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FOUR-LAMP FLASH TESTER FOR MULTIJUNCTION CELL CHARACTERIZATION

SHORT TECHNICAL DESCRIPTION

Tester function

The Tester is a measuring system for recording the I-V curves of the multijunction solar cells in the dark and under flash illumination in a wide range of intensities with variable spectrum. Photovoltaic conversion efficiency may be evaluated at I-V measurements of the individual cells using a reference cell for setting 1 sun illumination intensity (this reference cell is provided by customer).

The following main PV parameters of a cell under test are measured and calculated:

- short circuit current (I_{sc});
- open circuit voltage (V_{oc});
- current at maximum power point (I_m);
- voltage at maximum power point (V_m);
- I-V curve fill factor (FF);
- PV conversion efficiency (Eff).

Flash/Light Parameters

- Illumination intensity without lamp filtering, over 2 cm x 2cm area………...more than 10000X;

Light pulse duration of the flat part (at +/-2% stability)……………….............….1 millisecond;

- Spatial light uniformity across 2 cm x 2cm area at concentration……………:……5%, or better;
- System light intensity stability:…………………2% flash-to-flash over 1 hour, 3% over 4 hours;

Repetition rate of light pulses ....as fast as 1 pulse per 10-15 seconds.

Independent intensity variation for all four lamps.

Independent ignition moment variation for all four lamps.

Possibility to install glass filters of 50x50 mm^2 area (for instance, Schott glass filters, or interference filters) in front of the each of four lamps

Electronics & Computer Software

- Forward and reverse I-V characteristics under flash illumination and/or in the dark for cells with current up to 10A, voltage -5V/+10V (variable).
- IV data collection - light and dark IV curves. Ability to do a full reverse/forward sweep during the flat pulse section.
- Data collection: voltage sweep and control electronics by associated software; 16 bits of data measurement and collection.
- Indication of the Light, Voltage and Current oscillograms, as well as the I-V curves.
- Measurement and reporting of Isc, Voc, Imp, Vmp, FF, Efficiency.
- Computer with Windows operating system, data collection and analyses software (English language interface).
- Ability to save and print data.
- For a new customer: possibility to change above parameters and to adjust software in accordance with customer's request (free option).

Physical and Other

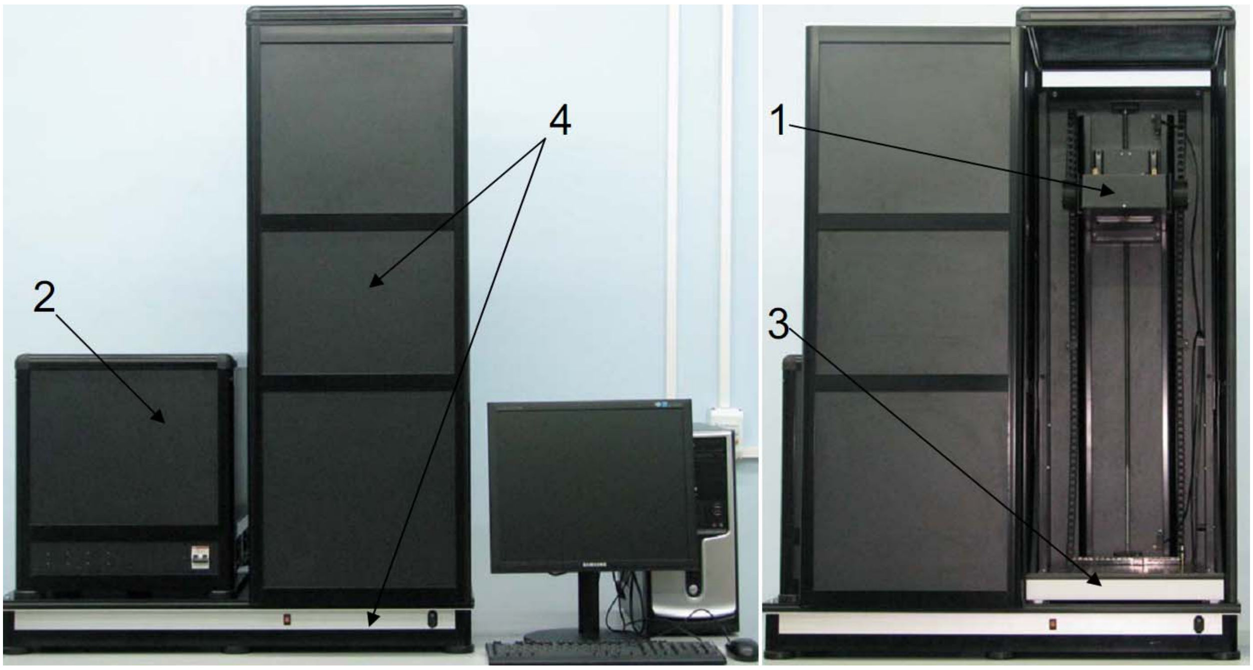
- Compact table-top design: base unit is 95 x 47 x 11 cm, on which light-protective housing of 44 x 48 x 117 cm and power supply of 44 x 44 x 48 cm are situated.

