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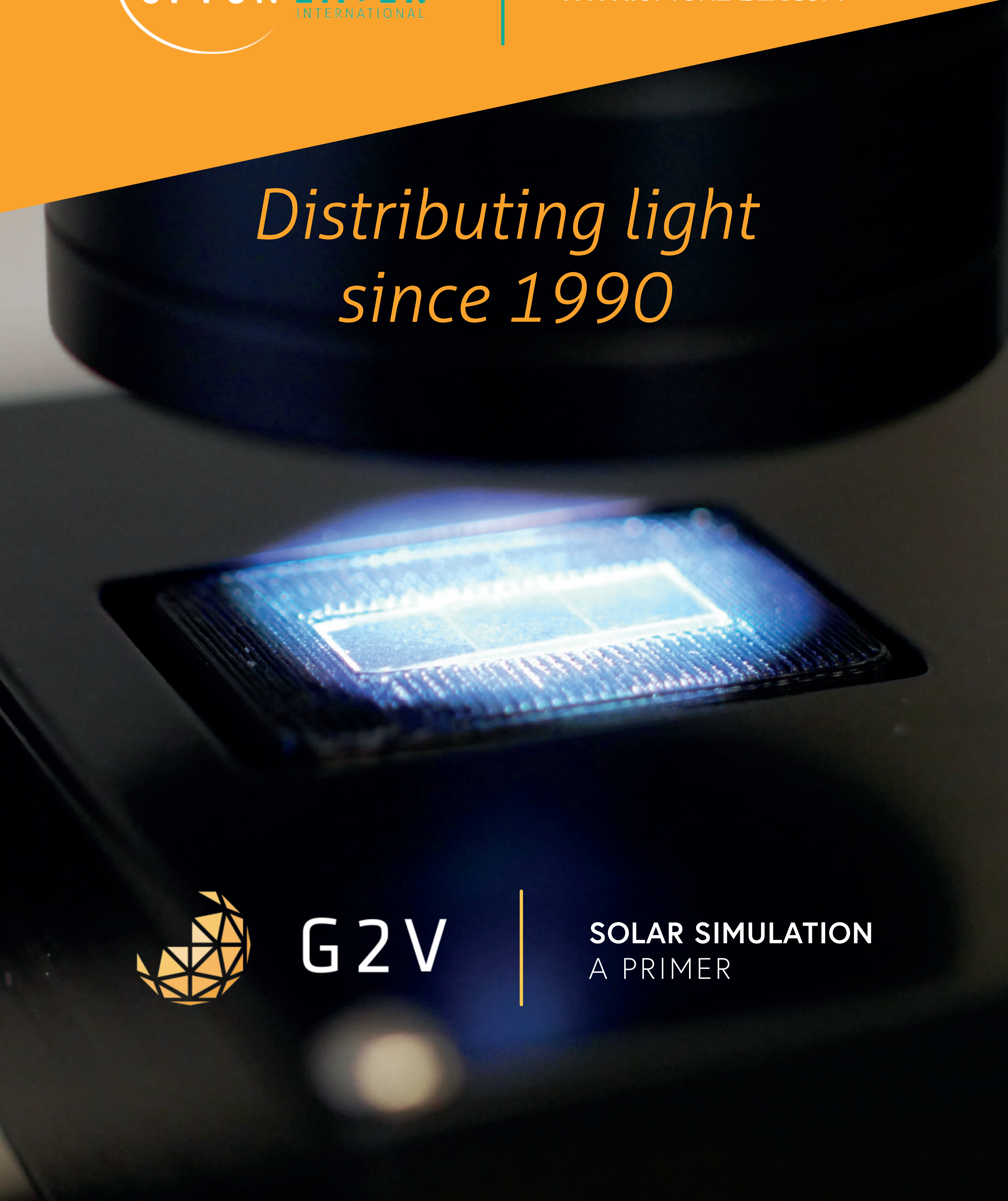

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SOLAR SIMULATION
A PRIMER


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Our Sun

Since the **sun powers all of the life processes on Earth, being able to harness its energy and light source to invent, test and apply technology for mankind's improvement is crucial.**

The sun is the brightest object in the sky and something we are all familiar with. **Life on our planet would not be possible without the sun.** It provides the energy for the plants we eat and those that decayed into the fuel we burn today to harvest energy.

This article outlines a concept called **'solar simulation' – a technology that mimics the sun for use in research labs, industry applications and commercial use.**

Written by G2V Optics Inc.

Contents

What is solar simulation?

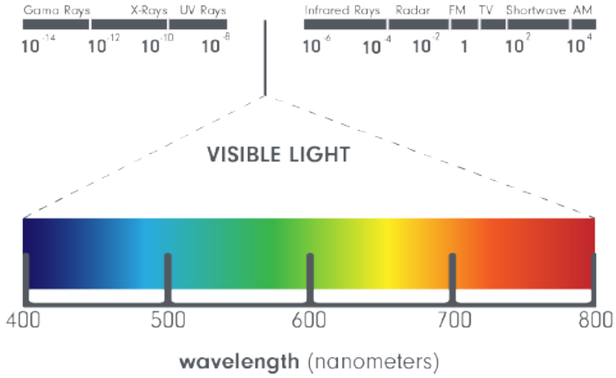
The main objective of solar simulation technology is to **produce illumination approximating natural sunlight in order to provide a controllable indoor test facility under laboratory conditions.**

The instrument used to simulate sunlight in a laboratory setting is called a solar simulator. A solar simulator has a light source that is designed to offer similar intensity and spectral composition to that of natural sunlight.

Sunlight is composed of all the colors that humans can see. We can separate light into different colors when we pass it through a glass prism (red, orange, yellow, green, blue, indigo, violet).

What is Sunlight?

Sunlight is composed of waves of different lengths (hence the term wavelength) and some of these waves represent the colors we see. The sun emits almost all wavelengths of light, even some that we can not perceive with our human eyes such as; **radio waves, microwaves, infrared (IR), ultraviolet (UV), X-rays and gamma rays.**



Similar to the element in your stove or oven, the sun emits light because of its temperature. We can closely approximate the sun's surface temperature to be about 5800 Kelvin (K), or 5500 Celsius (C).

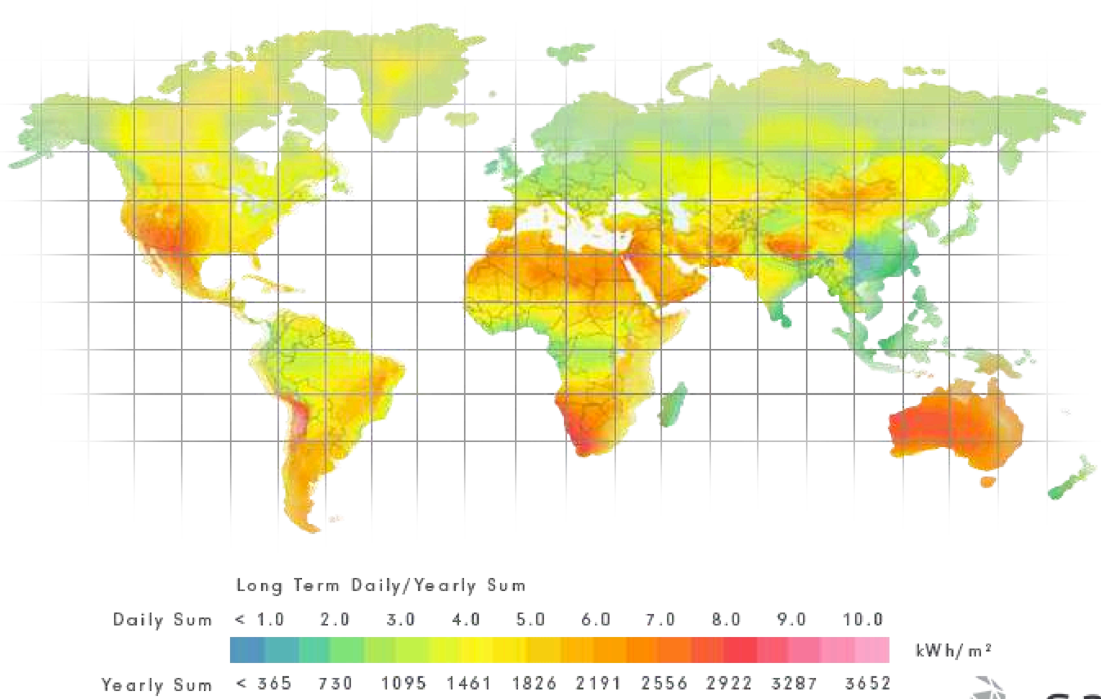
Sunlight comes from the energy emitted in the form of electromagnetic radiation given off of the hot surface of the sun. So the sun's radiation spectrum matches a 5800 K blackbody.

The amount of sunlight falling on the earth's atmosphere changes over a year by about 6.6% due to the variation in the earth/sun distance, and solar activity variations cause sunlight to change up to 1%. Additionally, all the radiation that reaches the ground passes through the atmosphere, which modifies the spectrum by absorption and scattering. As we can see, the specific physical and spectroscopic properties of sunlight are different in different parts of the world, year, day, and even altitude. In addition, due to the earth's curved surface, **the sun's radiation that reaches the earth's surface does not strike all areas of the planet at the same angle.** For example, when the sun is nearly overhead it hits directly near the equator but more obliquely near the poles.

The amount of sunlight falling on the earth's atmosphere changes over a year by about 6.6% due to the variation in the earth/sun distance, and solar activity variations cause sunlight to change up to 1%

Even though our eyes only perceive the visible portion of the electromagnetic spectrum, other wavelengths produced by the sun (such as UV or IR) also play an important role in many photochemical processes. For example, depending on the type of chlorophyll, plants can absorb wavelengths that range from the UV to the IR to produce useful energy. Additionally, materials (organic or inorganic) can be designed to absorb light in a broad spectrum of wavelengths even outside of visible light.

As we can see, the answer to what is sunlight is not that straight forward. To be able to consistently test photochemical processes in a lab setting, we need to have a standard definition of what is defined as sunlight and a reliable and controllable source of light. Artificial light, provided by solar simulators, allows you to mimic the sunlight spectra that meets international standards which are needed to have consistent and reproducible experiments.



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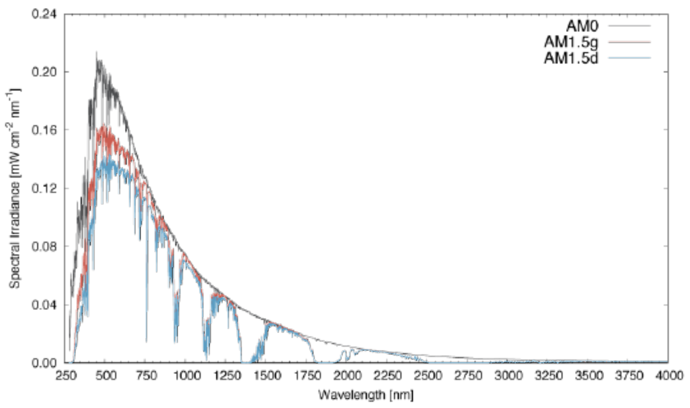
The Standardization of Artificial Sunlight

To be able to predictably rely on artificial sunlight, it was necessary to have standards that defined what is meant by sunlight. This was done in a set of workshops in 1975 and 1977 sponsored by ERDA and NASA where they published a report of standard terrestrial photovoltaic measurement procedures, including detailed descriptions of standard solar simulators.

