Optimizing an LED-Curing System

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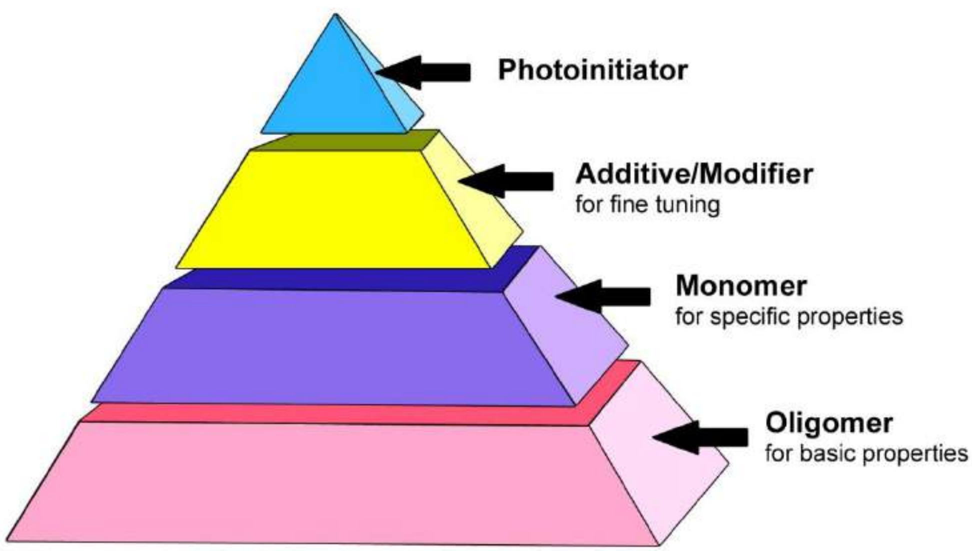
An Optimized LED Curing System is Essential for Process Efficiency

As a relative newcomer to the Light-Curable Materials (LCM) industry, LED-curing lights continue to evolve as an ultimate replacement for the mercury-arc lamps that have been the industry standard for several decades. LED-curing is attracting a great deal of focus in the industry, based on enticing promises of lower operating costs, longer useful life, cooler curing, and "green" attributes. Experts predict LED-curing lights will continue to evolve over time and eventually dominate light-curable coating, resin, potting, and assembly applications in industries such as medical, electronics, automotive, aerospace, appliance, and others. This evolution isn't without its challenges. As many manufacturers have experienced, simply inserting LED curing into an already-existing process is not a guarantee of success. This assumption of interchangeable parts can result in frustrating performance failures that ultimately cost manufacturers time and money. An often overlooked fact is that it is absolutely essential to match the wavelength of the LED-curing lamp with the absorption spectrum of the LCM photoinitiator in order to yield the required performance characteristics and insure a sound investment. This successful pairing is dependent upon having an optimized solution in which a cohesive combination of compatible LCM and LED-curing system is established.

What are the Components of a LCM?