- Total maximum weight is 100 kg.
- Measurement unit and power supply set for 220V AC, total power consumption is up to 1 kW.
- Computer PC Pentium Dual-Core CPU; 2,8 GHz, 1024 Mb, 500 Gb, HDD 500 GB, DVD-RW, monitor 19”.
- Installation CDs for the software
- Lamp lifetime of much more than 10,000 pulses.
- Spare xenon bulb set of 8 spare lamps.

Tester parts

Tester consists of the following parts:

1. Flash illumination system;
2. Illumination system power supply;
3. Measurement unit;
4. Support elements with light-protective housing.



External view of the Tester: with closed door of the light-protective housing (left) and opened door (right).

Flash illumination system

Illumination system with four flash lamps and ignition units ensures the following modes of operation:

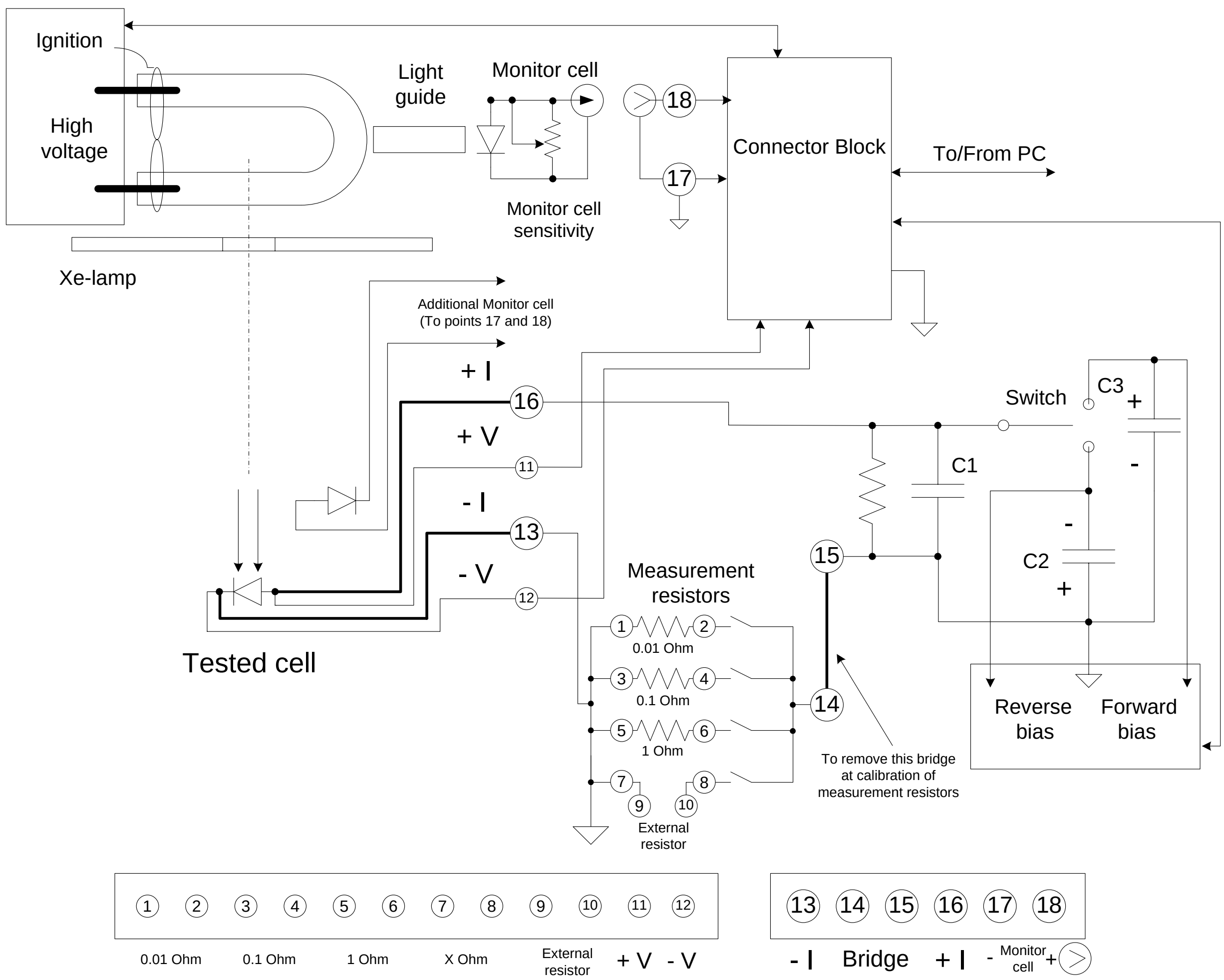
a) The shape of the light pulse is flat within about 1 msec duration (the time during which irradiance changes no more than by ±2%). The I-V curve is measured from one flash (operation mode “A”). This mode is used for characterization of the cells with a short life-time of photogenerated carriers (III-V cells). The intensity level is varied by changing the distance between the flash lamps and the cell. At the lowest position of the flash head the concentration ratios as high as 10000 suns can be achieved.

b) The I-V measurement is carried out point by point from flash to flash (operation mode “B”). Each pair of the I and V magnitudes is measured at the end of the flat part of each light pulse. This mode may be used for characterization of the solar cells based on materials with larger life-times of the photogenerated carriers.

