Specifying UV LED Curing Systems

Whitepaper

PRO PHOTONIX

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As UV LED based curing lamps continue to replace mercury lamps in industrial printers, 3D printers and production lines, the switch to a very different technology has required a new set of selection criteria. This whitepaper discusses the technical and commercial considerations to help you specify the optimum UV LED Curing system for your application. First, optimizing curing for your application including wavelength selection, key performance characteristics and optical options are discussed. Next, form factor considerations, control requirements and the importance of system validation are explored. Finally, reliability and cost of ownership are examined.

Optimizing Curing

In order to optimize curing in your application, it is important to understand your requirements in terms of wavelength, intensity or dose and light output profile.

Wavelength Selection

Wavelength selection is critical in curing applications as the optimum wavelength decreases curing time and improves the overall quality of the cure. For example, while 365nm light may be the optimum wavelength to cure based on the target materials absorption profile, 395nm may produce a better curing result due to the efficiency differences between 395nm and 365nm LEDs.

Key performance characteristics

Light output profile

It is important to define what light output profile is required for your application e.g. illumination area, uniformity level, and working distance range. UV LED lamps are designed in various form factors and a range of optical options are available allowing the illumination profile to be optimized to the required optical specification. For example, some applications require a collimated or narrow angled output beam of light to avoid UV light reflections from the target media back to the print head leading to cured blockages; see Figure 3 (a). The trade-off with these light sources is that generally the light output efficiency is lower in comparison to UV LED lamps with wider angle output profiles. Other applications require an angled output to ensure curing along a high aspect ratio profile, for example, in 3D printing applications; see Figure 3 (b). Finally, where the light output angle of the light is not an issue in the application, lamps may have no active optics maximizing the output from the lamp; see Figure 3 (c). ProPhotonix offers a range of optical configurations with the COBRA Cure FX series. For applications with more specific requirements, our optical engineers can design and develop a custom optical design to suit the application needs.

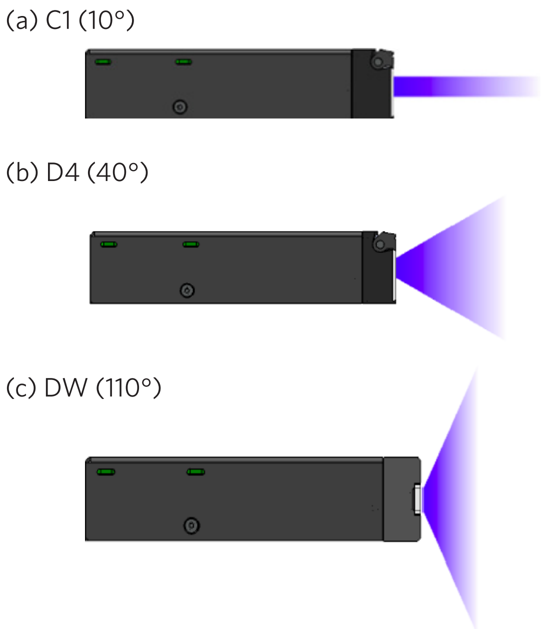


Figure 3. Optical Configurations, COBRA Cure FX Series (a) Low angle (collimated) (b) Medium angle (c) Wide angle

Working Distance

The working distance has a large bearing on the optical design requirement. UV LED lamps typically need to work over a short working distance range. For these applications, a relatively simple optical system of lenses and reflectors is suitable. Where items of varying size must be cured, intensity levels must be maintained over a wider range of working distances requiring UV LED lamps with a much wider depth of focus. Achieving this will mean that the aperture size of the light needs to be decreased, utilizing more complex optical arrangements. In more challenging applications, custom optical designs incorporating multi-lens systems can result in improved uniformity, greater flexibility and reduced downtimes.

Intensity & Dose Requirements

UV curable media require both a minimum intensity and a minimum dose for an effective cure. The intensity needs to meet a minimum level for the curing process to start and the dose needs to be at a certain threshold for total cure to occur; see Figure 4. If the intensity is too high, it can damage the curable material (ink or resin) even if there is sufficient dose; see Figure 5 (a). The intensity level must be balanced with the cure requirement while protecting the substrate; see Figure 5 (b). In this instance, the intensity and dose level has been optimized to produce an ideal cure. The intensity and dose values can change depending on a number of factors including, type of ink or resin used, thickness of cure, target substrate type and speed of the production line.

