2022

Corporate Guidance

"For Successful Future R&D of State-of-the-Art Thin Film Formation and Next Generation Solar Cells"

SPD Laboratory, Inc.
Hamamatsu 432-8011, JAPAN
Mission

We aim to introduce next-generation technology on the thin-film formation and solar cell fabrication towards scientists and engineers and then to make peoples' lives more comfortable by putting our accumulated intellectual properties to the solution of clean energy supply and environmental preservation problems in line with SDGs.

Corporate History

In 2004 Dr. S. Kaneko has founded the SPD Laboratory with the goal of spreading a spray pyrolysis deposition (SPD) for functional thin-film formation which he had been developing during his time at Shizuoka University since 1989. Bridging the gap between academia and industry with creative and tailor-made products has been our target from the beginning. Nowadays we are producing SPD machines, constructing dye-sensitized and perovskite solar cell fabrication systems, and developing further solar cell evaluation systems. Our company’s target is to supply customers the products of the best quality at a reasonable price.

What is a Spray Pyrolysis Deposition?

(1) Principles

Our SPD for functional thin film formation is basically performed under atmospheric pressure using simple apparatus consisting of an atomizer, air compressor, solution reservoir, and heater (Fig. 1). Starting raw materials solution is atomized towards heated substrate by a pneumatic system not consecutively but intermittently to hold a constant substrate temperature because a mixture of solution and air atomized lets the substrate temperature reduce.

Inorganic and organic metal compounds having any adapted solvent are all available as raw materials of SPD process. The original component and composition of starting solution are surely reflected in the deposited film except for easily evaporated additives; accordingly, this method gives the prescribed component and composition of film as planned.

(2) Deposition Process

Solid film deposition from liquid phase occurs in succession according to the following steps shown in Fig. 2:

1. Innumerable mists from an atomizer wet to make liquid film on the substrate just after sprayed and the boiling temperature of a solvent can be kept until its complete evaporation according to the Gibbs' Phase Rule, despite the substrate temperature which is set much higher than the boiling temperature of the solvent.

2. Temperature of the remained solute increases rapidly to yield metal clusters throughout thermal decomposition and/or chemical reaction.

3. Metal clusters could be converted instantly to compound clusters by reacting with negative ions in the solution.

4. Condensation and cohesion of these compound clusters on the substrate yield solid film finally.

(3) Features

SPD is one of the chemical thin film formation methods and makes dense and even thin films with film thickness 10 nm to 10 µm from starting solution. Complex compound and solid solution films are also available as non-equilibrium or meta-stable phases according to the control of starting solutions and substrate temperatures. The shape and size of particles in polycrystalline film, the microstructure, and texture are controllable by choosing deposition conditions. Further, film thickness increases in proportion to the concentration of starting solution, spray rate and time, and the number of cycles, and is affected by substrate temperature, the vapor pressure of solute, and wetting ability of starting solution.

It has been speculated that atomic diffusion or movement occurs to advance the crystallization of fine particles and the densification of texture in film, while the atomizing is stopped for avoiding the reduction of substrate temperature. This stopping could contribute to the quality of the deposited film.
Promising Future Developments

- Manufacturing and Sales of Transparent Conductive Oxide Thin Film (TCO)

We will use the SPD technique to prepare fluorine-doped tin oxide (FTO) and tin-doped indium oxide (ITO) thin films on a glass surface, which have high performance of electrical conductivity and visible light transmittance. These TCOs are applicable to display panels of cell phones, electromagnetic shielding glass, solar cells, and so on.

- R&D on Dye-sensitized Solar Cell (DSC) and Perovskite Solar Cell (PSC)

DSC consists of two kinds of an electrode; one is a photoelectrode coated with a porous layer of wide band-gap semiconductor and dye. The other is a counter electrode coated with a very thin layer of platinum. The space between these two electrodes is filled with an electrolyte.

Without any ultra-vacuum system, hazardous materials, and also with low cost, DSC and PSC both are attractive as next-generation solar cells in place of current expensive silicon solar cells. It is probable to save up to more than 50% of the cost by switching to DSC and PSC.

We have further initiated the research of PSC processing with a piezoelectric-inkjet-printing technology, and PV power analyzers with MPPT technique. global warming due to fossil fuel-based power plants and high risk with unmanageable radioactive waste in the nuclear power plants make those two energy production techniques not suitable for the future world.

We wish to contribute continuously to the development of next-generation solar cell research making a connection with a better solution to these problems through collaboration with highly motivated scientists and engineers.

- Supply of Novel Solar Cell Evaluation Systems

We have developed the first generation PV Power Analyzer VK-PA-25 (discontinued) with built-in Maximum Power Point Tracking (MPPT) function in 2015 and then delivered it to Prof. Segawa Group at the RCAST, University of Tokyo. By utilizing this, Prof. S. Uchida has patiently continued his research on PSC hysteresis and used the discussion on MPPT technique to evaluate real solar cell performance. This announcement was new to everyone’s memory. Particularly it was significant to clarify that the hysteresis of a stacked PSC was caused by its internal capacitance component. Built-in MPPT function in all of our PV Power Analyzers utilizes firmware level advanced MPPT algorithm which effectively maintains the cell at the maximum output conditions. This has been used in the evaluation of real solar cell performance which is different from the conventional I-V curve method.

Subsequently, other power analyzers, capacitance analyzers for thin film and supercapacitor, LED solar simulators have been developed so far.

- Instrumentation for solar cell fabrication and power storage process.

Clean and enormous energy supply is an urgent demand for favorable economic growth all over the world. We would like to construct photovoltaics with DSC/PSC and power storage with a battery/supercapacitor combined system for the achievement of this request just from now, making the use of our different experiences.

Thin Film Formation Systems

KV-100  
(SPD)  
KM-300  
(SPD)  
VK-TFP-120  
(Ink-jet Printing & Dispensing)
PV Power Analyzers & Super Capacitor and Battery Analyzer

Papers


Patents

1) JP4841574 "Dye-sensitized solar cell module and its fabrication method"
2) JP4945491 "Multilayered electrode and dye-sensitized solar cell with its electrode"
3) JP5227194 "Multilayered electrodes"
4) JP5743591 "Thin-film formation method and apparatus, and dye-sensitized solar cell fabrication process and its production system"
5) JP5963902 "Dye-sensitized solar cell fabrication process and its production system"
6) JP5979656 2 "Ultraviolet irradiation and curing apparatus"
# SPD System for thin film formation

## KV-25II

### Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate size</td>
<td>Up to 25 mm × 25 mm</td>
</tr>
<tr>
<td>Substrate temperature</td>
<td>Max. 550 °C</td>
</tr>
<tr>
<td>Spray distance</td>
<td>150 mm to 300 mm (with ±0.5 mm accuracy)</td>
</tr>
<tr>
<td>Reaction chamber</td>
<td>W320 mm x D360 x H360 mm</td>
</tr>
<tr>
<td>Teflon coated</td>
<td></td>
</tr>
<tr>
<td>External dimensions</td>
<td>W650 mm x D500 mm x H820 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>60 kg</td>
</tr>
<tr>
<td>Capacity of solution bottle</td>
<td>250 ml</td>
</tr>
</tbody>
</table>

### Features

- **Rotating spray nozzle**: Spray nozzle is mounted on motorized stage to move on a circular path in order to increase uniform coverage area. (Important for porous metal oxide films such as TiO₂ where direct physical deposition occurs by evaporating solvent instead of pyrolysis)
- **Easy settings and operation**: KV-25 can be controlled using on-board keypad and LCD or can be connected to a personal computer through the USB port. (Personal computer is not included to the machine)

### Utilities

- **Power supply and power consumption**: 100 VAC Single phase, 50/60 Hz, 1.5 kW or 240 VAC Single phase (on request)
- **Electrical standard**: RoHS compliant
- **Air source pressure**: Over 0.6 MPa (oil free air only, inlet: 6 mm ø)
- **Exhaust system**: Built-in exhaust pump with powder filters. Exhaust outlet: 45 mm

### Additional Features

- Automatic initializing (fill raw chemical into tubes), draining (return raw chemical back to bottle), and cleaning.
- Up to 9 sets of different operation parameters (programs) storage capacity.
- Included a real time liquid flow monitoring system to display actual spray volume in each spray and total volume sprayed.
- Substrate and heater temperatures, atomizing air pressure are digitally displayed on the LCD. (Continuously monitor those parameters and give warning message if deviate from preset range.)
- Heater controlled by cascade PID controller with 2 temperature sensors. Five different set of PID value can be stored for different temperature regions.
- Built-in exhaust pump with input and output dust filters. (Exhaust air may contain chemical vapor that should go through a laboratory fume hood)

