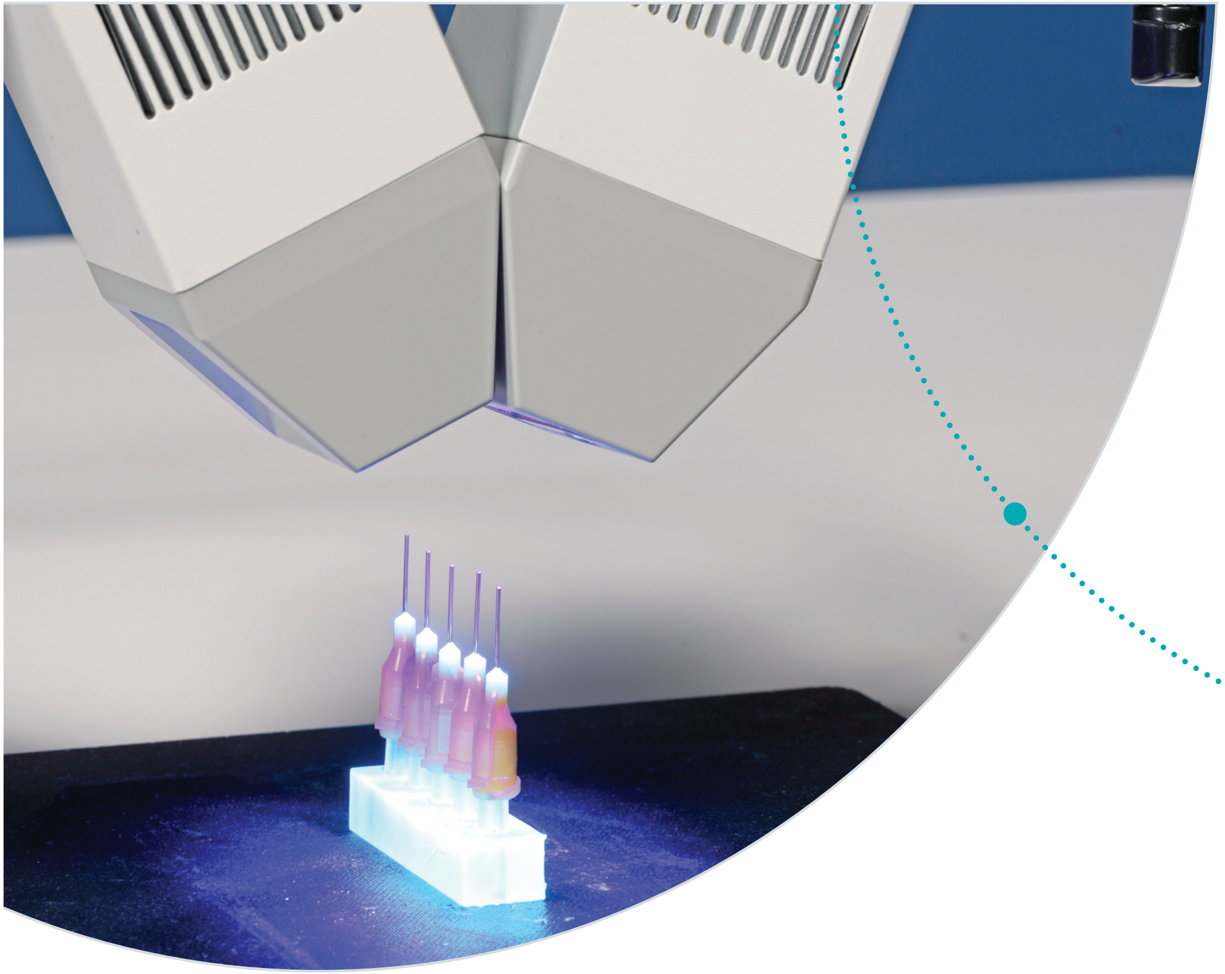

# Ensuring Success When Switching from Conventional Lamp to LED Light Curing Sources

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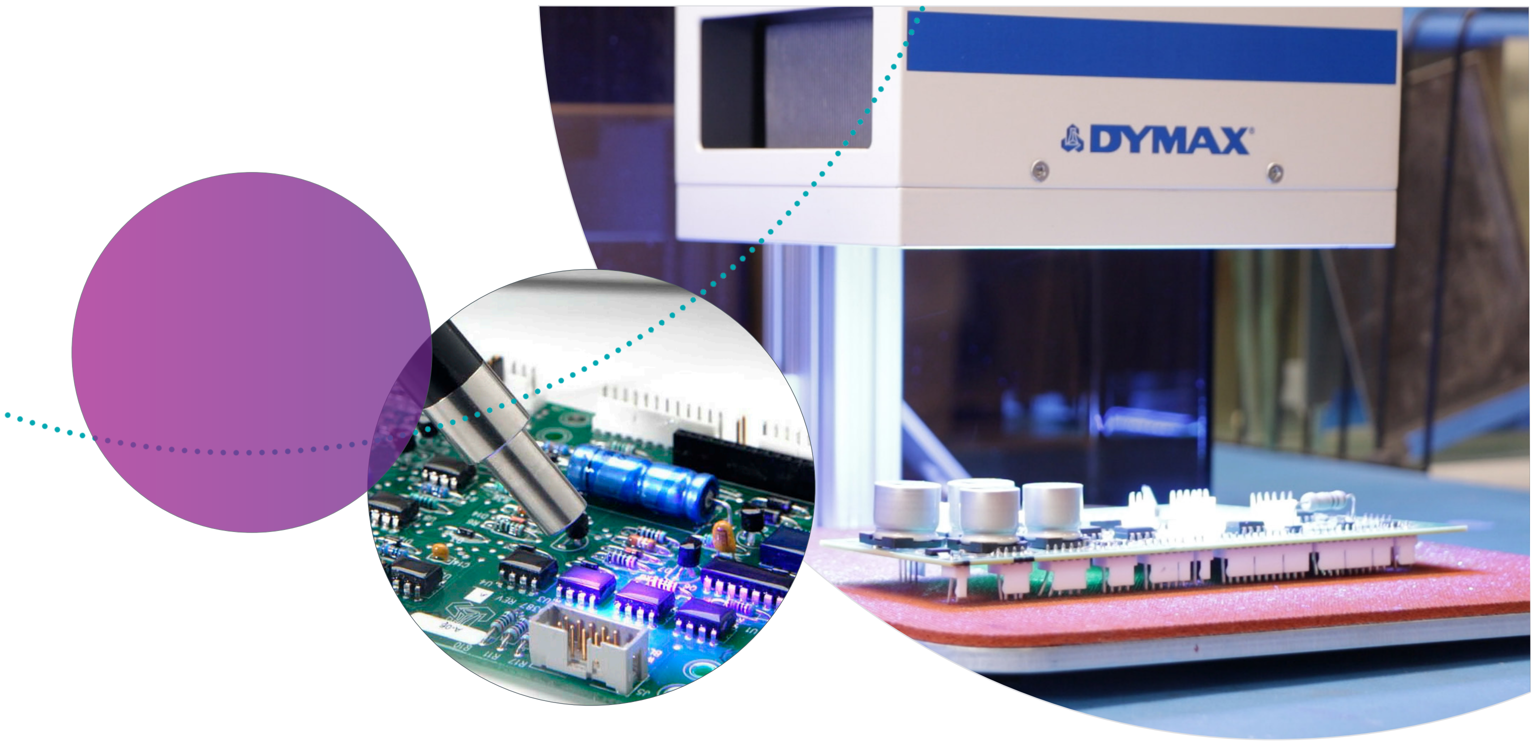



LEDs, or light emitting diodes, continue to gain popularity as a replacement for traditional light bulbs, not only in homes and public buildings, but also for use with light-curable materials (LCMs). The rise of LEDs is attributed to the notable benefits attached to them, and some advantages are associated specifically with light curing.