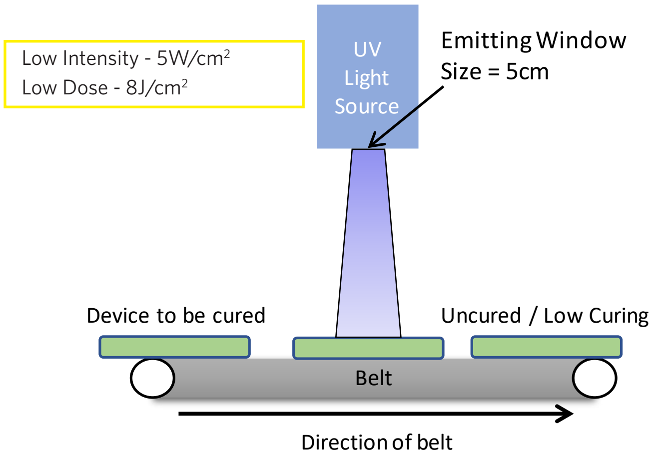


Figure 4. The image shows a UV LED lamp utilized for curing a device on a production line. At the stated intensity and dose, the device on the production line remains uncured or has only cured partially. In this case, the intensity and dose are both too low.

Lamp intensity is defined as the overall power of the lamp and is most often designated in watts. Light intensity at the target surface, denoted by the term irradiance, is a measure of the exposure per second and is most often quantified in watts/ cm^2. Light energy at the cure surface (dose) is a measure of radiant exposure (intensity x time), quantified as joules/cm^2. Measurement of irradiance and dose is essential in order to optimize cure conditions and maintain consistency in cure results.

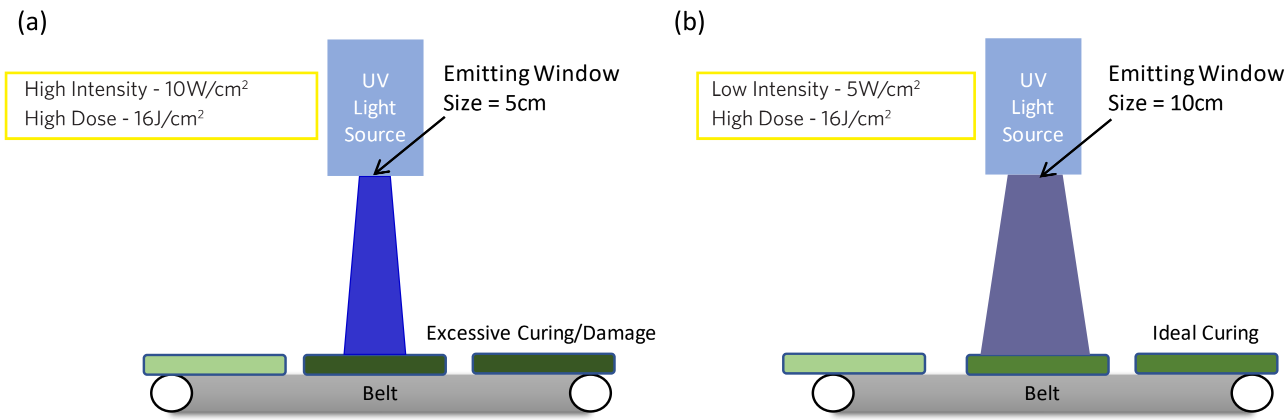


Figure 5. (a) In this instance the intensity and dose are too high resulting in damage to the target substrate producing an "overcure". **(b)** In this instance, the intensity and dose level has been optimized to produce an ideal cure.