Four Xenon flash lamps are used in the illumination system. Each lamp operates independently from an individual power supply sub-unit placed in Illumination system power supply. It is possible to install glass filters of 50x50 mm^2 area in front of the each of four lamps. Each stack of filters can be up to 10 mm in thickness.

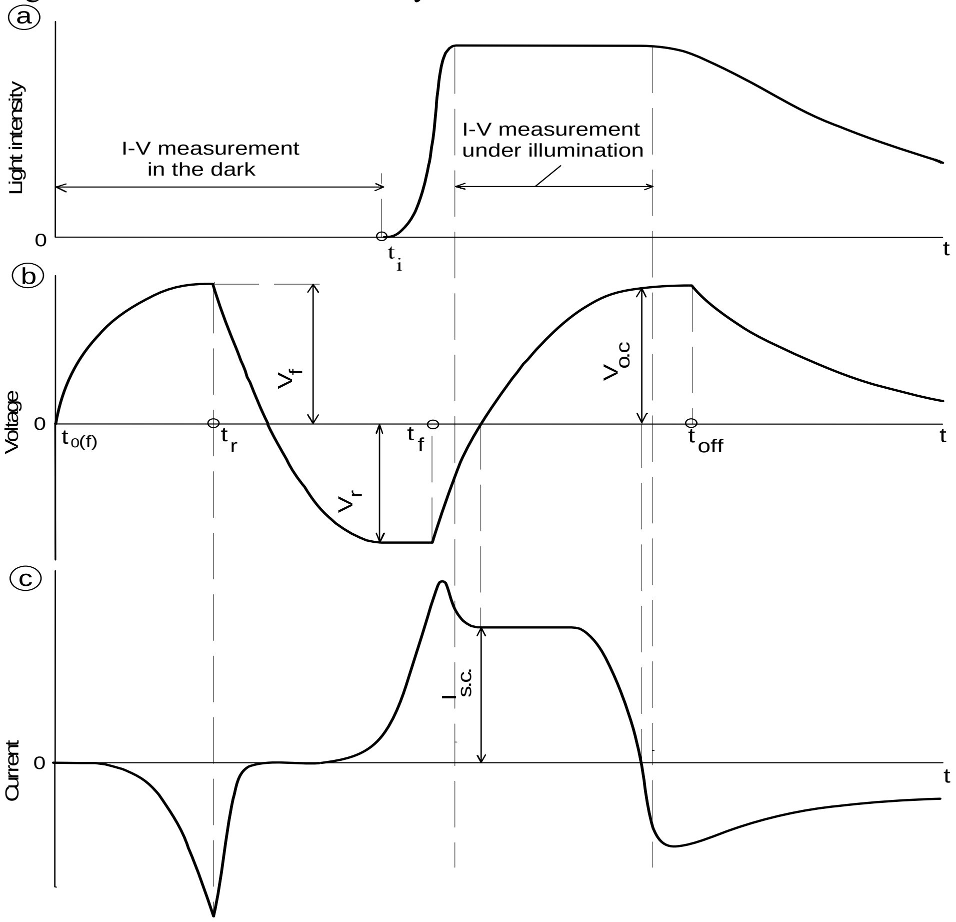
Measurement unit

The measurement unit includes terminal blocks, active electronic load circuit, and a connector block of a measurement circuit. It is supplied with a steel-made cover for fixing experimental equipment by means of magnetic force. Multifunctional data acquisition board itself is placed inside the Personal Computer. The lamp housing is supplied with a monitor cell (two of them – one-junction GaAs and three-junction InGaP/GaAs/Ge are included in a Tester set) to control intensity in oscillogram and to normalize measured current with respect to slightly non-constant light intensity during I-V curve measurement. Also, an additional monitor cell may be placed in measurement plane. In this case two monitor inputs should be connected with points 17 and 18 of the measurement unit instead of the regular monitor cell.



Layout of the measurements and simplified electric circuit of the measurement unit. Also, displacement of the points for test measurements and terminal blocks for connection with tested cell are shown situated on the upper desk of the measurement unit.

The active electronic load circuit (capacitors C1-3 with solid-state switcher and reverse/forward power units) provides an adjustable voltage applied to a tested cell in the range of -5 ÷ +10 V (independent variation of reverse and forward voltages) at automatic sweeping during a flash. The measured current lies in the range of 0 ÷ 10 A. The record time for one I-V curve is 1 millisecond in operation mode “A”. The measurement time for one pair of the “current-voltage” magnitudes is about 10 microseconds. A cell under test is connected with a voltage sweep circuit and with a measurement circuit by terminal blocks +/-I and +/-V. The voltage sweep circuit produces a bipolar pulsed voltage applied to a solar cell. Reverse and forward voltage values are set from a PC keyboard.



