

Protection from the Elements Part IV: Radiation Exposure

This Technical Briefing Note is Part IV in a series of Notes examining the environmental durability of pico-powered lighting products. Part IV focuses on solar radiation and its effect on plastics used in product housings and wiring assemblies.

Information contained in this article builds on previous Technical Notes available on the Lighting Global website.

Introduction

Pico-powered lighting products are, by design, exposed to radiation from the sun. Depending on the product configuration, this could mean anything from the solar module and external wiring to the entire product housing and all its internal components. Normal use of these products in sunlight will result in high levels of ultraviolet (UV) light exposure and daily thermal cycling, often in fairly hot and humid conditions.

This Technical Note will focus primarily on the exposure of polymers (plastics) to UV and heat from sunlight. Due to the wide range of available plastic materials, additives, and polymer blends (thousands of different polymer combinations are available), it is beyond the scope of this Note to define how any one of these plastics will tolerate radiation exposure from the Sun. The Note will instead focus on basic terminology and behaviors observed in plastics engineering design and describe how pico-powered lighting products can be expected to perform in the field.

Products with separate solar modules (classified as “fixed separate” or “portable separate” by Lighting Global) will have their solar modules, wiring, and sometimes connectors exposed to outdoor solar radiation. The lamp housing for portable products may also be subject to occasional exposure. Products that incorporate the solar module directly into the light housing (classified as “portable integrated”) will have the entire product exposed, including circuit boards, electronic components, and batteries.

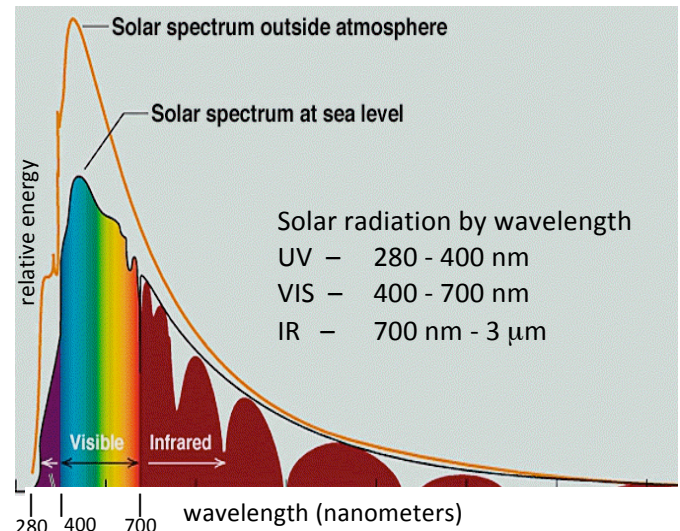


Figure 1. Solar radiation SPD

Spectral power distribution (SPD) of sunlight

Solar radiation that travels through our atmosphere and reaches the Earth’s surface is often classified into three regions by wavelength. Ultraviolet (UV) radiation is primarily responsible for photochemical damage in materials while visible (VIS) and infrared (IR) radiation causes the daily temperature cycling of products left in the sun. The energy distribution of sunlight (at sea level) is shown in Figure 1 and Figure 2.

Solar *irradiance* (light that falls ONTO a surface from the Sun and atmosphere) can be expressed as $W*s/m^2$, $kW*hr/m^2$, $Joule/m^2$, or Langley (Ly) ($1 Ly = 1 cal/cm^2 = 4.184 E^4 Joule/m^2$). Some plastics manufacturers will provide maximum cumulative exposure times for their polymers that can be used with average solar insolation data to estimate the radiation durability of parts made from these formulations.

