Phoseon TECHNOLOGY

Peak Irradiance & Energy Density

What They Are and How They Can Be Managed for UV Curing Applications

A Phoseon Technology White Paper

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Overview

In the printing industry, professionals have used an array of techniques, including forced air, infrared heat, electron beam and UV light to dry inks, coatings, and adhesives on everything from newspapers and magazines, to flexible and rigid packaging, labels, and signage. For industrial applications, energy from conventional ultraviolet (UV) arc and microwave lamps is often used to cure adhesives, coatings, paints and varnishes.

Historically, these methods have worked with various degrees of success, albeit with excessive heat and limited control of the final product, often resulting in less-than-perfect results and excessive scrappage. These drying methods are still widely used today. In some cases, non-UV processes are preferred.

While many manufacturers continue to use a broad range of techniques for their curing applications, an increasing number are embracing UV LED due to its numerous benefits, including the ability to generate higher yields, reduced scrap, lower running and maintenance costs and precision control.

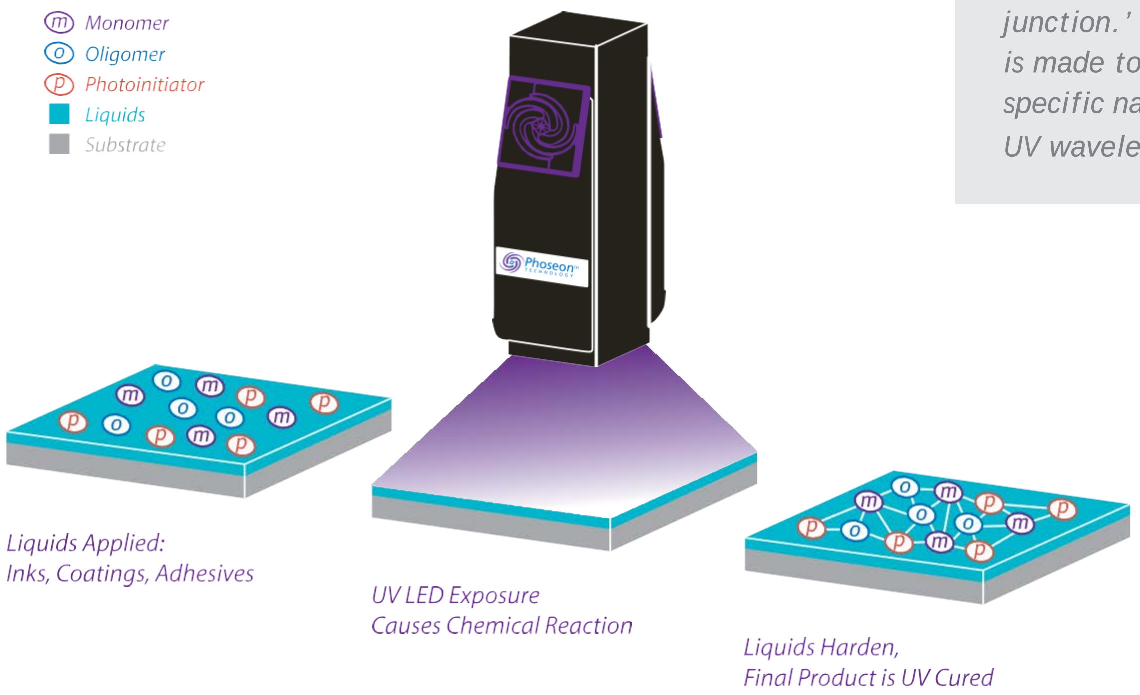
Furthermore, the UV output from LED curing systems remains consistent over the life of the device and provides a more uniform result than arc and microwave lamps. That means tighter process control, less downtime, greater plant utilization and an overall better and more consistent product.

How UV LED Curing Works

UV curing is a photopolymerization process that uses UV energy to change a formulation of non-crosslinked solids into a crosslinked solid. Upon absorption of the UV energy, photo initiators produce free radicals that initiate cross-linking with binders (monomers and oligomers) in a polymerization reaction to cure or solidify the ink, coating or adhesive. UV formulations also incorporate various additives such as stabilizers, wetting agents, adhesion promoters, defoamers and pigments to provide desirable characteristics or color of the cured material.