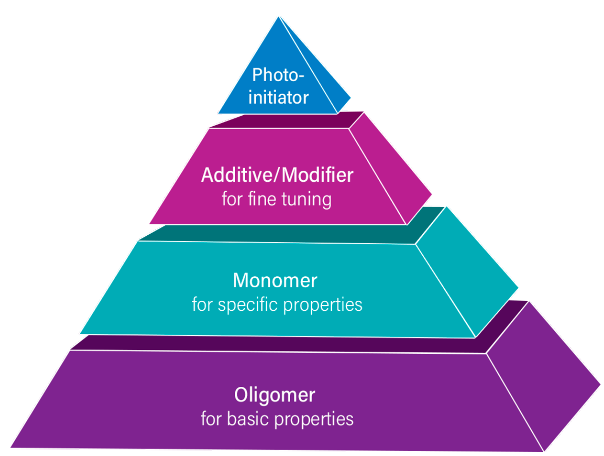
Because of the differences in the technology, however, making the switch from broad spectrum to LED curing energy sources is seldom a matter of simply replacing conventional lamps with LED units and leaving all else the same. To ensure success in curing LCMs with LED light sources, the chemistry of the material must be compatible with the specific LED system chosen, and any necessary application-specific adjustments must be made. What makes LEDs different? Is it really worth switching? What must be addressed during the migration process? Is the change possible? These questions are answered here.

## How LED Curing Works

To understand the benefits and limitations of LED curing, it helps to understand what actually happens during the curing process. When the LED light source emits energy of the correct spectral output for the LCM, the photoinitiator in the LCM fragments to form free radicals and the curing process begins. The free radicals begin to form polymer chains with the acrylates that comprise the LCM until all of the available radicals have attached and become a solid polymer. At that point, the end of the curing process, called termination, has occurred and the LCM has polymerized, or cured.

Most of this is the same as curing with broad- spectrum bulbs, with one critical difference. LEDs emit energy in a narrower portion of the spectrum than broad-spectrum lamps, which means the LCM must be designed to cure within the wavelengths emitted by the particular LED unit. This difference can affect the cure of many light-curable materials, especially when those materials were originally optimized to cure under broad-spectrum light.

**Figure 1.** Typical Components of a Light-Curable Material



## Advantages to LED Curing

There are several advantages to be gained in switching from a broad-spectrum to an LED curing source. For instance, LED systems operate at lower temperatures than conventional broad- spectrum lamps. Because some substrates are sensitive to higher temperatures, curing an LCM fully without damaging the substrate can require multiple passes under a broad-spectrum lamp at lower intensity levels. These multiple passes may be necessary to avoid thermal rise of the substrate or part that can be caused by a single pass of a longer duration. Those extra steps can be made unnecessary by switching to the cooler LED units.

Another benefit of LED curing sources is that they last longer. Although LEDs also degrade in intensity output over time, a typical broad-spectrum spot-cure lamp might last about 2,000 hours before intensity output levels degrade to about 50% of initial levels. Conversely, if properly designed, LED curing units can often provide over 50% of their original intensity output for much longer. Additionally, since LED units turn on instantly with no warm-up, there is no need to leave them on when they are not in use, which further increases their longevity. In all cases, a radiometer is essential for measuring intensity and ensuring a successful light curing process.