When specifying a UV LED curing system, it is better to over specify by 10 - 15% (e.g. intensity, dose, maximum operating temperature, etc.). This provides an operational safety margin and a longer lamp life. In general, if you need your production process to run faster, higher intensity light at the optimum wavelength will produce a faster cure. However, a balance needs to be struck between the required intensity and the consequences of this increase. An increase in intensity may require a lamp with a larger form factor or the LEDs may need to be overdriven to deliver the intensity required potentially impacting the lifetime of the lamp. ProPhotonix has recently launched a COBRA Cure FX1 Max, a lamp that utilizes the same form factor as the COBRA Cure FX1 but delivers 20% higher intensity while maintaining excellent lifetime. This level of lifetime performance is achieved by an in-depth understanding of LED sensitivities to thermal management and electrical current combined with in-house production capability.

Uniformity

Uniform light is extremely important in curing systems. If the light is not uniform, there is a high risk of uneven cure on the target media, as the non-uniform light can result in spotty or striped under curing. Most UV LED curing lamps provide uniformity suitable for a range of commercial applications. Light uniformity can be maximized by the LED lamp manufacturer through custom LED substrate and optical design. ProPhotonix designs and manufactures Chip-on-Board LED arrays in-house, and can design custom packages and lamps for specific customer applications.

COBRA Cure FX Series

COBRA Cure Mini

Figure 6. A selection of ProPhotonix' configurable standard product line of UV LED lamps

Form Factor Considerations

As with all lighting technologies, when specifying UV LED curing systems, there is a relationship between intensity and form factor with higher intensity requirements generally resulting in larger form factors. LED technology is fundamentally a more compact technology than traditional UV lamps. In practice, the lack of ancillary components required by UV LED technology provide additional space savings.

As a very flexible technology, UV LED lamps are available in a range of configurations. The intensity requirements of the application will be a major determinant in the choice of lamp but in some applications a narrow form factor is required to minimize the total distance between multiple print heads and the UV LED lamps. For a low intensity, cost-sensitive application requiring a compact form factor, a convection cooled lamp would be most suitable. With a higher intensity requirement, provided that the space is available to allow some increase in form factor, a fan-cooled solution may be ideal. Where space is restricted, but high intensity is a must then a water-cooled solution may be required. For each application, specifiers must balance performance, cost and complexity in their application.

Another consideration when specifying your UV LED lamp is to determine whether a standalone, stackable or modular system is the optimum choice.

Standalone systems are UV LED systems usually designed for a specific application that requires a fixed illumination profile. These systems are suitable for applications where the target cure area is stationary and the UV LED lamp moves in two dimensions on a rail such as desktop 3D printers or flatbed printers. With larger UV LED systems, the cost of replacement of an entire lamp and the downtime in production means that a stackable or modular solution may be more cost effective allowing a section of the lamp rather than the entire lamp to be replaced.

Stackable systems are UV LED systems where LED lamps can be placed side-by-side, for example a 300mm light maybe created by stacking four 75mm lamps side-by-side. A stackable lamp is a fully operational UV LED lamp and can operate independently of the lamp array. These lamps generally have edge-to-edge illumination so that the illumination profile is seamless between lamps. Each lamp can have its own power supply or share a power supply by daisy chaining the devices. This solution is cost effective for systems that require varying lengths.

Modular systems are LED lamps that can also be placed side-by-side. The key difference between modular and stackable systems is that a modular lamp is designed to form part of a complete system and cannot operate outside of the modular architecture. There are two types of modular system. The first has all the operational elements enclosed in the module itself. The second has some of its operational elements not enclosed in the module itself, for example the power distribution or thermal management system. The main advantages of modular systems are that very long lights (greater than 1m) can be supplied, the architecture can minimize the number of power supplies and cables required and control over multiple modules is more reliable than over a stacked system.

UV LED lamps typically require fan or water-cooled systems to guarantee reliable continuous operation over the entire operating temperature range although some low power lamps are available that rely solely on convection cooling. Fan-cooled systems do not require any ancillary equipment, but higher intensity fan-cooled systems may become bulky due to the requirement for bigger and/or more fans to regulate the temperature. In environments where there are airborne particulates, filters can be attached to the lamp's openings to reduce the access of these particles into the inner workings of the UV LED lamp.

