A step by step guide to selecting the "right" Solar Simulator for your solar cell testing application

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Solar Simulator or Xenon Light Source

There are many companies in the market place that claim to sell solar simulators, yet what they are really selling is a xenon light source. What are the differences between these two, even though they both use xenon short arc lamps? A solar simulator is a xenon light source; however a xenon light source is **not a** solar simulator. By definition of International standards (listed below in the footnote) for Solar Simulators, a solar simulator is the equipment used to simulate the solar irradiance and spectrum and it must fall into one of the three classes defined below.

If we take a xenon light source, then through the use of reflectors, filters and optics shape the light beam so that the three main characteristics of light beam meet the specified international standards, then it becomes a solar simulator. These international standards[1] define three classes of solar simulators; Class A, Class B and Class C and the acceptable tolerance for the three main characteristics, namely spectral match to sunlight, non-uniformity of the light beam and stability of the light beam over time. If a manufacturer does not clearly specify the class and tolerances for these characteristics, then chances are they are selling a xenon light source.

So the first thing you need to decide is what is needed for your application, a xenon light source or a solar simulator, keeping in mind that, in general, xenon light sources are cheaper than solar simulators

Type of Solar Simulator

There are two types of solar simulators available in the market for cell testing. First is "Steady State" (SS) system and the second is the "Pulsed Simulator" (PS) system. Pulsed simulators can be single-pulse or multi-pulse type. Following are some of the things to consider in choosing between these two types of solar simulators.

1. PS systems have lamp life that is typically between 40,000 to 1 million flashes[2], whereas the SS systems have a typical lamp life of 1,000 hours of continuous operation. If we take things at the face value; then 1 million flashes is better than 1,000 hours. Let us now consider the facts about cell testing. With a PS system,

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[1] American Standard: ASTM E927, European Standard: IEC # IEC 904-9 and Japanese Standard: JIS C 8912 & JIS C 9833
[2] According to a survey made by experts at PHOTON International Magazine (See Ref. 1)

between 40,000 to 1 million cells can be tested before there is a need to replace the lamp. Cell testing typically takes less than a second. However when we add the time for loading and unloading of cell into the equation typical throughput is 1,000 to 1,200 cells per hour. With the SS system we will be able to test 1 million to 1.2 million cells before there is a need to replace the lamp. It is worth noting that the total number of cells that can be tested with a SS system is limited by robotics, i.e. if the cell loading and unloading can be speeded up, more than 1 million cells can be tested with SS System before the need to replace the lamp. In addition, depending on the design efficiency of a SS system, it is possible to get much longer life than the typical 1,000 hours. For example, if one design is such that the lamp runs close to full power when new, then lamp life is likely to be close to the specified 1,000 hours. If, however, another design is such that the lamp runs at lower power when new then the lamp life is likely to exceed the specified 1,000 hours. Hence, solar simulators that use mirrors are inherently less efficient design since irradiance loss from each mirror is typically 5-10%.

2 Most PS systems typically have a flash duration of 2 ms to 10 ms; this means that the cell testing, i.e. I.V. measurement system must be able to perform the test within this short duration. Testing in this short duration is not a problem but generally means fewer data points for the I.V curve. It also means that the cell to be tested must be able to respond to the light in this short time duration. As a result it is important to know the response time of the device to be tested.

3 For PS systems, there is a claimed advantage that since the flash is for a short duration, the cell to be tested has no appreciable increase in its temperature. Whereas the general thinking is that using a SS system one must be concerned about the increase in the cell temperature during testing. Tests[3] have shown that for single crystal or multi-crystalline cells, regardless of the thickness of the cell there was no significant influence on the rate of the observed heat build-up effect when cell was under the light for up to 500ms. A typical test takes about 120 ms. Thus this perceived disadvantage of a SS system is not real.

<u>Spectral Range</u>

Most Solar simulator use Xenon lamp as the light source. The spectral output range of the Xenon lamp is typically between 200nm to >2,500nm. As such most of this spectral range is normally present in the light beam of all Solar Simulators depending on the reflector and/or mirror (if used) coating and the material used for Integrating Lens and Collimating Lens. The International Solar Simulator standards specify Air Mass Filter spectral range and the percentage of the total irradiance that must fall in each range. For example, the most common AM Filters are AM1.5G, AM1.5D and AM0. Following is the specification for these three filters as taken from the Standards. For AM1.5G the total specified Irradiance is 1,000W/m^2 or 100mW/m^{2}and for AM0 the total specified Irradiance is 1,353W/m^2 or 135.3mW/m^2. This level of irradiance is known as "one sun" irradiance.

[3] F. Granek and T. Zdanowicz (See Ref. 2, Section 3.2 page 60)

Wavlength Range (nm)	Percent of Total Irradiance		
	AM1.5 Direct	AM1.5 Global	AM0
300-400	Not specified	Not specified	8.0
400-500	16.9	18.4	16.4
500-600	19.7	19.9	16.3
600-700	18.5	18.4	13.9
700-800	15.2	14.9	11.2
800-900	12.9	12.5	9.0
900-1,100	16.8	15.9	13.1
1,100 – 1,400	Not specified	Not specified	12.2

Please note that the standards specify the percent irradiance in each waveband for a certain wavelength range, so almost all of the irradiance will be in the specified range. However, other wavelengths below and above the specified range will be present unless a conscious effort is made to remove those wavelengths.