### Applications

- Porous and dense thin film formation
- Transparent conducting oxide films (ITO, FTO, AZO etc.)
- Other functional films (TiO₂, ZnO, SnO₂, Cu₂O, SnS etc.)
**Specifications**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate size</td>
<td>Up to 100 mm × 100 mm</td>
</tr>
<tr>
<td>Substrate temperature</td>
<td>Max. 650 °C</td>
</tr>
<tr>
<td>Spray distance</td>
<td>150 mm to 250 mm (with ±0.1 mm accuracy)</td>
</tr>
<tr>
<td>Nozzle moving range</td>
<td>x-axis max: 150 mm, y-axis max: 150 mm</td>
</tr>
<tr>
<td>Reaction chamber</td>
<td>W320 mm x D360 x H360 mm with Teflon coating for corrosion resistance</td>
</tr>
<tr>
<td>External dimensions</td>
<td>W650 mm x D400 mm x H850 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>85 kg</td>
</tr>
<tr>
<td>Capacity of solution bottle</td>
<td>250 ml</td>
</tr>
</tbody>
</table>

**Special Features**

- Moving spray nozzle: Spray nozzle is mounted on motorized x-y stage and utilizes special spray line pattern to produce uniform film.
- Spray rate control: Liquid-feeding system of KV-100 equipped with an automated syringe pump allows user to set exact spray rate and total volume of liquid as initial parameters.
- Remote control operation: Can be connected to a personal computer through an USB port and controlled all the functions remotely. Unlimited number of recipes can be saved with the computer.

**Utilities**

- Power supply and power consumption: 100 VAC single phase, 50/60 Hz, 1.5 kW
- Electrical standard: RoHS compliant
- Air source pressure: Over 0.6 MPa (oil free air only, inlet: 6 mm ø)
- Exhaust system: Built-in exhaust pump with a dust filter for powder removal. Exhaust outlet: 50 mm

**Applications**

- Porous and dense thin film formation
  - Transparent conducting oxide films (ITO, FTO, ATO, AZO etc.)
  - Other functional films (TiO₂, ZnO, SnO₂, Cu₂O, SnS etc.)

**New Features**

- Built-in exhaust pump with input and output dust filters. (Exhaust air may contain chemical vapor. External scrubber must be used to clean exhaust air)
- Easy setting of operation parameters using front panel keypad and LCD.
- Up to 9 sets of different film making recipes can be stored in the memory.
- Can be control remotely through a personal computer. (PC is not supplied as a part of the machine)
- Spray rate and volume in each spray, and total volume are displayed on LCD.
- Automatic initializing and ending functions: removes air from the tubes at the beginning and drain chemical at the end. Automatic cleaning function: assists user to clean the system.
- Substrate and heater temperatures, and atomizing air pressure are displayed on a separate LCD. (KV-100 continuously monitors those parameters and gives warning messages if deviate from preset range.)
- Heater is controlled by cascade PID controller with 2 temperature sensors. Five different sets of PID values can be stored for different temperature regions.
Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate size</td>
<td>Up to 300 mm × 300 mm</td>
</tr>
<tr>
<td>Substrate temperature</td>
<td>Max. 700 °C</td>
</tr>
<tr>
<td>Spray distance</td>
<td>250 mm to 350 mm</td>
</tr>
<tr>
<td>External dimensions</td>
<td>W2000 mm × D1200 mm × H1900 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>Approximately 810 kg</td>
</tr>
<tr>
<td>Capacity of solution pod</td>
<td>1000 ml</td>
</tr>
<tr>
<td>Motion system</td>
<td>Closed-loop Servo Motors</td>
</tr>
<tr>
<td></td>
<td>X-axis max: 525 mm</td>
</tr>
<tr>
<td></td>
<td>Y-axis max: 525 mm</td>
</tr>
<tr>
<td>Movement speed of spray nozzle</td>
<td>150 mm/s Max.</td>
</tr>
</tbody>
</table>

Utilities

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply and power consumption</td>
<td>200 VAC Three phase, 50/60 Hz, 125 A</td>
</tr>
<tr>
<td>Air source pressure</td>
<td>150 NL/min, 0.5 MPa, Intake: Φ8 (oil free air only)</td>
</tr>
<tr>
<td>Exhaust system</td>
<td>Powder collection equipment: Cyclone separator Heat-resistant exhaust blower Exhaust outlet: 65 mm</td>
</tr>
</tbody>
</table>

Features

- Designed for substrates up to 300 mm by 300 mm. It utilizes three spray nozzles with special scanning pattern to reduce the overall coating time and produce highly uniform film.
- Largest coating area of 400 mm × 400 mm and multiple and orthogonal line-coatings.
- Detachable and washable inner walls of the reaction chamber, and also they are covered with ceramic coating films.
- Fully automatic operation with easy setting through touch sensing graphical operation terminal.
- Distance between the nozzle and substrate can be adjusted.
- Powerful ventilation of the downward flow and the cyclone powder separation system.
- Built-in exploded gas collection system.

Applications

- Porous and dense thin film formation
- Transparent conducting oxide films (ITO, FTO, ATO, AZO etc.)
- Other functional films (TiO2, ZnO, SnO2, Cu2O, SnS etc.)
Preparation of Quality Transparent Conductive Oxides for Next Generation Solar Cells through a Spray Pyrolysis Deposition

Shun-ichi Ohta, P. V. Viraj Jayaweera and Shoji Kaneko
SPD Laboratory, Johoku, Hamamatsu 432-8011, Japan

Abstract
Homogeneous 150mm square FTO transparent electrode with 81.4% transmittance and 6.9 Ω/sq. sheet resistance has been prepared by a spray pyrolysis deposition. The electrical properties of this film are improved as follows: resistivity 4.6×10¹⁴Ωcm, Mobility 25.0 cm²/Vs and Carrier Concentration 3.3×10²⁷/cm³. Post-annealing effect on both physical properties was confirmed also.

I. Introduction
FTO has been used for perovskite solar cells as a transparent electrode, which are continuing to request the supply of quality FTO for performance improvement. A spray pyrolysis deposition (SPD) is one of chemical wet processes for thin film formation on a substrate. SPD is mostly carried out using double flask of raw solution and compressed air at room temperature under an atmosphere, where gives tailored this films from atomized raw material solutions using simple apparatus with easy operation. The spraying operation in our technology is done not consecutively but intermittently by suppressing remarkable reduction of a prescribed substrate temperature between 200 and 600, depending on the components and composition of thin film deposited [1-3].

II. Experimental
A starting solution containing raw materials is atomized intermittently to a heated substrate in droplets with compressed air, holding a prescribed substrate temperature. Because it takes several seconds to recover the substrate temperature after one shot of spray (Fig. 1 and table).

III. Results and Discussion
The coating of 150 mm square and 800 nm thick FTO with a visible light transmittance 81.4% and a sheet resistance 6.9 Ω/sq. on 1.1 mm thick glass substrate was achieved by the above-mentioned SPD from a mixed ethanol solution including di-butyl tin (I) di-oxide and ammonium fluoride after optimizing deposition conditions, such as substrate temperature, intermittent time, rotation of substrate, nozzle moving velocity, and distance between nozzle and substrate. High quality of the FTO was assured also from small numerical deviations of transmittance and sheet resistance data measured at 36 different locations (Fig. 2).

Furthermore, we could obtain almost the same specifications of transmittance 81.4%, sheet resistance 7.1 Ω/sq and small deviation of transmittance in 300 nm square FTO film thickness 0.86 mm after dried on reagentment. It has been proved that our spray pyrolysis deposition is suitable for the preparation of quality transparent conductive FTO. The surface roughness and electronic properties of FTO obtained in this study will be discussed from AFM observation and Hall measurement, respectively (Figs. 3-5).