What is a UV LED?

UV Light Emitting Diodes (LEDs) are a solid-state device that produces light when an electrical current flows from the positive (p-type or anode) side of the circuit to the negative (n-type or cathode) side. This is called the 'p-n junction.' Each LED is made to produce a specific narrow range of UV wavelength.

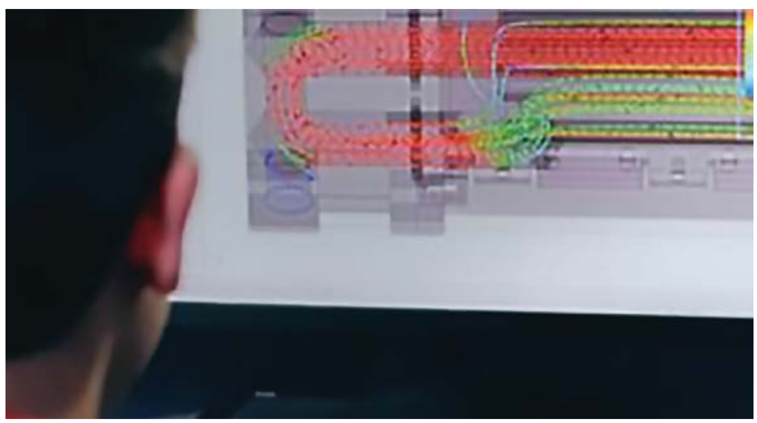


UV curing technology is utilized for drying inks, coatings, adhesives and other UV-sensitive materials through polymerization. UV LED improves on that process by enabling the use of thinner, heat-sensitive substrates, electronics and assemblies, while reducing harmful byproducts and improving workplace safety.

UV Not One-Size-Fits-All

UV curing refers to the unique way in which adhesives, coatings and inks are dried using photons from UV light sources rather than heat to drive evaporation of a solvent or water-based carrier. If you drive a car, use a smartphone, or drink single-serve beverages, there is a good chance that aspects of the product or packaging have been “cured” using UV light.

There are two key parameters of an LED lamp that should be understood for the purposes of optimizing cure and establishing a process window. Identifying this process window will result in the most durable and desirable finish, as well as acceptable adhesion and surface cure: peak irradiance (Watts/cm^2) and energy density (Joules/cm^2).



Peak Irradiance and Energy Density

Peak irradiance, also called intensity, is the radiant power arriving at a surface per-unit area. With UV curing, the surface is the cure surface of the substrate or part, and a square centimeter is the unit area. Irradiance is expressed in units of watts or milliwatts per square centimeter (W/cm^2 or mW/cm^2). Peak irradiance is instrumental in penetration and aiding surface cure.

Peak irradiance is affected by the output of the engineered light source, the use of reflectors or optics to concentrate or contain the rays in a tighter surface impact area, and the distance of the source from the cure surface. The irradiance for UV LEDs at the cure surface decreases quickly as the distance between the source and the cure surface increases.

Energy density, also called dose or radiant energy density, is the energy arriving at a surface per-unit-area during a defined period of time (dwell or exposure). A square centimeter is again the unit area and radiant energy density is expressed in units of joules or millijoules per square centimeter (J/cm^2 or mJ/cm^2). Energy density is the integral of irradiance over time.

A sufficient amount of energy density is necessary for full cure.

"The irradiance for UV LEDs at the cure surface decreases quickly as the distance between the source and the cure surface increases."