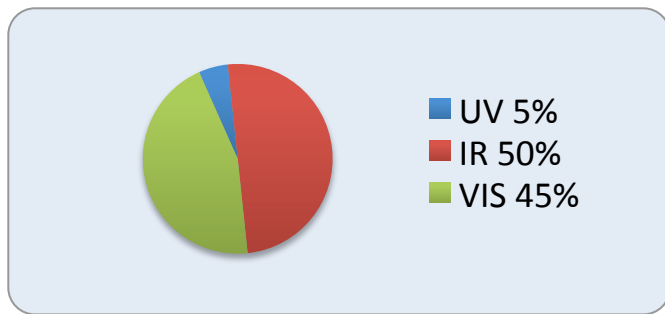


Figure 2. Solar spectrum energy distribution

Ultraviolet (UV) radiation damage

Long-term exposure to UV radiation below 400 nm can cause degradation of some plastic materials. This high-energy radiation can break molecular bonds in the polymer chains and lead to the formation of free radicals. This can result in discoloration (bleaching in dark opaque materials and yellowing in light colored and transparent materials), a weakening of the physical properties (often manifested as the plastic becoming inflexible and brittle), and external chalking.

Solar UVB radiation between 280 – 315 nm has the most energy and typically causes the most UV damage.

Yellowing

Some plastics turn yellow with exposure to UV radiation. Discoloration can be a surface phenomenon or it can penetrate deep into the material depending on the polymer type. This can pose a problem with the appearance of the product as well as an indication that UV damage is occurring.

There are several known and suspected photochemical mechanisms for the yellowing of plastics. The change in color is a symptom of UV damage and is caused by increased absorption of blue light. Higher blue absorption reduces the overall optical transmission of clear plastics and changes the color temperature of the transmitted light (decreasing the correlated color temperature (CCT) of light from an LED, for example).

For surface phenomenon in opaque materials, oxidation occurs that changes the chemical structure and reflective/ transmissive properties of the material. Even though this oxidation does not penetrate deeply into the material, it can still weaken plastics by allowing surface cracking (notch sensitivity).

UV resistance

Some plastics are naturally resistant to UV damage, while others can be made UV resistant through the use of additives. These additives fall into three main categories and provide differing degrees of protection. Most polymer base materials can be protected from UV damage by the use of appropriate additives.

Absorbers – The most common UV absorber is carbon black, a small particulate that can be added in varying concentrations (typically 2-3%) to the polymer feedstock. Absorber molecules work by absorbing incoming UV radiation and converting, or re-emitting, the radiation at longer, lower energy IR wavelengths, essentially converting the UV radiation into heat. PVC wire insulation is commonly treated with carbon black.

Other absorbers include pigment formulations of titanium dioxides (TiO₂), benzophenones, and benzotriazoles. Different pigments are suitable for different plastic types and desired color.

Quenchers – Nickel quenchers are often used in agricultural thin film applications where chemical interaction with pesticides and other chemicals may be a concern for other types of absorbers and stabilizers. Quenchers work much like absorbers, where the quencher molecules absorb the energy of the polymer chromophores and re-emit lower energy IR and fluorescent radiation.

Stabilizers – Hindered Amine Light Stabilizers (HALS) work differently than absorbers and quenchers. HALS interact with the free radical molecular bonds created by UV radiation and stabilize those bonds to essentially

Protection from the Elements Part IV: Radiation Exposure

Issue 15 November 2013

freeze the polymer chain at a chemical stage before macroscopic damage results. HALS can be added in very small concentrations and do not change the color of the material. They are considered very effective for long term UV resistance.

O-ring seals

Of the many O-ring materials, nitrile based rubbers are common and may not be the best choice for pico-powered solar products. Buna-N O-rings tend to degrade from UV exposure and are generally considered a poor choice were resistance to weathering is a material requirement.

Neoprene is considered an inexpensive alternative to Buna-N and does have adequate resistance to weathering. Other material types with good sunlight resistance are also available (silicone, EPDM, polyurethane, etc.) and can be chosen based on the particular requirement of the application where cost, compression set, durometer, resistance to abrasion, and availability play key roles in the design decision.

Solar thermal heating

All wavelengths in the solar spectrum are capable of heating products left in the sun, though IR wavelengths (~50% of the energy) are the largest contributor to the rise in temperature. Depending on the thickness, color, and material type, a product will experience both a surface temperature rise and an internal temperature rise to air pockets and components inside the enclosure (Table 1). These daily thermal cycles can stress the product through mismatched thermal expansions, condensation of high humidity air, and delamination of surface coatings and composite layered structures.