<table>
<thead>
<tr>
<th>Thickness (nm)</th>
<th>Reflectivity (%)</th>
<th>Carrier Concentration (cm⁻³)</th>
<th>Mobility (cm²/Vs)</th>
<th>Sheet Resistance (Ω/sq)</th>
<th>Transmittance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>4.6×10⁻³</td>
<td>1.3×10¹⁷</td>
<td>21.0</td>
<td>8.9</td>
<td>81.4</td>
</tr>
</tbody>
</table>

References

2016 MRS Fall Meeting, Boston, USA
Inkjet Thin-Film Coater (with Paste Dispenser)  
Model: VK-TFP-120

**Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Printing Heads</td>
<td>4</td>
</tr>
<tr>
<td>Type of Print Head</td>
<td>Piezoelectric</td>
</tr>
<tr>
<td></td>
<td>128 nozzle, 80 pl/droplet, 16.5 mm print width</td>
</tr>
<tr>
<td>Number of Dispensing Nozzles</td>
<td>2 (φ 0.2 mm to 1 mm)</td>
</tr>
<tr>
<td>Maximum Printable Area</td>
<td>120 mm × 120 mm</td>
</tr>
<tr>
<td>Substrate Temperature</td>
<td>RT – 155 °C</td>
</tr>
<tr>
<td>Printing Environment</td>
<td>Complete process perform in a nitrogen purge airtight chamber</td>
</tr>
<tr>
<td>Machine Control Method</td>
<td>Through the USB port using PC Software</td>
</tr>
<tr>
<td>Raw Materials</td>
<td>Up to 4 different chemical solutions for inkjet printing</td>
</tr>
<tr>
<td></td>
<td>Up to 2 paste for dispense coating</td>
</tr>
<tr>
<td>Raw Material Inserting Method</td>
<td>Filled in to 60 ml Syringes</td>
</tr>
<tr>
<td>Dimensions</td>
<td>L 600 × W 600 × H 760 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>50 kg</td>
</tr>
</tbody>
</table>

**Special Features**

Capability of making single or combined chemical film: Up to four different chemical solutions can be utilized to make single chemical or combined chemicals thin film formation by ink jet printing technique. Example: CH3NH3I + PbCl2, Spiro-OMeTAD.

Capability of Paste Dispensing for Film Formation: Up to two different thick coatings can be dispensed with a single nozzle (φ = 0.2 - 1 mm). Example: Conducting carbon past, Encapsulating resin, Ag paste, etc.

Automatic Loading/Purging Function: Machine will automatically pump raw chemical solutions to the printing heads and remove air from the system.

Automatic Draining Function: This function will pump raw chemicals safely back to the storage syringes.

Automatic Cleaning Function: This function automatically cleans print heads and all tubing using a given chemical solution.
Novel Spray Pyrolysis Deposition-based  
Dye-sensitized Solar Cell Fabrication System

Shoji Kaneko, P. V. Viraj Jayaweera, and Shun-ichi Ohta  
SPD Laboratory, Hamamatsu 432-8011, Japan

I. Introduction

Spray pyrolysis deposition technology (SPD) is one of chemical processes for obtaining thin-film from liquid phase. A starting raw materials solution is atomized toward a heated substrate by a pneumatic system not consecutively but intermittently to avoid an excess drop of a prescribed substrate temperature with mist (Fig. 1). 1

Among many types of solar cells, dye-sensitized solar cell (DSC) with medium functions of conversion efficiency and durability is the promising system from available resources and easy fabrication at a reasonable cost. DSC consists of various thin film materials such as FTO and TiO₂, and the enlargement of active area in DSC is needed for its practical uses, together with increasing conversion efficiency and durability. The mechanization of needed step in DSC fabrication process is all essential for good reproducibility of experimental data, and then leads to the industrial production in the near future.

II. DSC Fabrication Process

A photo-electrode of large area DSC is fabricated by making striped porous TiO₂ layer on FTO with Ag grid pattern, followed by dyeing with a Ru-complex solution, and also the same area multi-layered counter-electrode with three functions of catalytic activity, electric conductivity and durability against liquid-state electrolyte including iodine and iodide. This novel counter-electrode leads to the cost reduction of DSC by cutting down the consumption of catalytic platinum.

Both electrodes were stick together and liquid electrolyte is inserted to each cell through small holes in the counter electrode. All the connection in succession of each step could produce a continuous DSC manufacturing system with easy. We have finally developed a mechanized DSC fabrication system composed with several elementary processes including SPD, as shown in Fig. 2.

III. Results and Summary

1. We have attempted to enlarge the active area of DSC as an unit cell and obtained the conversion efficiency 5.6% in DSC with 3×7 cm² under AM 1.5 simulated sunlight. 2
2. It is about half of the conversion efficiency of DSC with the area 0.25 cm².
3. DSC module with 15×15 cm² in size basically prepared through the above fabrication process (Fig. 3) showed the conversion efficiency 7.4 % determined from the I-V curve shown in Fig. 4. 3
4. Deepak et al. also reported that the conversion efficiency 3.2 % of DSC module with 12×12 cm² in size prepared through the same fabrication process (Fig. 2) was obtained. 4 However, the sealing problem on liquid electrolyte should be solved in a short time for durability.

References:
Fabrication Process of Large Area Dye-Sensitized Solar Cell
Proposed by SPD Laboratory
## Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading method</td>
<td>Top electrodes: Automatically pick from the loading tray. About 135 sheets (assuming 0.2 mm thickness for a sheet) can be loaded to the tray. Bottom electrodes: Manually load on to the hotplate by user.</td>
</tr>
<tr>
<td>Unloading method</td>
<td>Automatically unload completed modules to the unloading tray. Tray can hold about 70 modules (assuming 0.4 mm thickness for a module). User should clear the tray before overflowing it.</td>
</tr>
<tr>
<td>Electrode pick-up method</td>
<td>Vacuum pads (4). Recommended maximum service temperature of rubber pads are 200°C. (Manufactures absolute maximum service temperature is 230°C)</td>
</tr>
<tr>
<td>Vacuum levels for weight blocks and flexible electrode sheets</td>
<td>For weight blocks: Full vacuum level of the pump. For flexible electrodes: Vacuum level can be lower until electrode deformation disappear by rotating 2 flow-control valves.</td>
</tr>
<tr>
<td>Size of electrodes (mm)</td>
<td>100 × 100</td>
</tr>
<tr>
<td>Number of pile-up locations on the hotplate</td>
<td>4</td>
</tr>
<tr>
<td>Top electrode aligning method</td>
<td>Pre-determined position on the bottom electrode. (User can change the offset distance of 2 electrodes in the program)</td>
</tr>
<tr>
<td>Positioning accuracy of robot (μm)</td>
<td>±5</td>
</tr>
<tr>
<td>Weight block size (mm)</td>
<td>100 × 100</td>
</tr>
<tr>
<td>Weight block thickness</td>
<td>0.1 - 15 mm (User can change the value in the program)</td>
</tr>
<tr>
<td>Maximum weight of the block</td>
<td>1.2 kg</td>
</tr>
<tr>
<td>Supported electrode thicknesses (mm)</td>
<td>0.05 - 5</td>
</tr>
<tr>
<td>Normal operation temperature of hotplate</td>
<td>150°C</td>
</tr>
<tr>
<td>Maximum recommended hotplate temperature</td>
<td>200°C</td>
</tr>
<tr>
<td>PC interface (for modifying programs)</td>
<td>RS-232, (USB to RS-232 converter will be supplied)</td>
</tr>
<tr>
<td>Power Supply</td>
<td>100 V AC, 50/60 Hz</td>
</tr>
<tr>
<td>Dimensions (W × D × H) (mm)</td>
<td>500 × 710 × 568</td>
</tr>
<tr>
<td>Weight</td>
<td>31 kg</td>
</tr>
</tbody>
</table>
Application:
This machine automatically fills electrolyte into an enclosed cell with a single filling-hole. Filling hole position can be programmed to anywhere in the 150 mm x 150 mm sample holding table.

Features:
- Vacuum aided filling technique need only one hole for a cell.
- Filling process is completely under the N₂ (or other inert gas) atmosphere.
- Return step save the excess electrolyte in the filling head and tubs.
- The exposure time of electrolyte in to vacuum is minimized.
- Minimum usage of N₂ gas.
- Automatically adjust tip height for different thickness cells.
- Self cleaning process helps to wash and dry all the tubes and tip.

Specifications:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum cell size (mm)</td>
<td>150 × 150</td>
</tr>
<tr>
<td>Filling Tip moving method</td>
<td>Automatic</td>
</tr>
<tr>
<td>Cell positioning method</td>
<td>Automatic</td>
</tr>
<tr>
<td>Automatic multi hole filling</td>
<td>Yes</td>
</tr>
<tr>
<td>Number of moving axis</td>
<td>X, Y, Z</td>
</tr>
<tr>
<td>Maximum moving range (mm)</td>
<td>200 (X, Y) 55 (Z)</td>
</tr>
<tr>
<td>Electrolyte bottle capacity (ml)</td>
<td>100</td>
</tr>
<tr>
<td>Rated Air Pressure (MPa)</td>
<td>0.6</td>
</tr>
<tr>
<td>Rated Vacuum level (mTorr)</td>
<td>100*</td>
</tr>
<tr>
<td>Control method</td>
<td>Computer Control*</td>
</tr>
<tr>
<td>PC interface</td>
<td>RS-232, USB</td>
</tr>
<tr>
<td>Control Software</td>
<td>EasyFill-2012-MA (Free of charge)</td>
</tr>
<tr>
<td>Vacuum Pump power ON/OFF</td>
<td>Automatic</td>
</tr>
<tr>
<td>Power Supply</td>
<td>100-240 V AC, 50/60 Hz</td>
</tr>
<tr>
<td>Dimensions (W × D × H) (mm)</td>
<td>304 × 304 × 422</td>
</tr>
<tr>
<td>Weight</td>
<td>14 kg</td>
</tr>
</tbody>
</table>
Solar Cell Power Evaluation System