So if a manufacturer claims an advantage over their competitor by claiming that their solar simulators have a wavelength range much wider than those specified above, then it is false claim since Xenon lamp has a much wider spectral range than those specified by the standards. Even though wavelength below and above the specified range are present, they contribute very little to overall irradiance level.

Spectral Match

The amount and type of solar radiation received on earth varies depending on several factors. These factors include, but are not limited to, the altitude, longitude, latitude, the time of the day, and the time of the year. These factors affect the air mass solar radiation has to pass through to reach the earth surface. For industrial cell testing purposes, the air mass has been standardized to AM0 (i.e. solar radiation in space), AM1D (Direct), AM1G (Global), AM1.5D, AM1.5G, AM2D and AM2G. For most non-space application, AM1.5G is considered the standard sun spectra. This spectrum is defined by the International standards. Class A (±25.0%) has the closest match to the sun’s spectrum, followed by Class B (±40%) and then followed by Class C (+100/-60%). If no tolerance for spectrum match is given for a system, then it should be considered a xenon light source and not a solar simulator. Generally, the closer the system spectrum matches the sun spectrum, the higher the class of solar simulator and the more expensive the solar simulator would be.

Intensity of the light beam

International standards have defined the intensity of the light for a solar simulator with AM1.5G filter as 1,000w/m^2. This level of intensity is called “one sun”. Often customers ask for a solar simulator with a certain lamp power (wattage). Unless an application requires testing under conditions of more than one sun, having a high power lamp solar simulator will result in more than one sun on small targets unless the target is moved far away from the light source. This will generally result in a poor uniformity of the light beam.

The correct way to select a solar simulator is to decide on the largest size cell that you need to test, and then select a system that has a light beam size commensurate with the cell size. Since by definition a solar simulator simulates sunlight, solar simulator with any size of the light beam must meet one sun irradiance intensity level.

Many times potential users of solar Simulators need a certain area of illumination (say 50mm x50mm) but they also specify the lamp power. Our SS50 system uses a 150W lamp, which gives a 50mm x 50mm area of illumination and one sun intensity. Now if a customer says that they want an area of illumination of 50mm x 50mm but they want 1kW Lamp. With 1kW lamp and an area of illumination of 50mm x 50mm, the output intensity is going to be at least six suns. If the test is going to be done at 1 sun intensity then the only way to reduce the intensity from 6 suns to 1 sun is to attenuate the light since the power to the lamp power supply cannot be adjusted down to produce one sun intensity without affecting the spectrum of the light and possibly turning the lamp off, since there is a minimum power required to keep a lamp in operation. So in this situation, to reduce the intensity to 1 sun, some form of Neutral Density Filter will have to be used, which is not an efficient way to operate the system. So the intent of this discussion is to say that when defining your requirements for a solar simulator; then, just define the area of illumination and the level of intensity needed. The manufacturer will select appropriate lamp power (depending on the design efficiency of their solar simulator) to meet these needs. If different Solar Simulator manufacturers use different power lamp to provide the same area of illumination and same level of intensity, then it is reasonable to assume that for a given area of illumination and a given level of intensity, the system that uses the highest power lamp is most inefficient design.

So clearly if the plan is to test samples of 50mmm x 50mm under one sun intensity conditions, then a solar simulator with 50mm x 50mm area of illumination and 1,000W xenon lamp is not the right solar simulator for the application under discussion. It also goes without saying that specifying both the area of illumination and the lamp power when testing is to be done at “one sun” irradiance level results in a conflicting requirement for the Solar Simulator Manufacturer.

Non-Uniformity

This characteristic refers to the uniformity of the light over the defined area of illumination. In solar simulators, this is one of the most difficult characteristics to meet. Sun’s radiation is very uniform. Once again, the international standards specify the non-uniformity for each class; Class A (≤2%), Class B (≤5%) and Class C (≤10%). The quality of the uniformity and its measurement method determines the class of the solar simulator. If the system does not even meet class C for non-uniformity, it should be considered a xenon light source.

Temporal Stability

This characteristic is a measure of the stability of the light beam over a short period of time (1s as per ASTM E927). In addition, the instability is also measured and reported over a period of 100 ms, and 1 minute. Once again, sun’s radiation is very stable over time and the international standards specify the temporal stability of the light beam for each class; Class A (≤2%), Class B (≤5%) and Class C (≤10%). The quality of the stability and the test method used to measure the stability, determines the class of the solar simulator. If the system does not even meet Class C for temporal stability, it should be considered a xenon light source.

The temporal stability is determined by the quality of the lamp and the power supply that is used to run the lamp. Many potential users of the Solar Simulator not only specify the class of the Solar Simulator they need, but they also specify the characteristics of the lamp power supply. For example, one customer specified the following:

Temporal Instability: Class B or better
Power supply:

- Output Voltage Ripple should be <0.2%
- Light Ripple should be <1% RMS

These two requirements are conflicting and contradictory. If the power supply is capable of meeting these specifications, then the Temporal Instability will be better than Class A, unless the lamp is of very poor quality. If only Class B Temporal Instability is required then power supply specifications are unnecessary or will end up increasing the system cost. It also places unnecessary system requirements on the manufacturers that are redundant considering the system performance requirements.