The service temperature of plastics varies by polymer type and also by the specifics of the application. Plastic parts under stress will behave differently from parts that are not stressed, and this can have implications where structural elements are under compression or tension and where thermal expansion between

different materials places bending loads on constrained parts. All polymers have a **glass transition temperature (T_g)** where the material undergoes a slow transition from a rigid microstructure to one where the polymer chains are increasingly able to slide past one another and allow the bulk material to flex and deform. Some plastics are used above their T_g and some are used below, with those used above their T_g tending to more flexibility and toughness. Polystyrene, for example, is usually used below its T_g and so is rigid but also brittle.

The maximum service temperature of plastics varies greatly with the specific polymer blend and the load that the parts experience (Table 2). Higher loads will lead to lower maximum service temperatures. While most plastics will tolerate the temperature gain from solar radiation, very hot solar conditions can potentially place parts of a plastic housing at or near the maximum service temperature for a few hours each day.

The temperature gain experienced by a product, including internal air pockets and subcomponent assemblies, will vary greatly. Product geometry, color, orientation, and exposure conditions all play a large role in the daily thermal cycles. Experiments on pico-powered lighting products performed by Lighting Global confirm general observations concerning the temperature rise of materials exposed to daily sunlight, and while results cannot be assumed to apply to any particular product, these observations can serve as product design guidelines.

Table 1. Results of solar simulation temperature tests

Temperature measurements of product surfaces and internal air pockets		
ambient	surface	internal
25 - 35 °C	55 - 70 °C	47 - 85 °C

Protection from the Elements Part IV: Radiation Exposure

Issue 15 November 2013

Some products may allow a portion of the visible and infrared solar spectrum to pass through the plastic housing and into the interior airspace. This radiation can then be absorbed by internal surfaces and components, where it heats the components and local air pockets. A greenhouse effect may occur in this interior space, where reduced convective cooling allows a heat gain that results in raised temperatures above the surface temperature of the housing (where Lighting Global estimates that surface temperatures of plastic housings can reach or exceed 70 °C, with internal air pockets and components potentially reaching 85 °C or higher in very hot conditions).

Solar thermal cycling

Daily temperature cycling will stress a product's housing as it expands and contracts according to the **thermal expansion coefficients** of the materials involved. This stress will be most acute where materials with very different expansion coefficients are held rigidly together or one component constrains the expansion of another. The coefficient of linear thermal expansion is typically designated by the Greek letter " α " and has units of (10^{-6} m/mK) where m/mK = meter/(meter \cdot °K).

Another phenomenon common to enclosed or sealed assemblies concerns the expansion and contraction of air with daily thermal cycling. Hot air will expand and escape the enclosure, and, upon cooling, colder air (and any moisture it contains) will be drawn in. This can set up an ideal situation for condensation on interior surfaces that can lead to water buildup. "Weep holes" on the underside of the enclosed spaces are sometimes used to allow air and water to escape from interior air pockets.

References

1. University of Tennessee Dept. Physics & Astronomy
<http://csep10.phys.utk.edu/astr162/lect/light/spectrum.html>
2. SpecialChem
<http://www.specialchem4polymers.com/tc/uv-stabilizers/index.aspx?id=mechanism>
3. www.ciesin.org
<http://sedac.ciesin.columbia.edu/ozone/docs/UNEP98/UNEP98p62.html>
4. www.cabot-corp.com/wcm/download/en-us/sb/uv%20weathering.pdf

Special thanks to the Madison Group for their assistance reviewing this Note (www.madisongroup.com).

Table 2. Properties of plastic groups (base polymers) commonly used for electronic housings

	transparent	translucent	opaque	uv resistant?	uv resistant w/ additive	glass transition temp °C	max service temp. °C	Coefficient of thermal expansion α (10^{-6} m/mK)
abs			x	n	y	105	80	70-75
acrylic	x	x	x	y	y	105	90	70-77
polyamide (nylon)		x	x	y	y	45	130	90-95
polycarbonate	x	x	x	n	y	145	125	66-70
polyethylene HDPE		x	x	n	y	-80	120	100-200
polyethylene LDPE		x	x	n	y	-125	80	100-200
polypropylene		x	x	n	y	0	135	100-180
polystyrene	x	x	x	n	y	100	75	30-210
PVC	x	x	x	n	y	80	70	50-55