Specifications

- **Filling Technique**: Vacuum back filling. Need only one hole per cell.
- **Number of filling heads**: 2
- **Size of cell (mm)**: 100 × 100
- **Capacity of loading tray**: 4 cell modules. (2 modules will be filled simultaneously)
- **Filling speed**: 2 modules per minute
- **Rated Vacuum level (mTorr)**: 100
- **Vacuum pump**: Single stage rotary oil pump
- **Electrolyte bottle capacity (ml)**: 100
- **Supported module thicknesses (mm)**: 0.5 - 5
- **Control method**: Computer Control
- **Control Software**: EasyFill-2014-MCA (Free of charge)
- **Maximum recommended hotplate temperature**: 200 C
- **PC interface (for modifying programs)**: RS-232, (USB to RS-232 converter will be supplied)
- **Power Supply**: 100 V AC, 50/60 Hz
- **Dimensions (W × D × H) (mm)**: 304 × 304 × 422
- **Weight**: 20 kg
Perovskite Solar Cell (PSC) Preparation Process
Proposed by SPD Laboratory, Inc.

Step 1: Patterned Transparent Conducting Oxide (TCO) Layer and TiO$_2$ (n-type Semiconductor) Layer Preparation by Spray Pyrolysis Deposition (SPD)

**SPD Apparatus**
KV-100

**Top View of the Cell Growing Process**
1. Glass
2. Mask
3. FTO
4. Mask
5. TiO$_2$

**Cross Sectional View of the Cell Growing Process**
1. Glass
2. Glass
3. Masking
4. FTO film formation
5. Glass
Perovskite Solar Cell (PSC) Preparation Process Proposed by SPD Laboratory, Inc.

Step 2: Perovskite Layer ($\text{CH}_3\text{NH}_3\text{PbI}_3$), Spiro-OMeTAD (p-type Semiconductor) Layer and Back Contact Preparation by Piezoelectric Drop On Demand Inkjet Printing Technique

Outside View

Inside View of Reaction Chamber

Top View of the Cell Growth Process

Cross Sectional View of the Cell Growth Process

Perovskite Film Coating

Spiro-OMeTAD Film Coating

Conductive Graphene Coating

Encapsulating cell using EVA, SIRhAgSnLin Polyethylene
**Product Information**

**LED Solar Simulator**

**Type VK-SS-50**

Innovative Solar Simulator Design Utilizing LED Light Sources

- Variable Output Adjustment from 0.0001 to 1.0 Sun
- User Settable Spectral Control
- Self Calibrating with Built-In Intensity Measurements
- More Than 20,000 Hours LED Lifetime
- Motorized sample mounting stage
- 30 mm \times 30 mm Output Beam Size

**Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulator Class</td>
<td>A (JIS C8912)</td>
</tr>
<tr>
<td>Independent LED Control</td>
<td>Independently drives 22 LEDs spaced over the spectrum from 370 nm to 1030 nm</td>
</tr>
<tr>
<td>Spectral Matching</td>
<td>Within ( \pm 5% ) of AM 1.5 G spectral characteristics in the range of 370 to 1030 nm (at irradiance of 1000 W/m(^2))</td>
</tr>
<tr>
<td>Illumination Area and Distance</td>
<td>30 mm \times 30 mm and 200 mm</td>
</tr>
<tr>
<td>Irradiation Intensity</td>
<td>74 mW/cm(^2) (integrated irradiance at 370 nm)</td>
</tr>
<tr>
<td>Real-time Intensity Calibration</td>
<td>Built-in calibrated Si photodiode allow user to perform intensity calibration anytime.</td>
</tr>
<tr>
<td>Illuminance Stability</td>
<td>within ( \pm 1% ) / h (after 30 minutes of lighting)</td>
</tr>
<tr>
<td>Illuminance Distribution</td>
<td>within ( \pm 5% ) (within effective irradiation area of 25 mm x 25 mm) within ( \pm 2% ) (within effective irradiation area of 10 mm x 10 mm)</td>
</tr>
<tr>
<td>Software</td>
<td>Communication with the PC by Bluetooth. The irradiation light spectrum can be adjusted by changing all 22 LEDs individually. It automatically adjusts to the set spectrum and measures the real output spectrum. Setting value recipes can be saved.</td>
</tr>
<tr>
<td>Cooling method</td>
<td>Forced air cooling</td>
</tr>
<tr>
<td>Irradiation Direction</td>
<td>Downward irradiation</td>
</tr>
<tr>
<td>Motorized sample mounting stage</td>
<td>Automatically select user sample and Si reference cell.</td>
</tr>
<tr>
<td>Input voltage</td>
<td>Single phase 100 V ( \pm 5% ) 50/60 Hz</td>
</tr>
<tr>
<td>Dimensions</td>
<td>400 \times 400 \times 550 mm (Lamp) 320 \times 150 \times 450 mm (control box)</td>
</tr>
<tr>
<td>Weight</td>
<td>( \sim 20 ) kg</td>
</tr>
</tbody>
</table>

**Solar Cell Power Evaluation System**

** Innovative Solar Simulator Design Utilizing LED Light Sources**

- Variable Output Adjustment from 0.0001 to 1.0 Sun
- User Settable Spectral Control
- Self Calibrating with Built-In Intensity Measurements
- More Than 20,000 Hours LED Lifetime
- Motorized sample mounting stage
- 30 mm \times 30 mm Output Beam Size

**Specifications**

<table>
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<tr>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>Illumination Area and Distance</td>
<td>30 mm \times 30 mm and 200 mm</td>
</tr>
<tr>
<td>Irradiation Intensity</td>
<td>74 mW/cm(^2) (integrated irradiance at 370 nm)</td>
</tr>
<tr>
<td>Real-time Intensity Calibration</td>
<td>Built-in calibrated Si photodiode allow user to perform intensity calibration anytime.</td>
</tr>
<tr>
<td>Illuminance Stability</td>
<td>within ( \pm 1% ) / h (after 30 minutes of lighting)</td>
</tr>
<tr>
<td>Illuminance Distribution</td>
<td>within ( \pm 5% ) (within effective irradiation area of 25 mm x 25 mm) within ( \pm 2% ) (within effective irradiation area of 10 mm x 10 mm)</td>
</tr>
<tr>
<td>Software</td>
<td>Communication with the PC by Bluetooth. The irradiation light spectrum can be adjusted by changing all 22 LEDs individually. It automatically adjusts to the set spectrum and measures the real output spectrum. Setting value recipes can be saved.</td>
</tr>
<tr>
<td>Cooling method</td>
<td>Forced air cooling</td>
</tr>
<tr>
<td>Irradiation Direction</td>
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<td>Motorized sample mounting stage</td>
<td>Automatically select user sample and Si reference cell.</td>
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</tr>
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<td>Dimensions</td>
<td>400 \times 400 \times 550 mm (Lamp) 320 \times 150 \times 450 mm (control box)</td>
</tr>
<tr>
<td>Weight</td>
<td>( \sim 20 ) kg</td>
</tr>
</tbody>
</table>
PV Power Analyzer
Type VK-PA-100

One Instrument for 5 Different Laboratory Applications:
- Solar cell I-V characterization (Voc, Jsc, FF, n, Rs, Rsh)
- Maximum Power Point Tracking with Pmax & Efficiency vs. time plot
- Four quadrant I-V analysis (Dark I-V, Stepwise Cyclic Voltammetry)
- Four probe resistance measurements (Sheet resistance, Resistivity)
- Use as a potentiostat or Galvanostat

Specifications

<table>
<thead>
<tr>
<th>Measurement Range</th>
<th>Voltage: ±10 V</th>
<th>Current: 1 A (3 A Pulse) with 5½-digits resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring Technique</td>
<td>Digital Source Meter Type</td>
<td></td>
</tr>
<tr>
<td>Inputs</td>
<td>Front: 4 probes for PV devise</td>
<td>Back: 4 wire connector for reference cell (light intensity measurement)</td>
</tr>
<tr>
<td>A/D Converters</td>
<td>16 Bit (2 independent ADCs for V &amp; I measurements)</td>
<td></td>
</tr>
<tr>
<td>User Interface and data collecting</td>
<td>Computer software is provided for control of all the functions and data logging. Measurement data can be saved as a text file and directly plotted on Microsoft Excel graph. (Windows based PC required)</td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>Bluetooth wireless communication</td>
<td></td>
</tr>
<tr>
<td>Power Requirement</td>
<td>100 – 240 VAC (50-60 Hz)</td>
<td></td>
</tr>
<tr>
<td>Electrical standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimensions, Weight</td>
<td>88 mm x 210 mm x 350 mm, 2.5 kg</td>
<td></td>
</tr>
</tbody>
</table>

Features of Solar Cell I-V Tracer
User selectable START, END and STEP voltages. Plots current and power vs. voltage curves. Calculated results include Voc, Isc, Jsc, Pmax, Vmpp, Impp, FF, Rs, Rsh, nactive, and ngeo. User can set the desired scan speed, scan time, or holding time. Advanced I-V option allows initial, middle, and end point holding times. I vs. t transient plot for all data points and/or under a selected fixed voltage.