In this report **the standard illumination intensity was chosen to be 1000 Watts per square meter (W/m^2) and the air mass of AM1.5 Global was chosen as the spectral composition to represent sunlight on earth.**

Both of these standards are still being used by the ASTM standard for commercial solar simulators. The AM1.5G spectra can be seen below:

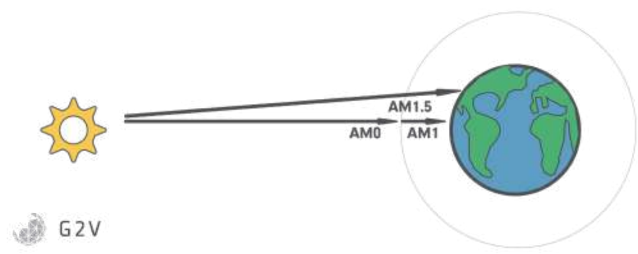


What Does Air Mass Have To Do With Sunlight?

The atmosphere can be divided into large volumes with common properties. **Air masses are large portions of gasses and particles that have similar temperature, chemistry and pressure.** These common physical properties affect how solar intensity decreases as it travels through the atmosphere. When it comes to solar simulation, Air Mass (AM) is a fundamental concept that we need to consider if we want to mimic, as closely as possible, the solar radiation as experienced on the surface of the earth. The **solar spectrum is generated by the sun's surface**, which has a temperature of about 5800 K. The sun's emitted spectrum, as seen from space, is equivalent to the electromagnetic radiation emitted by a black body at that temperature. The light from the sun travels 150 million km and arrives at Earth's orbit. Because it has traveled through the vacuum of space, there has been no change in the spectrum, and this is what we call **Air Mass 0, indicating that the sunlight has not interacted with any of the earth's atmosphere.**

However, when the solar spectrum is measured on Earth, it is shifted slightly from black body radiation due to the scattering of blue light and the absorption of red light by the earth's atmosphere. **The more atmosphere sunlight passes through, the greater the attenuation.**

Air mass is defined as the path length of the direct sunbeam through the atmosphere expressed as a ratio relative to the sun at the zenith (a zenith is an imaginary point directly above a particular location) above a sea-level location. In this case, the sun's direct radiation passes vertically through the atmosphere in the shortest possible path. This is known as Air Mass 1.

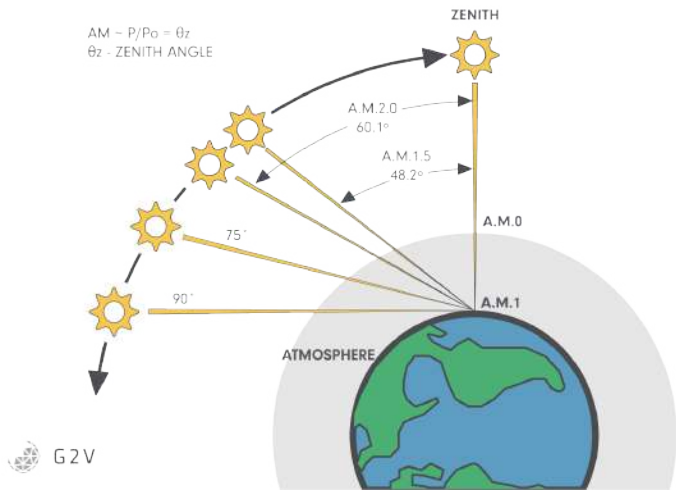


The spectrum generated by sunlight at Air Mass 1 is commonly known as "Air Mass 1 Global" (AM1G) radiation spectrum, meaning "one atmosphere". The spectrum generated by sunlight at AM1 (at 0° from the zenith) to AM1.1 (at 25° from the zenith) is a useful range for estimating the performance of solar cells in equatorial and tropical regions. Because it passes through no air mass, the extraterrestrial spectrum is called the "Air Mass 0" (AM0) spectrum.

A first-order approximation for air mass is AM~1/cos z where z is the zenith angle in degrees. This approximation is reasonably accurate up to around 75 degrees, but overestimates air mass at high zenith angles, because the atmosphere has a maximum height. There are a number of approximations that provide a better estimate of air mass across the full range of zenith angles, some even including the effects of atmospheric refraction (for example, in the open ocean, the sun is visible before it has risen above the horizon, because light has been bent by the atmosphere around the curve of the earth).

Now that we understand what AM0 and AM1 are let's take a deeper look at AM1.5, which is the air mass chosen as a standard spectra to represent sunlight.

Because most major population centers of the world (Europe, China, Japan, the United States, northern India, southern Africa and Australia) lie in mid-latitudes, an AM number that represents mid-latitudes is the most commonly used to characterize the performance of solar cells. **AM1.5 atmosphere thickness represents a zenith angle of z=48.2°.**



During the summer months, the AM number for mid-latitudes is less than 1.5, and higher figures apply during the morning and evening. Therefore, AM1.5 is a useful representation of the atmosphere thickness as a yearly average for mid-latitudes. This air mass of 1.5 was selected as the standard spectra in the 1970s for standardization purposes based on a solar radiance analysis in the United States.

Other AM values are used to approximate sunlight at regions other than mid-latitudes or at higher elevations. AM2 and 3 (z=60° and z=70° respectively) for example, is useful to determine the solar performance of some devices (e.g. solar cells) at higher latitudes such as those in northern Europe. An AM value of 40 is typically regarded as being the air mass value of the horizontal direction (z=90°) at the equator.

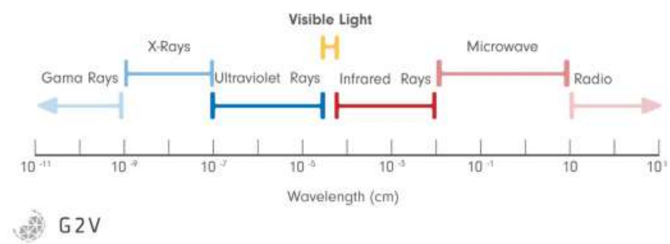
Standard spectrums include AM0, AM1.5G, AM1.5D (direct radiation that does not include scattering). These are defined by ASTM and other standards bodies in an effort to provide standard test conditions so that experiments and results can be compared, and get a reasonable approximation for real-world performance.

What is the solar spectrum?

Solar spectrum is defined as the electromagnetic spectral distribution emitted by the sun or received by a collector or instrument on Earth.

The sun radiates solar energy or sunlight by electromagnetic waves over a range of wavelengths known as the Solar Spectrum.

The Sun emits radiation from X-rays to radio waves, but the surface of the earth receives mainly wavelengths between 350 nm and 4000 nm. The region visible to humans is restricted to 400 nm to 700 nm, approximately 43% of the total energy.



The solar spectrum is generated by the sun's surface, which has a temperature of about 5800 K. The emitted spectrum from the sun seen from space is equivalent to that of electromagnetic radiation emitted by a black body at that temperature. However, when measured on Earth it is shifted slightly from that of a black body radiation due to the scattering of blue light and the absorption of red light by the atmosphere. The more atmosphere through which it passes the greater the attenuation of the radiation. **Complex atmospheric processes may considerably modify the solar spectrum that reaches the earth's surface.**

For example, gas-phase H_2O and CO_2 are strong absorbers of solar infrared radiation. In the visible range, precipitation, clouds, and sandstorms reduce solar radiation. Because most ultraviolet radiation is absorbed from the solar spectrum and does not reach the earth's surface, **the peak of the solar radiation that reaches the earth's surface, is in the visible part of the spectrum.** Of the total radiation, about 3/4 ultimately reaches the earth. The energy distribution within the solar spectrum is approximately 5% UV, 43% visible and 52% infra-red. For standardization purposes, the sun spectrum was chosen have a solar irradiance of 1000 W/m^2 (solar irradiance is the amount of solar energy that arrives at a specific area of a surface during a specific time interval) and an air mass spectrum of AM1.5.

How many Lumens is the sun?

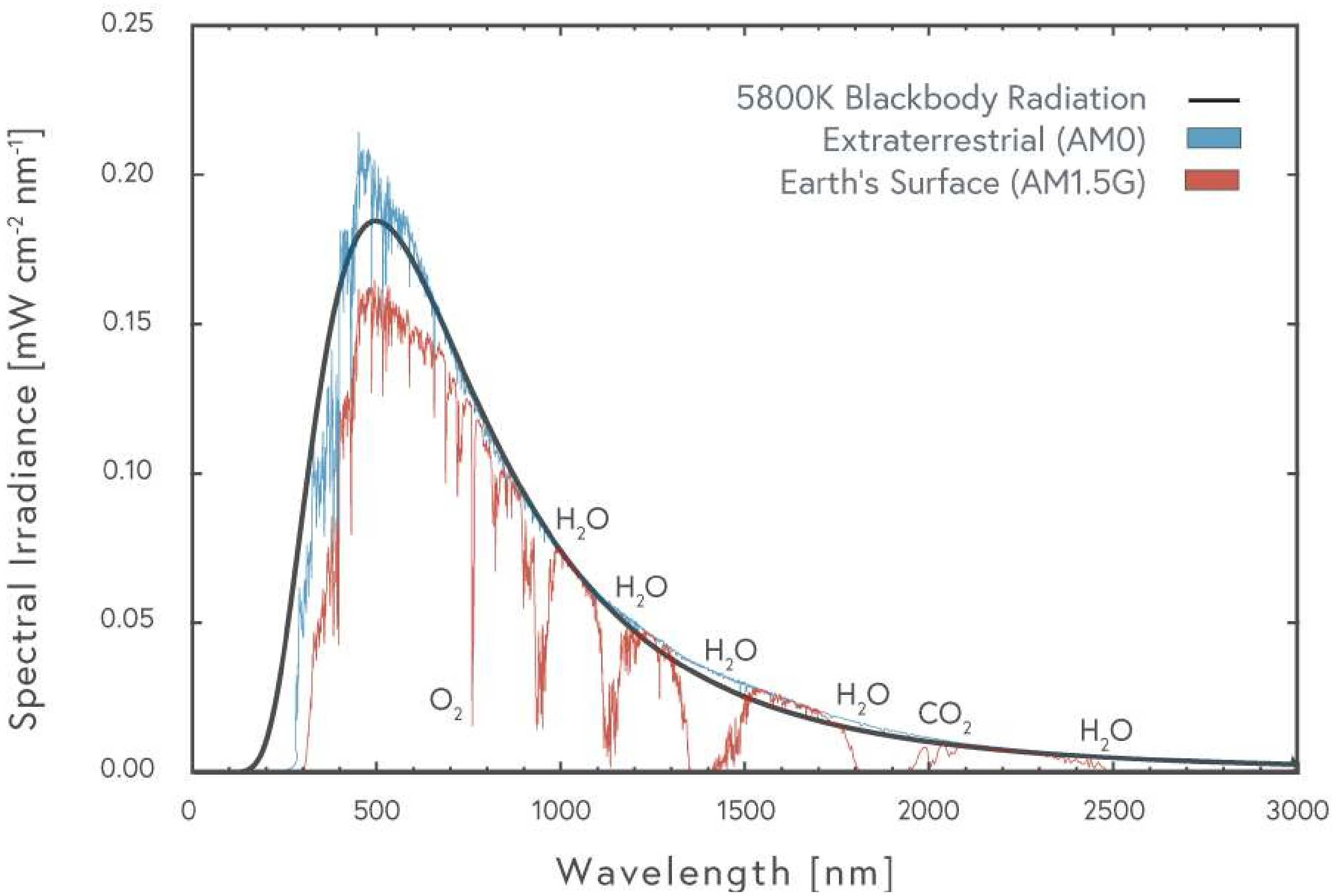
The short answer is that **the sun has an illuminance of about 100k lux (lumens per square meter) on a perpendicular surface at sea level.**

