
Save as .bt file (This text file can be opened	with Notepad or WordPad)	Open CV data file
Save as .csv file (This comma separated value	ues file can be open with Excel)	and recaclculate
Save as Microsoft Excel file with graphs		area
C Save each curve in a separate Excel fil	le	
Save curves in a same Excel file until 1	close the file	
Live Update Excel Graph (Attention III	This option may take long time to complete the graph)	
Information:		
	0	

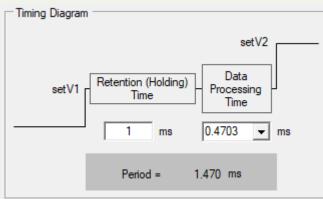
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	А	В	С	D		E	F	G	Н
1 VK-	PA-300 PV Power Analyzer (Ver. 6.1.3	17) PV I-V Data			VK-PA-300 PV Powe	r Analyzer (Ver. 6.	1.3.17) PV I-V Data	1	
2	Date =	4/19/2020					e = 4/19/2020		
3		7:29:17 PM					e = 7:29:47 PM		
	Comment =	:				Commer	nt =		
4									
5	Open Circuit Voltage (V _{oc}) =	3.4316E-01	v		Open	Circuit Voltage (V _o	c) = 3.4274E-01	v	
6	Short Circuit Current (I _{sc}) =	4.0490E-03	А		Shor	t Circuit Current (I _s	c) = 4.0311E-03	A	
7	Short Circuit Current Density (J _{sc)} =	1.6196E-02	A/cm ²		Short Circuit	t Current Density (J	_{c)} = 1.6124E-02	A/cm ²	
8	Fill Factor (FF) =	0.300				Fill Factor (F	F) = 0.299		
9	Efficiency (active area)=	1.666	%		Ef	ficiency (active are	a)= 1.654	%]
10	Efficiency (geom. area)=	0.416	%		Ef	ficiency (geom. are	a)= 0.414	%	
11	Voltage at Max Power Point (V _{mpp}) =	1.9978E-01	v		Voltage at Ma	ax Power Point (V _{mp}	p) = 1.9978E-01	v	
12	Current at Max Power Point (I _{mpp}) =	2.0846E-03	A		Current at Ma	ax Power Point (I _{mp}) = 2.0701E-03	A	
13	Max power =	4.1647E-04	w			Max powe	er = 4.1355E-04	w	
14	Active Area =	0.2500	cm ²			Active Are	a = 0.2500	cm ²	1
15	Geometrical Area =	1.0000	cm ²			Geometrical Are	a = 1.0000	cm ²	1
16	Light Intensity =	100.000	mW/cm ²			Light Intensi	v = 100.000	mW/cm ²	
17	(1) Retention (Holding) Time =		ms		(1) Rete	ntion (Holding) Tim		ms	
18	(2) Scan Speed =		mV/s			(2) Scan Spee	d = 778	mV/s	
19	(3) Scan Time =	1	5			(3) Scan Tim	e = 1	5	
20	User Setting =		3			User Settir	-	3	
21	ADC integration Time =		ms			ADC integration Tim		ms	
22	Total waiting time per ADC reading =		ms			ime per ADC readir	-	ms	
	otal holding time at each volatge step =		ms			at each volatge ste		ms	
24 25	Voltage Measuring Range = Current Measuring Range =		± mA ± mV			ege Measuring Rang ent Measuring Rang		± mA ± mV	
25	Measured Scan Time =		z mv			Measured Scan Tim		s	
27	Series Resistance (R _s) =		Ω			eries Resistance (R		Ω	
28	Shunt Resistance (R _{sh}) =		Ω			hunt Resistance (R.		Ω	
28	Software Version =		17		51	Software Versio		12	
30	Firmware Version =					Firmware Versio			
31	Serial Number =	-					er = 1220160002		
32	Time (s)	Voltage (V)	Current (A)	Power (W)	Tim	ne (s)	Voltage (V)	Current (A)	Power (W)
33	1.247900E-01		-9.9932E-03	-4.8814E-03		0.1247899		1 -0.009993239	
34	1.583010E-01	4.8846E-01	-9.9934E-03	-4.8813E-03		0.1583009	0.48807409	4 -0.009993344	-4.8775E-03
35	1.918110E-01			-4.8812E-03		0.1918119			-4.8770E-03
36	PV IV data MPPT vs. time dat		-9 9935F-03 V I-t data / CC	-4 8813F-03 Charge Discharge	e data 📝 PV IV Cha	0 2253219 art MPPT Chart	0 48803383 CV Chart PV		-4 8769F-03
		a <u>i</u> iv data <u>i</u> P	· · · · · · · · · · · · · · · · · · ·	onarge bischarge		at a minimum chart			•

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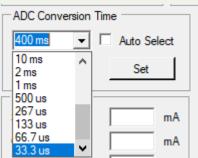
Example of Excel file for I-V data generated from VK-PA-300

(8) Advanced User Settings:

Our analyzers allow more flexibility to modify and monitor hardware.



Timing diagram will show you the details of real timing of voltage set point and data reading point.



User has access to change the integration time of Analog to Digital Converter (ADC).

VK-PA-300 PV Power Analyz	er Software		- 0
V Tracer MPPT POT/GAL C	Cyclic Voltammetry Data Save Option	a Analyzer Settings Help	
Connection Post	Keasuring Range Votage Votage : \$125 V • Gurrer4: \$100 mA • Read Set Tening Dagram et	System Reset Peset We Configuration G* 4 We Mode C* 2 We Mode setV2	
Comp. Current : Set Voltage :	mA mA mV mV mV	Holding) an ma 67.052 • ma	PGA Calibration Constants Principle Principl
Mode : Rea	d Read Array	Read COM Pot Read Error	Negative Vistage Protection 200 V Test Read Write Save to EEPR
			Setal # 1220160002 Auto Correct Offset Primeare Ver 00000000 Show V_Shutt
			V-PGA 0 Oear Full Range Cus Ran offset V-PGA 0 V Offset V Offset
			U JPGA 0 Clear Cus Ram

System Reset	
Reset	
Wire Configaration	
4 Wire Mode	
C 2 Wire Mode	

- Analyzer can be "Reset" using the software button remotely.
- > Four or two wires configuration can be selected.

(9) Wireless Bluetooth Connection:

- Control command and data communication between PV analyzer and a computer is established by a Bluetooth communication.
- There is no wire connections between PV power analyzer and the computer where you installed the control software.
- User can conveniently place PV analyzer and computer in a two separate places in the laboratory.



08/12/20

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