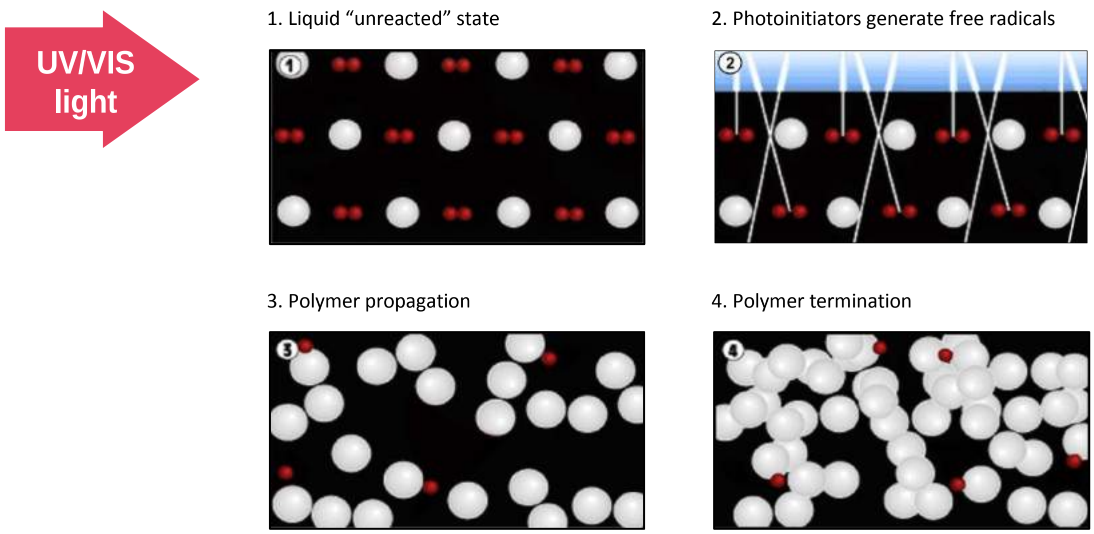
Typical components of a light-curable material:



How Does the UV Light-Curing Process Work?

The UV light-curing process begins when the photoinitiator in the LCM is exposed to a light-energy source of the proper spectral output. The molecules of the LCM split into free radicals (initiation), which then commence to form polymer chains with the monomers, oligomers, and other ingredients (propagation), until all of the ingredients have formed a solid polymer (termination) (See Figure 1). Upon sufficient exposure to light, the liquid LCM is polymerized (cured).

Figure 1. *Light-Curing Process*



What are the Benefits of LED Curing?

LED curing offers several advantages over broad-spectrum arc lamp curing including:

- High electrical efficiency and instant on/off capability for lower operational costs
- Long service life that eliminates bulb replacement and reduces maintenance costs
- Compact equipment that reduces the size and cost of the light-curing system
- Cool light radiation extends curing capabilities for heat-sensitive substrates
- "Green" attributes eliminate mercury and ozone safety risks and handling costs
- Narrow wavelength spectrum emission minimizes substrate thermal rise

These advantages help make manufacturing more efficient and are driving the transition from broad-spectrum arc lamp curing to LED curing.

How Can I Select the Right System for LED Curing?

In order to implement LED-curing technology into any application, it must first be determined if all aspects of the process are conducive to this approach. Substrate material, LED curing compatible formulation, cure speed requirements, and post-cure bond characteristics are all key to successful results.

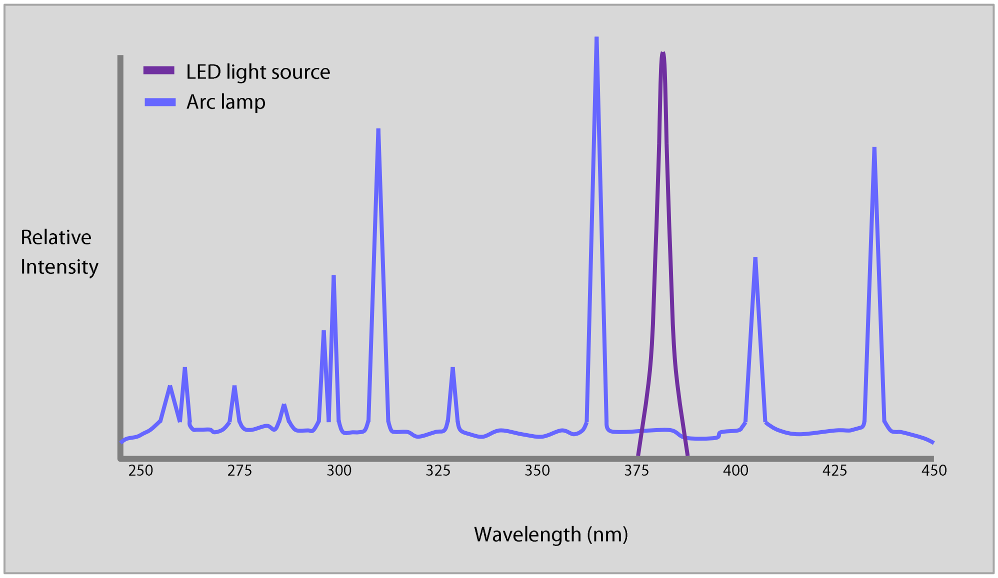
How Is The Right System Selected?