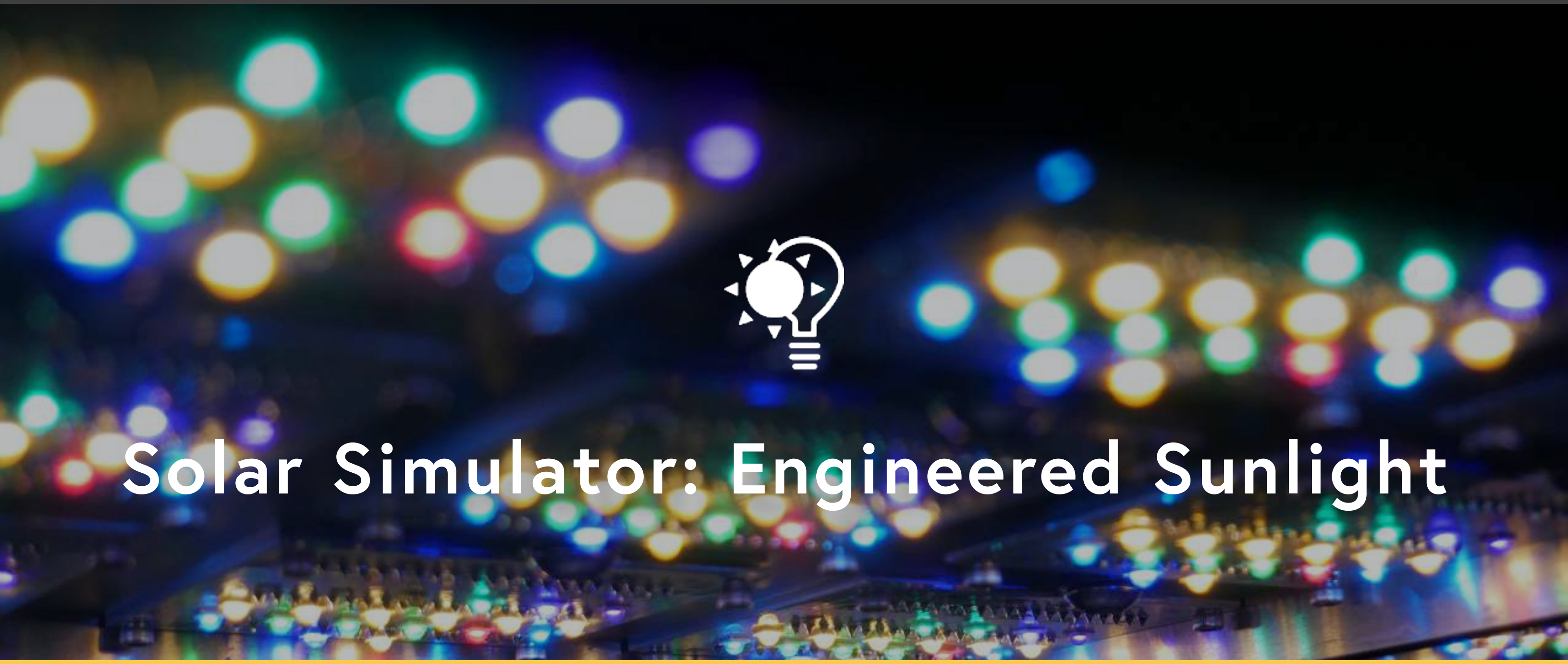
However, as far as the solar industry is concerned, 'radiometric' units are preferred. To understand why, we need to take a more in depth look into what a lumen is.

Lumen, represented by the symbol lm, is the SI unit of luminous flux. Luminous flux is used in **photometry as the measure of light's perceived power.** It is important to understand that photometry measures light in terms of its perceived brightness to the human eye rather than the fundamental power density of a spectrum of light.

Therefore, luminous flux differs from the measure of the total power of light emitted, termed radiant flux, in that it takes into account the human eye's sensitivity to different wavelengths.

Luminous flux is a weighted average of a light spectrum in the light of the visible wavelengths, and light outside of it does not contribute. However, even within the visible spectrum, not all wavelengths of light are equally visible or equally effective at stimulating human vision, because of the spectral sensitivity of the human eye.





Solar Simulator: Engineered Sunlight

A solar simulator is a device whose light source offers similar intensity and spectral composition to natural sunlight. Solar simulators (also called “sunlight simulators”) are scientific equipment used to replicate sunlight in controlled laboratory environments. **They are essential for research and testing of products and processes that either use or are affected by sunlight – like solar cells, solar fuels, sunscreens, plastics, coatings, and other photosensitive materials.**

The major components of solar simulators are a light source and power supply, optics and filters used to modify the output beam, and the controls needed to operate the simulator.

There are two approaches to produce “artificial sunlight”:

1. Subtractive: take a broad spectra light source and filter/use optics to reduce the spectra to something more closely matching sunlight, and additional processing to increase uniformity
2. Take narrow-band light sources and add them together to create the desired spectra (and use optics to increase uniformity).

Because there are differences in the way artificial light is generated and the way sunlight is generated, it is necessary to take additional steps to match both sunlight’s intensity and spectral composition.

There are three criteria used to evaluate the match between natural sunlight and a solar simulator’s output:

Solar simulators are essential for research and testing of products and processes that either use or are affected by sunlight - like solar cells, solar fuels, sunscreens, plastics, coatings, and other photosensitive materials.

Light sources

The main component of the solar simulator is the light-source. The most widely used light source is a short-arc and long-arc Xenon (Xe) lamp but other light sources are also used such as: metal halide (MH) arc lamps, quartz tungsten halogen (QTH) lamps and more recently light emitting diodes (LEDs).

The Xenon arc lamp has dominated the market for the past 40+ years because the Xenon bulb has a relatively continuous spectrum from 300 nm to 2000 nm.

However, when compared to LEDs, **lamp-based systems generally have lower temporal stability, higher operating cost and a shorter lifetime.**

LEDs can also be used as a light source and offer several advantages over other systems such as:

- Their output can be adjusted within microseconds,
- They provide a stable light output over time and
- The light output source can be controlled with a 30 nm – 50 nm resolution.

Recent advancements in LED technology has allowed this technology to push to a full sun spectral coverage from 300 nm to 1850 nm.

Read more about the different types of solar simulator light sources below.

Note: **for Solar simulators, it is convenient to describe the irradiance of the simulator in terms of "suns."** One "sun" is equivalent to irradiance of one solar constant which is equal to 1000 W/m^2 (1 sun=1000 W/m^2).

Emission Technology	Spectral Match	Temporal Stability	Number of Spectra	Maximum Suns	Bulb Lifetime	Initial Cost	Operating Cost
Xe	300 nm - 2500 nm	High	1 - 3	10,000	2,000	Medium	Medium
Metal Halide	300 nm - 1200 nm	Med	1 - 3	1,000	6,000	Medium	Medium
Tungsten Halogen	400 nm - 2500 nm	–	1 - 3	25	2,000	Low	Medium
LED	300 nm - 1850 nm	Very High	Very High	1.1	10,000+	High	Low

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Power supply

These are typically dictated by the light source used. For example, arc lamp power supplies are typically highly complex devices that have to manage a high voltage ignition stage in order to establish the arc. QTH lamps will require a comparatively simpler DC source with a compatible power output. And LED will require a relatively simple power supply.

Optics

Optics & filters are often used, but aren't actually necessary for all light sources. When using solar simulators, you are using an artificial light source to generate the spectra needed. However, there may be differences between artificial light sources and natural sunlight, both in intensity and spectral composition.

Filters and optics are used and can be modified to cause the output light to closely resemble the desired spectra.

The optical layout of a solar simulator varies considerably depending on many variables: light sources used, the area of illumination, the spectral output.

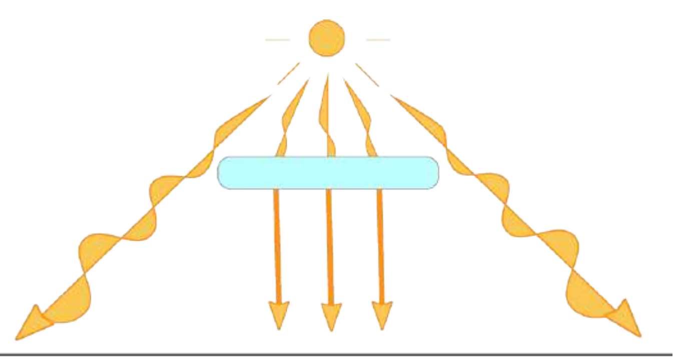
Usually, major concerns for the optical system of a solar simulation system, beyond the fact that it should be able to attain its required classification, is that it should be simple to use and maintain.

A collimator lens can be added to solar simulators to generate a collimated beam in which the electromagnetic radiation has parallel rays and as a result the light spreads minimally as it travels.

When a collimating lens is not used, the beam angle will be larger. Additionally, an integrator lens is also typically used in solar simulators to achieve beam uniformity.

Systems that do not use the aid of any lenses to homogenize the light typically require a minimum of two mirrors to change the beam direction, homogenize the light beam and collimate the light, which results in loss of light.

A lambertian back reflector can also be added to solar simulators to randomize the direction of the reflected light and provide a more uniform radiance.



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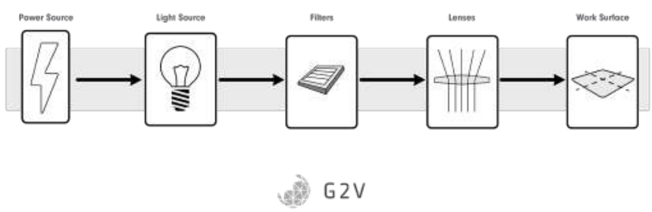
The quality of a solar simulator is graded on the spatial uniformity across a defined illumination area, the temporal stability through the experiment, and the spectral match to the sun from a clearly defined reference spectrum.

Solar simulators can be divided into two general categories: **continuous or steady-state and pulsed.**

The continuous type is a form of light source in which illumination is continuous in time. This type of device is most commonly used for low intensity testing of one or up to several suns (1000 W/m^2).

The second type is the pulsed system. This simulator has flashes/pulses with typical durations of milliseconds and very high intensities of up to several thousand suns are possible.



History of Solar Simulators

Indoor solar simulation started at the beginning of the 1960s with a series of research programs that were sponsored by NASA.

These programs were aimed at developing a ground test facility that can simulate the space environment for earth satellites and other spacecraft testing. The chamber for this testing was named "Space Environment Test Chamber" and in this chamber, a solar simulator was used to simulate the space solar radiation.

After testing and comparing, a mercury Xenon lamp was chosen as the best light source. Jet Propulsion Laboratory (JPL) NASA created a series of several large solar simulators to meet the increasing test requirement for space technology.

In 1986 the European Space Agency (ESA) created a solar simulator to meet the European space plan. The ESA solar simulator was larger and had a simpler optical set up than that of JPL. Later Russia, South Korea, and Japan constructed their own large-scale solar simulators.

These space solar simulators paved the way to much of the fundamental research and testing for solar simulation today.

Solar simulators are needed to have a common basis for comparing solar devices and for the design of large arrays. This created an industry need for testing solar cells and other devices under control conditions and thus a need for accessible solar simulators.

Several companies such as Hoffman Electronics Corp. (using a combination of Xenon arc lamps and tungsten bulbs), Optical Coating Laboratory (modifying light sources via optical filters) along with Spectrolab X25 were some of the pioneers of standard solar simulator design and manufacturing.

