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The Large Area Pulsed Solar Simulator (LAPSS)

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ABSTRACT

The Large Area Pulsed Solar Simulator (LAPSS) has been installed at JPL. It is primarily intended to be used to illuminate and measure the electrical performance of photovoltaic devices. The simulator, originally manufactured by Spectrolab, Sylmar, Calif., occupies an area measuring about 3 m wide X 12 m long. The data acquisition and data processing subsystems have been modernized. Tests on the LAPSS performance resulted in better than ±2% uniformity of irradiance at the test plane and better than ±0.3% measurement repeatability after warm-up. Glass absorption filters reduce the ultraviolet light emitted from the Xenon flash lamps. This results in a close match to three different standard airmass zero and airmass 1.5 spectral irradiances. The 2-ms light pulse prevents heating of the device under test, resulting in more reliable temperature measurements. Overall, excellent electrical performance measurements have been made of many different types and sizes of photovoltaic devices.

Since the original printing of this publication, in 1993, the LAPSS has been operational and new capabilities have been added. This revision includes a new section relating to the installation of a method to measure the I-V curve of a solar cell or array exhibiting a large effective capacitance. Another new section has been added relating to new capabilities for plotting single and multiple I-V curves, and for archiving the I-V data and test parameters. Finally, a section has been added regarding the data acquisition electronics calibration.

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INTRODUCTION

The Large Area Pulsed Solar Simulator (LAPSS) is now operational at JPL. It is primarily designed to illuminate and measure the electrical performance of photovoltaic devices with areas ranging from 1 cm^2 to 4.5 m^2, and it is useful for studying other types of light-sensitive devices. The LAPSS is an excellent, close-spectral-matched light source for obtaining accurate electrical performance measurements on all types of single-junction photovoltaic devices. Because of the close spectral match and lack of intense spectral lines or absorption bands, reasonably accurate results are also obtained when using only this single light source for testing thin-film, tandem-junction amorphous silicon devices.

Since the original printing of this publication, in 1993, the LAPSS has been operational and new capabilities have been added. This revision includes a new section relating to a significant improvement, the installation of a method to measure the I-V characteristics of a cell or array exhibiting a large effective capacitance. In addition, this revision includes a new section relating to the new capabilities for plotting single and multiple I-V curves, and for archiving the I-V data and test parameters. Finally, a section has been added to describe the data acquisition electronics calibration.

LAPSS System Performance

The LAPSS produces a 2-ms light pulse from two Xenon flash lamps. Their intensity is adjustable over a wide range without altering the chosen spectral irradiance. The short duration of the light pulse prevents heating of the test cell/array, resulting in more reliable temperature measurements and improved data accuracy. The LAPSS data-acquisition system acquires a full current-voltage (I-V) characteristic curve during a single light pulse.

The uniformity of the irradiance at the test plane is ±2 percent over a 2.1 m X 2.1 m rectangular area, as shown in Fig. 1. Repeated measurements over a period of several weeks show that measurement repeatability is better than ±0.3 percent after a 30-minute warm-up time, but is no worse than ±1 percent without warm-up. This contributes to the highly accurate measurements.