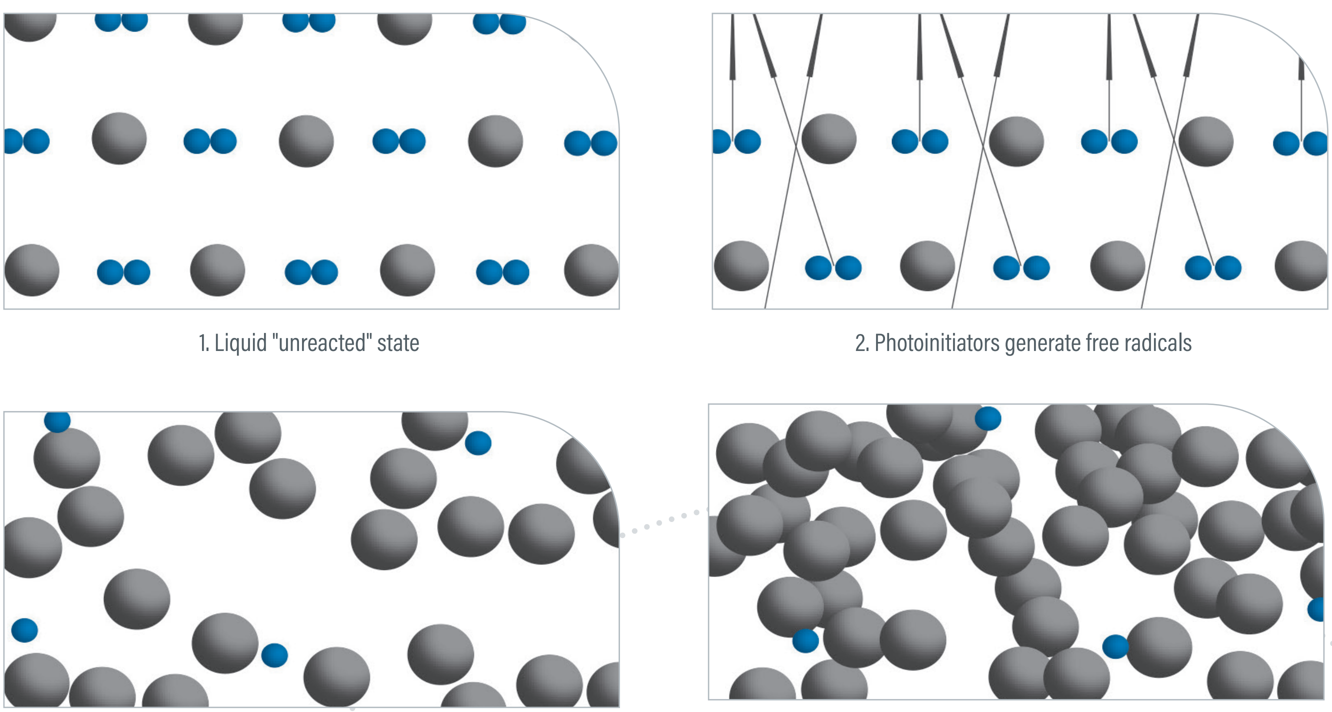
Furthermore, LEDs provide a more uniform distribution of light across the cure area for more consistent results. They are also much more electrically efficient and more environmentally friendly than mercury-arc curing lamps, thus eliminating safety hazards and cutting costs.

## Getting Enough Information to Switch Successfully

Changing from broad-spectrum lamps to LED light sources usually requires more than just lamp replacement. As stated previously, the LCM must be compatible with the selected LED system. Working with a total-solution provider who understands all aspects of the light curing process will be helpful when migrating to an LED curing

**Figure 2.** Polymerization Process

In the light-curing process, the molecules of the LCM split into free radicals, which then begin to form polymer chains with the monomers, oligomers, and other ingredients until all of the ingredients have formed a solid polymer. Upon sufficient exposure to light, the liquid LCM is polymerized (cured).



1. Liquid "unreacted" state

2. Photoinitiators generate free radicals

3. Polymer propagation

4. Polymer termination

source. Such a provider can perform application studies with specific substrates and process requirements to ensure the material's chemistry and the LED system work together for reliable cures and an optimized process.

Why are application studies necessary when so many specifications are already freely available? Unfortunately, the information on manufacturers' data sheets and websites often does not consider all of the variables involved in light curing. Application- specific data is often missing, including information on substrate compatibility and bond-line geometry. Not all adhesive manufacturers clearly state the irradiance and spectral distribution requirements for optimal curing performance. And, data sheets don't typically cover variations that can occur between batches during the manufacturing process; specifically differences in energy peaks that are found in some LED curing units.