Then, in the 1970s due to the development of the photovoltaic industry, having a standard measuring method became a necessity. Early in the development of photovoltaic (PV) cells, the performance was tested with light sources that needed to be continually calibrated by using expensive large-scale space simulator chambers. A standard was important in order to determine the performance of samples from a single source, to compare samples of different designs, to study changes in device performance as a function of time, and to provide system design data to engineers and marketing. Because of this, the first solar cell standard procedure was set in 1975 and updated in 1977.

In 1978 the Subcommittee on Photovoltaic Electric Power Systems of ASTM Committee E-44 started developing standard methods for measuring the electrical performance of photovoltaic devices. In 1985 a series of revised ASTM standards were finally available.

Solar simulators are fundamental for photovoltaic measurements being done in both research and industry, and since the illuminated current vs. voltage (I-V) is sensitive to the spectrum, intensity, and temperature, looking for new light sources and developing higher accuracy optical systems based on the leading standards became a priority.

Additionally, standard PV solar simulators had issues with lowering the average power and temperature fluctuations (caused by prolonged exposure to the light). As solar cell manufacturers started to ramp up manufacturing, large area simulators that were capable of testing modules were developed. To minimize power use and excessive heat generation, the illumination times were reduced, decreasing the measurement time. As a result of trying to solve this issue, the pulsed solar simulators were designed and developed. In parallel, additional solar simulator development continued, including the development of multi-source simulators for improved accuracy, high-intensity simulators for multijunction and concentrator systems, and LED systems. With the development of high power LED technology in the 1990s, solar simulators were developed to use this new light source, which offered advantages such as tunable spectra, high accuracy, long operating life, and output control of the light source with a 30 - 50 nm resolution. LEDs consume less energy, pack much smaller than conventional lamp-based housing and LEDs can be controlled within microseconds or operated stably at one light output intensity continuously for a long time.

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Class AAA Standards for Solar Simulators

Whether using an artificial illumination source for photovoltaic characterization, photochemistry experiments, or environmental testing, correct maintenance and use of your light source will improve your experimental results. When searching for a solar simulator you will continuously come across the term "Class AAA" rating – but what does it mean? If you're not quite sure what that is, and how it applies to your research, we have the answer.

The standards are set by governing bodies such as ASTM, IEC, and JIS and are used to determine the quality and accuracy of a solar simulator device's illumination. The specific standards that govern solar simulation are JIS-C8912, IEC 60904-9, and ASTM-E927-10.

Some classes you may see range from Class C to Class AAA, depending on the solar simulator – which may lead one to think that a Class AAA simulator is better than a Class A simulator.

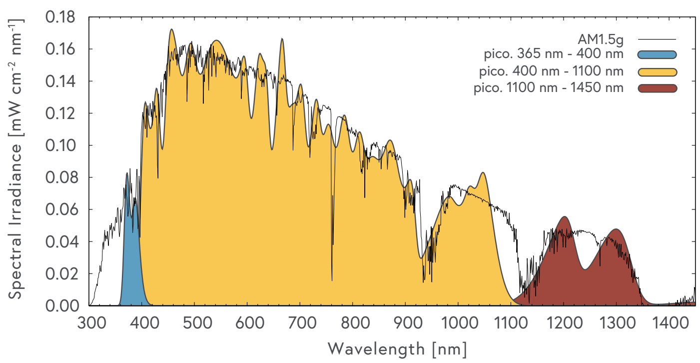
In fact, **"Class AAA" is a shorthand for three different parameters of the standard, meaning Class A Spectral Match, Class A Spatial Uniformity, and Class A Temporal Stability.**

While the ASTM, IEC, and JIS standards vary slightly, the overlapping minimum requirements for each Class are tabulated below:

	Spectral Mismatch To All Intervals	Spatial Non-Uniformity (%)	Temporal Instability Short Term (%)	Temporal Instability Long Term (%)
A	0.75 - 1.25	2	0.5	2
B	0.6 - 1.4	5	2	5
C	0.4 - 2.0	10	10	10

Class A Spectral Match

The spectral match is a measure of accuracy between the output of a solar simulator and a target spectra. It is evaluated using the amount of light produced within specific wavelength bands compared to the standard spectra and reported as "spectral mismatch". Most scientific research uses the AM1.5G spectra, however, research in different environments (like in space – AM0, on the surface of Mars, or sub-surface aquatic environments) each have different spectral profiles. Some solar simulators have tunable spectra – learn more about this in this variable spectra section. **To calculate spectral match of a solar simulator to the AM1.5G spectrum, the 400 nm – 1100 nm region, is divided into six wavelength bands.** Each band is required to contain a particular percentage of the total integrated irradiance between 400 nm and 1100 nm. Spectral Match (SM) is calculated as the ratio of the actual percentage of irradiance falling on the interval measured and the required percentage of irradiance.



Based on the value of spectral match obtained from the equation, the solar simulator may be classified as class A, B or C for spectral match.

The Class A spectral match requires a factor of 0.75 – 1.25 between the artificial light source and the standard spectra in each wavelength region.

If your research focuses on improving solar cell efficiency for energy production, you can improve the link between your results and real-world application by utilizing the spectral match provided by a Class AAA solar simulator.

Class A Spatial Uniformity

Spatial uniformity describes the distribution and consistency of irradiance over an area. The parameter is reported as "spatial non-uniformity" and is calculated from the difference of the maximum and minimum irradiance values in an area.

Spatial uniformity is crucial to ensuring an even distribution of light across an entire experimental area. The Class A should have a spatial non-uniformity of less than 2%. Solar simulators may have a total illumination area that is much larger than the Class A uniformity area, so it's important that the high-uniformity area can cover your samples.

In order to quantify spatial non-uniformity of a solar simulator the irradiance of the simulator beam over the test area is mapped. The test area is divided into a grid of measurement positions and the following equation that is found on the standards is applied to calculate the non-uniformity in percentage terms.

$$Non-uniformity = S_{NE} = 100\,\%\,\frac{E_{maximum} - E_{minimum}}{E_{maximum} + E_{minimum}}$$

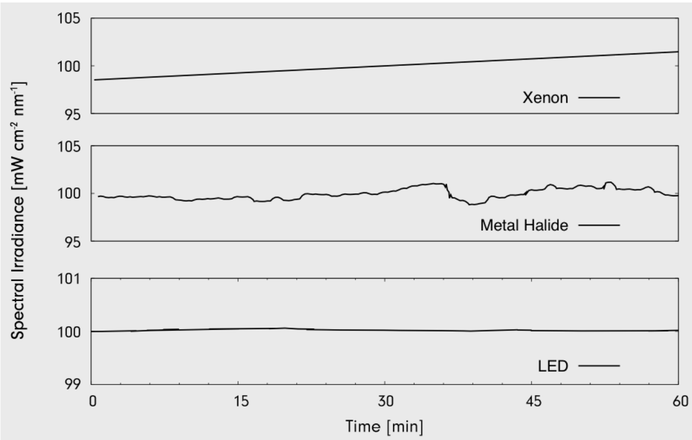
The number of measurement positions depends on the size of the test area and the standard being used.

Class A Temporal Stability

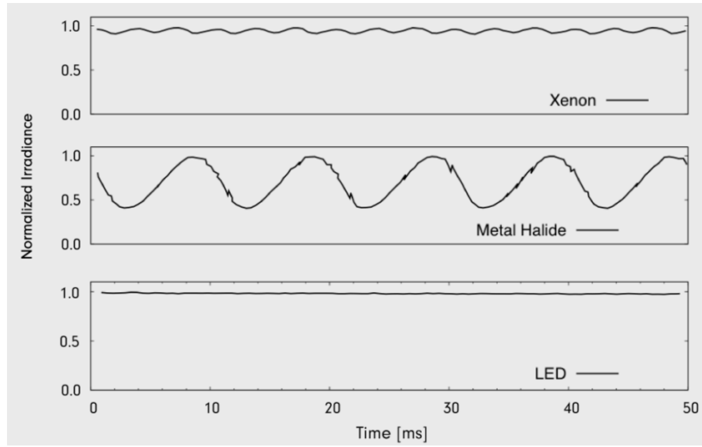
Temporal Stability is the consistency of light output over a period of time.

Traditional solar simulators (e.g., Xenon, metal halide, or tungsten bulb-based lamps) are known for changing spectra and drifting intensity over time, whereas more advanced LED technology has substantially better stability and longer lifetime.

Instability Time Minute Scales



Instability Sub Second Scales



Another thing to take into account is the fact that different light sources have different temporal stability at different time scales (minute vs sub-second time scales). For example:

- Xenon lamp is unstable in a minute time scale but has a relatively better stability in a sub second time scale
- A metal halide lamp unstable in a minute time scale and very unstable in a sub-second time scale
- An LED light source is very stable both minute and sub-second time scale.

Whether performing experiments that require several months of continuous light or when testing multiple devices consecutively, **you would require the lowest temporal instability in order to gather accurate data on the performance of your devices.**

Two parameters are used for measuring temporal stability; short term instability (STI) and long term instability (LTI).

STI relates to the data sampling time of a data set (irradiance, current, voltage) during a current-voltage (I-V) measurement. This value of temporal instability may be different between data sets on the I-V curve. STI is determined by the worst case in this situation. For batch testing of modules or solar cells that during I-V measurement have no irradiance monitoring, the STI is related to the time period (minutes to hours) between irradiance determination.

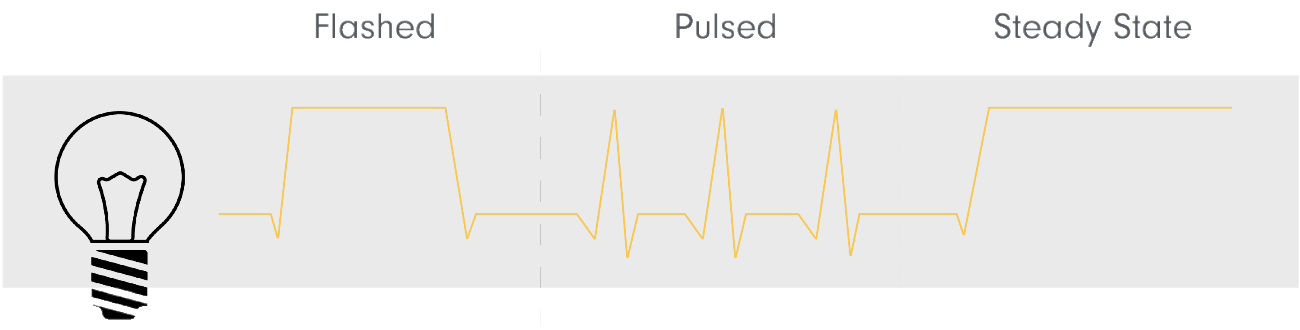
LTI is related to the time period of interest. For I-V measurements this refers to the time for measuring the entire I-V curve. For irradiation exposure tests it is related to the time period (hours to months) of exposure. The following equation is used when determining temporal instability of irradiance (in percent):

When it comes to choosing the right solar simulator for your research, the Class AAA rating is necessary, but depending on your experiments, it may not be sufficient. Some solar simulators offer performances that surpass Class AAA rating in spectral mismatch (smaller range than 0.75-1.25), spectral non-uniformity (less than 2) and temporal instability (less than 0.5 for short temp and less that 2 for long term). It's important to consider how the limitations in the classifications may impact your results, especially if your research is sensitive to changes in time or responds to different spectral ranges

$$Instability = T_{IE} = 100\,\%\,\frac{E_{maximum} - E_{minimum}}{E_{maximum} + E_{minimum}}$$

When it comes to choosing the right solar simulator for your research, the Class AAA rating is necessary, but depending on your experiments, it may not be sufficient. Some solar simulators offer performances that surpass Class AAA rating in spectral mismatch (smaller range than 0.75-1.25), spectral non-uniformity (less than 2) and temporal instability (less than 0.5 for short temp and less that 2 for long term). It's important to consider how the limitations in the classifications may impact your results, especially if your research is sensitive to changes in time or responds to different spectral ranges.