Features of Maximum Power Point Tracking (MPPT) Function
Analyzer acts like the best load for the cell to extract maximum power point (MPP) and keep tracking MPP continuously. Plots Pmax, Vmpp, Impp, and Efficiency vs. time curves and also display current/power vs. voltage plots.

Features of Full Range I-V Function
User selectable START, END, STEP voltages and SCAN SPEED (mV/s). Plot current vs. voltage curve for given number of voltage sweep cycles in potentiostat mode. Can be used in 3 electrodes liquid cell with reference electrode.

Four Probes Resistance Measurement
Three special functions included to easily measure sheet resistance, resistivity, and resistance. Geometric correction factors are automatically calculated according to size and measuring probe location on the sample which are entered as parameters. Measurement range 2.0 x 10⁻³ to 5.0 x 10⁴ Ω.
Specifications

<table>
<thead>
<tr>
<th>Measurement Range</th>
<th>Voltage: ±10 V Current: ±1A (±3 A Pulse) with 5½-digits resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measuring Technique</td>
<td>Digital Source Meter Type</td>
</tr>
<tr>
<td>Inputs</td>
<td>Front: 4 probes for PV devise</td>
</tr>
<tr>
<td>A/D Converters</td>
<td>24 Bit (2 independent ADCs for V &amp; I measurements)</td>
</tr>
<tr>
<td>User Interface and data collecting</td>
<td>Computer software is provided for control of all the functions and data logging. Measurement data can be saved as a text file (.csv or .txt) and directly plotted on a Microsoft Excel graph. (Windows based PC required)</td>
</tr>
<tr>
<td>Communication</td>
<td>Bluetooth</td>
</tr>
<tr>
<td>Power Requirement</td>
<td>100 VAC (50-60 Hz)</td>
</tr>
<tr>
<td>Electrical standard</td>
<td>RoHS compliant</td>
</tr>
<tr>
<td>Dimensions, Weight</td>
<td>260 mm(W) x 350 mm(D) x 133 mm(H) , 6 kg</td>
</tr>
</tbody>
</table>

Features of Solar Cell I-V Tracer

User selectable START, END and STEP voltages. Plots current and power vs. voltage curves. Calculated results include $V_{oc}$, $I_{sc}$, $P_{max}$, $V_{mppt}$, $I_{mppt}$, $FF$, $R_s$, $R_{sh}$, $Ƞ_{active}$, and $Ƞ_{geo}$. User can set the desired scan speed, scan time, or holding time. Advanced I-V option allows initial, middle, and end point holding times. $i$ vs. $t$ transient plot for all data points and/or under a selected fixed voltage. Programmed Continuous IV function allows user to take series of IV curves on given time intervals.

Features of Maximum Power Point Tracking (MPPT) Function

Analyzer acts like the best load for the cell to extract maximum power point (MPP) and keep tracking MPP continuously. Plots $P_{max}$, $V_{mppt}$, $I_{mppt}$ and Efficiency vs. time curves and also display current/power vs. voltage plots.

Features of Potentiostat/Galvanostat Function

Plot the current vs. time under a given constant voltage or constant current. User can directly measure the open circuit voltage, and short circuit current of the cell.

Features Cyclic Voltammetry (CV)

Allows user to get both three electrode and two electrode CV plots for given voltage range, scan speed and number of cycles. This function mimics the analog triangle wave of voltage without digital voltage steps.
# PV Power Analyzer

## Type VK-PA-Pico

For Pico Ampere Range I-V Tracing and Pico Watt Range Maximum Power Point Tracking (MPPT)

## Specifications

<table>
<thead>
<tr>
<th>Measurement Range</th>
<th>Voltage: ±10 V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current: Max. ±5 mA, Min. 10 pA</td>
</tr>
</tbody>
</table>

### Current Measuring Ranges

- ±5 mA (resolution 160 nA)
- ±2.5 mA (resolution 80 nA)
- ±1.25 mA (resolution 40 nA)
- ±600 μA (resolution 20 nA)
- ±300 μA (resolution 10 nA)
- ±120 μA (resolution 4 nA)
- ±60 μA (resolution 2 nA)
- ±30 μA (resolution 1 nA)
- ±15 μA (resolution 500 nA)
- ±7 μA (resolution 250 nA)
- ±3.5 μA (resolution 100 nA)
- ±1.8 μA (resolution 60 nA)

### User Interface and Data Collection

- Computer software is provided for control of all functions and data logging. Measurement data can be saved as a text file and directly plotted on Microsoft Excel graph.

### Communication

- USB

### Power Requirement

- 100 – 240 VAC (50-60 Hz)

### Dimensions, Weight

- 210 mm (W) x 350 mm (D) x 88 mm (H), 3.0 kg

## Pico Ammeter

In this mode, analyzer works as an ideal ammeter (voltage drop < 5 μV) to measure short circuit current of solar cell.

## Potentiostat

In this mode, analyzer measures current under a constant voltage given by user. Voltage, Current, Power or Resistance is displayed onscreen. It is also possible to plot those parameters against time.

## I-V Tracer

In this mode, user can select START, END, and STEP voltages and scan condition (desired scan speed, scan time, or holding time). Analyzer plots current and power vs. voltage curves. Calculated results include $V_{oc}$, $I_{sc}$, $P_{max}$, $V_{mpp}$, $I_{mpp}$, $FF$, $R_s$, $R_{sh}$, $\eta_{active}$, and $\eta_{geo}$. Advanced I-V option allows to set initial, middle, and end point holding times. Also plots I vs. t transient curve for all data points and/or under a selected fixed voltage.

## Maximum Power Point Tracking (MPPT)

In this mode, analyzer acts like the best load for solar cell to extract maximum power and keep tracking MPP continuously. Plots the $P_{max}$, $V_{mpp}$, $I_{mpp}$ and Efficiency vs. time curves and also displays current/power vs. voltage plots.
## Capacitor/Battery Evaluation Systems

### Specifications

| Measurement Range and Accuracy | 1pF - 1 nF with 1% accuracy  
1nF - 1F with 0.6% accuracy |

| Measuring Technique | Based on discharge time measurement of RC circuit for two given voltage levels. Time measurements perform using precision timer with 217 ps resolution. Instrument continuously calibrating against known capacitors to eliminate stray capacitance and propagation delays in the electronic circuits. |

| User Configurable Parameters | Maximum charging voltage (0.5 – 3.3 V)  
Upper and lower voltage levels for discharge time measurement |

| User Interface and data collection | Computer software is provided for control of all functions and data logging. Measurement data can be saved as a text file and directly plotted on Microsoft Excel graph. (Windows based PC required) |

| Communication | Bluetooth |

| Power Requirement | 100 – 240 VAC (50-60 Hz) |

| Electrical standard | CE  
RoHS compliant |

| Dimensions, Weight | 210 mm (W) x 350 mm (D) x 88 mm (H)  
~3.0 kg |
Capacitor and Battery Analyzer

Specially designed for electric-double layer capacitors (EDLCs), battery, and solar cell research

- Source and measure up to 20V and 10A
- Versatile control software provides all necessary data analyzing tools with automated curve fitting to evaluate capacitance, power, energy of EDLCs, and capacity, cycles life testing of batteries.

  - Constant current charge-discharge test
  - Cyclic voltammetry curve
  - Self discharge analysis etc...

