UV LEDs – Where are they now?

Utilizing the technology in print applications

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LEDs' benefits which include their long life to lower power consumption and improved environmental footprint have helped drive the broad adoption of the technology first in the general lighting market, and now in the UV space. This article reviews the evolution of UV LEDs and includes a market discussion of the current technology and adoption, factors that can affect UV curing (irradiance, dosage, exposure and spectral content), how UV LED curing systems can be used as a drying solution in printing applications, and tips for selecting the right solution.

A variety of new print opportunities, performance advantages and productivity enhancements can be leveraged with the use of UV LEDs. Commercially, key drivers including pricing, performance, and support from formulators of adhesives, coatings, and inks, have influenced and encouraged the rate of adoption.

Market overview and adoption

Over the years, LEDs have overcome technological challenges to become a commercially viable solution. Previously existing barriers included low output power/efficiency, high cost, integration/qualification time, cure quality and materials compatibility. The industry has invested many resources and time to overcome these barriers to ensure that the technology is now viable for commercialization.

Unlike other sources such as arc lamps, LEDs emit a narrow spectrum of light at specific wavelengths and can be classified into four bands: Vacuum UV (100–200 nm), UVC (200–280 nm), UVB (280–315 nm), and UVA (315–400 nm). The spectral output of arc lamps is distributed across the entire UV band, while typical UVA LED outputs fall between 365–405 nm, with spectral content at specific bands. The most mature and commonly adopted UVA LED wavelengths are 3 nm, 385 nm, 395 nm and 405 nm; the majority of print applications and inks respond to and are formulated for 395 nm.

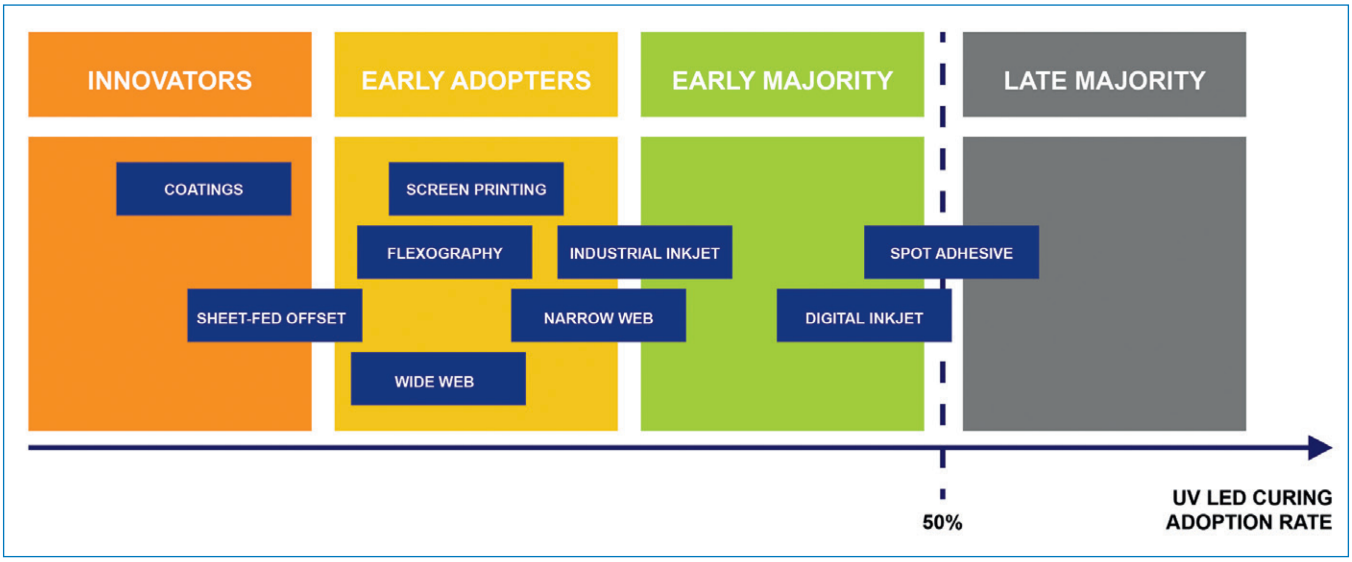
Adoption depends on application

Adhesive curing is still by far the most established application for UV LEDs; initial adoption was primarily in smaller area/spot configurations utilizing adhesives. Success in this market segment was attributed to a lower cost of investment and greater availability of compatible materials (the figure below shows the rate of implenentation in different applications).