Phase #1 Adhesive	Phase #2 Dispense	Phase #3 Curing Equipment
In selecting the adhesive, the following performance characteristics and application conditions need to be identified. • LED curable • Viscosity (flows or thixotropic) • Durometer (rigid or soft) • Adhesion properties to your substrates • Is the substrate UV blocking? • Cure time meets production requirements	In selecting a dispense system, the following criteria needs to be established. • Type of dispense application (dot, potting, bonding two substrates, coating, bead, or sealant) • Will the adhesive be applied manually or with automation? • Is this a new or existing dispense system? • What size container will the adhesive be dispensed from? (syringe, cartridge, cylinder, or pail)	In selecting the curing equipment, the following characteristics need to be identified. • Does the wavelength of the equipment match the adhesive? • Do you need a spot lamp, flood lamp, or conveyor system? • Wand mounted or cabinet-mounted LED light source?

Can I Simply "Drop" LED Curing into My Current Process?

While a direct replacement of your broad-spectrum arc lamp with an LED-curing light is possible, an evaluation of many other process parameters is essential. An adhesive formulated for an arc lamp might perform poorly when cured with an LED light source. The wavelength distribution emitted by an arc lamp and an LED is quite different (Figure 2) and direct replacement of an arc lamp spot-curing system with an LED spot-curing system—without evaluation and process adjustment—can result in substandard bond performance. Differences in LED wavelength distribution and intensity necessitates the evaluation (if not formulary modification) of the chemistry and curing-energy dosage. There are some adhesives that provide the flexibility to use both types of light sources without changes to the process. Verification is strongly recommended to ensure successful results. Replacing an arc lamp with an LED light source could be as simple as modifying curing parameters of an existing process, or more complex such as changing of the adhesive to one properly formulated for the spectral distribution characteristics of the LED light source.

Figure 2. *Various adhesive bond-performance results when cured with a conventional arc lamp and LED light sources*



It is essential to match the wavelength of the LED-curing lamp with the adhesive photoinitiator's absorption spectrum. This pairing is dependent on having an optimized solution.

How Does Power Impact Performance?

A thorough review is required to properly interpret the claimed power ratings and associated advantages of LED-curing systems. Qualifying direct comparisons of power can be achieved by focusing on the following areas:

- <u>Power Expressed as Intensity</u>

  Intensity is the measure of electromagnetic radiation in all frequencies or wavelengths at the surface of an object. In reference to light-curable chemistry, the electromagnetic radiation is in the UV or visible range wavelengths. Standard units of measure of intensity are milliwatts per square centimeter (mW/cm^2).

- <u>Intensity at the Surface of the Substrate</u>

  Determining the intensity at the substrate surface removes process variables and misinformation such as claimed power, transmission losses, and lens variables such as divergence angle. Intensity is measured with a radiometer. When measuring intensity, it's important to consider that significant variation can exist in the measurements depending on the brand of radiometer. When comparing irradiance among prospective light-curing systems, using a radiometer that is specifically designed to measure intensity levels at the frequency(ies) emitted from the curing-light source is recommended. At the very least, the same radiometer should be used for all comparative measurements. Incorporation of a radiometer that is specifically designed to address the source frequencies will ensure accurate readings.

- Claimed Power Versus Useable Intensity

  The claimed power of LED-curing lights is almost always quoted as power emitted from the lightguide. However, two factors influence how much radiation or light actually reaches the substrate surface: (1) the divergence angle of the energy emitted from the light source and (2) the inverse-square law in radiography.