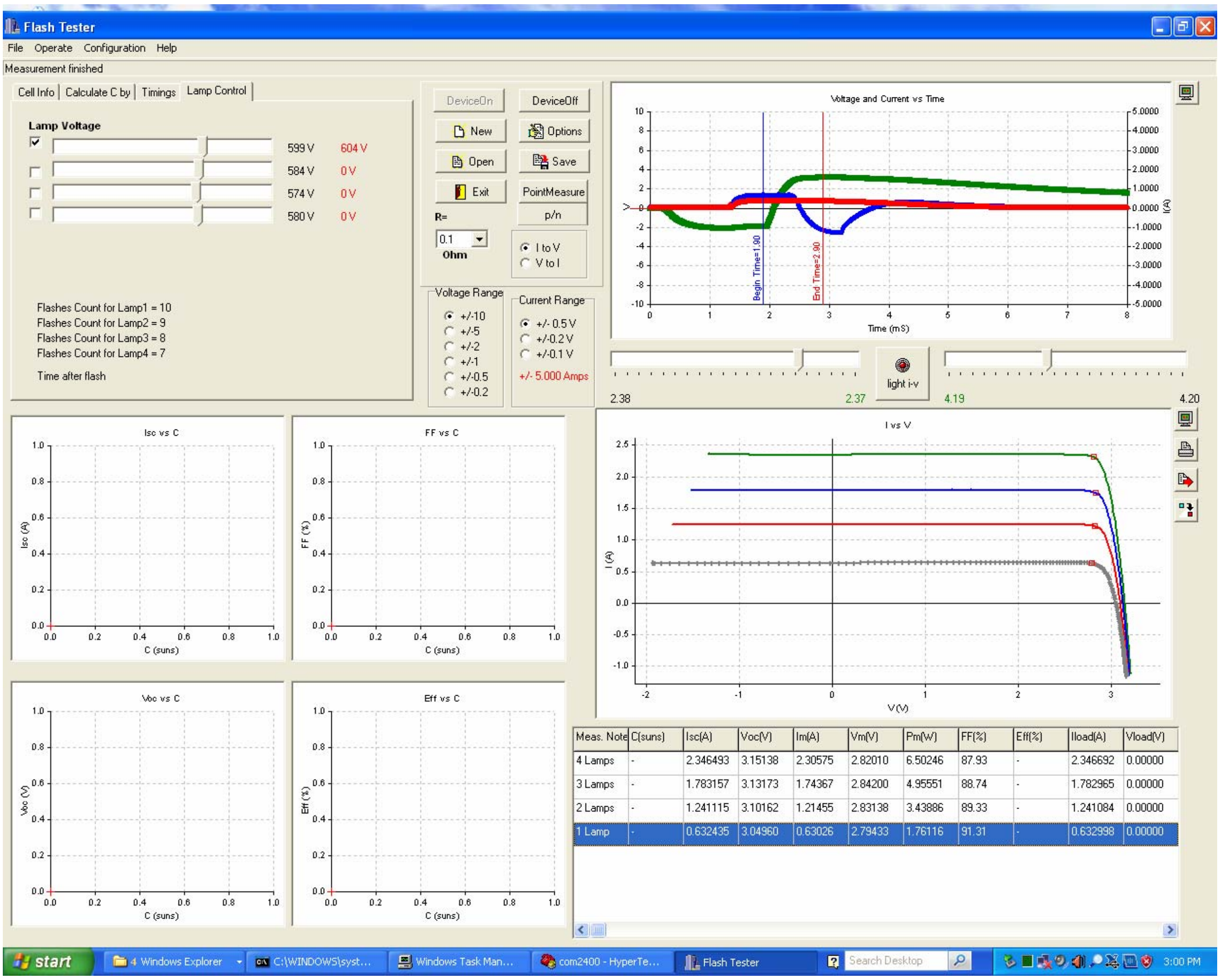
Time-dependences of the flash illumination intensity (a); voltage applied to a solar cell (b); and current flowing through the solar cell (c).

The measurement circuit consists of a four-channel analog-to-digital converter with calibrated measurement resistors (1, 0.1, 0.01 Ohm; external measurement resistor of different value may be used as well) and a digital circuit (virtual memory oscilloscope). Pairs of “Voltage” – “Current” data for each moment of the measurement are introduced into PC in a digital form where the I-V curves are constructed. The digital controller is characterized by 16 bit resolution.

Measurement circuit together with computer record the voltage and current magnitudes from solar cell, as well as photocurrent from a monitor cell. On the base of these data the construction of the "illuminated" or "dark" I-V curve is carried out. One of the inputs in the analog-to-digital converter is used for the light control or for the photocurrent measurement in a monitor cell.