In the printing industry, UV LEDs are most commonly seen in inkjet/digital printers, with narrow web following quickly behind as it moves from early adopters to the early majority. Availability of higher output LEDs has in turn enabled higher-performing UV LED drying solutions, capable of addressing faster, more demanding print speeds to be introduced.

Price pressures and increased competition are driving costs down so that LED-enabled solutions are no longer cost-prohibitive for integration onto print platforms that require a larger area of cure. Moreover, technology advancements, availability of expanded UV LED formulation options, and partnerships among hardware and materials suppliers have expanded the industry's knowledge base and LED expertise to accelerate validation. Collaboration has aided market acceptance and commercialization of

UV LED technology adoption – application trends



Source: Yole UV LED 2016 Technology Manufacturing and Application Trends Report

Performance Advantages	Productivity Enhancements	Ease of Integration
Deeper & more reliable cure	Higher yields, consistent & reliable curing	Small form factor & no shutters or exhaust ducting required
Higher degree of process control & reliability	Faster print speeds & support for combination printing	Adaptable with added features; output control & monitoring, instant on/off
Support for thicker films & darker/ more opaque colors	Less down time	Scalable: increase speeds & expand cure area
Faster print speeds & adhesion	Expanded print capabilities	Environmental Benefits
Customizations & unique finishes on different materials	Lower maintenance & operational costs	Low energy consumption & no VOCs

Source: Excelitas

Benefits of UV LED curing for print applications

newer machines utilizing next-generation technology.

UV LEDs for printing

Printing processes have evolved dramatically over the years from printing presses to modern-day offset, flexography and digital printers. UV printers are a fast-growing sector and UV LEDs in this segment are displacing traditional mercury arc lamps as the curing source for UV inks. Arc lamps have provided an effective solution for many years with broad spectrum and high output at various peak wavelengths in the UVA, UVB, and UVC regions. The disadvantages of older mercury lamp solutions such as shorter lifespans, higher operational costs, reliability, uneven curing, and heat generation can be eliminated by using LED solutions.

Low power consumption, long lifetime, environmental benefits, low temperature curing, instant on/off, reduced total cost of ownership, and increased functionality are driving the integration of UV LED solutions. Previously existing barriers to LED adoption have been overcome; these are highlighted below for reference, with a review of today's situation.

Output power and efficiency – UV LED efficiency has dramatically improved, and concentrated high-power systems created by grouping arrays of LEDs have become more readily available to support higher throughput capabilities. Ongoing enhancements will continue to enable faster operation speeds with no impact on cure quality or performance.