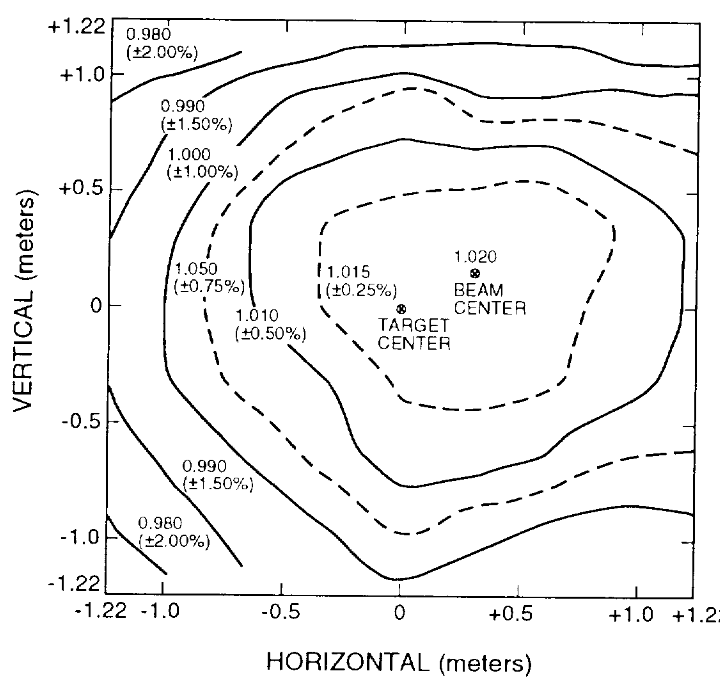

Figure 1. LAPSS Relative Uniformity of Intensity Contour Map.

Through the use of ultraviolet absorption filters and horizontal slit filters, the LAPSS can provide spectral irradiance distributions with a close spectral match to three different standard spectral irradiances, in accordance with References 1, 2 and 3. The standard spectral irradiances are the 136.7 mW/cm² airmass zero spectrum (AM0), the 100 mW/cm² normalized airmass 1.5 global spectrum (AM1.5G), and the 100 mW/cm² normalized airmass 1.5 direct spectrum (AM1.5D). The close match to these standard spectral irradiances is shown in Figs. 2, 3 and 4. The LAPSS can also be used unfiltered if a substantially higher intensity is required at wavelengths between 300 and 400 nm. Typical results are shown in Fig. 5.

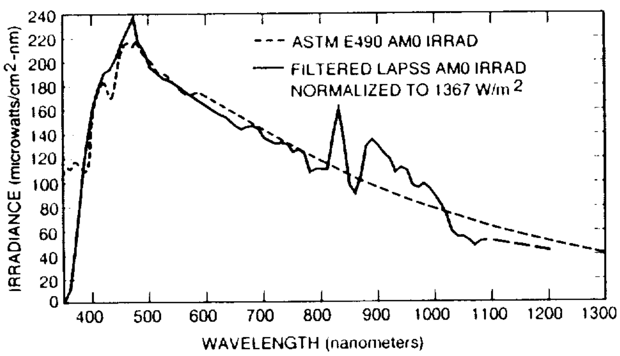

Figure 2. Spectral Irradiance (AM0, Filtered LAPSS vs ASTM).

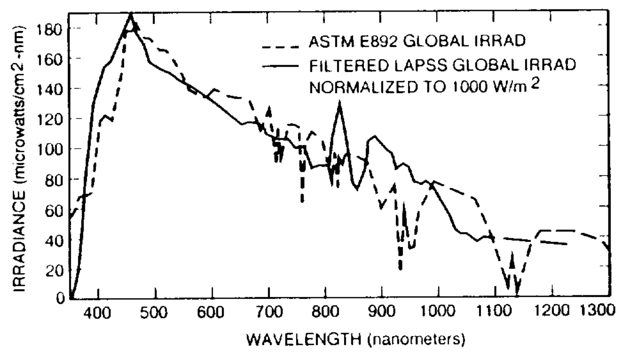

Figure 3. Spectral Irradiance (AM 1.5 Global, LAPSS vs ASTM).

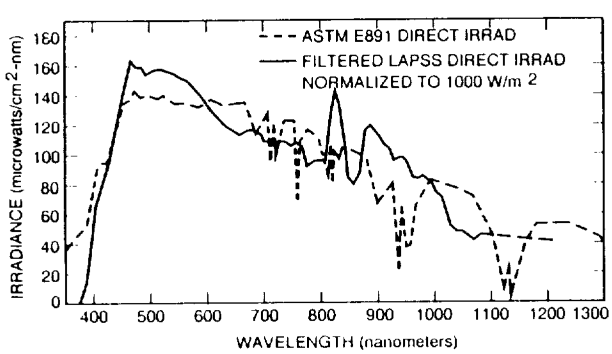

Figure 4. Spectral Irradiance (AM 1.5 Direct, LAPSS vs ASTM).

