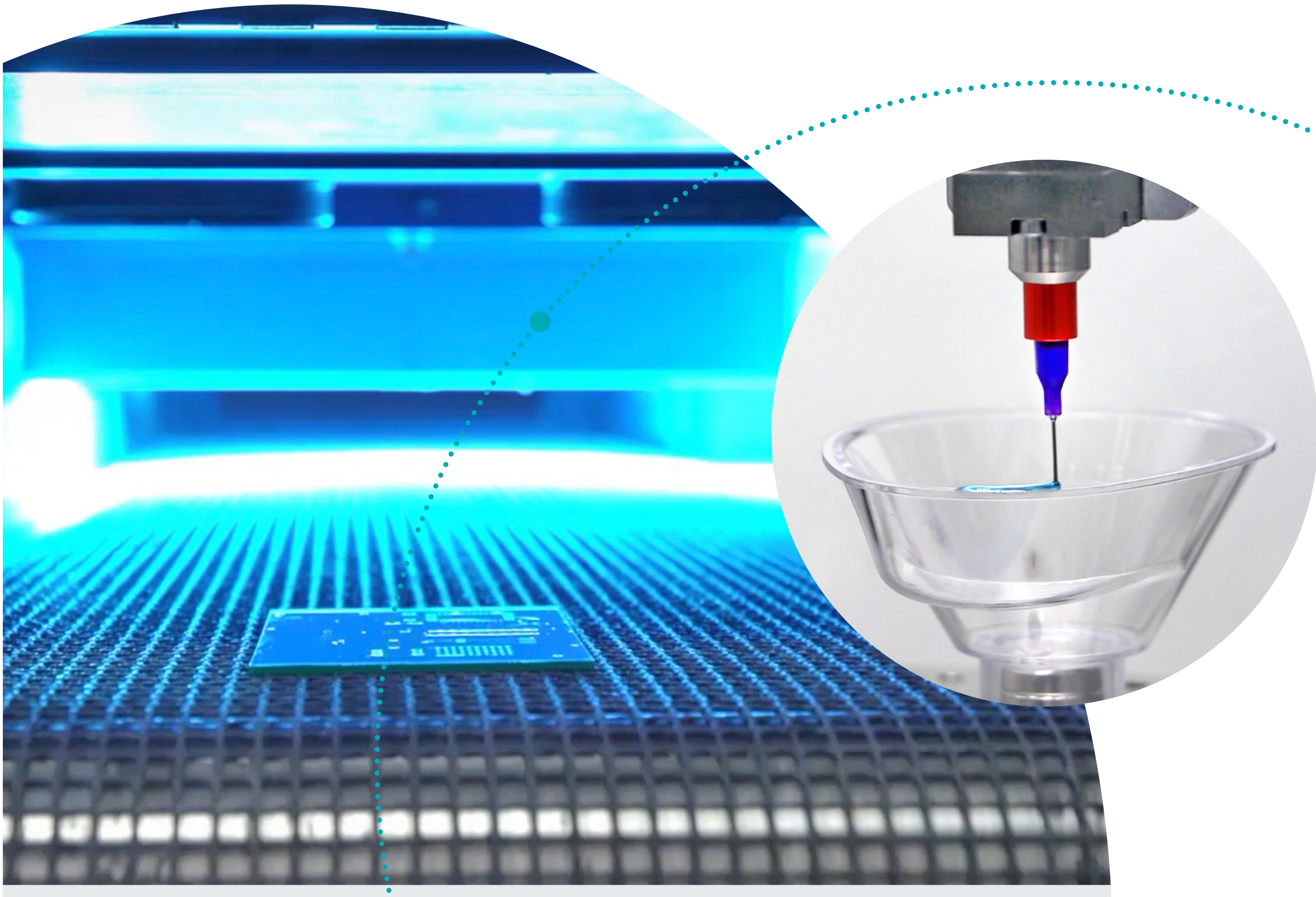
GUIDE TO SELECTING AND USING
LIGHT-CURABLE MATERIALS



Introduction

Light-Curable Materials* (LCMs) can offer users tremendous benefits over other types of materials. Over the last 40+ years, many advances have been made in material and curing equipment technology and thousands of companies, worldwide, now use light-curing technology to assemble and protect their parts.

