LIGHT THE WAY

Pamela Lee explores the benefits of UV LED and discusses how best to utilise this technology in print applications

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Light-emitting diodes (LEDs) have been broadly adopted in the general lighting market, and now in the ultraviolet (UV) space, due to their many benefits – from their long life to lower power consumption and improved environmental footprint. The rate of commercial adoption has been positively affected by improved pricing, performance, and support from formulators of adhesives, coatings, and inks.

The use of UV LEDs has generated new print opportunities, performance advantages and productivity enhancements, helping manufacturers to differentiate their applications and further driving acceptance and successful integrations of LEDs onto printer platforms.

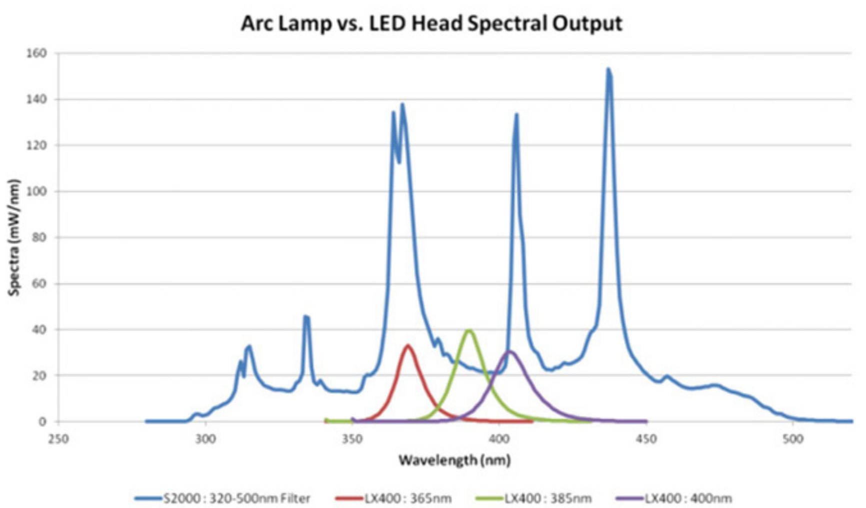
MARKET OVERVIEW AND CURRENT STATE OF ADOPTION

Technological challenges, including low output power/efficiency, high cost, integration/ qualification time, cure quality and materials compatibility, have been surmounted over the years so that today's UV LED solutions are commercially viable.

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 (100–200nm), UVC (200–280nm), UVB (280–315nm) and UVA (315–400nm) – see **Figure 1**).

The spectral output of arc lamps is distributed across the entire UV band, while typical UVA LED outputs fall between 365–405nm, with spectral content at specific bands. The most mature and commonly adopted UVA LED wavelengths are 365nm, 385nm, 395nm and 405nm; the majority of print applications and inks respond to – and are formulated for 395nm.

Adhesive curing remains by far the most conventional application for UV LEDs, which were initially used primarily in smaller area/ spot configurations utilising adhesives. Lower cost of investment and greater availability of compatible materials stimulated success in this market segment. A Yole Développement research report, 'UV LED Technology & Application Trends,' shows implementation



	UVV	UVA	UVB	UVC
Lamp*	40%	45%	12%	3%
365nm LED	1%	99%	0%	0%
400nm LED	97%	3%	0%	0%

Fig. 1: UV Lamp vs. LED Head Spectral Output

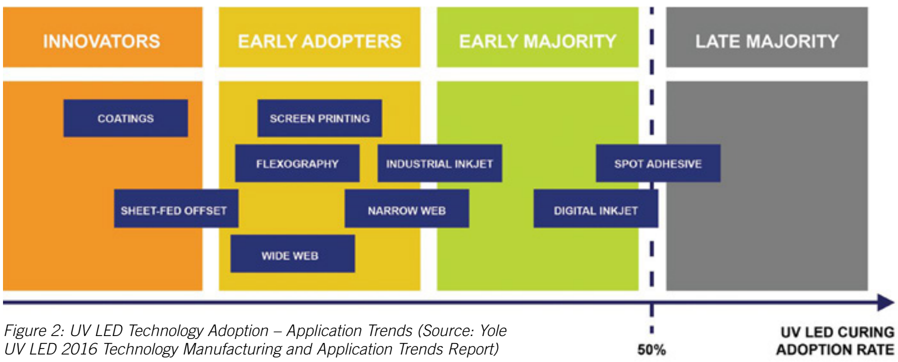


Figure 2: UV LED Technology Adoption – Application Trends (Source: Yole UV LED 2016 Technology Manufacturing and Application Trends Report)

Fig. 3. Excelitas Technologies' OmniCure AC Series of UV LED curing solutions

rates in various applications (see **Figure 2**).

In the printing industry, UV LEDs are most frequently used in inkjet/digital printers, with narrow web close behind. Availability of higher output LEDs has in turn enabled higher-performing UV LED drying solutions, capable of addressing faster, more demanding print speeds.

Increased competition is driving costs down so that LED-enabled solutions are no longer cost-prohibitive for integration onto print platforms requiring a larger area of cure. In addition, 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 supported market acceptance and commercialisation of newer machines using next-generation technology, demonstrating that UV LEDs can successfully replace traditional lamps.