While the data sheet from an LED light-curing manufacturer may state that a unit emits an energy peak at a particular frequency, the real spectral accuracy of the LEDs may require testing for verification, as lower-quality LED units have been found to emit light over a wider range of ineffective peak energies. If a material is optimized to cure at a certain wavelength and the LEDs emit a different peak energy from what is necessary, under-curing is a likely result.

## Selecting an LED-Compatible LCM

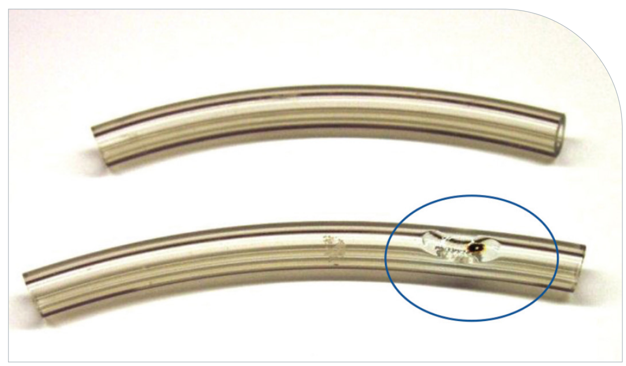
Because an LCM is formulated based on specific requirements for each application, it is typically selected first when setting up a light curing system. Once the LCM has been selected, the optimal curing equipment can be reviewed and chosen based on the LCM requirements, bond-line size and geometry, and other process parameter requirements.

With this in mind, the possibility exists that an LCM that works well with broad-spectrum lamps may need to be replaced for a successful switch to LED curing. That said, some materials do work well with both types of light sources. Before going through the process of selecting a new LCM, and without making any assumptions, first verify whether your existing material will work. Even if it's a material that is compatible with both LED and broad-spectrum lamps, you will likely need to make some process adjustments to ensure success. Otherwise, you may find unexpected differences in post-cure performance.

In the event you do need to select a new material, there are a few things to consider, many of which are considerations whether you're choosing a material for broad spectrum or LED curing. What is the ideal viscosity for your application? How rigid should the material be once it has cured? How well will it bond to the substrate? Does the substrate allow curing energy to pass through? What is the target cure time in your manufacturing process?

For thermally sensitive substrates, the cooler temperature range of LED curing is an obvious advantage. Yet, it is important to remember that even with the narrow spectral range of LED light sources, the energy emitted can still be absorbed by the LCM and the substrate, resulting in a thermal rise.

**Figure 3.** Close-up photo of a part damaged by the heat generated during curing



The photo compares parts exposed to conventional (bottom) and LED (top) light-curing energy sources

Additionally, all adhesives, coatings, and potting material formulations are at least somewhat exothermic, releasing additional heat while curing. The more quickly a material cures, the greater the thermal reaction. It is useful to keep this in mind when determining the optimal intensity and exposure time for a particular application.

If an LED system is especially appealing because of its cool temperatures — whether for small parts, thermally sensitive materials, or energy-absorbing materials — be cautious not to mitigate the benefits by choosing a severely exothermic LCM. If there is some flexibility permitted for the materials comprising the substrates, it is better to choose materials that are thermally stable.

Of course, the primary concern for the overall setup when migrating to LED is that the selected LCM is formulated to work properly with the spectral-distribution characteristics of the LED light source. Yet, given everything to consider, choosing the material first will make choosing the correct LED system much simpler.

## Process Changes for Use With Existing Materials

If an existing LCM for a broad-spectrum setup will also work with an LED system, some processes will likely need to be ad justed. Depending on the variations in energy being emitted from each light source, there may be differences in the strength of the material bonding to the substrates, the hardness of the cured LCM, and the amount of both unit intensity and exposure time necessary to fully cure the material. Additionally, the expected thermal rise of the substrates and the LCM may change with the narrower frequency range emitted from the LED light source.