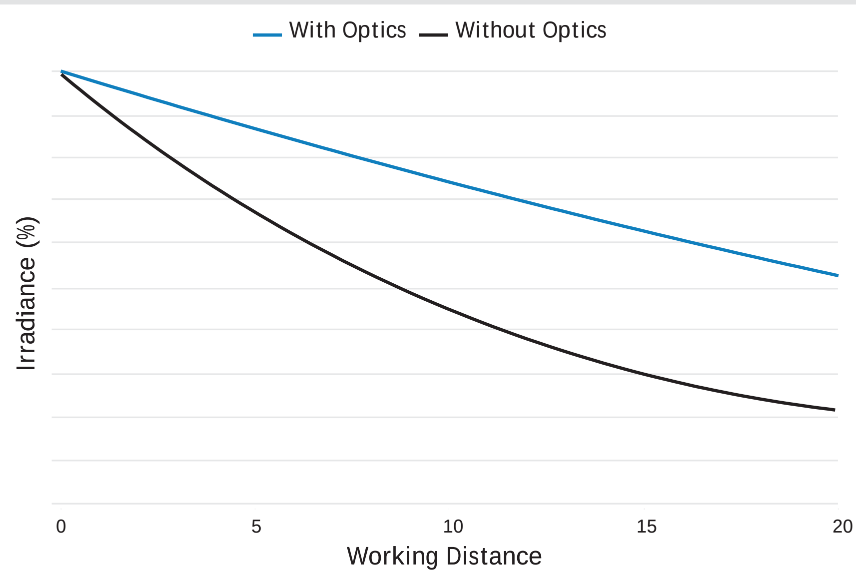
Finding the Right Combination

Conventional arc lamps typically emit peak irradiance in the range of 1 to 3 Watts/cm^2, while microwave lamps generally emit as much as 5 Watts/cm^2. Phoseon's UV LED curing systems currently emit peak irradiance up to 16 Watts/cm^2, for air-cooled heads and 24 Watts/cm^2 for liquid-cooled heads.

Over the past 15 years, increasing UV LED peak irradiance has been instrumental for curing a growing number of formulations in a wide array of applications. Today, many UV formulations have been optimized for UV LED sources, and a higher peak irradiance often is no longer necessary. Research reveals that in many cases, excessive irradiance can negatively affect or hamper proper curing. Sometimes turning down the irradiance and providing more energy density is the way to improve cure for faster line speeds.

The light source's proximity to the substrate is important because irradiance decreases with distance. Manufactures can use optics to manipulate a higher irradiance over a greater distance. With or without optics, vendors compensate for this with different LED arrays, optical elements, or a combination of both.

Irradiance vs Working Distance From Understanding UV Output

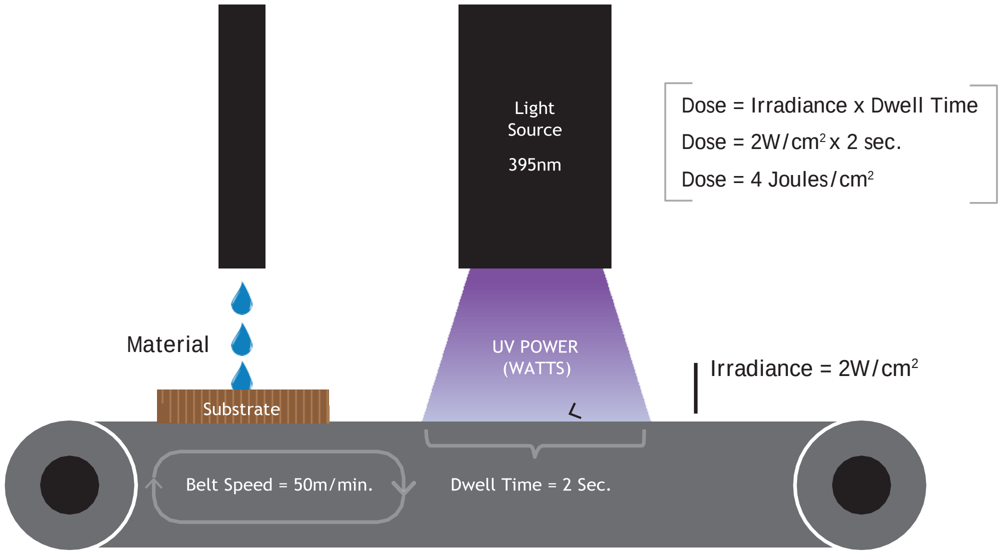


Energy density is a factor of the output of the engineered light source, the number of UV sources, and the exposure time. In other words, increasing the irradiance, slowing the line speed, or adding more or wider lamps will all increase energy density for a given installation. It is important to understand that not all products with the same irradiance deliver the same energy density.