UV LEDS FOR PRINTING

Printing processes have evolved considerably over time from printing presses to modern-day offset, flexography and digital printers. UV printers are a fast-growing sector, where UV LEDs are displacing traditional mercury arc lamps for curing UV inks. Lamps provided an effective solution for many years with broad spectrum and high output at various peak wavelengths in the UVA, UVB and UVC regions. However, LED solutions eliminate the disadvantages of older mercury lamp solutions – such as their shorter lifespans, higher operational costs, reliability issues, uneven curing, and excessive heat generation.

The benefits of low power consumption, long lifetime, environmental benefits, low temperature curing, instant on/off, reduced total cost of ownership, and increased functionality are driving integration of UV LED solutions. Previous barriers to LED adoption have been overcome; these are detailed here/overleaf for reference, with a review of where they stand today.

Output power and efficiency: UV LED efficiency has dramatically improved, and concentrated high-power systems created by grouping arrays of LED die have become more readily available to support higher throughput capabilities. Ongoing enhancements will continue to enable faster operation speeds with no negative 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 long lifetime and efficiencies including reduced power consumption, limited maintenance and downtime, and easy integration. The price premium for LED is also narrowing as costs decline for UV LED hardware and compatible inks. These cost reductions will continue as LED yields continually improve and the overall demand for UV LEDs increases. The economic gains associated with utilising UV LED systems in printers are shortening the payback period.

Materials compatibility: When UV LED curing systems were first introduced, the availability of compatible inks, adhesives and coatings was limited. In fact, there may have been insufficient collaboration between materials providers and curing system suppliers to pre-qualify and optimise the formulations in advance of market introduction. Many of the existing materials formulations did not respond well to the narrow spectrum of LEDs. Costs for the few available UV LED options were prohibitively high, while performance was not yet competitive with legacy lamp formulations. However, the landscape has dramatically

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

Table 1: Benefits of UV LED curing for print applications

changed, and ink formulation has improved, significantly enhancing the materials' responsiveness to UV LEDs. Lower energy doses are needed for faster and more efficient cure, and ink properties have been optimised for enhanced surface cure, finish, and chemical resistance. Costs for LED-tailored materials have come down. As the market further matures, a wider range of proven solutions will become available.

"LEDs can provide a more even and uniform cure than traditional curing solutions"

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 progressing to explore UVC as a possible method for further improving surface cure. LEDs can also provide a more even and uniform cure than traditional curing solutions, which produce uneven irradiation across the cure area. Excelitas' OmniCure AC Series of UV LED curing solutions can provide tight uniformity for consistent and even curing by leveraging a patented technology to individually control LED modules and adjust the output, enabling customised outputs for tighter process control (see **Figure 3**).

ADVANTAGES FOR PRINTERS

In addition to the general benefits of LEDs, UV LED enabled printers also benefit from performance advantages, productivity enhancements, environmental benefits, and easy integration. Some of these key benefits are further highlighted above in **Table 1**.

UV SOURCES AND FACTORS THAT AFFECT A CURE

The UV curing process requires polymerisation of a photosensitive material such as an ink, adhesive or coating. Photo-initiators activate the hardening process, and cross-linking solidifies the material when sufficient energy is received to complete the reaction. In this procedure, spectra content is important. If the LED wavelength does not match the absorption spectra of the photo-initiator, the material will not cure. In addition to delivering sufficient energy and wavelength match, other factors also impact the cure. **Figure 4** illustrates the process of UV curing, while **Table 2** shows key parameters that affect cure.

Fig. 4: UV curing process

	Parameter	Description
1.	Irradiance (W/cm^2)	The minimum threshold required to initiate polymerisation, where peak irradiance is inversely proportional to working distance.
2.	Dosage/Energy Density (J/cm^2)	The number 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.

Table 2: Key UV curing parameters

Very high irradiance on its own will not necessarily produce the best result, as high peak energy may not be not enough to fully cure the material and increasing the exposure time would worsen the results. 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.

SELECTING THE RIGHT UV LED SYSTEM

Determining the right UV source for a given application can be challenging. As mentioned earlier, the specifications alone do not always dictate how well a system will perform in a specific process. The best results are achieved with applications testing and integration to optimise the solution.

Factors to consider when selecting an LED dryer include:

1. Material to be cured
   a. Compatibility with chemistry – is the formulation tailored for UV LEDs?
   b. Photo-initiator wavelength match – 365nm, 395nm, 405nm?
   c. Substrate – are there any special characteristics of the material or known challenges/characteristics to consider?
2. Application requirements
   a. What irradiance and dose are needed to cure the material?
   b. Process speed required
   c. Working distance, cure area/size
   d. Homogeneity needs
3. Installation considerations
   a. Air vs. water cooling – are there any restrictions or preferences for the type of integration? Are chillers & tubing (for water-cooled) available? Are there limitations with airflow (for air-cooled)?
   b. Mechanical size – restrictions in form factor, need for scalability, etc.

CONCLUSION

Compared to traditional lamp solutions, UV LEDs bring enormous benefits to printing processes. Adoption of UV LED curing onto print platforms will continue to increase and will further progress from inkjet and narrow web to screen, flexo and wide web. Constant improvements in UV LED technology and materials formulations will continue to enhance output and performance supporting faster print speeds, and costs will become more competitive to make larger scale printers even more economical. ■

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