The Different Types of Solar Simulators



Continuous or Steady State Solar Simulators

A steady-state solar simulator has a light source that is continuous over time. Most of the specifications from the standards directly apply to this type of solar simulator. Steady-state tends to be used for smaller areas and is most commonly used in low-intensity testing. They are usually able to generate between 1 sun (1sun=1000 W/m^2) up to several suns. Steady-state solar simulators can have several different types of lamps to be able to extend the spectrum in the far IR.

Pulsed & Flashed Solar Simulators

Pulsed and flashed solar simulators, unlike the steady state, do not have continuous light source over time. This type of solar simulator was invented to prevent heat build up in the tested device generated by lamp light source. Not having continuous illumination can be achieved by either having a light source that is turned on and off (flash solar simulators) or by using a shutter to block the light.

Flashed Solar Simulators

The first method involves a flash of illumination that lasts several milliseconds. Using this method each flash may be able to generate very high intensities of up to several suns. The main issue that sometimes arises from this type of simulator is that it is technically challenging to obtain reproducible intensities and spectra from one flash to the other.

Because the light source is not continuously on, temporal stability does not apply directly to this simulator but we can measure reproducibility by comparing one flash to another.

Pulsed Solar Simulators

Alternatively, instead of having the light source turned on and off, a shutter can be used to quickly block or unblock the light from a continuous source. Typically, these pulses range from 100 milliseconds (ms) and up to 800 ms for special Xe Long Pulse Systems.

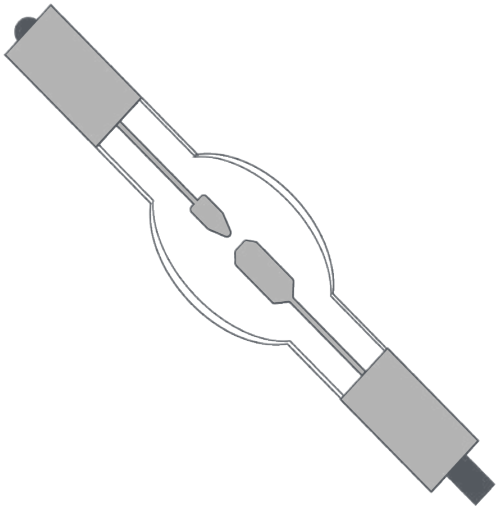
Solar Simulator Light Sources

Solar simulators can also differ in spectra and irradiance distribution. Solar simulators can use many different types of lamps as a light source or a combination of lamps. The type of lamp determines the spectral power distribution and can be modified using optical filters. The optics determine efficiency and irradiance geometry.

Solar simulators can be classified as A, B, or C based on the spatial uniformity across a defined illumination area, the temporal stability through the experiment, and the spectral match to the sun from a clearly defined reference spectrum.

Below is a description of the most common types of light sources used in a solar simulators: xenon arc lamp, metal halide arc lamp, quartz tungsten halogen lamp and LEDs.

Xenon arc lamps



Xenon arc lamps are the most widely used light source for solar simulators. The main reason for this is that it provides a stable spectral that matches reasonably well to sunlight even unfiltered.

Xenon arc lamps have a spectrum almost identical to that of a sun at 5800 K. It does generate strong emission lines in the infrared from 800 nm -1000 nm but these can be eliminated using optical filters.

An additional advantage that the xenon arc lamp has is that when there are variations in power, this does not result in any significant shift in the spectral balance. Also, high-pressure short arc lamps are able to produce high intensity light beams. However, there are several disadvantages with a xenon arc lamp when used in solar simulators.

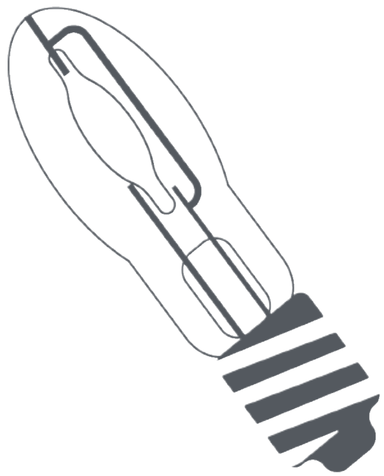
Pros:

- Stable spectra
- Good match to sunlight spectrum
- Power variation has negligible effect in spectral balance
- Can produce high intensity beams

Cons:

- Require complex and expensive power supplies
- High xenon gas pressure in the lamp during operation, is a safety concern
- Power supply instabilities significantly affect amplitude stability in the output
- Aging of the lamp alters the spectral irradiance enhancing the infrared contribution and reducing the ultraviolet
- Filters create a permanent mismatch that cannot be corrected and can burn from prolonged exposure to the Xenon bulb which results in a systematic drift in output that can be difficult to detect
- Bulbs have a short life and are relatively expensive

Metal Halide Arc Lamps



The metal halide arc lamp is an arc source utilizing a mercury vapor arc with metal halide additives and it produces illumination that matches the spectra typically for temperatures in the range of 5000 K to 6000 K.

It was introduced as the light source for solar simulators when the compact source iodide was developed.

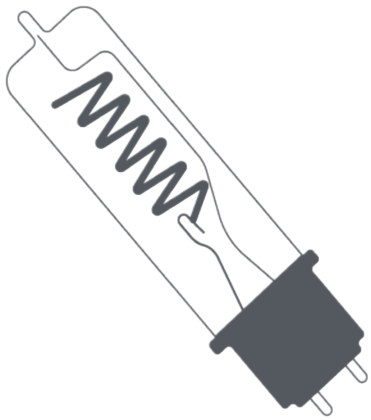
Pros:

- High temporal stability
- Good spectral quality that closely matches the sun spectrum
- Lower pressure than xenon arc lamps

Cons:

- Emits large amounts of IR energy and insufficient amounts of UV irradiation
- Generates a low collimation beams (meaning it disperses with distance) which limits its application in experiments that need high collimation requirements (ex. High concentrated solar simulators, standard solar simulators for PV testing).
- It experiences light flux reduction overtime

Quartz Tungsten Halogen Lamps



Commonly referred to as QTH, Quartz Tungsten Halogen is an incandescent lamp that consists of a tungsten filament in a sealed transparent container that has a mixture of an inert gas and a halogen.

They are more commonly used in multi-source solar simulators because the tungsten filament can only reach temperatures of less than 3400 K which is lower than the 5800 K of the surface of the sun. As a result, they radiate weaker in the shorter wavelengths (blue and UV portion) but stronger in the infrared portion.

Pros:

- Ideal black body match in the infrared
- Minimal UV emission
- Relatively inexpensive

Cons:

- Lower color temperature than the sun
- Poor spectral match in the visible range
- Usually need to be combined with another light source

Light Emitting Diodes (LEDs)

LEDs are solid-state devices that don't require the maintenance or have the hazards related to a pressurized lamp.

When used in solar simulators, they are able to provide a more dynamic functionality solar simulator that meets the experimental needs for solar energy.

In the past, the main issue was the light intensity insufficiency when fully LED solar generators were designed but the issue was later solved when researchers were able to develop high power LED technology. In 2012 researchers from the University of Illinois at Urbana-Champaign (UIUC) presented a fully LED solar simulator design, which covers the AM1.5G solar spectrum and achieves Class C uniformity over an area of 100 mm × 50 mm.

Currently, LED based solar simulators are able to achieve any AM spectra to precision well in excess of that required by the standards.

LED as a light source has been shown to have several advantages when compared to traditional light sources such as lower cost, they are more compact, and typically consumes less power.

Pros:

- Output control of the light source with a 30 nm – 50 nm resolution
- Lower energy consumption
- Longer lifetime of 50 khours – 100 khours (compared to ~1 khour for arc lamps life expectancies) which reduces maintenance cost to a minimum
- LEDs can be controlled very fast within microseconds or operated stable at one light output intensity continuously for long time

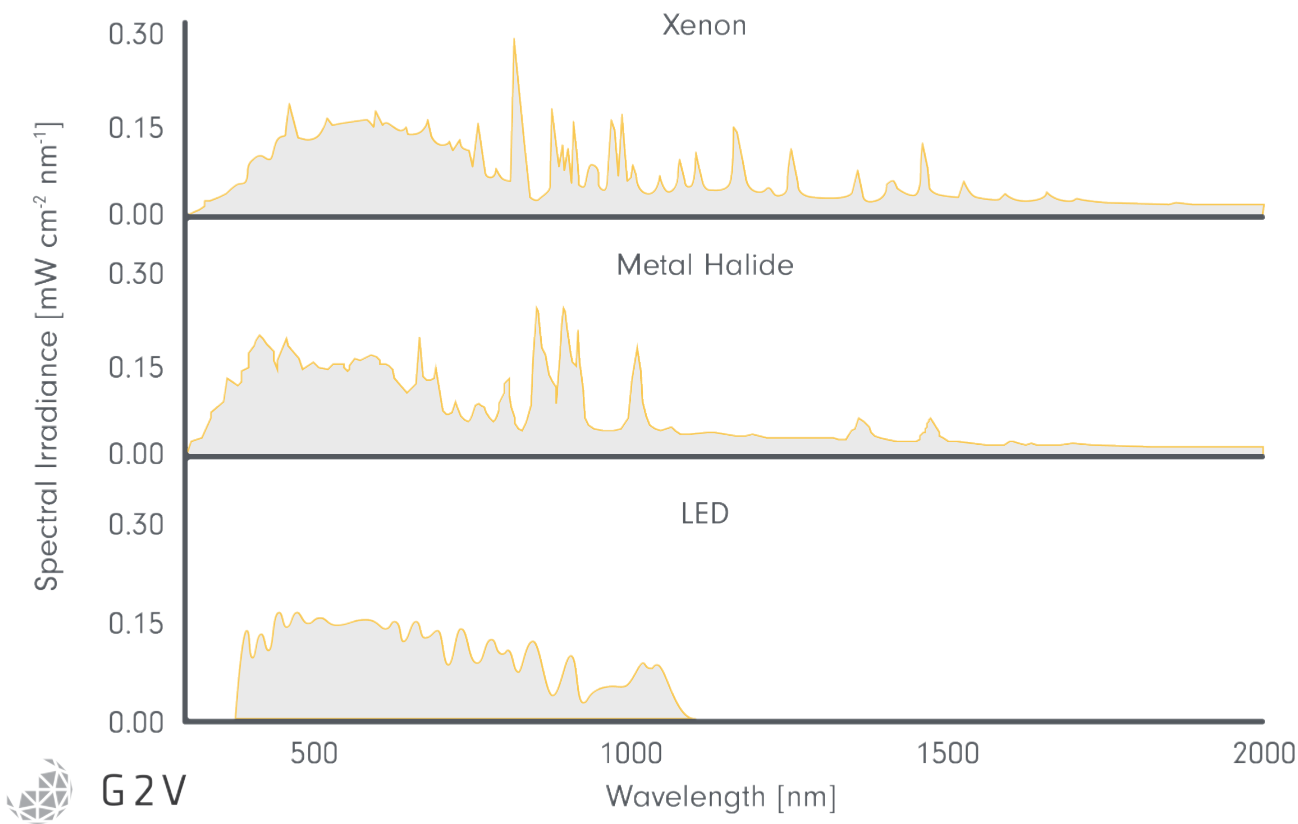
Cons:

- Only available in discrete wavelength
- It is expensive to have light below 360 nm and above 1100 nm.
- Intensities are too low for concentrating solar simulator

Spectrum Comparison for Different Light Sources.