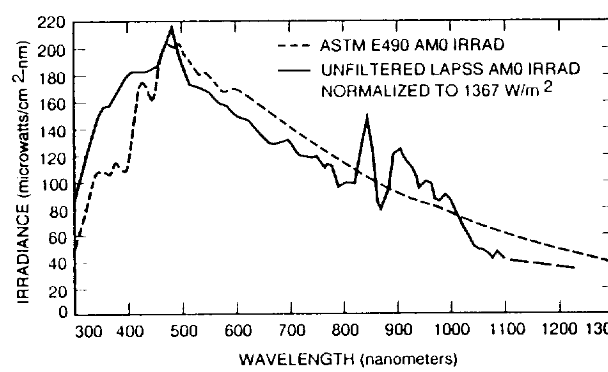

Figure 5. Spectral Irradiance (AM0, Unfiltered LAPSS vs ASTM).

LAPSS Capabilities

With the appropriate filtering in position, the LAPSS can be used for the low-cost, secondary calibration of reference solar cells or arrays in the standard irradiances without a strict requirement for matching spectral responses. As described in Reference 4, a comparison is made with a primary reference cell or balloon flight standard cell having a spectral response characteristic with only some similarity to that of the test cell/array. This method has shown excellent agreement with worldwide round-robin measurements, as described in Reference 5.

Since the LAPSS has an excellent spectral match to a choice of standard spectral irradiances, more dependable current-temperature coefficients can be measured for those irradiances. Voltage-temperature coefficients can also be measured. These measurements can be obtained on reference cells, balloon-flight standard cells, or other photovoltaic devices with dimensions of 10 cm X 15 cm or less. The test cells are heat-sinked to a thermoelectric module, which is temperature-controllable from about 5° to 80° Celsius. A 30 cm X 30 cm thermoelectric module is also available for similar measurements on larger devices.

Solar cells and small arrays can also be characterized for their performance at different intensities while controlled to different temperatures within the previously mentioned range (5° to 80° Celsius). A number of slit filters are available for intensities of 5, 10, 15, 20, 25, 50, 60, 70, 80, 90, 100 and 136.7 mW/cm^2. This range of intensities is available at the standard (11 m) lamp-to-target distance. Devices measuring 11 cm X 11 cm, or less, can be tested at a range of intensities nine times the above when moved to within 3.6 m of the lamps.

Some photovoltaic devices, such as silicon back-surface field cells or amorphous silicon cells, exhibit a large effective capacitance. An I-V curve, obtained with the LAPSS high-speed data acquisition system, begins to soften sometime before Maximum Power (P_{max}) is attained, and the measured voltage continues below normal even upon reaching the Open Circuit Voltage (V_{oc}) condition. This capacitance can be several hundred microfarad for a large single cell, as is described in Reference 6. However, measurements taken at fixed loads during the 1.5-ms lamp flash tend to stabilize after a few hundred microseconds. Any error generally prevails near P_{max}, and it can be determined by using the LAPSS Single-Point Mode 1 option. This option allows the LAPSS operator to use the LAPSS electronic load as a fixed load at any desired load point. When properly adjusted, it can provide a reliable measurement of P_{max} to compare with the P_{max} from an I-V curve. A series of measurements at different fixed loads can be made to reveal the true shape of the I-V curve if the cell or array has large effective capacitance.