- Divergence Angle Decreases or Increases Power

  The emitting end of the lightguide is the final optical component in the light-delivery path. The divergence angle determines the degree to which the energy spreads out after it leaves the light source. As the light diverges, the power per unit area (expressed as mW/cm^2) on the substrate surface is diminished.

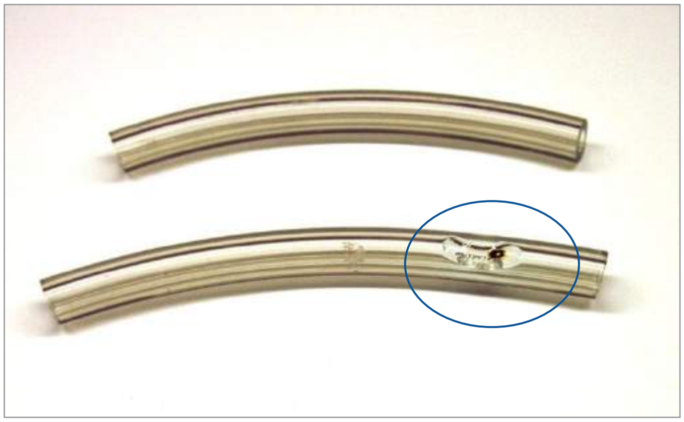
- Inverse-Square Law

  The inverse-square law describes the transmission losses that occur due to the distance between the emitting end of the lightguide and the substrate. Less power is transmitted to the substrate surface as the emitting end moves further from the substrate. As you double the distance between the emitting end of the lightguide and the substrate, the light intensity or energy impinging on the substrate decreases by a factor of 25 percent. This principle illustrates why the most valuable information is determining the intensity level at the point of cure. Delivered power or intensity provides only a partial comparison of LED light-curing systems. Spectral distribution of the prospective light sources must also be evaluated. Furthermore, the spectral output and intensity must be aligned with those required by the adhesive formulation. It is spectral-distribution information combined with irradiance measurements that enables a relative comparison among light-curing systems.

Can I Use LED Curing with Heat-Sensitive Substrates?

LED sources do not generate or emit the multiple frequency irradiances across the spectrum as found in a conventional lamp. LEDs operate in a narrow spectral range that is specific for adhesive curing, resulting in “cooler” curing characteristics. However, when energy from an LED source reaches the substrate or chemistry being exposed, it has two options. Depending on the absorption characteristics of the irradiated materials (substrates and chemistry), the energy may be absorbed or reflected. Energy that is absorbed will generally cause some level of thermal rise of the materials being exposed. Even under the “cool” energy supplied by an LED light source, the substrate and the chemistry can experience a thermal rise that may alter their structure and influence bond performance. Some light-curable chemistries are exothermic and release heat during the curing process. This heat reaction can add to the heat generated by radiation adsorption.

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



The image above compares parts exposed to conventional (bottom) and LED (top) light-curing energy sources. Exposure parameters:

Intensity: 8,000 mW/cm^2

Distance: 10 mm

Exposure Time: 20 seconds

Consider the impact of heat in developing the bonding process for an assembly application. Applications impacted by heat generation include those involving small parts, thermally-sensitive materials, energy-absorbing materials, and adhesives, coatings, or potting materials that exhibit exothermic curing. If your substrate absorbs any frequency of energy, you may choose to use an LED light source. If your application has flexibility in terms of the materials of construction, select materials which are thermally stable.

Conclusion

LED-curing technology, by offering significant cost savings and efficiencies in adhesive, potting, coating, and assembly applications, will eventually become the industry standard; however, by itself, is only part of the picture. The most seamless homogenization of the technologies required for a specific application needs to insure that the component substrate(s), adhesive, dispense methodology, and curing approaches are all in optimized harmony with each other. A cohesive combination of compatible LCM and LED-curing system must be established. Selection of equipment and LED-curable chemistries should derive from real-world application studies.

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