For the spectra generated by the xenon and the metal halide lamp, we get a very wide bandwidth ranging from 200 nm to well past 2500 nm. Additionally, the xenon and the metal halide lamp spectra show large spikes which are inconsistent with the target spectrum (these spikes usually have no significant impact on solar cell characterization).

On the other hand, for the LED system we see a narrow emission bands, tuned to match the 400 nm to 1100 nm range specified in the ASTM standard and no spikes are observed.



LEDs when used in solar simulators, they are able to provide a more dynamic functionality solar simulator that meets the experimental needs for solar energy.

What is Variable Spectra?

Variable spectrum, multi-channel, programmable spectra, dynamic spectra – All terms found while searching for a solar simulator, but what exactly do they mean?

Most solar simulators on the market today ship with what is called a "fixed" spectrum, typically with a AM1.5G match. This means that the intensity of the light can be dimmed, however the spectral profile cannot be changed.

With a variable spectrum module, both the spectrum and intensity the light emits can be adjusted and changed, making a much more versatile instrument.

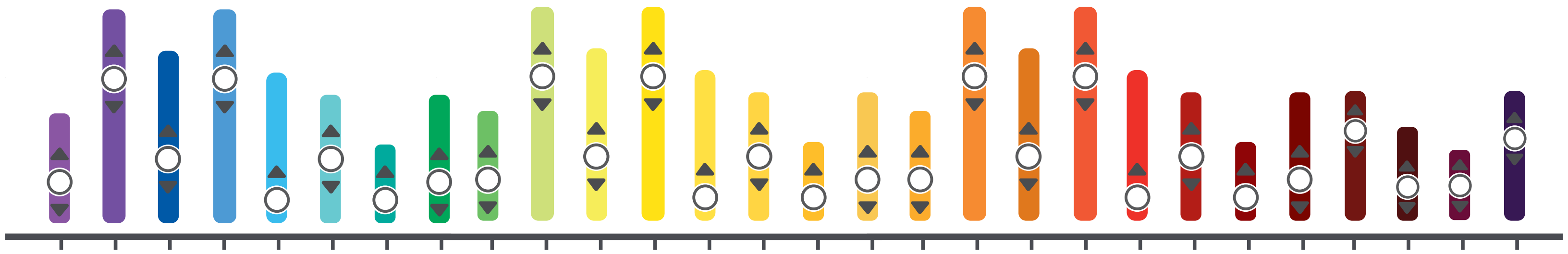
For many applications the AM1.5G spectra doesn't make sense. In these cases, it is essential to have the ability to characterize at a different spectrum.

If the research being conducted is not done for mid-latitudes applications, a solar spectrum representative of other air masses may be needed.

For example, in the development of photovoltaic materials for use in orbital satellites, you may need a spectrum that represents that of the sun in outer space. Therefore, an AM0 spectrum should be used in order to perform an accurate test.

Or when developing photocatalysis systems, they should be just as functional in the northern hemisphere during the winter months, as at the equator in the summer months. So you may need to run tests using AM1 for the equator, AM 1.5G for the mid-latitude and AM2 or AM3 for high latitudes such as those in northern Europe.

With programmable spectra, this is possible. Traditionally, a lab would require individual instruments or different filters in order to replicate AM1.5G, AM0, AM1, AM2 etc. Now with variable spectrum technology, a single piece of research equipment can reliably reproduce virtually any naturally occurring spectra (and a large range outside of natural conditions as well). This decreases overall expenses, all while improving research.



Now with variable spectrum technology, a single piece of research equipment can reliably reproduce virtually any naturally occurring spectra.

What Do You Use a Solar Simulator For?

A solar simulator, simply put, is a source of photons. Therefore if you need photons to conduct your research then you will need a stable light source in order to have reliable and reproducible data.

Photons are the elementary particle of light and exhibit properties of both waves and of particles.

Photons have different energies depending on wavelength; the shorter the wavelength the higher the energy. When they interact with matter, depending on the energy of the photon, a chemical reaction may take place if the photon is absorbed by a molecule or atom – this is known as photochemistry.

In nature, photochemistry is responsible for some of the reactions that are fundamental for life such as; photosynthesis, formation of vitamin D and our ability to see.

Because photochemical reactions happen through a different pathway than those that are driven by temperature (they are usually able to proceed through high energy intermediates which overcome high activation energies in a short period of time), they are typically faster.

On the flip side, because light is so efficient at driving some chemical reactions, it can also be destructive – causing photodegradation of materials like plastics, organic molecules, DNA, etc.

So, you can use a solar simulator to conduct many experiments that requires a stable light source. A solar simulator with a stable light source allows you to gather reliable and reproducible data that is needed for experiments conducted in photoscience.

What Specifically can you Use Solar Simulation for?

Solar simulators are commonly used for testing solar cells, sunscreens, plastics, sunlight sensitive devices and other materials in a controlled laboratory setting. A solar simulator is useful in experiments that require a stable and reliable light source.

You can use a solar simulator if you need to study any type of phenomenon that is driven by light (photons), for example in:

Photobiology

To be able to study the effects of light in living organisms, damage to DNA, skin cancer, photosynthesis, bioluminescence, light therapy, etc.

Photooxidation

To study the effect of light on the degradation of crude oil, water treatment, Polymer degradation, free radical formation, etc.

Photodegradation

To study the effects of light in photodegradation of food, photobleaching, photodegradation in agricultural products, photodegradation of pharmaceuticals

Photovoltaics

To study the conversion of light into energy by testing solar panel performance in different regions, new potential materials, etc.

Photocatalysis

The acceleration of a chemical reaction by using a material which absorbs light as the catalyst..

Sunscreens

To test the performance of sunscreens overtime, determine if they are broad spectrum or determine the SPF (Sun Protection Factor).

*** Or to use solar simulators in the testing of any of the thousands of other light driven reactions. ***

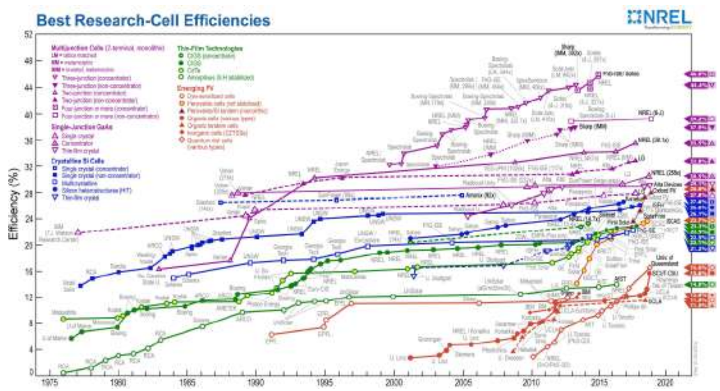
Research Illumination for Photovoltaics: Solar Cell Testing

Solar cells (also known as a photovoltaic system) convert the energy from light (usually solar energy) to electric energy by a process known as the photovoltaic effect. They can be made from a single crystal (e.g. perovskite solar cells), crystalline (e.g. silicon) or amorphous material (e.g. amorphous silicon). Solar cells work by absorbing sunlight which generates either electron-hole pairs or excitons. Then, charge carriers of opposite types are separated and extracted into an external circuit generating electricity and thus renewable energy.

When working with solar cells, the best measure for its performance is to calculate its efficiency.

Solar panels are a collection of solar cells. Most commercially available solar panels have at least a 10% efficiency but significantly higher efficiencies are currently attainable as published by the NREL best research-cell efficiencies.

In order to accurately calculate the efficiency of solar cells, you need to use a Class AAA solar simulator.



NREL - Best Research Cell Efficiencies

Additionally you need to perform standardized testing that allows the comparison of devices manufactured at different companies and laboratories with different technologies to be compared.

The standards for cell testing are:
1. Air mass 1.5 spectrum (AM1.5G) for terrestrial cells and Air Mass 0 (AM0) for space cells.
2. Intensity of 100 mW/cm2 (1 kW/m2, also known as one-sun of illumination)
3. Cell temperature of 25 °C (~300K)
4. Four point probe to remove the effect of probe/cell contact resistance

Measuring solar cells requires a stable light source that closely matches the conditions of sunlight. You need to match both the intensity and the spectrum to the AM1.5G standard. Your first idea might be to simply use the sun itself. But as previously stated in the section there are variations in atmospheric conditions and the solar spectrum changes throughout the day and year which requires correction to compare results accurately.

The solution is to use a sun simulator that provides
1. A spatial non-uniformity of less than 1%.
2. A variation in total irradiance with time of less than 1%,
3. Filtered for a given reference spectrum to have a spectral mismatch error of less than 1%.

These requirements are essential in obtaining an accuracy of better than 2%.

Research Illumination for Photoelectrochemistry

Photoelectrochemistry is a field of science that studies the interaction of light with electrochemical systems. One of the main fields of photoelectrochemistry is semiconductors which are commonly used in photovoltaic devices. One of the uses of semiconductors is create artificial photosynthesis (photogeneration cells).

Segments of Photoelectrochemistry:

Sunscreens and Cosmetics

Solar simulators are very useful in many fields of photochemistry. For example, they are essential when studying sunscreens. Experiments need to be conducted to determine the Sun Protection Factor (SPF) of a given sunscreen. One technique is based on calculations according to Cosmetics Europe (COLIPA) protocols, which measures the transmittance of a given sunscreen sample across the UV spectrum weighted against the erythemal effect and solar intensity at each wavelength. This is done by first taking the pre-irradiated UV-vis absorbance of the sample and then using the equation below to calculate the SPF value.

$$SPF_{\text{in vitro}} = CF * \sum_{290}^{320} \left(\frac{EE(\lambda) * I(\lambda)}{T(\lambda)} \right)$$
$$= CF * \sum_{290}^{320} EE(\lambda) * I(\lambda) * Abs(\lambda)$$

where EE is the erythemal effect spectrum, I is the solar intensity spectrum, T is the sunscreen transmittance, Abs is the sunscreen absorbance, and CF = 10 so that a standard 8% homosalate sunscreen would calculate to an SPF of 4. The normalized values of EE*I, which are constants measured in 5 nm increments, define a sunscreen which transmits all light as having an SPF of 1.0, while one that absorbs all light as having an SPF of infinity.

In the table below, we see the values for EE*I that need to be used in the equation. These values are standards that are used by the cosmetics industry for the given wavelength. Erythemal Effect Table

Erythernal Effect Table

Wavelength (nm)	EE*I
290	0.0150
295	0.0817
300	0.2874
305	0.3278
310	0.1864
315	0.0839
320	0.0180
Total	1.0000

The sample is irradiated at different time intervals using a solar simulator, taking the UV-vis absorbance and re-calculating SPF after each irradiation with the solar simulator. Solar simulators provide a way to run experiments on how sunscreens and many other cosmetics react and/or degrade when exposed to sunlight.

Photocatalysis

Solar simulators are increasingly useful in testing visible light photocatalysis.

Photocatalysis describes chemical transformations that require light as an energy input to proceed.

To test visible light activated photocatalysis, you need to have a stable light source of visible light in order to get reliable and reproducible data and to be able to accurately assess and compare the performance of the photocatalytic reaction, study the reaction pathway, accurately calculate yield among other variables.

A solar simulator is a perfect instrument to be able to provide light source for photocatalytical studies.