Testing Cells and Arrays with High Effective Capacitance

To obtain the necessary data for revealing the true I-V curve of a cell or array exhibiting high effective capacitance, a new test method has been developed. The LAPSS operator must perform a sequence of five lamp flashes. A standard, full I-V curve is obtained during the first lamp flash. Subsequently, four additional lamp flashes are performed at fixed loads using "Single Point Mode 1" and referencing the initial I-V curve. The mode 1 control is used to load the test article at specific locations on the I-V curve. The first should be where the current is a few percent less than I_{sc}, but before the maximum power point. The second should be near maximum power current. The third should be where the current is about 50% of I_{sc}, and the fourth should be near V_{oc}, where the current is only a few percent of I_{sc}. Based upon the I_{sc} measured during the initial I-V curve and the voltage and current measured during the four fixed load measurements, the computer software then calculates a delta V for each point on the initial I-V curve and develops a corrected full I-V curve.

The uncorrected and the corrected I-V curves of a 2 cm X 2 cm silicon back surface field reflector (BSFR) solar cell is shown in Fig. 6. The I-V curve of this cell has also been measured with an Spectrolab X-25, a short-arc, Xenon solar simulator. Since the I-V data is obtained by changing the load slowly, the cell capacitance is not an issue. The result is a curve that is a duplicate of the corrected LAPSS I-V curve.

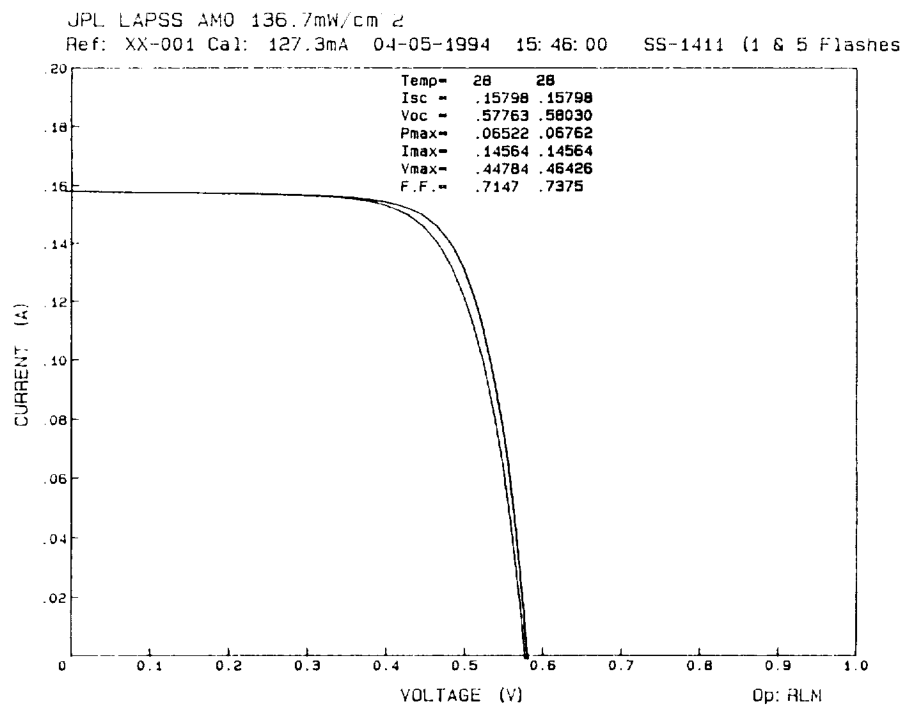

Figure 6. Corrected and Uncorrected I-V Curves of an Si BSFR Solar Cell Obtained With an LAPSS.

More-detailed information about the LAPSS subsystems, calibration, filters, and lamps is provided in the attached appendix.

REFERENCES

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5. H. Ossenbrink, R. Van Steenwinkel, and K. Krebs, "The Results of the 1984/1985 Round-Robin Calibration of Reference Solar Cells for the Summit Working Group on Technology, Growth and Employment," Commission of the European Communities, Directorate-General for Science Research and Development, Joint Research Centre, Ispra Establishment, April 1986. (Reprint EUR 10613 EN)

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APPENDIX

Pulsed Illuminator Subsystem

The pulsed illuminator subsystem irradiates the test cell or array and a reference solar cell. Some test cells are shown in Fig. 7. The primary components of this subsystem are the Pulse-Forming Network (PFN) and the Illuminator Assembly, which are shown in Fig. 8.