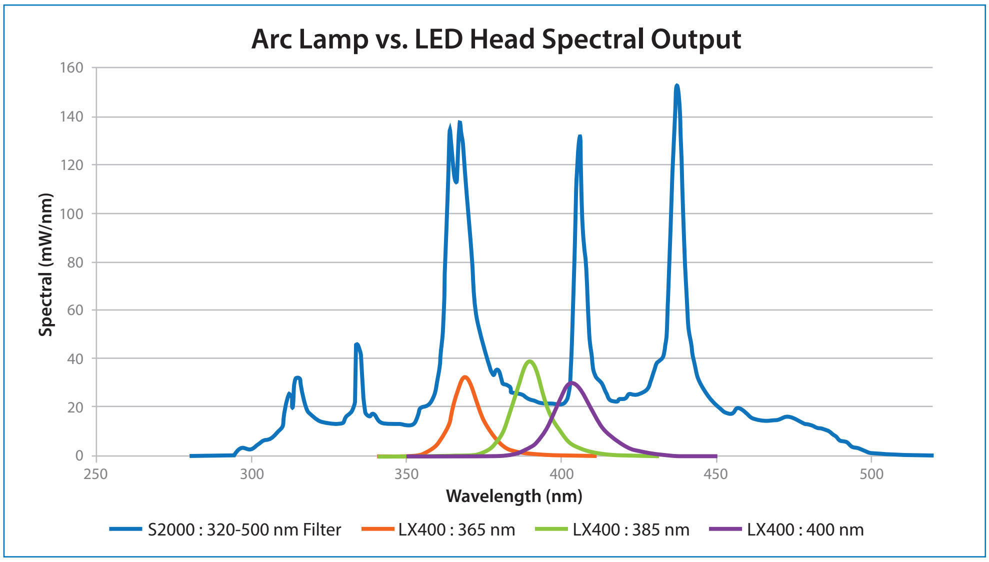
Cost – While the upfront investment of an LED system is higher than its lamp-based counterpart, the acquisition cost is quickly offset by efficiencies (reduced power consumption, limited maintenance and downtime, easy integration) and long lifetime. The price premium for LED is also narrowing as the costs of UV LED hardware and compatible inks come down. As LED yields continually improve and the overall demand for UV LEDs increases, the costs will further reduce.

Materials compatibility – When UV LED curing systems were first introduced, the availability of compatible inks, adhesives and coatings were limited. In fact, it could be argued that there was insufficient collaboration between materials providers and curing system suppliers to pre-qualify and optimize the formulations in advance of market introduction. Many of the existing materials formulations did not respond well to the narrow spectrum of LEDs, and of the few available UV LED options that did, costs were prohibitively high and performance was not yet competitive with legacy lamp formulations. However, the landscape has dramatically changed and there has since been a marked enhancement in ink formulation, with significant improvements to the material's responsiveness to UV LEDs. Lower energy doses are needed for faster and more efficient cure, and ink properties have been optimized for enhanced surface cure, finish, and chemical resistance. Costs for LED tailored materials have come down.

Cure quality – Tailored formulations for UV LED curing have addressed the reactivity of materials to accelerate both cure rate and quality. Unique finishes and support for a wider range of substrates can be achieved by leveraging features of LED solutions (such as on/off pulsing that is not possible with traditional lamps). UVA LEDs also provide a deeper and more reliable cure with strong adhesion. Developments are currently under way to explore UVC as a possible method for further improvements to the surface cure. LEDs can also provide a more even and uniform cure than traditional curing solutions, which produce uneven irradiation across the cure area – typically with varying outputs from the middle to the edges.

In addition to the general benefits of LEDs, UV LED enabled printers also profit from performance

UV lamp vs. LED head spectral output



Source: Excelitas

advantages, productivity enhancements, environmental benefits, and easy integration. Some of these benefits are further highlighted below:

UV sources & factors affecting cure

The UV curing process requires polymerization of a photosensitive material such as an ink, adhesive or coating. Photoinitiators trigger the process of hardening, and cross-linking solidifies the material when sufficient energy to complete the reaction is received. In this process, spectra content is important, and LED wavelength must match the absorption spectra of the photoinitiator or the material will not cure. In addition to delivering sufficient energy and wavelength match, other factors also impact the cure.

To understand how these parameters affect cure, consider the analogy to grilling a steak. Cooking the perfect steak requires the right amount and combination of heat and time, quality of meat and seasoning. It is important to start with a good cut of meat and seasoning, or in a curing process, the appropriate formulation and wavelength match.