The purpose of this guide is to inform current and prospective users about LCMs and curing equipment so that they may make the best choice in the selection and use of this technology.

The guide is not intended to answer all questions with respect to LCMs and equipment. For more information, contact your Dymax Sales Representative, Dymax Application Engineering or visit the Dymax website. Literature can be downloaded directly from the site.

* Light-Curable Materials, or LCMs, is a general term for the technology described in this guide. Past papers and literature authored by Dymax and other companies have more specifically referred to this technology as Light-Curing Adhesives, or LCAs. Recent advances in light-curing technology have created new classes of materials, such as thick layer coatings, gaskets, sealants, potting and encapsulating systems and dome coatings. Throughout this guide, LCMs will be used to better describe the broad range of products now available.

Dymax Overview

Dymax provides advanced assembly solutions based on its proprietary line of value-added specialty adhesives, coatings, and UV-curing equipment.
The company's mission is to be a leading source of technologically advanced, high-performance adhesive solutions designed to enhance manufacturing processes through higher quality and greater efficiency.

Dymax has over 40 years of experience providing leading manufacturers with customized formulations to meet unique application requirements, primarily for assembly and protection. Dymax does not manufacture UV inks or varnishes. Coating applications typically range from 0,05 mm - 6 mm.

Thin Layer Curing Resins	Thick Layer Curing Resins
Inks, clear overprint coatings, floor coatings, photoresists and decorative coatings	Structural adhesives, sealants and encapsulants
 Typical Thickness 5-50 microns (*special applications to 300 microns)	 Typical Thickness .05 to 6 mm typical 

Since its founding in 1980, Dymax has established a market-leading position in its primary served markets:

- Aerospace
- Appliance
- Automotive
- Electronics
- General Industrial
- Medical Device
- Optical
- Telecom
- UV-Curing Equipment

The company offers a full line of high-performance materials, which allow its customers to reduce processing time and per unit production cost as well as improve overall product quality in a safe and environmentally friendly manner. Primary product trademarks are listed below:

BlueWave®	Curing Equipment
Encompass®	Materials formulated with Ultra-Red® and See-Cure technology
Light Weld®	UV-Curable Materials
MD®	Medical Adhesives
Multi-Cure®	Light-Curable Adhesives with Secondary Cure
SpeedMask®	Light-Curable Masks
Ultra Light-Weld®	UV/Visible Cure Materials
Ultra-Red®	Red Fluorescing Materials

Why Choose a Light-Curing Process?

The most common answer to this question is "speed," as most light-curable materials cure fully in 1-30 seconds. "Speed" provides dramatic cost reducing benefits:

- **Shorter cycle times** – Less work-in-progress and shorter lead times.
- **Increased capacity** – Bonding steps that may have been bottlenecks with slower systems are no longer bottlenecks.
- **Less floor space** – Elimination of ovens, humidity chambers, conveyors and racks.
- **Simple and better automation** – Indexing time on a line is reduced, inspection can be completed on-line, and the complexity of fixturing during the curing process is reduced.

Often overlooked, but many times more significant than speed, the **one-component** nature of light-curable materials provides additional cost reducing benefits:

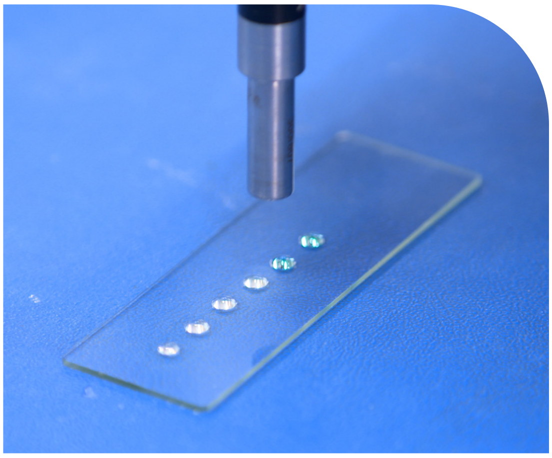
- **Lower capital costs** – Dispensing systems for one-component materials cost significantly less than systems for two-component materials.
- **No pot life problems** – Two-component systems generally have pot lives (the time between when a multiple component system is mixed and when it is dispensed or thrown away) measured in minutes or hours. Two-part systems that cure in less than 30 minutes have pot lives of less than 10 minutes. As a result, two-component systems, especially those with shorter cure times, require frequent purge cycles and often result, regardless of operational precautions, in clogged mixing elements.
- **No hazardous waste** – Material purged from a system that remains uncured is usually classified as hazardous waste. The A and B components of a two-component system are hazardous when not fully cured. Since Dymax products are one component systems, there is no off-ratio mixing or purging. You can cure 100% of your product, thus eliminating waste.

Of course, product performance is a critical factor in selecting between different technologies. LCMs offer greater adhesive strength to a wider range of substrates and exhibit a wider range of other physical properties than any other comparative technology. (See the section "Choosing the Right Material").

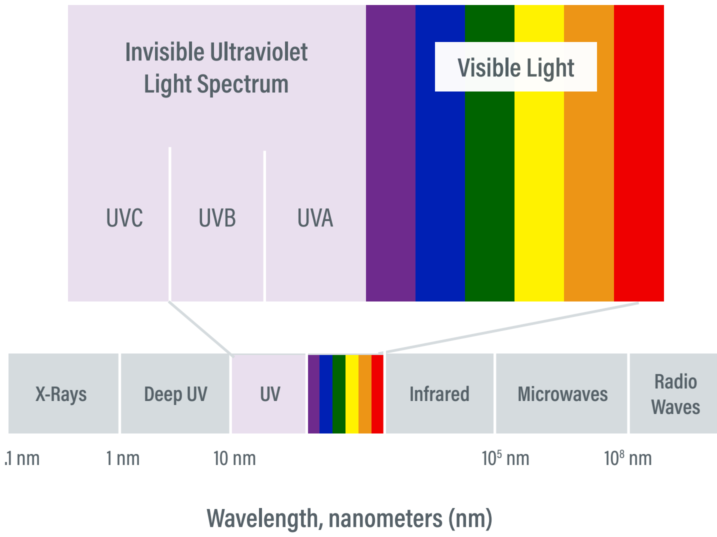
How Do LCMs Work?

LCMs utilize energy provided by ultraviolet (UV) or visible light to start a curing reaction. In all practical systems, light emitted by a source reacts with a photoinitiator sensitive to UV light or UV and visible light. Different LCMs utilize photoinitiators sensitive to different ranges of UV and visible light. It is therefore important to match the material being cured with the source of light being used to cure the LCM.

Most light-curable resins used for assembly and thick layer curing (from 0.003" - 0.25+", or .05 mm - 6+ mm), including all LCMs manufactured by Dymax, utilize a broad spectrum of UV light with a concentration in the UVA range to achieve cure. Some materials also use visible (blue) light for cure. The simplified electromagnetic spectrum at the bottom of the page illustrates the ranges of light useful for curing purposes.



ELECTROMAGNETIC SPECTRUM



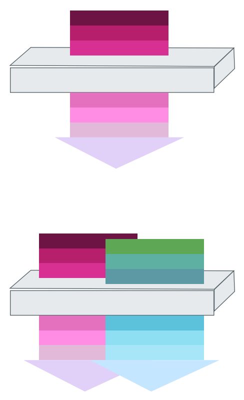
Visible (blue) light can be an important feature in many cases because:

- Visible light cure allows materials to be cured between substrates that block UV light but transmit visible light, i.e., many plastics.
- Visible light cure increases the cure speed of LCMs since a greater portion of the electromagnetic spectrum is available as useful energy.
- Visible light penetrates through LCMs to a greater depth, enhancing cure depth.