Research Illumination for Environmental Testing

Solar simulators are widely used in environmental testing. For example, in the study of environmental aquatic systems, a wide variety of photochemical reactions with active chromophores occur in natural waters when illuminated by wavelengths in the solar spectrum.

In order to study aquatic systems (eg. photochemical degradation of organic chemicals in aquatic media) or to test the photochemical degradation of different pollutants, a stable light source that mimics natural sunlight is needed.

Photocatalysts

Another use of solar simulators in environmental science is for testing photocatalysts.

A photocatalyst increases the rate of a chemical reaction without itself undergoing any permanent chemical change by using a light.

Most of the substances used as photocatalysts are semiconductors. Semiconductor photocatalysts tend to be heterogeneous catalysts (a type of catalysis in which the catalyst occupies a different phase from the reactants and products making them very useful in the treatment of organic contaminants in water and air.

The most common material used for this purpose is TiO_2 although other types can also be used.

To test the performance of photocatalysts that are meant for environmental purposes, you need to use a light source that mimics sunlight which a solar simulator provides.

Furthermore, it is advantageous to have a solar simulator with variable spectrum capability so that you can test photocatalyst performance in environments that represent different places in the world.

Research Illumination for Photobiology

Light is a fundamental component of life on our planet. Photobiology is a large discipline that includes studies of both the beneficial and harmful effects of light. It covers topics from the atomic level to that of ecological communities.

Biologists need to be able to simulate natural light to study how sunlight interacts with living organisms.

For example, studying photosynthesis is extremely important because of our quality of life (better food sources, CO_2 conversion to Oxygen) and our very existence, depends on it.

Photosynthesis research can show us how to produce new crop strains that will make much better use of the sunlight they absorb, develop new herbicides by disrupting photosynthesis, etc.

Many photosynthesis studies require a controlled laboratory environment, including a solar simulator. Solar simulators are also used in other areas of photobiology such as to study vision, biological effects of ultraviolet radiation, circadian rhythms, and bioluminescence.

Additionally, another important use of solar simulators is to conduct photostability studies.

Stability testing is a key aspect while formulating any pharmaceutical product. The photostability studies are conducted with the main objective of ensuring that light exposure does not lead to dangerous changes in the dosage of the active ingredient.

In 1996, the Food and Drug Administration (FDA) issued the ICH Harmonized Tripartite Guideline on Stability Testing of New Drug Substances and Products for industry and notes that light testing should be an integral part of stress testing.

The stress testing requires a light source capable of producing an output similar to the D65/ID65 emission standard (i.e. artificial daylight that is designed to produce an output similar to the D65/ID65 emission standard).

Research Illumination for Medical Treatments

Solar simulators are commonly used in many types of phototherapy. Phototherapy is used to treat medical conditions using light. One of the major uses of phototherapy is in the treatment of skin disorders such as eczema, psoriasis, vitiligo, itchy skin and T-cell lymphoma.

Phototherapy typically involves using light to reduce cell growth and skin inflammation. It can also be used to study sleep disorders, and in cancer treatments such as Photodynamic Therapy (PDT).

PDT is a treatment that uses special drugs, called photosensitizing agents, along with light to kill cancer cells. The drugs only work after they have been activated or “turned on” by light.

Solar simulators are useful in studying and characterizing potential drugs that can be used as a photosensitizer for photodynamic therapy.

Additionally, solar simulators can be used with the intent of using UV exposure to induce cancers in mice and other biological test subjects, to provide an experimental foundation for testing other things such as skin lotions, chemotherapeutic drugs, and more.

Research Illumination for Space

Solar simulators were initially created to help simulate the space environment for earth satellites and another spacecraft testing, and they are still being used for this purpose.

The environment in space is quite different. Because there is no atmosphere, the solar spectrum is different (AM0). A satellite orbiting the earth undergoes rapid day-night cycles and is in direct sunlight for 50% or more of its operational lifetime. The intensity for AM0 is 1366 W/m^2, much brighter than we see on Earth. Because of the extreme cost of launching something to orbit, there is a need for ground-based sun simulators that can mimic the optical environment of orbit to adequately perform testing before launching something into space.

Multijunction solar cells use a combination of semiconductor materials to capture and convert a large range of photon energies. While multijunction solar cells are extremely expensive, they have much higher performance in terms of W/kg. When balanced against the launch costs, the additional expense can be justified, provided that they can be optimized in advance. Consequently, solar simulators that are optimized for AM0 are required to test space solar cell performance.

In addition, solar simulators that provide the AM0 spectrum are used to improve the understanding of chemical evolution in organic-rich astrophysical environments (comets, meteorites, Titan, interstellar medium), and where organic matter is being looked for (Martian surface and subsurface).

Solar ultraviolet photons are a major source of energy to initiate chemical reactions in the solar system, and many experimental programs on Earth are devoted to studies of the evolution of organic molecules through such chemical reactions.

How to Choose the Best Solar Simulator for Your Needs?

How you choose a solar simulator will depend on what you are going to use it for. First, you need to decide if you want a steady state (continuously on) solar simulator or a pulsed solar simulator.

Pulses last between 2 milliseconds (ms) to 10 milliseconds. So you need to make sure your experiment can be done within that frame time.
Since you are taking pulsed measurements you will have fewer data points in your IV curve.
Pulsed simulars will not increase the temperature of your experiment. So if temperature is a concern then a pulsed solar simulator will be beneficial.
Another factor that you need to take into account is the spectral match. Depending on which experiment and how exact you want your data to be, you may also need a solar simulator that very closely matches the sun spectrum.

Class A (±25%) has the closest match to the sun's spectrum, followed by Class B (±40%) and then followed by Class C (+100/-60%).

Typically the closer it matches the spectra the more expensive the solar simulator would be. If no tolerance for spectrum match is needed then a lamp may be more appropriate.

Intensity of the light beam is another factor that needs to be taken into account. The international standards define the intensity of the light for a solar simulator with an AM1.5G filter at 1,000W/m^2 – which is called 1 sun. Unless your experimental needs require testing under more than one sun, the excess wattage will result in more than one sun in small targets. The best way to select the power of a solar simulator is to determine the largest area you will be testing and then determine how many suns you want those areas to have (typically since the point is to mimic the sun, the beam should mimic 1 sun).

Non-uniformity refers to the uniformity of the light beam on the illuminated area.

The international standards specify the non-uniformity for each class; Class A (≤2% for area of illumination equal to or less than 30cm x 30cm, or a diameter of 30cm and ≤3% for area of illumination is greater than 30cm x

30cm, or a diameter of 30cm and ≤3% for area of illumination is greater than 30cm x 30cm, or a diameter of 30cm), Class B (≤5%) and Class C (≤10%).

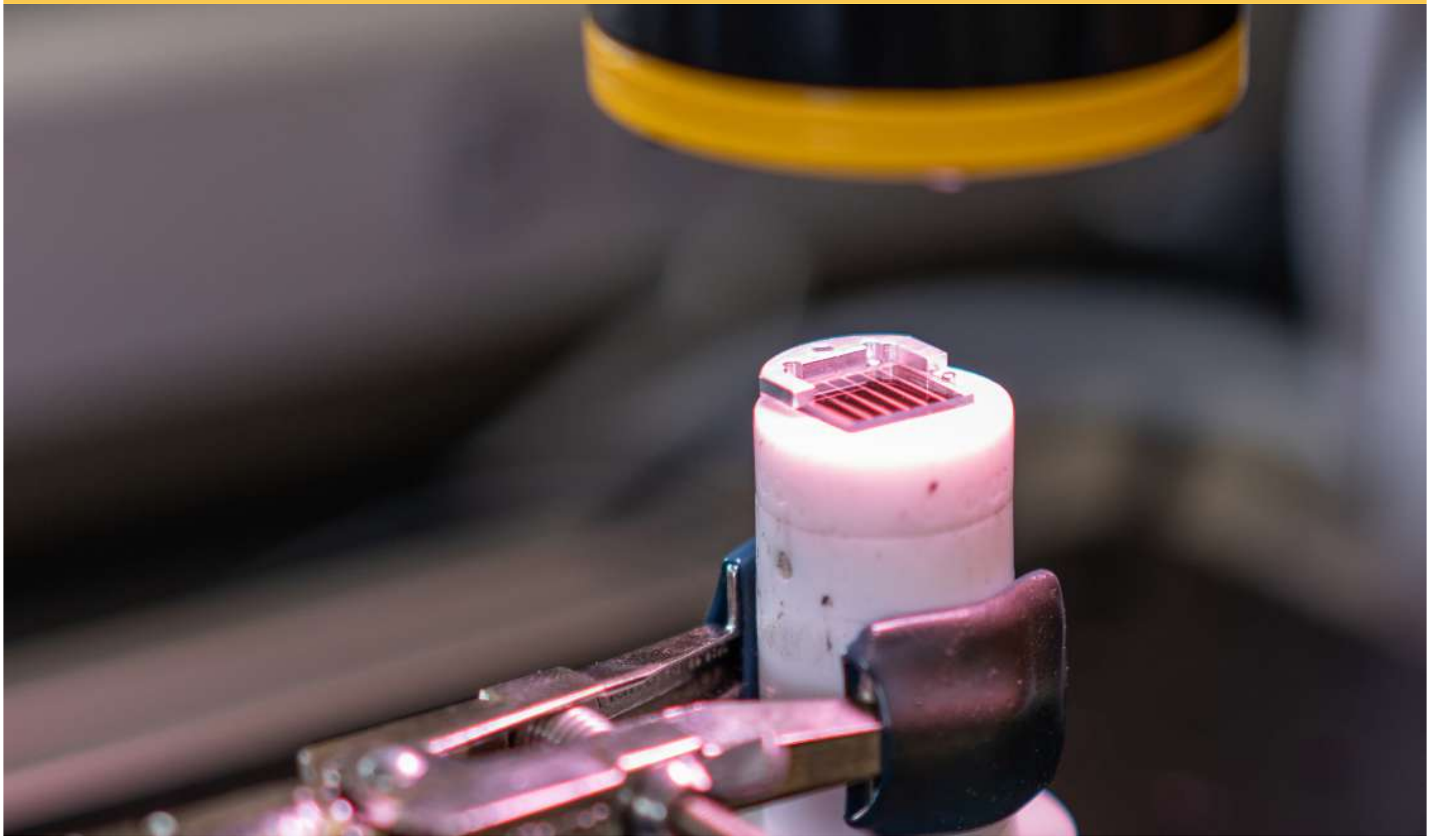
If your experiment requires a very uniform beam over the illuminated area you need to choose a solar simulator that meets Class A requirement. However, if this is not an important factor in your experimental setup (for example a stirring solution) then a Class B or C or even a lamp may be sufficient.

Temporal stability measures how stable the irradiation beam is over time. International standards define a Class A Temporal Stability (≤2%), Class B (≤5%) and Class C (≤10%).

Solar radiation is very stable, so if you need to closely mimic the sun then you need to choose a Class A simulator. However, if changes on the irradiation beam will not affect your experiment (for example a Qualitative measurement) a lower Class may be used.

A shutter is a very convenient component of a solar simulator. If a shutter is not present in a solar simulator, the alternative is to turn the lamp on and off. However, depending on your light source turning the system on and off may reduce its lifetime. So an aspect to consider is whether the shutter is automated or manual. This is a very important consideration depending on the type of research that will be conducted. For example, when testing new photocatalyst performance where throughput is not an issue, manual control may be sufficient. On the other hand, if you will be testing many samples or want to have more flexibility, an automated shutter may be the right choice.