Software Description

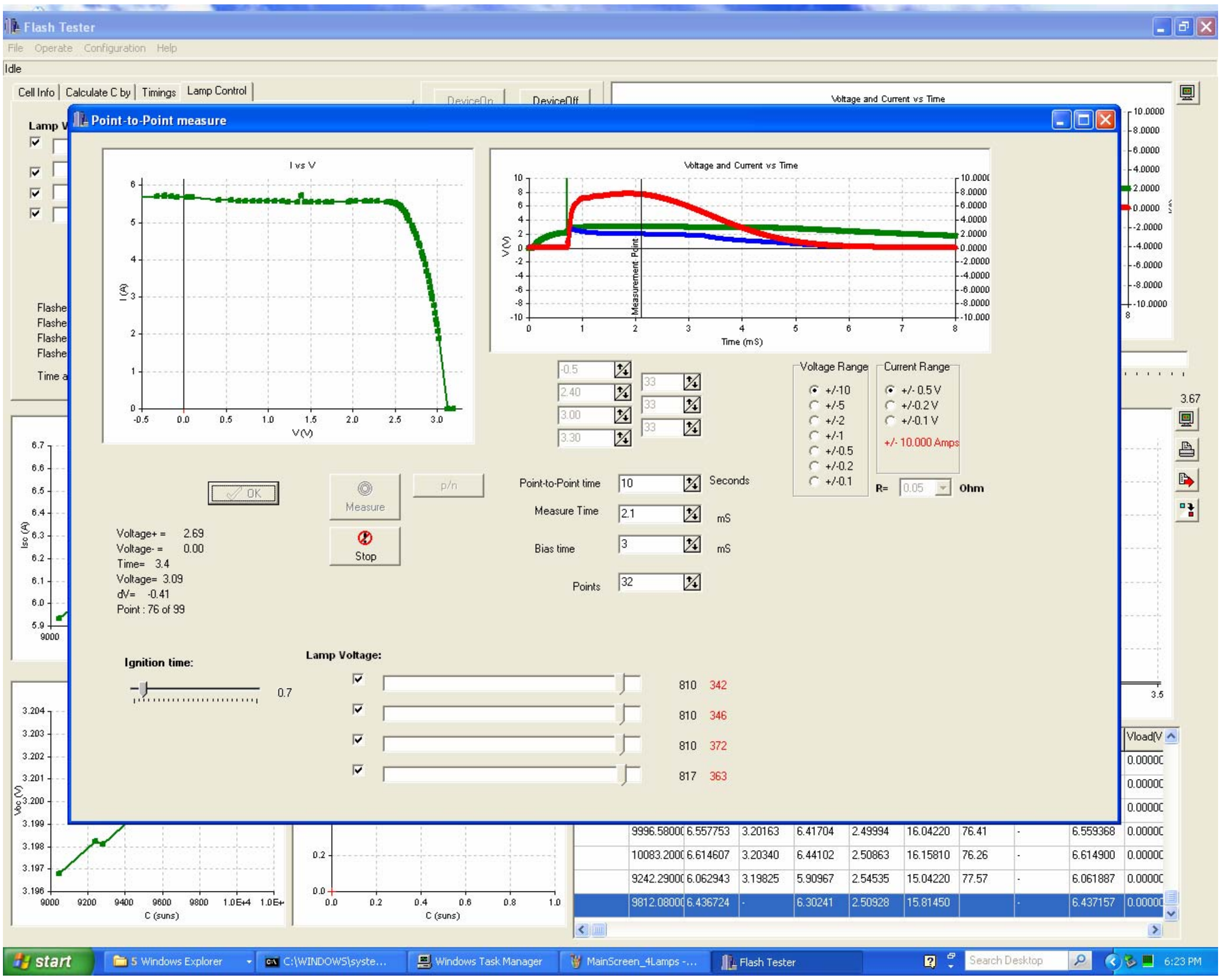
Specially developed software is used in the Tester. This software (see the next part) includes the following functions: input data on a cell under test (Cell ID, type, structure, area) and a monitor cell used in a given measurement procedure, the measurement resistor magnitude, etc.; provides recording, indication and representation of I-V curves (both graphically and digitally), control of the irradiation intensity, voltage and current wave forms as a function of time, calculation of standard I-V curve parameters (I_{sc}, V_{oc}, I_{opt}, V_{opt}, P_{max}, FF, Eff.).



Monitor screen view with data of a solar cell measurement.

Point-to-point measurements (regime "B")

The I-V measurement is carried out point by point from flash to flash (operation mode "Point measurement"). Each pair of the I and V magnitudes is measured at the end of the flat part of each light pulse. This mode is used for characterization of the solar cells based on materials with longer life-times of the photogenerated carriers.



Monitor screen view with data of a solar cell measurement in the point mode.