Factors influencing the cure speed of LCMs include (in no particular order):

- Light intensity on the LCM (will vary with thickness)
- Light wavelength present at LCM
- Photoinitiator sensitivity to light wavelength
- LCM resin composition

Curing bulbs (also called lamps) vary in their spectral output. Sometimes filters modify the spectral output of a curing system. Dymax equipment is optimized for curing Dymax as well as most other light-curable adhesives and coatings. The important thing to remember is that the output of a curing lamp must be matched to the absorption of the photoinitiator in LCMs.



What are the Basic Types Of LCMs?

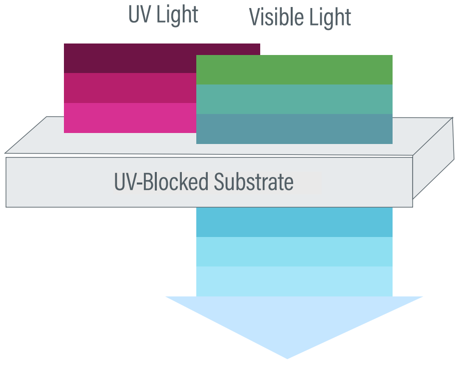
There are two basic types of LCMs: acrylates and epoxies. Dymax manufactures both.

Acrylate Systems

The term "acrylate" is a shorthand term for a broad range of materials including acrylates, methacrylates, and similar functional groups. Acrylate systems react when exposed to UVA light (always) and visible light (in many cases). The materials exhibit a very broad range of properties. Depending on additives, acrylate systems can be produced which are colored (i.e., red, blue, or black), opaque, fluorescing (often a requirement for in-line inspection), or thermally conductive. The physical properties of acrylates can be varied more than epoxies. These properties include adhesion, viscosity, durometer, and appearance. Since they can be made to cure with visible light, fluorescing and red or blue acrylate formulations are common.

Cure speeds with acrylate resins depend on formulation specifics, and of course, on the intensity and nature of light used to cure them. Practical cure speeds range (mostly) between 0,5 - 15 seconds. Depth of cure also varies with formula and process specifics. Typical cure depths range from 2,5 mm - 15 mm.

Acrylate LCMs can also be made to react with heat or activator. This is useful when light can not be used to cure the material due to the presence of a "shadow." Acrylate LCMs typically can not be cured with moisture or air. Cure options are shown on specific Product Data Sheets.



Visible light-curing materials are useful when working with UV-blocked but visibly transparent substrates


UV/Visible potting to 15 mm with acrylate LCMs

Surface tack is sometimes observed with acrylate LCMs. Surface tack is caused by the interference of atmospheric oxygen with the free radical cure mechanism on the surface of acrylate resins. In most cases, surface tack can be eliminated by altering the curing process (greater light intensity, longer cure time, or a slight adjustment in the wavelength of light used). Some acrylate LCMs will not cure tack-free. Most of these products were designed for applications where the LCM is not exposed to air, i.e., in bonding applications between two substrates.

Epoxy (Cationic) Systems

Epoxy LCMs, sometimes called "cationic systems" by virtue of the type of photoinitiator employed as opposed to the chemical make-up of the resin, comprise the second main class of LCMs. The range of properties which can be achieved with epoxy LCMs, is somewhat narrower than that achievable with acrylate LCMs. Nevertheless, epoxy LCMs may be formulated to exhibit a few advantages over some acrylate LCMs. These include:

- Tack-free cure (no oxygen inhibition)
- Superior adhesion to certain substrates

Development of full properties of light curing epoxies often takes longer than for light curing acrylics. Heat is sometimes used to accelerate cationic LCM cure. Cationic LCM cure is impeded by moisture/humidity.