- Can be used as a potentiostat or a galvanostat with 4 probes

Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Range</td>
<td>Max. Voltage: 20 V</td>
</tr>
<tr>
<td></td>
<td>Max. Current: 10 A (pulse)</td>
</tr>
<tr>
<td></td>
<td>8 A (continuous) with 5½-digits measuring resolution</td>
</tr>
<tr>
<td>Measuring Technique</td>
<td>Digital Source/Measure Unit</td>
</tr>
<tr>
<td>Inputs</td>
<td>Front: 4 probes</td>
</tr>
<tr>
<td>A/D Converters</td>
<td>24 Bit (2 independent ADCs for V &amp; I readings) up to 30,000 SPS</td>
</tr>
<tr>
<td>User Interface and data collection</td>
<td>Computer software is provided for control of all functions and data logging. Measurement data can be saved as a text file and directly plotted on *Microsoft Excel graph. (Windows based PC required)</td>
</tr>
<tr>
<td>Communication</td>
<td>Through a USB port</td>
</tr>
<tr>
<td>Power Requirement</td>
<td>100 – 240 VAC (50-60 Hz)</td>
</tr>
<tr>
<td>Electrical standard</td>
<td>CE and RoHS</td>
</tr>
<tr>
<td>Dimensions, Weight</td>
<td>320 mm(W) x 450 mm(D) x 150 mm(H) , 10 kg</td>
</tr>
</tbody>
</table>

Built-in Software Features

For EDLCs Analysis:

- Measurement of constant current charge-discharge test with given voltage compliance.
- Plot cyclic voltammetry curve
- Curve fittings for ideal RC model and nonlinear real model R-CPE(Q, α).
- Calculation of energy vs. time plots
- Calculation of energy vs. power curve
- Self discharge analysis
- Cycle life testing

For Battery Analysis:

- Measurement of constant current charge-discharge curve with given voltage compliance.
- Analysis of both charge and discharge data
- Self discharge analysis
- Cycle life testing
- Limit based analysis (voltage, current, temperature, ohmic value)

General capabilities:

- I-V tracing for solar cell
- Use as potentiostat with 4 wires
- Use as galvanostat
- 4-probe resistance measurement
- Use as lead-acid, Li-ion, Li polymer battery charger up to 8A and 20 V
- All data and graphs can be directly save as *Microsoft Excel files
- All measurement parameters can be saved and reload when needed to repeat at the same experiment
Constant Current Charge Discharge

Voltage (V)

Current (A)

Time (s)

Screenshot of Charge/Discharge tab

Cyclic Voltammetry Curve

Current (A)

Voltage (V)

Screenshot of Cyclic Voltammetry (CV) tab
Specifications

<table>
<thead>
<tr>
<th>Type of Measurement</th>
<th>Incident Photon-to-electron Conversion Efficiency (IPCE), Spectral response (A/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength Range</td>
<td>340 - 1000 nm (calibrated photo diode limits) 0 - 1400 nm mechanical limit</td>
</tr>
<tr>
<td>Light Source</td>
<td>Halogen Photo Optic Lamp [OSRAM XENOPHOT®] 3400 K. Life time of Halogen lamp is greatly enhanced due to variable power operation technique where lamp is operated at less than half of rated power.</td>
</tr>
<tr>
<td>Irradiation modes</td>
<td>Natural (Halogen lamp spectrum) Constant energy Constant photon (Constant energy or photon Irradiation mode is achieved by controlling the halogen lamp current. Automatic calibration process performs the calibration of lamp current to keep constant energy or photon output).</td>
</tr>
<tr>
<td>monochromatic light power on sample</td>
<td>1 to 100 μW (400 - 1000 nm range)</td>
</tr>
<tr>
<td>Measuring technique</td>
<td>Optically chopped (1 – 21 Hz) light beam is split into two parts (double beam technique) then incident on Device-Under-Test (DUT), and calibrated Si reference (REF) cell. Simultaneously digitized DUT and REF signals (short circuit currents) were Fast Fourier Transform (FFT) to obtain power spectrum (filter out only the chopped frequency component).</td>
</tr>
<tr>
<td>Grating</td>
<td>12000G/ 500nm blaze</td>
</tr>
<tr>
<td>Filters</td>
<td>Up to 5 different high-order light cut filters can be installed. L-37 and R-64 installed.</td>
</tr>
<tr>
<td>Recommended sample size</td>
<td>10 mm x 10 mm</td>
</tr>
<tr>
<td>White light (bias) source</td>
<td>Three watts white LED (output power can be set through the software).</td>
</tr>
<tr>
<td>Sample mounting stage</td>
<td>This system equipped with motorized sample mounting stage. User can remotely switch the sample and standard Si photo diode in order to do baseline calibration or verify accuracy of measurements.</td>
</tr>
<tr>
<td>User Interface and data collecting</td>
<td>Computer software is provided free of charge to control all of the functions and data logging. Measurement data can be saved as a text file and directly plotted on a Microsoft Excel graph. User interface is designed such that normal user can be performed measurements by setting just the scan wavelength range. Also advanced user can control hardware settings such as grating and filter changing position FFT bin size and also able to get raw I vs. t and FFT data.</td>
</tr>
<tr>
<td>Communication</td>
<td>Bluetooth</td>
</tr>
<tr>
<td>Power Requirement</td>
<td>100 – 240 VAC (50-60 Hz) Input voltage selection switch available to set the correct input voltage range.</td>
</tr>
<tr>
<td>Dimensions Weight</td>
<td>91 cm x 47 cm x 29 cm, 20 kg</td>
</tr>
<tr>
<td>PC</td>
<td>Windows based PC is needed to install control software, despite not included to the standard setup and can be added as an option.</td>
</tr>
</tbody>
</table>
Power Management Board for Energy Harvesting Applications

**Description**

The circuit board is designed to collect and manage microwatt (μW) to milliwatt (mW) power generated from various DC sources such as photovoltaic (solar) cells or thermoelectric generators. This unit implements a high efficiency boost converter/charger for products and systems with tight power and operational requirements. This DC-DC boost converter/charger requires only microwatts of power to start working.

**Characteristic**

- Ultra Low Power, High Efficiency DC-DC Boost Converter/Charger
- Continuous energy harvesting from low voltage input supply: VIN ≥ 130mV
- Ultra-low quiescent current: IQ < 330nA (typical)
- Cold start voltage: VIN ≥ 600mV (typical)
- Programmable Dynamic Maximum Power Point Tracking (MPPT).

**Energy source input voltage**

0.13V - 3V (Cold start voltage is 600 mV)

It will continue energy harvesting from VIN as low as 130 mV

**Energy storage component and Voltage**

2.5 V - 5.25 V Energy can be stored to rechargeable li-ion battery, thin-film battery, super-capacitor, or conventional capacitor. By default unit is set to 3.1 V. Please request us if you need different storage voltage.

**Working environment temperature**

-40 ~ 85 °C

**Boost mode switching frequency**

up to 1MHz

**Working mode**

cold start mode, boost mode, thermal protection cut-off mode

**Example input sources**

Solar cell, thermo electric generator, micro wind generator etc...
### Specifications

| Description | The circuit board is designed to collect and manage microwatt (μW) to milliwatt (mW) power generated from various DC sources such as solar cells or thermoelectric generators. In addition to the highly efficient boosting charger, this board includes a highly efficient nano-power buck converter in the output stage. A supercapacitor (0.22F 5.5V) is installed onboard as a storage. |
| Characteristic | • Ultra Low Power, High Efficiency DC-DC Boost Converter/Charger  
• Programmable step down regulated output Buck Converter  
• Continuous energy harvesting from low voltage input supply: VIN ≥ 100 mV  
• Full operating quiescent current: 488 nA (typical)  
• Cold start voltage: VIN ≥ 600mV (typical)  
• Programmable Dynamic Maximum Power Point Tracking (MPPT) |
| Energy source input voltage | 0.1V – 5.1V (Cold start voltage is 600 mV)  
It will continue energy harvesting from VIN as low as 100 mV |
| Energy storage component and Voltage | 0.22 F, 5 V Supercapacitor mounted onboard  
Energy can be stored to rechargeable li-ion battery, thin-film battery, super-capacitor, or conventional capacitor. Voltage range is 1.3 V - 5.3 V (Can be set to your voltage requirement) |
| Working environment temperature | -40 ~85 °C |
| Switching frequency | Boost charger up to 1MHZ, Buck converter up to 500 kHz |
| Working mode | Cold start mode, boost mode, thermal protection cut-off mode |
| Example input sources | Solar cell, thermo electric generator, micro wind generator etc... |
Wireless Data Logger Specifications

Description
This unit can read up to 7 channels of voltage (with 24-bit resolution) and wirelessly transfer to PC software for display & plot. Also there are several programmable digital and analog output channels available to control external devices. This unit comes with user friendly control software and can be integrated with SPD Lab PV Power Analyzers, and capacitor and Battery Analyzer.