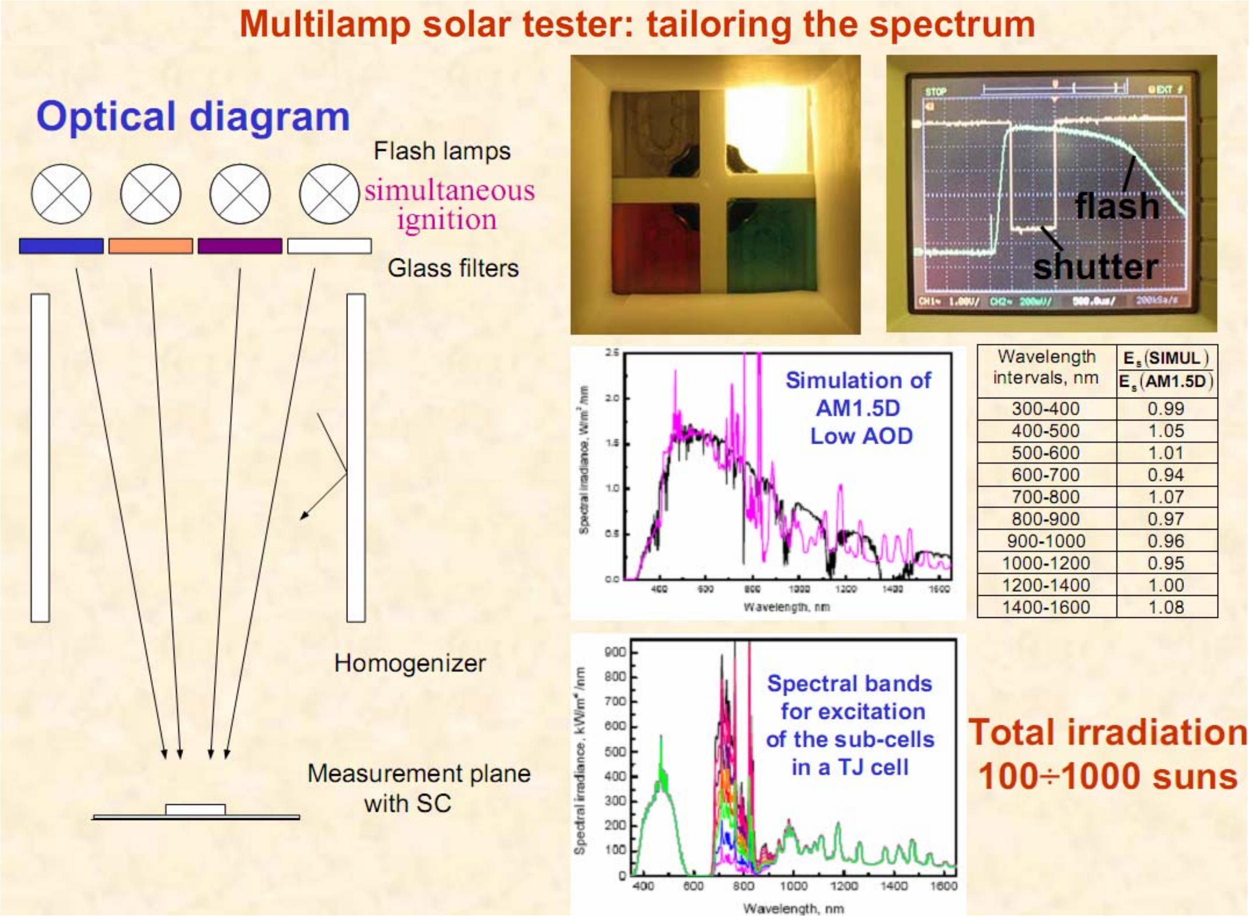
Set the number of points, voltage range, current range and voltage intervals with corresponding number of points to be measured, cell polarity (p/n or n/p), measurement resistor.

Set the ignition time and lamp voltage.

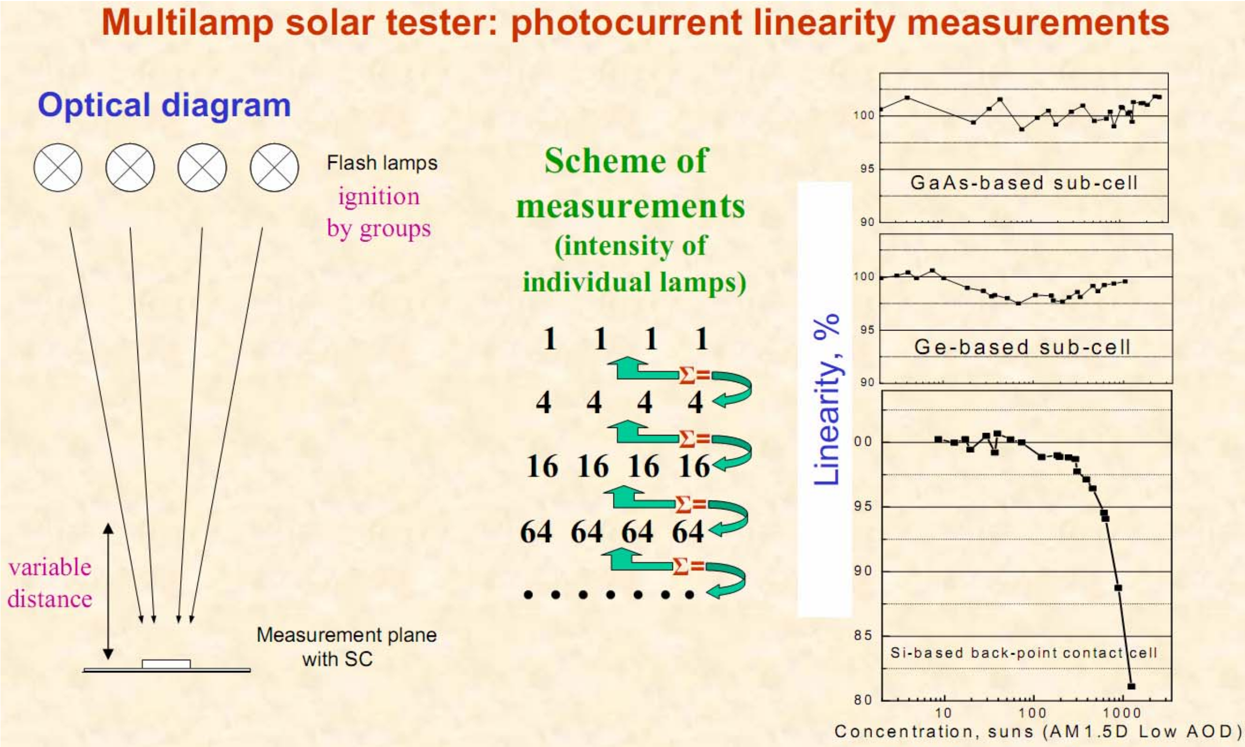
It is recommended that point-to-point time should be 20 seconds. Measurement time should be 2 ms, bias time should be 5 ms.