Water-cooled systems are often more compact than fan-cooled systems, less noisy and can offer higher power. However, the system will need to accommodate a chiller. The advantage of fan-cooled systems is there is no requirement for a cooling liquid (e.g. chilled water) that would need to be supplied to your system and are therefore less expensive to operate and maintain.

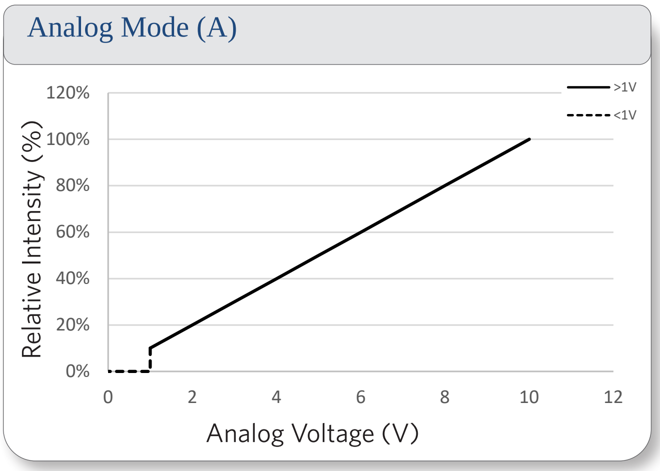
System Validation

Once the above criteria (wavelength, optical, form factor) have been determined, perhaps the most critical step is system validation. Most UV LED manufacturers will supply you with demonstration products to test in your system. It is vital to complete this testing as what may seem like small variations in a specific application can significantly affect overall performance. Different ink formulations, for example, may not respond as expected and should always be tested. Other issues, such as airflow from the lamp, unexpected light reflections and integration issues may be highlighted during this critical phase.

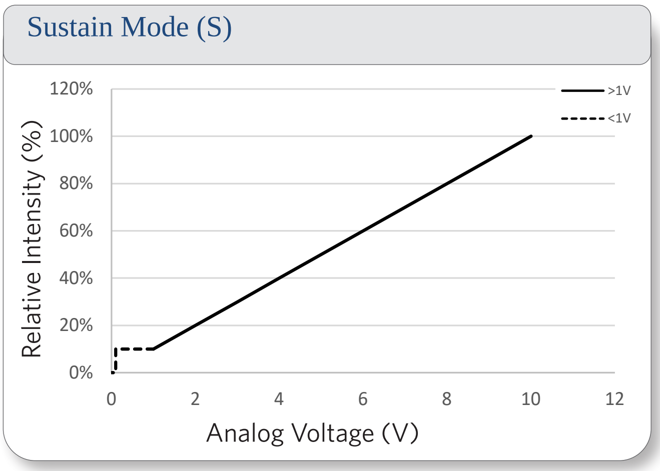
Control requirements

When you have validated the lamp works in the system, other application requirements should be considered. Different levels of control may be required or may provide opportunities to optimize your UV LED curing system. ProPhotonix can supply UV LED lamps with control options that allow the lamps to run continuously over a long period of time, to be flashed for short periods of time or set up so that dimming of the entire lamp or individual LED strings can be realized.

Intensity Response to Analog Control



Turns off at 1V



Turns off at 1V. From 300mV to 1V, lamps operate at 10% intensity.

Figure 7. The first graph shows ProPhotonix "Analog mode" where intensity response turns on at 1V and linearly scales to 100% intensity at 10V. The second graph shows ProPhotonix' "Sustain mode" turns on at 300mV. From 300mV to 1V the lamp operates at 10% intensity. From 1V, the lamp linearly scales to 100% intensity to 10V.

As a digital technology, LED lamps can be factory set to configurable intensity profiles. For example, the COBRA Cure FX series allows users to choose the optimum intensity profile to suit their needs; see Figure 7. With LED technology, the relationship between current or voltage applied and intensity is not linear. In the COBRA Cure FX series, firmware corrects for this ensuring a precise linear response. A non-linear response makes it more difficult for the user to precisely set the lamp to their desired process outcomes. The maximum intensity of an LED lamp can also be factory set. More complex configurations are also possible, for example, the lamps can remain off until the voltage is increased to 1V where it then instantly turns on at 10% of its maximum intensity setting.