Finally, another component that you may need to have in a solar simulator is the light intensity feedback. This will give you the ability to monitor the light intensity output. This is especially important when there are light power supply fluctuations. Additionally, this gives you the ability to normalize your IV measurements to account for power fluctuations.



Summary

The main objective of solar simulation is to produce illumination approximating natural sunlight in order to provide a controllable indoor test facility under laboratory conditions.

- The instrument used to simulate sunlight in a laboratory setting is called a solar simulator.
- A solar simulator is a device whose light source offers similar intensity and spectral composition to natural sunlight. Solar simulators (also called "sunlight simulators") are scientific equipment used to replicate sunlight in controlled laboratory environments. They are essential for research and testing of products and processes that either use or are affected by sunlight, like solar cells, solar fuels, sunscreens, plastics, coatings, and other photo-sensitive materials.
- For solar simulators, it is convenient to describe the irradiance of the simulator in terms of "suns." One "sun" is equivalent to the irradiance of one solar constant, which is equal to 1000 W/m^2 (1 sun=1000 W/m^2).
- Light is composed of waves of different lengths (hence the term wavelength) and some of these waves represent the colors we see.
- Standard illumination intensity was chosen to be 1000 Watts per square meter (W/m^2) and the air mass of AM1.5 Global was chosen as the spectral composition to represent sunlight on Earth.
- When it comes to solar simulation, Air Mass is a fundamental concept that we need to consider if we want to mimic, as closely as possible, the solar radiation as experienced on the surface of the earth.
- Air mass is defined as the path length of the direct sunbeam through the atmosphere expressed as a ratio relative to the path length when the sun is at the zenith above a sea-level location.
- The spectrum generated by sunlight at Air Mass 1 is commonly known as "Air Mass 1 Global" (AM1G) radiation spectrum, meaning "one atmosphere". The spectrum generated by sunlight at AM1 (at 0° from the zenith) to AM1.1 (at 25° from the zenith) is a useful range for estimating the performance of solar cells in equatorial and tropical regions. Because it passes through no air mass, the extraterrestrial spectrum is called the "Air Mass 0" (AM0) spectrum.
- Luminous flux is used in photometry as the measure of the perceived power of light. It is important to understand that photometry measures light in terms of its perceived brightness to the human eye rather than the fundamental power density of a spectrum of light.
- Class AAA, according to the IEC 60904-9, ASTM E927 & JIS C8912 standards, is a shorthand for three different parameters of the standard, meaning Class A Spectral Match, Class A Spatial Uniformity, and Class A Temporal Stability. This allows you to perform tests with the highest precision.
- The spectral match is a measure of the amount of light produced within specific wavelength bands compared to the standard spectra and reported as "spectral mismatch".
- Spatial uniformity describes the distribution and consistency of irradiance over an area.
- Temporal stability is the consistency of light output over a period of time.

- Solar simulators can be broadly classified into two categories: flashed or pulsed and continuous or steady state
- There are four major types of light sources for solar simulators; short-arc and long-arc Xenon (Xe), metal halide (MH) arc lamps, quartz tungsten halogen (QTH) lamp and more recently light emitting diodes (LEDs)
- LED solar simulators can offer the best temporal stability, 30 nm – 50 nm resolution, lower energy consumption, longer lifetime of 50 khours to 100 khours and can be controlled very quickly within microseconds or operated stably at one light output intensity continuously for a long time.
- Solar simulators can be used to mimic the sun in any laboratory setting where you want to produce repeatable results. Solar simulators can be used in many areas of research such as:
    - PV cell/module and material testing
    - UV testing of materials and products
    - Plastics, paints, and coatings
    - Textile/fabric
    - Cosmetics/Sunscreens
    - Degradation Studies of Material
    - Biomass study
    - Aerospace
    - Environmental Science
    - Catalysis
    - Photoelectrochemical water splitting
    - and many others

With an increasing desire to use renewable energy and a growing concern on how to protect our skin and belongings from sun; research around sunlight has become increasingly important. So if you are studying photovoltaic solar panels to harness the sun’s energy or you are developing better sunscreens to protect us from the sun or you are doing any other type of research that involves sunlight – acquiring advanced solar simulation technology for precision measurement is a must.

Frequently Asked Questions

Can we use a lamp as a light source instead of a standard solar simulator?

Not if you want reliable reproducible measurements. A lamp (of any type), will give irradiation that, without filters, will not reproduce the sun spectrum. Additionally, if you do not have a power supply that is stable you will have variations of irradiance intensity over time. If you need to conduct experiments that require a light source that closely mimics the sun, you need to use a solar simulator.

Is there a problem in measuring solar cell efficiency using a white light source instead of a solar simulator?

Yes. A light source that has not been designed and calibrated to mimic sunlight spectrum will not give you an accurate measurement of solar cell performance. In order to be able to compare your solar cell measurements to other solar cells you need to have a light source that provides you with the standard spectrum.

What is spectral mismatch in solar simulation?

It is a measure of the amount of light produced within specific wavelength bands compared to the standard spectra.

Will there be UV in the light produced by an AM1.5G solar simulator?

It depends on the lighting technology. Under the Class AAA designation, ultraviolet light between 300 nm and 400 nm is not specified. For Xenon bulbs there will be a small amount of UV, where as for LED solar simulators the UV can be omitted entirely.

What is AM1.5G Spectrum?

Is the air mass spectrum standard at mid-latitudes.

FAQ

Can solar simulators be used for microbial cultures?

Yes, you can use a solar simulator to conduct any type of research that needs a light source that mimics the sun. Additionally, with Variable spectra technology, you can match the spectrum to your desired environment.

How do you best choose a solar simulator?

Whether you need a pulsed or a steady state simulator, solar simulators should be chosen according to your needs (see the How to Choose section)

Is there a need for any special environmental requirements like temperature or humidity control or clean room for the operation of a solar simulator?

No, there is no need to have any special environment unless your specific research requires it (for example a glove box).

Notes

ENGINEER THE SUN

LED Solar Simulators from G2V

pico.™

High Precision Class AAA Small Area Solar Simulator.
To find out more please visit: g2voptics.com/pico

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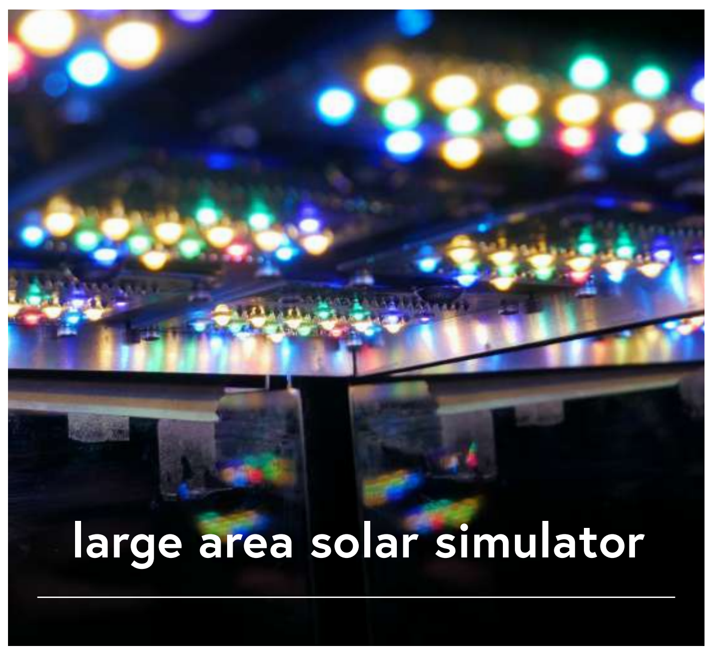

High Quality Class A+AA Large Area Solar Simulator.
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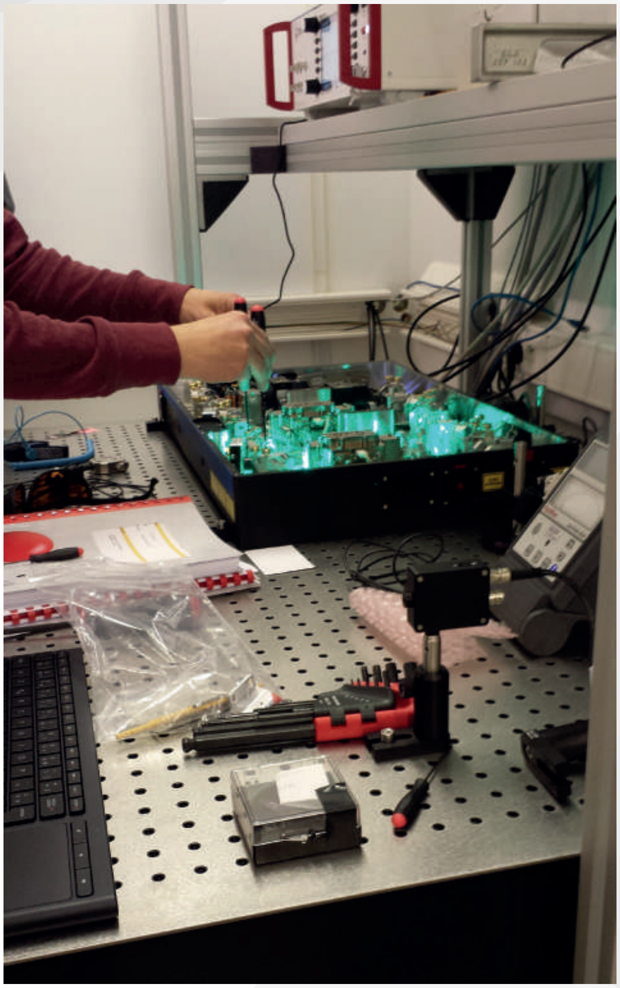
SUPPORT & SAV

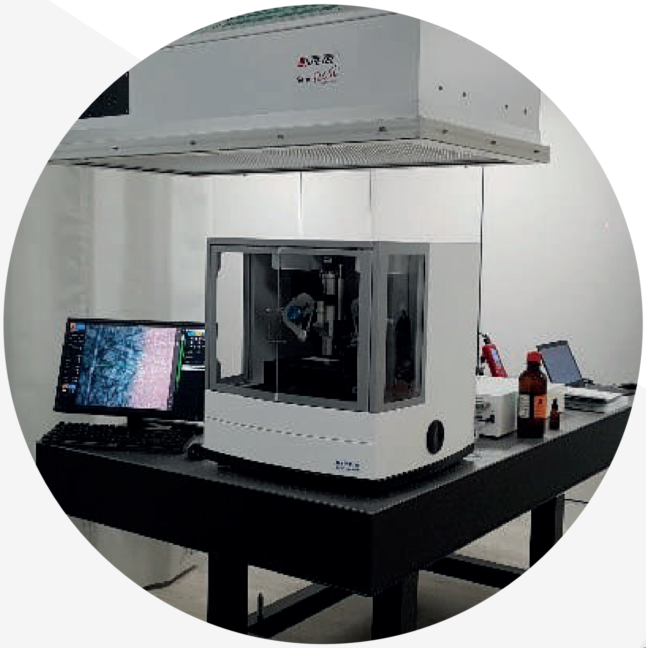
Notre département SAV assure le suivi de tous les produits commercialisés par Opton Laser. Notre équipe répondra à toutes vos questions d'ordre technique et vous conseillera sur votre application.

Nous assurons l'installation, la réparation et la maintenance des matériels, soit dans notre laboratoire, soit sur site, lorsque les délais l'exigent.

Nous proposons également :

- des prêts pour la validation du matériel ou pour des études de faisabilité,
- des essais dans notre laboratoire avec nos équipements de démonstration,
- des formations sur site pour vos équipes techniques,
- et des calibrations.





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