Energy density also is impacted by the speed at which the substrate or part passes under the lamp; or conversely the lamp passes over the substrate or part. Theoretically, if a material is curing sufficiently at 50m/min, then increasing the speed to 100m/min while doubling the irradiance will result in delivery of twice the energy density, which should cure the material sufficiently. Increasing the irradiance of a given lamp will increase the energy density by the same percentage. The cure surface is subsequently exposed to the same amount of dose. Unfortunately, most real-world applications are never perfect, and the chemistry doesn't always scale up according to theoretical models of UV output.

Some materials don't cure faster when additional irradiance is provided. Increasing the belt speed to 100m/min sometimes requires double the dwell time, not an increase in irradiance.

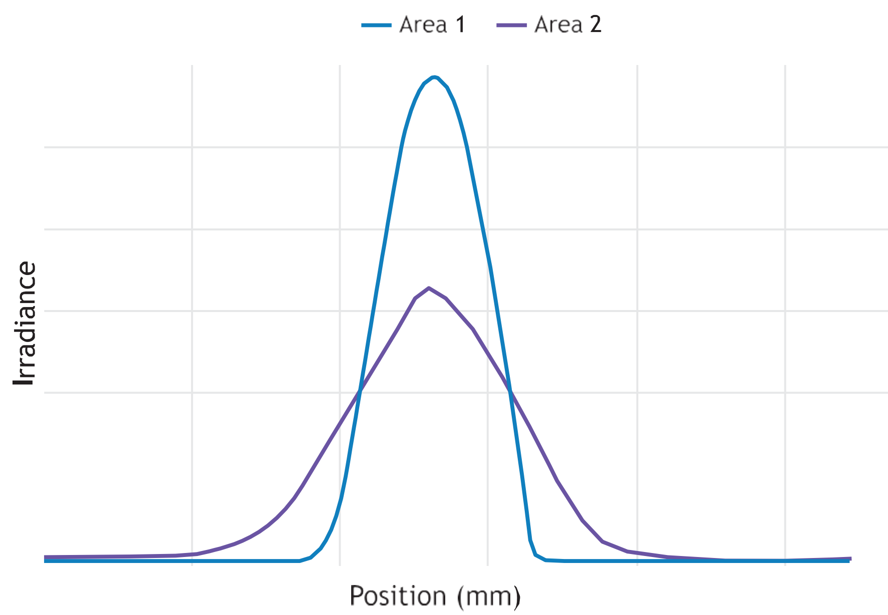
Irradiance vs Position From Understanding UV Output



What is the expected lifetime of the UV LED light source?

Because of Phoseon's rigorous reliability efforts, lifetime testing of light sources has now surpassed 70,000 hours of operational on-time, with light source irradiance being greater than 80% of its original output when the test first began five-plus years ago. For perspective, utilizing a single shift workweek of 2,000 hours per year, 70,000 hours equates to 30 years of UV LED operating on-time.

Wavelength From Understanding UV Output



As previously detailed, energy density is the integral of irradiance over time. In other words, it's the area under the irradiance cure. In the image above, the UV power under Area 1 and Area 2 of the respective curves is equal, but each curve provides different peak irradiance. A material may cure better scanning across Area 2 with lower peak irradiance and a longer dwell time. Another material may be more suitable to Area 1.

Think of it like medication. A doctor may instruct a patient to take one 50mg tablet (irradiance) 4 times a day for 10 days (dwell time). The same dose can be delivered two alternate ways:

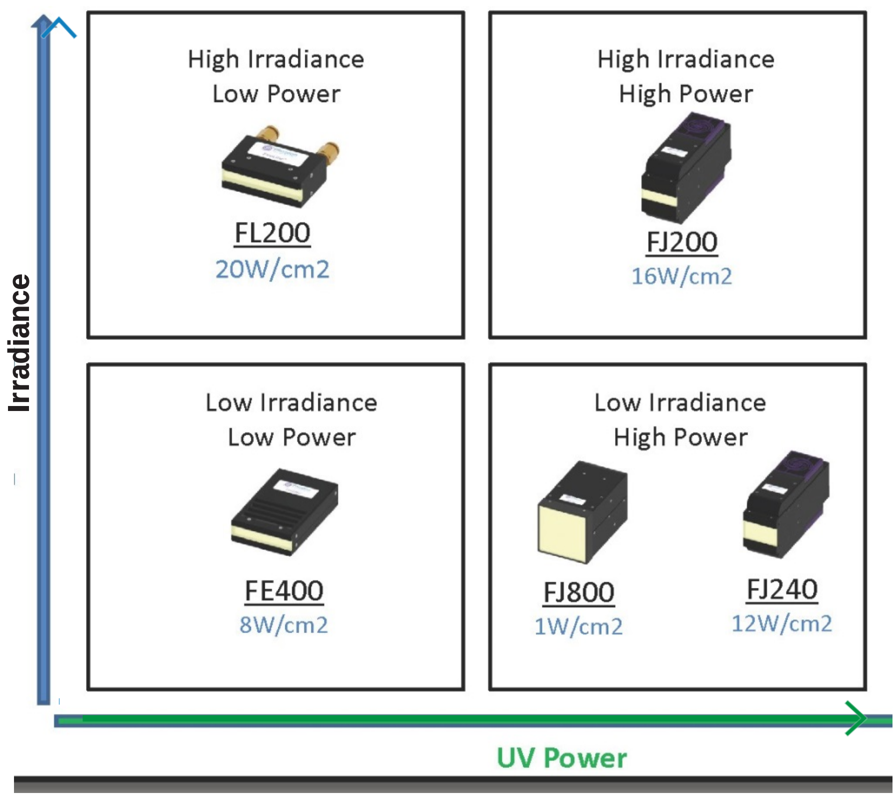
- Take four 50mg tablets (200mg) once per day for 10 days;
- Take one 50mg tablet twice a day for 20 days.

Although the dose is the same for all three methods, according to the doctor, the two alternatives are not optimal. UV curing is similar in that the goal is to optimize the dose to properly cure the formulation.

Another analogy is baking a cake. The recipe (dose) calls for an oven temperature (irradiance) over a period of time (dwell time). It instructs to heat the oven to 350°F and then bake the cake for 30 minutes, which results in a cake that is completely baked through, without burning. The cake experiences 350°F for 30 minutes. This is akin to the energy density, or dose, required to fully bake all the cake batter. If the cake is baked at twice the temperature for half the time, the cake burns. Conversely, if the cake is baked at half the temperature for double the time, it may not be baked in the center (not fully cured).[1]

For an individual lamp, peak irradiance is not impacted by line speed. It is an absolute magnitude of output that does not vary. But don't assume a high irradiance lamp provides high energy density; it may or it may not. Phoseon Technology has developed a large portfolio of products with varying maximum peak irradiance levels and energy densities to fit most curing needs. The idea is to match the correct UV curing source to the needs of the application.

Products Group by Irradiance from Understanding UV Output



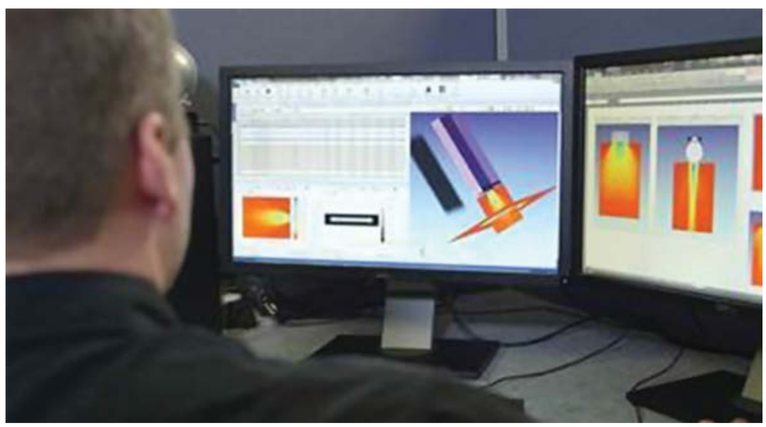
[1] Special thanks to Paul Mills for guidance and analogies

"For some applications, a high peak irradiance is beneficial, for others it can diminish cure."

What's More Important: Irradiance or Energy Density?

In any curing situation, users often ask: What's more important, peak irradiance or energy density? Unfortunately, the answer depends on the implementation and both play an important role in cure.