As is the case when choosing any LCM, it is necessary to determine what process changes must be made to achieve reliable, successful cures, and to ensure those changes will work for your application.

## Choosing the Correct Dispensing System

The dispensing system may need to change any time a new material is selected. It's a matter of what is optimal for the chosen material and the specific application process. For instance, if the chosen LCM is highly viscous, a ram pump will likely produce better results than a pressure pot.

Other considerations include what type of dispense application should be used, such as dot, potting, coating, bead, or sealant; whether the LCM will be applied by a person or a ma- chine; and what size container will be used, whether syringe, cartridge, cylinder, or pail.

**Figure 4.** BlueWave® QX4


The BlueWave QX4 is a high-intensity LED multi-head spot-curing system with a controller and up to four LED heads. The LED heads and focusing lenses can be used in any combination.

## Ensuring Success With Curing Equipment

With the selected LCM in mind, choose an LED system that provides the spectral output and intensity required by the material's formulation for a reliable, successful cure. It is essential that the wavelength of the curing energy emitted matches the absorption spectrum of the photoinitiator in the LCM. It's important to note that will not always be the 365-nm peak typically found in mercury-arc lamps. As stated above, LED light sources emit at different wavelengths, which can affect the cure achieved. Their narrow, bell-shaped wavelength distribution can peak in the UV or visible light range, depending on the LED, and it is that peak energy that will affect the curing ability of the LCM.

For the physical setup of the LED system, wand-mounted and cabinet-mounted LED light sources are options, and each has advantages and disadvantages depending on the application. Wand-mounted LED units are notably smaller and more versatile. Cabinet-mounted systems with standard lightguides take up more space, but allow for efficient energy generation and heat dissipation in the control cabinet, which results in more consistent intensity output with less regulation. These cabinet-mounted systems also allow for retention of fixturing and mounting previously used with conventional lamp-style spot-cure systems.

For either option, the power ratings of LED curing systems should be examined objectively, as they are often used as sales tools without expressing the reality of a system. To interpret power ratings and their associated advantages correctly, it is important to understand them.

Intensity is the measure of electromagnetic radiation in all frequencies or wavelengths at the surface of an object. With light- curable chemistry, that radiation is in the UV or visible range and is measured in milliwatts per square centimeter ($mW/cm^2$).

Radiometers are used to measure intensity. Though they are useful tools, the measurements taken can vary significantly between brands, so the same radiometer should be used for any measurements taken for comparative purposes. If comparing irradiance in prospective light curing systems, use a radiometer that is specifically designed to measure intensity levels at the frequencies emitted from the curing-light source to ensure ac- curate readings.

To eliminate confusion due to variables such as intensity degradation based on distance and divergence angle of emit- ted energy, determine the power level as it will be at the point of cure, rather than at the emitting point of the lightguide or LED wand.

The claimed"power" or"intensity" of LED curing units is often quoted as the power level when it is emitted from the light- guide, but the inverse-square law in radiography and the divergence angle of the energy emitted from the light source both affect how much energy actually reaches the material. The in- verse-square law describes the transmission loss that occurs as the distance between the emitting end of a lightguide and the substrate surface increases. As this distance doubles, the intensity level that actually reaches the substrate/LCM surface decreases by a factor of four. Additionally, the divergence angle of the light from the emitting end of the lightguide determines the degree to which the energy spreads out after it leaves the light source. As the light diverges, the power per unit area on the substrate surface is diminished.

Of course, intensity is not the only factor to consider when choosing an LED system. Data about the spectral distribution should be considered in tandem with irradiance measurements to make adequate comparisons, and both the intensity and the spectral output should be aligned with the requirements of the selected LCM.

Success when switching to an LED system from broad-spectrum lamps depends on careful consideration of all the factors involved, from the LCM to the curing unit selected for the application. With attention to detail and proper compatibility of all components, along with sufficient adjustments to manufacturing processes, it is certainly possible to enjoy a smooth transition to the benefits of LEDs.

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