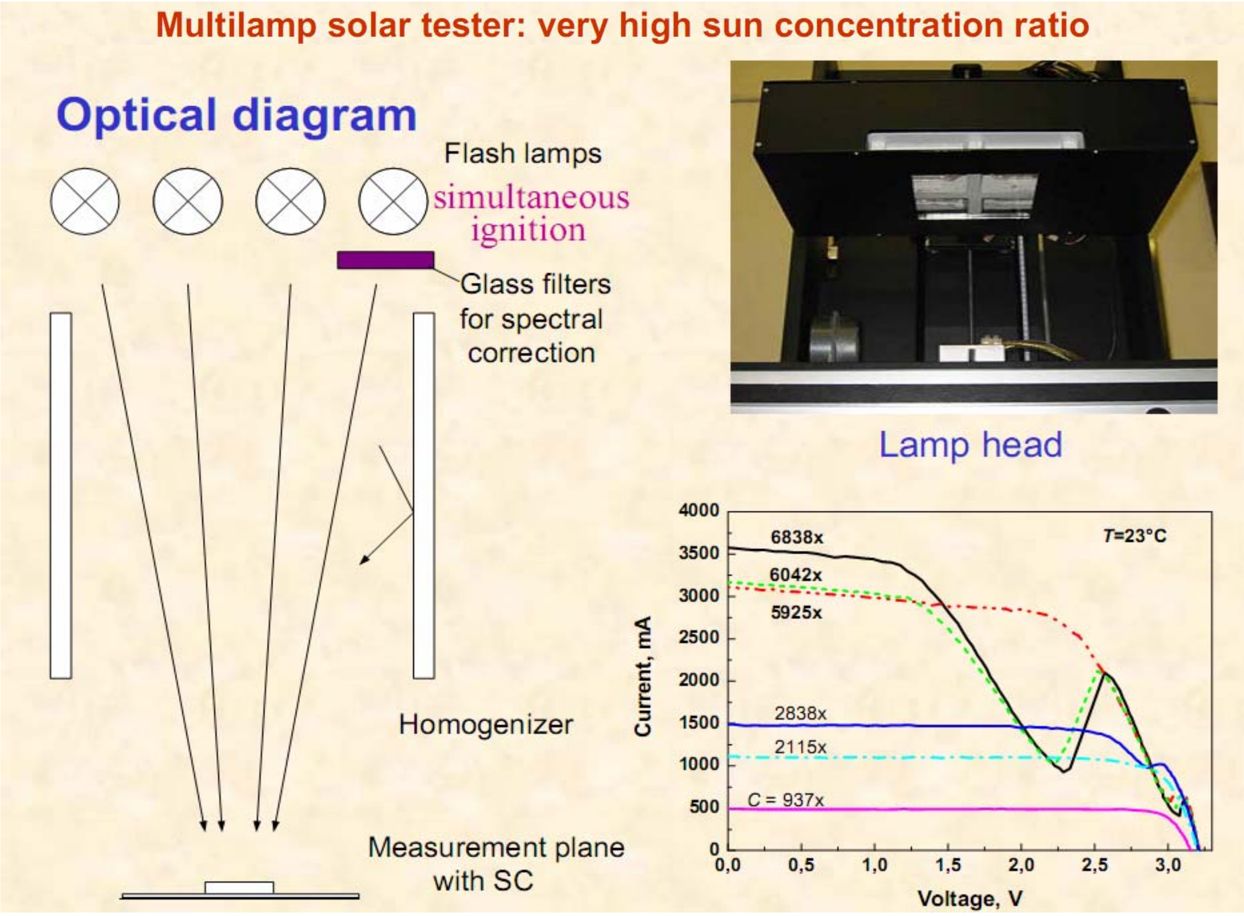
The measurement procedure starts after pressing “Measure” button.