A minimum "threshold" irradiance is needed to start the polymerization process, and then a dwell time of dose is needed to finish the curing process. For some applications, a low dose is required. For others, a larger dose is needed. For some applications, a high peak irradiance is beneficial, for others it can diminish cure. The formulation and substrate also have a large impact on what is required as well as the material handling.



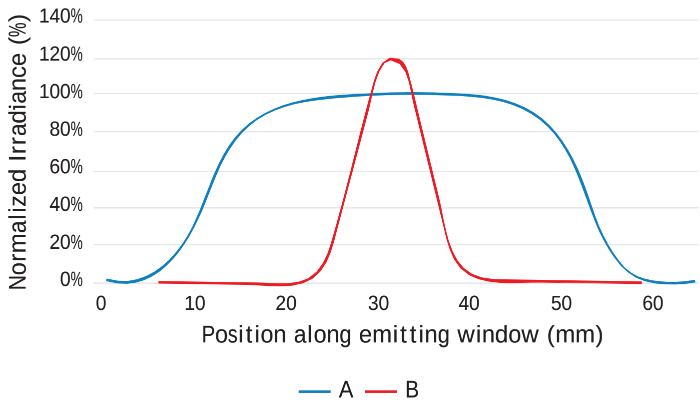
Considerations

UV curing is application-specific. The substrate, formulation and UV energy must be combined to maximize each contribution and minimize each shortcoming. For instance, increasing material thickness from 10 µm to 20 µm drastically impacts the cure, as the photons have 2x the density to penetrate and polymerize the material. Increasing the belt speed from 50m/min to 100m/min requires double the irradiance for the same curing reaction and dose, all else being equal. But as with most things in life, doubling the speed may lead to other unknown or unforeseen challenges and may not be optimal.

Each wavelength has unique properties and must be matched with the correct photo initiator to ensure proper cure. In general, longer wavelengths (UVA and UVV) result in deeper through-cure.

Also, beware of marketing claims, such as "highest irradiance." A product may have a higher peak irradiance compared with another product, but it may have drastically reduced energy density.

Wavelength from Understanding UV Output



The type of material being cured and what type of light source will best match the curing needs must be considered for each application. Working closely with the ink, coating or adhesive supplier, the light source supplier and the integrator or machine builder will result in a well-matched total solution.

"Each wavelength has unique properties and must be matched with the correct photo initiator to ensure proper cure."

Which Lamp is Best for Me?

What determines the proper lamp for a specific printing application? Ink suppliers provide cure parameter specifications, but each supplier typically derives those specifications from bench top lab testing using their own, established test methods. For example, two different inks from two different suppliers can have the same cure parameter specifications. However, those specifications likely are derived using two different test methods, including the use of different UV LED lamps. What if supplier A ink and supplier B ink have the same curing specifications:

- Peak wavelength = 395nm
- Irradiance = 6W/cm²

Both inks require 6W/cm² to start the curing process and both are designed for lamps with a peak wavelength of 395nm. But, how much dose or dwell time is required to complete the cure? Unfortunately, it can be difficult to determine. Additional information on the specification sheet may help, especially if recommended belt speed and the lamp used in testing is known. To add one more bit of confusion, ink specification data sheets clarify their curing parameters as, “your results may vary” — and they usually do. However, it is a starting point.

Phoseon Lamp Output Profiles from Understanding UV Output

	FireEdge™ FE400	FireJet™ FJ200	FireJet™ FJ240
Lamp Model			
Window Width	10mm	20mm	40mm
Output Profile			