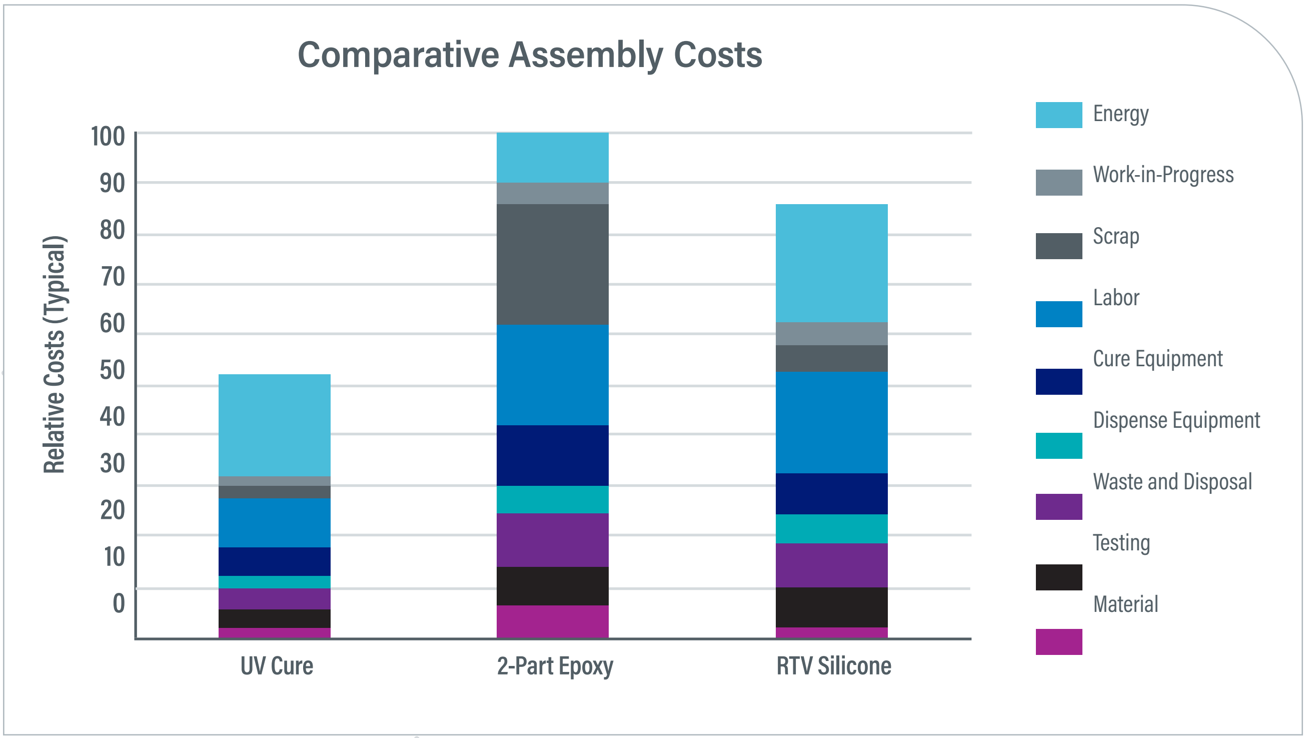
Is Light Curing Right for My Application?

Three factors are important in answering this question; performance, the presence of shadow areas around LCMs, and process costs and benefits.

Performance requirements are normally the most important consideration in selecting an adhesive or coating. Dymax products excel in a number of dimensions. Product characteristics are discussed in later sections.

Shadow areas, places where a LCM or coating may intentionally or unintentionally be applied, limit the number of applications where LCMs can be utilized. Secondary heat cure can sometimes be used to assure cure in shadowed areas.

Very often, LCMs are chosen for an application to reduce production costs. There are numerous ways in which a light cure process can lower cost. The chart below shows relative manufacturing costs of three common assembly methods. Material costs usually comprise a small portion of total production costs.



How Do I Choose the Right LCM for My Application?

The following sequence is recommended to choose the right material for your application. Working through this sequence is best done in consultation with a Dymax Application Engineer or Sales Representative.

Step 1. Adhesion. In most situations, the first consideration in choosing any assembly material is adhesion. Whether the application is bonding, coating, encapsulating, sealing or potting, candidate materials must demonstrate adequate adhesion to applicable substrate(s). Substrate selector charts are useful for selecting an initial group of product candidates.