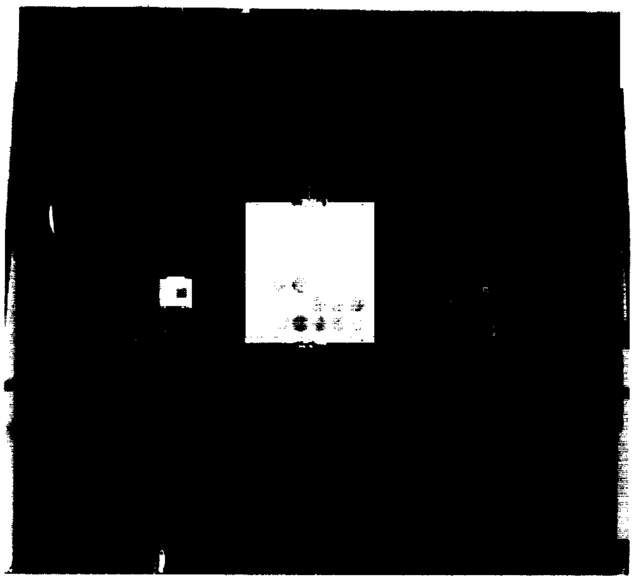

Figure 7. Solar Array and Reference Cell Mounted on 2.4 m X 2.4 m Target Area.

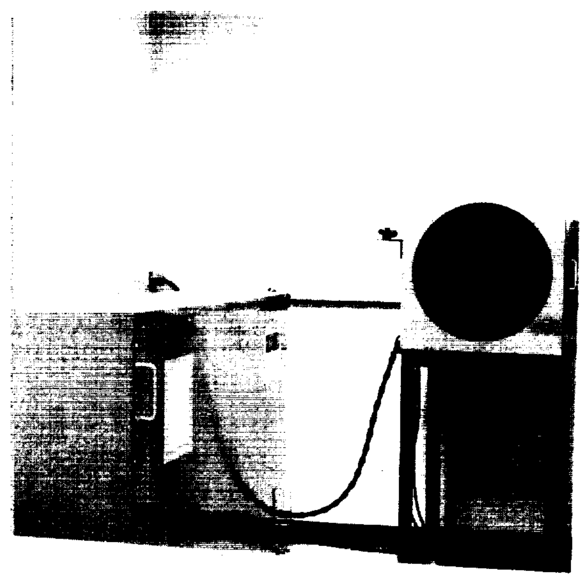

Figure 8. The Pulse-Forming Network (left) and the Illuminator Assembly (right).

The PFN is basically a high-voltage DC power supply capable of charging 2000 Mfd of storage capacitors up to 5000 volts in about 10 seconds. The supply contains large pulse-forming inductors that are used when the capacitors are discharged through the Xenon lamps. The charge voltage is presettable and is sensed with a built-in charge voltage sensor.

The Illuminator Assembly consists of two Xenon flash lamps, an RF lamp igniter, and baffling to constrain the light to the target plane. When the preset charge voltage is reached, the lamps are RF ignited, causing the PFN capacitors to discharge through the series-connected lamps, by way of the pulse-forming inductors.

The result is a sustained operation of the lamps for about 2 ms, with the intensity ringing about ± 3 percent at a frequency of about 3100 Hz. The peak power to the lamps is over 7 megawatts with the standard charge voltage of 2700 volts, which is achieved after 7 seconds of capacitor charging.

The Data-Acquisition and Data-Processing Subsystem

The data-acquisition and data-processing subsystem is synchronized with the illuminator subsystem and simultaneously measures the I-V performance characteristics of a test cell/array and a reference solar cell. The primary components of the updated data-acquisition and data-processing subsystem are the original LAPSS control console with a built-in high-speed electronic load, an ISAAC 2000 data-acquisition system with analog-to-digital converters, a Compaq Deskpro 286 personal computer (PC), an Epson FX-286 printer, and a Hewlett Packard 7475A X-Y plotter.