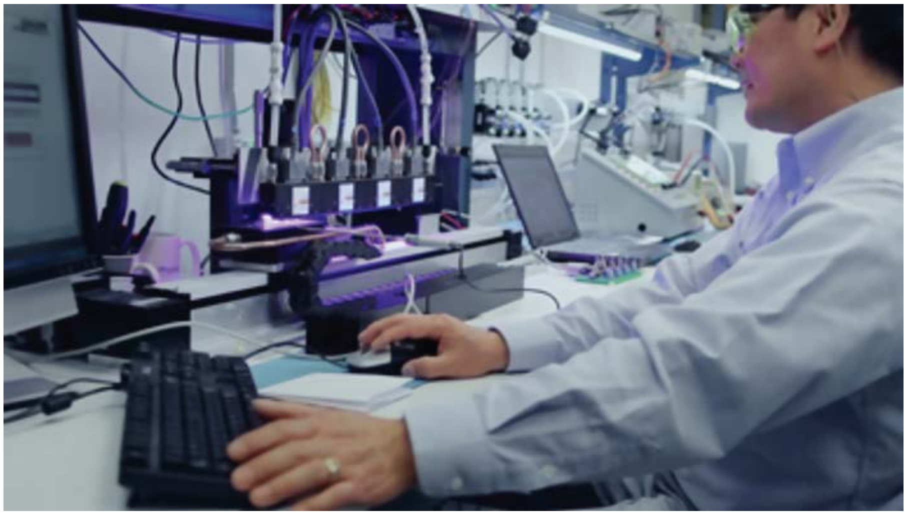
With limited ink curing information, which Phoseon lamp is the best solution for supplier A and supplier B inks? Although all three lamps provide sufficient threshold irradiance, each of these lamps deliver different levels of energy density. Which one will work best?

Let Phoseon Help

With all the variables, finding the UV LED curing technology to produce the proper peak irradiance and energy density for your specific digital inkjet, screen, web offset, flexography or industrial coating application may seem complicated.

Phoseon Technology has the broadest range of UV LED curing systems available, each specifically designed for the various UV curing applications. FirePower™, FireJet™ and FireEdge™ air- and water- cooled products are designed to provide superior process stability and consistency for an array of small and wide printing needs.

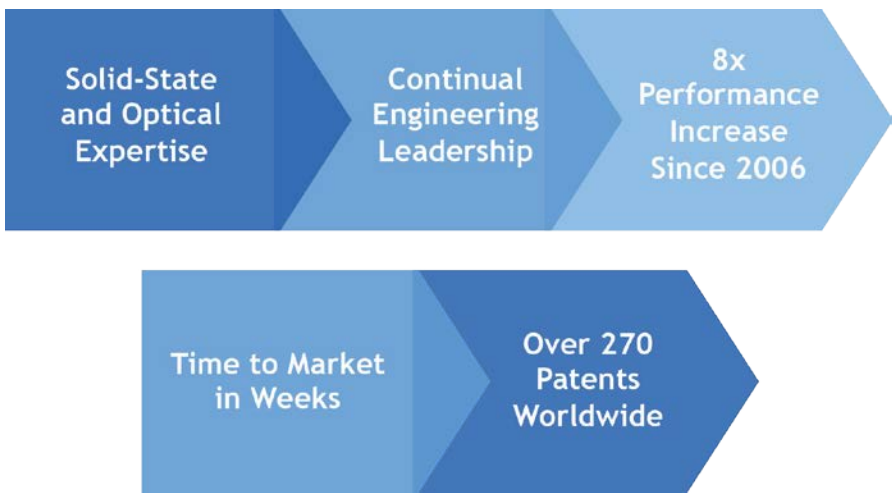
Phoseon Technology's experienced sales staff and applications engineers are the most knowledgeable in the industry at matching its UV LED products to the intended applications and know how to adjust the configurations for more demanding applications that involve specialty chemistry, faster press speeds, tight spaces, and wide webs.



The Phoseon Advantages

In 2002, Phoseon Technology pioneered the use of LEDs for UV curing applications using the polymerization process to dry adhesives, coatings, inks and other UV sensitive materials. Today, Phoseon products are successfully curing UV applications worldwide and represent the largest installed base of an UV LED systems company.

With more than 270 patents worldwide, Phoseon has earned the reputation for technological innovation, quality and reliability. As the market leader with the broadest portfolio of UV LED lighting offerings for our key markets, we welcome the opportunity to work jointly with you in developing further innovative solutions.



Author

Joe Becker, Product Marketing Engineer, Phoseon Technologies

For more information about Phoseon Technology products and services, please contact:

Joe Becker, joe.becker@phoseon.com

About Phoseon Technology

The world leader since 2002, Phoseon Technology pioneered the use of LED technology for Life Science and Industrial Curing applications. Phoseon delivers innovative, highly engineered, patented LED solutions. The company is focused 100% on LED technology and provides worldwide support.

Contacts

For more information about Phoseon Technology suite of products, visit **http://www.phoseon.com/** or call **(503) 439-6446**