Device monitoring functions can also be built in to ensure stability across the lifetime of the lamp such as thermal monitoring of the LED substrate temperatures, short circuit monitoring or in rush voltage protection. Safety features such as interlocks can also be installed.

The digital nature of LEDs mean they can work with multiple communication protocols including Ethernet, I2C, RS485 and Analogue control. Communication with the lights can be implemented in special circumstances using optical communication (optical fiber) rather than electronic communication when electronic noise in the working environment is an issue.

Reliability

Reliability of a UV LED lamp is very important to ensure reduced downtime, long replacement cycles and low cost of ownership. LED technology is inherently more reliable than traditional technologies but the reliability of a UV LED curing lamp does not stem from the LEDs devices. At ProPhotonix, we design our lamps for reliability. We have extensive experience in LED technology and design and validate all products in-house through DFMEA and manufacturing FMEA. All of our products are built to the highest standards in our ISO-certified production facility. Every lamp is stress tested with significantly reduced air flow at maximum operating temperatures through a software-controlled cycle of varying operational parameters. ProPhotonix products are RoSH-3 compliant and third-party CE and UL certified.

Lifetime Considerations

As LED based lamps age, the output degrades slowly over time. UV LED Lamps are generally specified to L90 or L80. A lifetime of L90 at 10,000 hours means the light output will reduce from 100% to 90% of its maximum intensity in no less than 10,000 hours. L80 at 20,000 hours means the lamp will degrade from 100% to 80% of its maximum intensity in no less than 20,000 hours. For this reason, it is better to over specify on key specifications such as intensity, dose and maximum operating temperature. This provides an operational safety margin and a longer operational lamp life.

Cost of Ownership

Only a limited set of UV LED wavelengths exists and each wavelength has a limited set of power levels available. The best combination of wavelengths and the number of LEDs for each system must be optimized based on the performance specifications and the target cost. Designing systems that necessitate precise control of hundreds or thousands of LEDs requires multiple LED drivers and complex software structures. If not optimally designed, the electronics can increase the system costs significantly. It is important to note that the best solution should take into account not only the up-front costs of the system, but also the lifetime costs in comparison to alternative solutions and the measured impact on the business' total cost of ownership. Compared with traditional lamp systems, LED systems offer significant benefits over the life of the lamp. Operating costs will be lower due to instant-on/off and more efficient energy consumption than traditional UV sources. UV LEDs are safer to work with since they avoid emissions in the short-wave regions of the UV spectrum that can cause health and safety concerns for workers. UV LEDs are environmentally friendly and do not generate ozone. UV LEDs do not generate excess heat and as such are a "cool" cure technology ideal for curing materials on heat-sensitive substrates such as wood or plastics that might be damaged by the high temperatures generated from mercury lamps. Maintenance costs will be lower because of the extended life of LEDs providing less production downtime versus the changeout required by mercury lamps. Heavy metal disposal is eliminated because LEDs do not contain mercury. Operating efficiency is improved as a result of the unique control capability of light uniformity, speed of flash and precise spectral output. UV LED Lamp manufacturers offer a variety of lamps. ProPhotonix' COBRA Cure series takes a unique configurable approach to our customer offering. The customer can select the platform according to their intensity and dose requirements and then configure the optical and electronic options to their application needs. ProPhotonix also partners with OEMs to develop solution where application requirements are more specific.

Conclusion

Selecting the best UV LED curing module, the optimum wavelength at the correct intensity or dose and with the best light profile for your application will improve cure quality, increase throughput and deliver consistent performance over time. When considering a UV LED module, be aware that significant differences can exist in the optical output, expected lifetime and performance. The system's performance depends on how well the module is designed and manufactured. When specifying a UV LED lamp, the most important questions to ask are related to operating environment, size, wavelengths, power and uniformity and control requirements.

To learn more about our UV LED Curing Systems visit: https://www.prophotonix.com/led-and-laser-products/uv-led-curing-systems/