Annex I: Several examples of Four-lamp solar tester use



V.D.Rumyantsev, V.M.Andreev, V.R.Larionov, D.A. Malevskiy, M.Z.Shvarts
Indoor characterization of multijunction concentrator cells under flash illumination with variable spectrum Fourth International Conference on Solar Concentrators for the Generation of Electricity or Hydrogen (ICSC-4) El Escorial, Spain, March 12 - 16, 2007



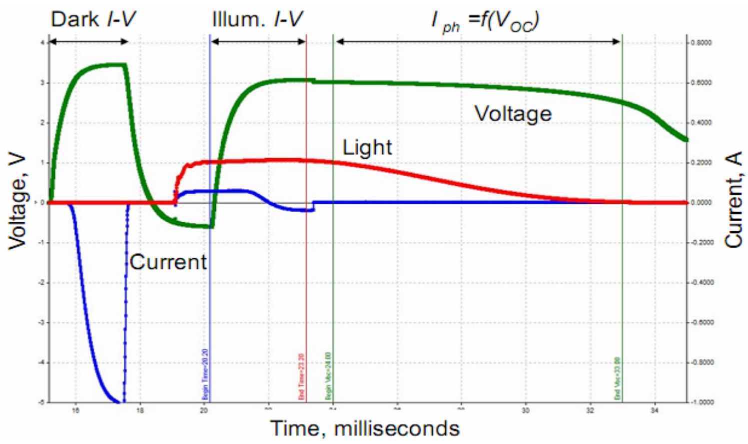


V.M.Andreev, E.A.Ionova, V.R.Larionov, V.D.Rumyantsev, M.Z.Shvarts, G.Glenn "Tunnel diode revealing peculiarities at I-V measurements in multijunction III-V solar cells", *Proceedings of the IEEE 4th World Conference on Photovoltaic Energy Conversion* May 7-12, 2006, Hawaii, pp. 799-802.

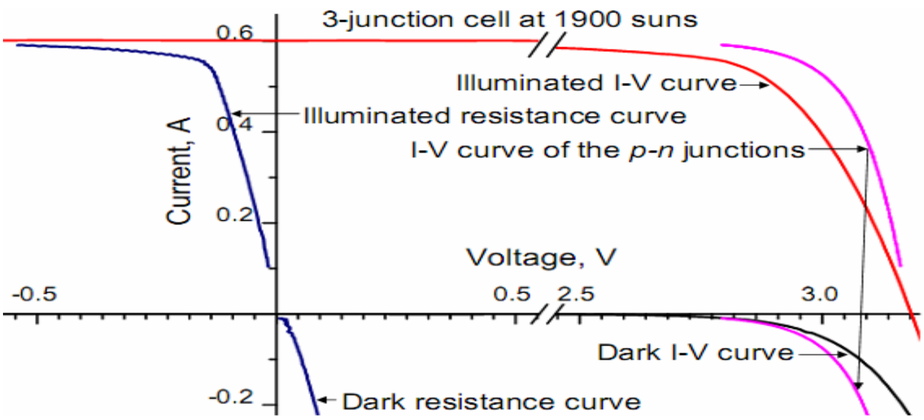
Annex II: Additional hard- and software for possibility to evaluate cell internal resistance components in I-V measurements under flash illumination.

At fabrication of the concentrator SCs one of the central problems is a radical reduction of the internal Ohmic losses. The "illuminated" $\boldsymbol{I}$-$\boldsymbol{V}$ curve (as well as that in the dark) may be represented as the $\boldsymbol{I}$-$\boldsymbol{V}$ characteristic of the $\boldsymbol{p}$-$\boldsymbol{n}$ junction deformed by voltage drop across the internal "lumped" and "distributed" resistance components [1]. To define the internal resistance components from the measured $\boldsymbol{I}$-$\boldsymbol{V}$ curve, uncertainty due to the $\boldsymbol{p}$-$\boldsymbol{n}$ junction curve shape should be eliminated. It is more appropriate to analyze the shape of a "resistance curve", which is constructed by subtraction of the voltage coordinates of the illuminated or dark $\boldsymbol{I}$-$\boldsymbol{V}$ curve of the SC from those of the $\boldsymbol{p}$-$\boldsymbol{n}$ junction at the same magnitudes of flowing current. In turn, the $\boldsymbol{p}$-$\boldsymbol{n}$ junction $\boldsymbol{I}$-$\boldsymbol{V}$ curve of a real SC can be constructed as a dependence of photocurrent $\boldsymbol{I_{ph}}$ on open circuit voltage $\boldsymbol{V_{oc}}$ in varying illumination level between low enough level and that producing $\boldsymbol{I_{ph}}$ of the required magnitude**.** In the simplest case of a SC model with series resistance, the "resistance curve" is a straight line. In a "classical" case the "resistance curve" may be characterized by tilting angles of chord and two tangents to the curve, which are the sums of "lumped" and of certain parts of the "distributed" resistances [1]. In a general case, not only one, but several components of the "distributed" resistance may exist, so that shape of the "resistance curve" may indicate this.

[1] V.M.Andreev, V.A.Grilikhes, V.D.Rumyantsev: "Photovoltaic conversion of concentrated sunlight", John Wiley & Sons Publishing House, Chichester, 1997, 294 pp. Chapter 2, "Ohmic Losses in Solar Cells".



Oscillogram of light, voltage and current pulses at *I-V* measurements of the concentrator solar cells under flash illumination. Light plateau is 1 ms in duration.



Dark and illuminated I-V curves as well as the curves for p-n junctions and internal resistance curves for an InGaP/GaAs/Ge triple-junction cell. Illuminated resistance curve has two segments: one of them corresponding to lumped (series) resistance (it is dominant in dark resistance curve as well), and upper segment corresponding to a non-uniformly distributed resistance component.