Voltage Ranges
<table>
<thead>
<tr>
<th>Voltage Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 V</td>
</tr>
<tr>
<td>2.5 V</td>
</tr>
<tr>
<td>1.25 V</td>
</tr>
<tr>
<td>625 mV</td>
</tr>
<tr>
<td>312 mV</td>
</tr>
<tr>
<td>156 mV</td>
</tr>
<tr>
<td>78 mV</td>
</tr>
</tbody>
</table>

Voltage Reading Resolution
<table>
<thead>
<tr>
<th>Voltage Reading Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>298 nV</td>
</tr>
<tr>
<td>149 nV</td>
</tr>
<tr>
<td>74 nV</td>
</tr>
<tr>
<td>37 nV</td>
</tr>
<tr>
<td>19 nV</td>
</tr>
<tr>
<td>9 nV</td>
</tr>
<tr>
<td>5 nV</td>
</tr>
</tbody>
</table>

Number of Analog Input Channels
7

Data Conversion Rate (SPS)
Maximum 30,000 samples per second

Input Impedance
80 MΩ (<50 SPS), 10 MΩ (>2000 SPS)

Temperature coefficient of internal voltage reference
±20 ppm

Analog to digital conversion resolution
24-bit

Number of trigger Input (0 - 3.3V)
1 (voltage data reading can be synchronize with this input)

Optional digital input/output
Customizable up-to 20 digital input output

Control Software
Data logger control software is supplied with the system (can be integrated to VK-PA series and VK-CA series analyzer software)

Communication method with PC
Bluetooth

Power supply
DC 5V (AC adaptor is supplied)

Dimension
W 5 cm  D 18cm, H 7 cm

Weight
~350 g
Remote Switching System

VK-SW-16

**Specifications**

| Description | This unit consists of 16 2-way switches (relay) that can use to switch up to 10 A of current. Individual outputs of all 16 switches are available for user to wire as their requirement. Each switch can be controlled through the software wirelessly (Bluetooth). This unit comes with user friendly control software and can be integrated with SPD Lab PV Power Analyzers, and capacitor and Battery Analyzer.
|
|---|---|
| Number of channels | 16 |
| Maximum load current | 10 A |
| Control Software | Switching system control software is supplied with the system (can be integrated to VK-PA series and VK-CA series analyzer software) |
| Communication method with PC | Bluetooth |
| Power supply | DC 12V (AC adaptor is supplied) |
| Dimension | W 5 cm, D 18 cm, H 7 cm |
| Weight | ~350 g |
For sheet resistance, resistivity measurements
Customizable tip shapes, gaps, and arrangements
Excellent repeatability

**Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Four Probe Arrangement</td>
<td>Linear or Square (or as requested by customer)</td>
</tr>
<tr>
<td>Probe Gap</td>
<td>Customizable (minimum gap 1.6 mm)</td>
</tr>
<tr>
<td>Tip Height Adjustment</td>
<td>5 mm fine movement with side hand lever</td>
</tr>
<tr>
<td></td>
<td>Table top to tip distance can be set (by rotating top knob) from 10 - 100 mm</td>
</tr>
<tr>
<td>Tip shapes</td>
<td>Customizable with one of following available tip shapes</td>
</tr>
</tbody>
</table>
## Sample Holder

for electrical connections

**Type VK-SH-150**

![Sample Holder Image]

- Four spring tensioned electrical contact probes
- Ideal for I-V, CV, or capacitance measurements
- Independently adjustable probe positions
- Customizable sample holder for different size samples

### Specifications

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table size</strong></td>
<td>150 × 150 mm</td>
</tr>
<tr>
<td><strong>Sample size</strong></td>
<td>Customizable</td>
</tr>
<tr>
<td><strong>Number of contact probes</strong></td>
<td>4 in standard model, can be increased if requested</td>
</tr>
<tr>
<td><strong>Sample mounting method</strong></td>
<td>Easy retraceable sample mounting block with 4 magnets</td>
</tr>
<tr>
<td><strong>Contact Probe position</strong></td>
<td>Each contact probe position can be freely adjusted as users preference.</td>
</tr>
<tr>
<td><strong>Type of contact probe</strong></td>
<td>Customizable with different size and shape probes</td>
</tr>
</tbody>
</table>

![Contact Probe Images]
Origin of the Hysteresis in I–V Curves for Planar Structure Perovskite Solar Cells Rationalized with a Surface Boundary-induced Capacitance Model

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For efficient hybrid solar cells based on organometal halide perovskites, the real origin of the I–V hysteresis became a big issue and has been discussed widely. In this study, simulated I–V curves of different equivalent circuit models were validated with experimental I–V curves of a planar perovskite solar cell with the power conversion efficiency (PCE) of 18.0% and 8.8% on reverse scan (from open circuit to short circuit) and forward scan (from short circuit to open circuit), respectively. We found that an equivalent circuit model with a series of double diodes, capacitors, shunt resistances, and single series resistance produces simulated I–V curves with large hysteresis matching the experimentally observed curves. The electrical capacitances generated by defects due to the lattice mismatch at the TiO2/CH3NH3PbI3 and CH3NH3PbI3/spiro-OMeTAD interface are truly responsible for the hysteresis in perovskite solar cells.

Perovskite solar cells based on CH3NH3PbI3 have attracted enormous attention in the last few years due to their outstanding performance as photovoltaics. The power conversion efficiency (PCE) of the devices has dramatically improved over 20% in a relatively short duration.1,2 Despite the unique properties and higher efficiencies, several important issues, e.g., mysterious hysteresis in I–V curves and durability of stabilized performance, still remain for commercialization.3,4 It has been found that the hysteresis strongly depends on the device architecture, where the planar structure and A3O5 mesoscopic perovskite cells show relatively large hysteresis than TiO2 mesoscopic structure devices.5 The typical planar structure of SrSO3F:FTO/compact TiO2/CH3NH3PbI3/spiro-OMeTAD/Au suffers from severe hysteresis in the I–V measurement.11,12 The reverse scan (from the open circuit to the short circuit) always shows higher PCE than the forward scan (from short circuit to the open circuit). Hence, such hysteresis in the I–V curves creates ambiguity about the actual performance of the device, which is being suspected to be over-estimated.13

The origin of hysteresis has been discussed on the intrinsic properties like ferroelectric polarization and/or ionic migration of the perovskite to date. However, there was no direct evidence that could support the above claims. It has been reported that passivation of TiO2 layer by C60 or use of phényl-C61-butyric acid methyl ester (PCBM) instead of TiO2 in inverted device structure reduces the hysteresis.11,13 The passivation could minimize the trap states and improve electron transfer through the interface of TiO2/CH3NH3PbI3, resulting in the reduction of hysteresis.13 On the other hand, PCHM in the inverted cell could extract the carriers (electrons) more efficiently than TiO2 without accumulation at the interface, and the hysteresis was eliminated in another standpoint, lattice mismatch of the interfaces containing organic compounds could be ignored and consequently the hysteresis was reduced. The importance of lattice mismatch is widely known and discussed for inorganic thin film solar cells.14 Due to the higher expansion coefficient of CH3NH3PbI3 than TiO2, an interfacial stress is created at the interface of TiO2/CH3NH3PbI3, which changes with temperature.15,16 The above reports strongly suggest that defects and/or traps at the interface between compact TiO2 and CH3NH3PbI3 play an important role in causing the hysteresis. The charge trapping/detrapping and/or charge accumulation caused by the lattice mismatch or voids at this interface act as capacitors. In the present study, we confirm “a double diode equivalent circuit model,” including the interfacial capacitive components, where the hysteresis essentially comes up due to carrier accumulation at the interfaces.

For the model study, we used high efficiency planar perovskite solar cells showing large hysteresis in the I–V curves. The planar structured perovskite solar cells using a TiO2 substrate coated on flat FTO substrate (SPD laboratory, sheet resistance 7 Ω/square, average transmittance in visible range 81%, and FTO thickness 800nm) were fabricated by the one-step solution deposition method. CH3NH3PbI3 was prepared using mixed halide precursors (PbCl) and CH3NH3I dissolved in dimethylformamide (DMF), as described previously.17,18 Spiro-OMeTAD was used as a p-type hole extracting layer. Finally, a gold back contact layer was deposited on spiro-OMeTAD under vacuum by the thermal evaporation method. The cross-sectional SEM image of the device is shown in Figure 1. The device comprised a 50 nm compact TiO2 layer, a 350 nm CH3NH3PbI3, a 260 nm spiro-OMeTAD, and an 80 nm Au metal back contact (Figure 1). Photovoltaic characterization of the device was done by taking I–V curves under AM1.5G (100 mW cm–2) solar irradiation, measured by a reverse scan from +1.2 to +0.5 V and forward scan (from +0.5 to +1.2 V), active area 0.0314 cm2. I–V curves (Figure 2) of the cell showed large hysteresis. Table 1 lists the photovoltaic parameters of the cell; reverse scan PCE of 18.0%, Jsc = 24.0 mA cm–2, Voc = 1.034 V, and FF = 0.73, forward scan PCE of 8.8%, Jsc = 22.9 mA cm–2, Voc = 0.852 V, and FF = 0.43.

In order to validate hysteresis in I–V characteristics, we considered several equivalent circuit models and obtained I–V
Figure 1. Cross-sectional SEM image of perovskite solar cells deposited on flat FTO substrate.