The LAPSS control console, which is shown in Fig. 9, contains the majority of all system components for operating the LAPSS except for the ISAAC 2000, printer and x-y plotter. The high-speed electronic load is basically composed of eight 150-Watt silicon power transistors. During the 2 ms of sustained illumination, the high-speed electronic load is connected to the test cell or array, and the load is swept from I_{sc} to V_{oc} condition. As was mentioned earlier, the LAPSS Single-Point Mode 1 option is used for applying a fixed bias to the LAPSS electronic load that converts it to an adjustable fixed load. Simultaneously, a short circuit is applied to an unloaded reference cell to measure its I_{sc}, short-circuit current. In addition to the regular reference cell input, there is a special provision for measuring the millivolt output of a balloon flight standard having built-in load resistor.

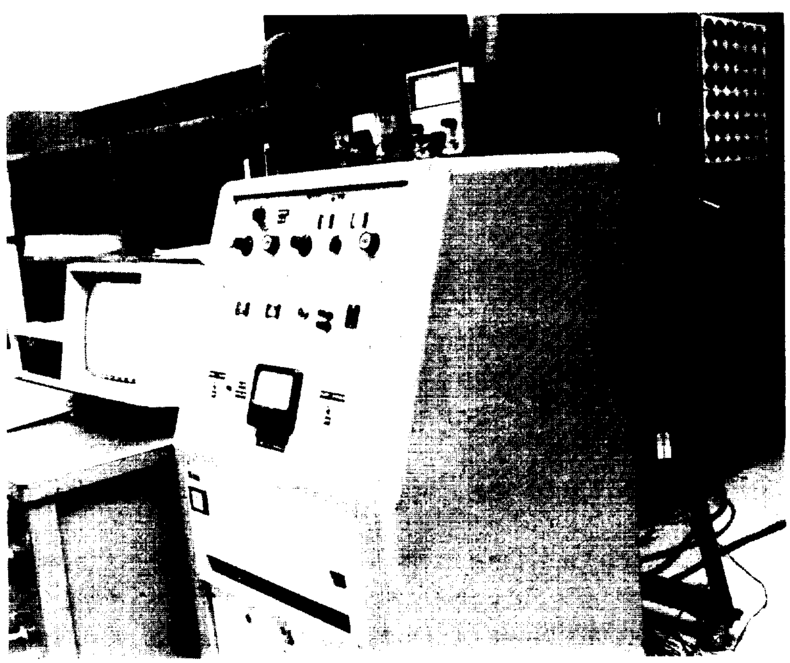

Figure 9. The LAPSS Control Console, With the Compaq Deskpro 286 PC and the Target Area.

At 15-microsecond intervals during the electronic load sweep, the cell or array voltage, and current, and the reference cell or balloon flight standard cell signal are simultaneously sampled by the ISAAC 2000. The analog data is sequentially converted to digital data and stored in the ISAAC 2000 memory.

At the conclusion of the lamp flash, the digital data is sent to the computer where it is corrected for lamp intensity variations. The data is then converted to engineering units of voltage and current. The resulting data is also corrected for any difference between the desired temperature and the actual operating temperature using standard or manually inputted temperature coefficients. The data is then listed in tabular form on the PC monitor with a summary of derived parameters, including test cell/array I_{sc}, V_{oc}, P_{max}, I_{pmax}, V_{pmax}, Fill Factor, and Efficiency. There are provisions for printing, plotting, and archiving the I-V data and test parameters. They are described below.

Data Printing, Plotting, and Archiving

Data identical to that displayed on the PC monitor can also be sent to the printer in a tabular format, including a listing of the derived parameters. If desired, only a summary of the derived parameters, including test cell/array I_{sc}, V_{oc}, P_{max}, I_{pmax}, V_{pmax}, Fill Factor, and Efficiency will be printed. A series of measurements printed out in this summary form may be averaged, if desired.