Other Factors

In general, the SS solar simulator designs have an elliptical reflector that collects and focuses the light. The light is then passed through an integrator lens of some type. Finally, the light beam is passed through a collimating lens to collimate the beam. Now let us discuss the merits or drawbacks of each one of these components individually.

Reflectors

Almost all reflectors have hole in the top for the lamp to pass through and make electrical connection. This hole casts a shadow in the light beam, which is very difficult to remove without the use of an integrator lens and meet at least Class B of the standard. There are some systems that do not use any integrator lens. As a result, the beam uniformity is not up to par. In fact meeting the non-uniformity part of the solar simulator standards is much more difficult than any other characteristics. In addition, the type of coating or lack thereof on the reflector surface affects the spectrum and the efficiency of the light collected and reflected for focusing. Generally the reflectors without coating are cheaper and usually have higher attenuation than the coated reflectors. Good quality reflectors have quartz coating on top of an aluminum coating.

Integrator Lens

The integrator lenses are generally made of quartz. Quartz has an average of 95% light transmission, thus use of integrator lens results in minimal loss of light yet contributes significantly to the beam uniformity. Systems that do not use integrator lens usually rely on metallic mirrors to reflect and homogenize the light. Once again, depending on the quality of these mirrors and the type and quality of the coating on mirror surface, typically only 80-90% of the light is reflected. Naturally, the more mirrors are used the more loss of light. So the use of mirrors instead of using the integrator lens results in more light loss thorough reflection from the mirror and the beam uniformity is not as good as a system that uses integrator lens. The only disadvantage of using an Integrator lens is higher cost than mirrors. However, the cost is more than offset by the uniformity and the quality of the beam.

Collimating Lens

The use of collimating lens results in some light transmission losses. Depending on the collimating lens material, these losses could be anywhere from 5-10%. The degree of collimation for a system that uses a collimating lens is typically <3 degrees. Without the use of the collimating lens the beam angle is typically greater, in some cases double that of a collimated beam. In a system that does not use integrator lens or collimating lens, typically a minimum of two mirrors are required to change the beam direction, homogenize the light beam and to some extent, collimate the light, thus resulting in light transmission losses and a light beam that does not have good collimation and uniformity.

In addition, in systems which use the reflective mirrors to direct the light from the source to the target need to be refocused every time there is change in the size of the target, i.e. testing of different size cells? It would also be imperative to check and if necessary, adjust the intensity every time mirrors are refocused. This could be a very time consuming task. In contrast, systems with integrator lens and collimating lens design have a collimated uniform beam, regardless of the target size, i.e. any size cell can be tested without having to change or refocus any thing. This also means that there is no need to check and adjust the intensity every time there is a change in size of cell that is tested.

Once again the only disadvantage of using a collimating lens is its cost, which is even higher for larger size beam areas. This cost is more than offset by the quality of the collimated beam, which allows the testing of any size cell up to the limit of the size light beam without having to refocus, retest and if necessary adjust the light beam intensity.

Shutter and Shutter Control

A shutter is a must unless the solar simulator is going to be used on an automated line, in which case the test cells are moved in and out of light beam by robotics. The alternative to a shutter is turning the xenon lamp on/off as required. However, each on/off cycle of the xenon lamp generally results in a loss of lamp life of as much as 4 hours. Some systems have a feature whereas the xenon lamp operating current is reduced to a lower level when the shutter is closed, thus increasing the lamp life beyond the normal expected life of 1,000 hours. So even in automated line test setting it may be beneficial to have a shutter.

The next consideration is whether the shutter should have manual or automated control. This choice will depend on the method and the number of devices to be tested in a given time and the cost of manual vs. automatic shutter control. For example, in a research type of environment, where throughput is not a major driving factor, then manual shutter control may be sufficient. On the other hand if the cost differential is not significant, then, if desired, an automated shutter control gives the flexibility of using the system in production environment as well.

Light Feedback and Control

A light feedback and control system usually enhances the utility of a solar simulator. In general, the quality of the xenon lamp power supply determines the temporal stability of the light beam. However, even the highest quality xenon lamp power supplies result in some variation/ fluctuation, no matter how small. A light feedback and control system can minimize the intensity fluctuations caused by xenon lamp power supply. In addition, when coupled with I-V measurement software, this capability can be used to measure the intensity at the time of each I-V Measurement and use software algorithms to “normalize” the I-V measurement, i.e. remove the variation in data as a result of variation in light beam intensity. This feature is very useful for more precise I-V measurement of cells.

References

1 “Market survey on cell testers and sorters”, PHOTON International. The photovoltaic Magazine 10, 48-57 (2002).

2 “Advanced system for calibration and characterization of solar cells”, F. Granek and T. Zdanowicz, Opto-Electronics Review 12(1), 57-67 (2004)