Figure 2. $I-V$ curves for photovoltaic device based on planar structure perovskite solar cells measured at different scan directions (black dots forward scan, circle for reverse scan) under AM1.5G (100mW/cm²).

Table 1. Photovoltaic parameters retrieved from $I-V$ curves for the best planar structure perovskite solar cell.

<table>
<thead>
<tr>
<th>Scan directions</th>
<th>$J_{sc}$/mA cm$^{-2}$</th>
<th>$V_{oc}$/V</th>
<th>FF</th>
<th>PCE/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse</td>
<td>24.0</td>
<td>1.034</td>
<td>0.73</td>
<td>18.0</td>
</tr>
<tr>
<td>Forward</td>
<td>23.9</td>
<td>0.852</td>
<td>0.43</td>
<td>8.8</td>
</tr>
</tbody>
</table>

curves by simulation using MultiSim Electronic Workbench application (from National Instruments). The widely used equivalent circuit of a solar cell comprises a diode, a series resistance ($R_s$), and shunt resistance ($R_{sh}$) (Figure S1). The series resistance ($R_s$) represents the total resistance of the device, while the shunt resistance ($R_{sh}$) represents the resistance to leakage current. The above standard equivalent circuit was used in the Multisim's on-screen circuit board. In this simulation, we used a modulation power source as shown V1 in the Figure S1, Figure S2, and Figure 3. Voltage $V_2$ shown in Figure S1 controls the frequency of triangle wave, which represents the scan speed of $I-V$ curves. The voltage was linearly swept with the triangle wave as shown in Figure S3 to simulate the reverse scan and forward scan. To plot $I-V$ curves across the simulated cell was monitored on-screen oscilloscope provided in the software. Two input channels are assigned. A for the measured voltage at both ends of dummy resistance R5 to evaluate the current and B for voltage.

Initially, $R_s$ and $R_{sh}$ values were set to calculate series and shunt resistance of the experimental $I-V$ curve for reverse scan. Experimental $I-V$ curve was successfully simulated with $R_s = 3.82$Ω cm$^{-2}$ and $R_{sh} = 90.0$Ω cm$^{-2}$ by confirming accuracy of the model simulation method. As shown in Figure S1, the simulated $I-V$ curves did not change with the scan directions. This confirmed that the standard equivalent circuit having a single diode with a series and a shunt resistance does not hold good $I-V$ simulation showing hysteresis. Then, taking the carrier accumulation into account, we incorporated a capacitor in parallel to $R_{sh}$ in the equivalent circuit (Figure S2). However, adding a capacitor to the standard equivalent circuit also did not simulate the experimental hysteretic $I-V$ curves (Figure S2). Finally, we tested an equivalent circuit model (Figure 3) composed of two diodes connected in series, two capacitors, two shunt resistances ($R_{sh1}$ and $R_{sh2}$), single series resistance ($R_s$), and two current sources.

The fitting parameters of the circuit model for the simulated $I-V$ curves are summarized in Table S1. For this model, fitting parameters ($R_s$, $R_{sh1}$, and $R_{sh2}$) were chosen by using calculated series and shunt resistance values from the experimental $I-V$ data (Figure 2). The initial $C_1$ and $C_2$ were randomly selected. Then, parameters were optimized (by trial and error method) to minimize deviation between the simulated and experimental curves.

As shown in Figure 4, the simulated $I-V$ curves of this double diode equivalent circuit showed hysteresis, matching closely with the experimental $I-V$ curves. According to this equivalent circuit model, perovskite solar cells may consist of two active junctions with drastically different capacitances developed from carrier accumulation at the interfaces. The Cl$_2$NH$_3$PbI$_3$ layer is sandwiched between n- and p-type contacts and forms two interfaces. It has been already reported that Cl$_2$NH$_3$PbI$_3$ forms two active junctions: one with the n-type TiO$_2$ and the other with p-type spiro-OMeTAD. The interface between TiO$_2$ and Cl$_2$NH$_3$PbI$_3$ shows a large lattice mismatch. These mismatches produce high electrical capacitance at the interface. On the other hand, the interface between the spiro-OMeTAD/Cl$_2$NH$_3$PbI$_3$ layer having less mismatch creates a relatively smaller capacitive component at the interface. Hence, in the equivalent circuit model, we attribute the first part comprising a diode (D1), large capacitor (C2), and shunt...
resistance (Rsh2) to the TiO2/CH3NH3PbI3 interface. The second part with a diode (D1), single smaller capacitance (C1), and shunt resistance (Rsh1) can be attributed to the CH3NH3PbI3/spiro-OMeTAD interface.

In conclusion, we clarified the origin of hysteresis in the I−V curves of a planar perovskite cell using different equivalent circuit models and simulation of their I−V curves. A planar cell showing hysteresis, PCE of 13.9% on reverse, and 8.8% on forward scan was used for validating the equivalent circuits. We found that the standard equivalent circuit with a diode, series resistance, and shunt resistance does not reproduce the hysteresis of I−V curves. Even for the incorporation of a capacitive component in the circuit, the model also did not match the experimental I−V curves. However, an equivalent circuit model composed of two series connected diodes, two capacitors, two shunt resistances, and a series resistance reproduced the hysteresis of the experimental I−V curves. This result suggests that the perovskite cell has two active interfaces: TiO2(CH3NH3)2PbI6 and CH3NH3PbI3/spiro-OMeTAD. The hysteresis is essentially caused by carrier accumulation at these active interfaces. We believe that the lattice mismatch or voids present at the TiO2/CH3NH3PbI3 interface create high electrical capacitance and the other interface with less defects exhibits low capacitance, where hysteresis was in good agreement with the simulation.

The authors thank for financial supports from New Energy and Industrial Technology Development Organization (NEDO, Japan).

Supporting information is available electronically on J-STAGE.

References and Notes
Determination of unique power conversion efficiency of solar cell showing hysteresis in the I-V curve under various light intensities

Ludmila Cojocaru1, Satoshi Uchida2, Koichi Tamaki3, Piyankarage V. V. Jayaweera3, Shoji Kaneko1, Jotaro Nakazaki1, Takaya Kubo1 & Hiroshi Segawa1,4

Energy harvesting at low light intensities has recently attracted a great deal of attention of perovskite solar cells (PSCs) which are regarded as promising candidates for indoor application. Anomalous hysteresis of the PSCs is a complex issue for reliable evaluation of the cell performance. In order to address these challenges, we constructed two new evaluation methods to determine the power conversion efficiencies (PCEs) of PSCs. The first setup is a solar simulator based on light emitting diodes (LEDs) allowing evaluation of the solar cells at wider range of light intensities, ranging from 100 to 10 mW cm⁻². As the overestimate error, we found that the PCEs of dye sensitized solar cell (DSC) and PSCs increase dramatically at low light intensities conditions. Due to the internal capacitance at the interfaces on hybrid solar cells, the measurement of current below 10⁻² mW cm⁻² shows a constant value given high PCE, which is related to the current density and origin of the hysteresis. The second setup is a photovoltaic power analyzing system, designed for tracking the maximum power (P_max) with time. The paper suggests the combination of the LED solar simulator and P_max tracking technique as a standard to evaluate the PCE of perovskite solar cells.

Efficient power generation under weak irradiation is essential for indoor applications or installation and installation in cloudy places. However, solar cells performances are usually evaluated by solar simulators with 100 mW cm⁻² irradiance (AM1.5G) as described in IEC60904-3 etc., as seen in the solar cell efficiency tables. This condition (1 sun) is almost equivalent to direct sunlight at AM1.5G. In the case of dye-sensitized solar cells (DSCs) and perovskite solar cells (PSCs), better performances have been reported under weak irradiation conditions. Performance measurement of solar cells at very low irradiance levels is well established, yet their measurement conditions depend largely on the measurement parameters. Establishing a standardized method for evaluation under weak irradiation is a necessary step for reliable reports on PCE of solar cells designed for indoor applications.

The general method to determine the PCE of solar cells is to measure the photovoltaic behaviour by scanning the bias potential. The results are expressed as a current density → voltage (I–V) curve or an output electric power → voltage (P–V) curve, and the ratio of the maximum output power (P_max) to the irradiation intensity is described as the conversion efficiency (η). Therefore, accurate current → voltage (I–V) measurement is essential for the evaluation of solar cells. However, the anomalous I–V hysteresis of PSCs is a problem for reliable evaluation of the PCE. Since different I–V curves are obtained depending on the voltage scan direction, two conversion efficiencies are obtained for a device. The recent rapid rise of PSCs, which exhibit PCEs more than 22%, demands accurate determination of the PCE values. There are reports on evaluating the PCE by continuous measurement of photostatic under applied bias potential, where P_max was obtained. However, the temporal change in P_max could not be followed.

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