The X-Y plotter reconstructs an I-V characteristic curve from the tabular data displayed on the screen. The source of the data may be either from a real-time test or from archived data, but not both. Derived parameters and test conditions are also included on the plots. Up to six I-V curves may be plotted on a single paper including their corresponding parameter sets. This provides a convenient means for plotting a family of curves to display the effects of a changing condition or parameter.

There is a provision for saving each set of raw data and its corresponding header of test parameters at the time the data is taken. This information is saved on the PC hard disk drive and may be retrieved for viewing at a later time. If desired, changes may be made in the corrected temperature or in the temperature coefficients used. The data may then be reprinted or replotted.

Calibration of the Data Measurement Channels

At present, three data channels are used to obtain data during a lamp flash. As discussed earlier, two of the channels are for the current and voltage outputs of the test article. The third channel is for either the current output of a reference cell or the voltage output of a balloon flight standard. Initially, these channels are all DC analog channels. Their gains are adjusted to provide zero to 5 volt DC output, for all current and voltage ranges. The analog outputs are connected to the input of the ISAAC 2000 data acquisition system.

The ISAAC 2000 has four 12-bit analog-to-digital converters. Three are presently in use to accept the zero to 5 volt DC signals and convert them to digital outputs (zero to 4095 counts). Once the gains of the analog amplifiers are adjusted, a calibration of each channel is made.

Accurately known values of zero, middle range, and full range voltage or current are delivered to their corresponding analog inputs. The converted digital output is recorded along with the measured values of the inputs for all voltage and current ranges. This information is held in a data file that is used by the LAPSS software to convert the digital output to engineering units of volts and amperes.

Close-Matched Spectral Irradiance Options

Glass absorption filters used with the LAPSS have previously shown no notable change with time in their spectral characteristics, as described in Reference 4. Two different Schott™ glass absorption filters have been selected to reduce the level of ultraviolet light being emitted from the illuminator assembly. This is done to provide a closer match to desired spectral irradiance distribution. When the 136.7 mW/cm^2 airmass zero (AM0) spectrum or the 100 mW/cm^2 normalized airmass 1.5 global (AM1.5G) is required, a 1-mm thick Schott™ GG-395 filter is used. If the 100 mW/cm^2 normalized airmass 1.5 direct (AM1.5D) spectrum is required, then a 2-mm thick Schott™ GG-4 filter is used.

Depending on which filter is in use, the slit width of the horizontal slit filter is adjusted to provide the desired intensity according to a reference cell or balloon standard calibrated in the desired spectral irradiance distribution (i.e., AM0, AM1.5G or AM1.5D).

Lamp Aging and Intensity Reduction

Previous tests have shown that after 100,000 lamp flashes had been registered on the control console flash counter, there was no significant change in the spectral output of the lamps. This number of flashes is equivalent to just under 6 minutes of total operating time if one were to include the 0.5-ms rise time and the 1.0-ms fall time of each lamp flash. The EG&G model FX47C-6.5 lamps are usually replaced after about 100,000 flashes. Replacement lamps have exhibited only minor variations in intensity, spectral irradiance distribution, test-plane uniformity or pulse shape when accurately positioned in the illuminator assembly and operated at the same charge voltage.

The Pulse Network Voltage (PNV) is maintained at a value of 2700 volts to maintain lamp color temperature. Intensity reduction is performed by inserting a horizontal slit filter inside the illuminator assembly in front of the vertical lamps. A smaller slit dimension will cause a proportionally lower intensity to be emitted from the illuminator assembly. The spectral irradiance distribution is not measurably affected because the PNV to the lamps is held constant. The light uniformity at the test plane is also not measurably affected because the slit width has no notable effect on the dispersion of the light upon the 2.1 m X 2.1 m area in the center of the target plane.

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16. Abstract

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