Now consider irradiance as a parallel to the grill temperature. An extremely hot barbecue (i.e., very high irradiance) on its own will not necessarily produce the best result. Excessive heat may char the outside, but leave a still cold piece of meat for which no chef would earn any Michelin stars! Thus, this would be similar to an ink that is not thoroughly cured. The very high peak energy is not enough to fully cure (or cook) the material and increasing the cooking (exposure) time would worsen things, and in the case of the meat, completely burn it.

On the other hand, a very low temperature grill would have equally abhorrent results. Cooking the steak for a longer time can somewhat compensate for the low heat, but a minimum grill temperature is needed to sufficiently raise the meat's internal temperature. Regardless of exposure time and despite high energy density, a cooked steak (aka polymerization) is just not possible. However, if the temperature is set within a reasonable range, the steak can be cooked "just right" by varying the amount of grill time to ensure sufficient energy is delivered.

It goes without saying that bigger is not always better and a slower press does not always resolve curing issues. Specifications alone do not determine the quality and compatibility of materials in a curing process, and all the parameters must be appropriately matched to achieve an optimal result. This leads us to the question of how best to select a UV LED solution for your drying process.

Selecting the right UV LED system

When choosing a UV source, it can be a challenge to determine if a particular solution is right for the specific application. As mentioned earlier, the specifications alone do not always dictate how well a system will perform in a specific process. The best results will require applications testing and integration to optimize the solution.

Factors to consider when selecting an LED dryer include

1) Material to be cured

- Compatibility with chemistry: Is the formulation tailored for UV LEDs?
- Photoinitiator wavelength match: 365 nm, 395 nm or 405 nm?
- Substrate: Are there any special characteristics of the material or known challenges/characteristics to consider?

2) Application requirements

- What irradiance and dose are needed to cure the material?
- Process speed required
- Working distance, cure area/size
- Homogeneity needs

3) Installation considerations

- Air vs. water cooling: Are there any restrictions or preferences for the type of integration? Are chillers and tubing (for water-cooled) available? Are there limitations with airflow (for air-cooled)?
- Mechanical size: Restrictions in form factor, need for scalability, etc.

Conclusion

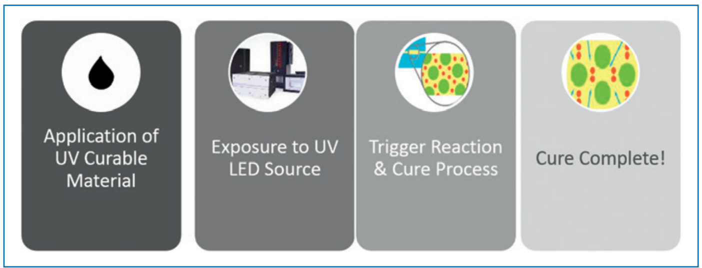
UV LEDs bring significant benefits to printing processes when compared to traditional lamp solutions. Adoption of UV LED curing onto print platforms will continue to rise and the market will see growth from inkjet and narrow web to screen, flexo and wide web.

Continual enhancements in UV LED technology and materials formulations will further enhance output and performance to support faster print speeds. Moreover, costs will soon be more competitive to make larger scale printers further economical.

	Parameter	Description
1.	Irradiance (W/cm^2)	The minimum threshold required to initiate polymerization, where peak irradiance is inversely proportional to working distance.
2.	Dosage/Energy Density (J/cm^2)	The amount of photons seen at the substrate over "x" period of time, and is the time integration of irradiance. Sufficient energy must be received to convert and complete the reaction.
3.	Exposure/Dwell Time (s)	Duration of time the substrate is exposed to the UV energy. Typically a function of speed/conveyor and size of emitting window.
4.	Spectral Content/ Wavelength	Wavelength match will determine compatibility with and responsiveness to material formulation /effectiveness of cure.

Source: Excelitas

There are four key UV curing parameters: irradiance, dosage/energy density exposure/dwell time and the spectral content/wavelength



Source: Excelitas

An example for UV LED curing solutions for print applications: Excelitas Technologies OmniCure AC Series