Choosing material candidates based on adhesion:

- Determine candidates from substrate or product selector guides.
- Evaluate the adhesion of candidates using a pick test on the substrates to be bonded. (Your Dymax representative can show you how to do this simple test.)
- Evaluate LCM adhesion under the real life stresses the part will experience. It may be necessary to over stress the bond area to accelerate candidate testing.

All adhesives and coatings are weakest when peel forces are applied. If the part and joint will be subjected to peel forces, material evaluations should be conducted taking into account anticipated forces and use conditions.

Step 2. Rheology. Next, consideration should be given to how the light-curable resin will be applied and how the material will flow once it is applied. High viscosity materials resist flow more than low viscosity materials. High thixotropy materials also show greater resistance to flow than low thixotropy materials. High thixotropy materials become thinner when they are sheared. Products that do not thin with shear are called Newtonian. Gels have the properties of high viscosity and high thixotropy. These properties are desirable when negligible material flow after dispensing is required. Dymax utilizes an intuitive nomenclature for distinguishing different rheologies. The letters appear as suffixes on standard product names:

VLV	Very Low Viscosity
LV	Low Viscosity
T	Thick
VT	Very Thick
Gel	Non-Sag Gel

The table below lists some common materials along with their approximate viscosities and rheology.

Table 1. Viscosity Illustrations of Everyday Items

Viscosity (cP)	Every Day Item	Rheology
1	Water	Newtonian
100	Vegetable Oil	Newtonian
2.500	Maple Syrup	Newtonian
10.000	Corn Syrup	Newtonian
25.000	Tooth Paste	Thixotropic
250.000	Peanut Butter	Thixotropic

Step 3. Physical Properties. Next, consideration should be given to other desirable physical properties. Normally, these include hardness, elongation, modulus, environmental resistance, appearance, etc. Physical properties are described on individual Product Data Sheets and can vary over a very wide range from one LCM to another. Besides offering a broad range of standard products, Dymax provides custom formulation services to meet specific application requirements.

Physical properties over the Dymax product range include:

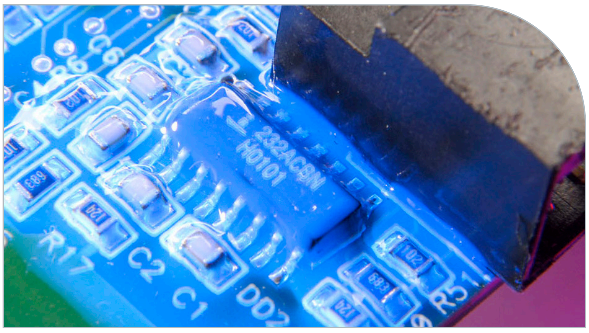
Color	Colorless to straw, or colored; blue, black, red, fluorescent, etc.
Clarity	Crystal clear to opaque
Viscosity	50 cP to 1.000.000 cP
Durometer Hardness	Shore 00-40 to D-90
Tensile @ Break	60 to 12.000 psi
Elongation @ Break	0% to 750%
Modulus of Elasticity	50 to 4,000,000 psi
Water Absorption (24 hours)	0,01% to 140% & water soluble
Linear Shrinkage	0,1% to 20%
CTE (varies with temperature)	43 to 600 ppm/°C
Thermal Limits	-60°C to 200°C
Refractive Index (ND20)	1,419 to 1,585
Cure Speed (source dependent)	0,1 to 90 seconds
Cure Depth	1 mm to 25 mm

NOTE: Physical properties are sometimes linked. All combinations of properties cannot be achieved in a single formulation.

Resistance to real-life stresses is an important criterion for choosing a material. In particular, temperature cycling, maximum operating temperature, solvent resistance, resistance to light (especially sunlight) and moisture are often critical factors in selecting an LCM. Dymax products have performed well under common stress conditions in thousands of applications. Different Dymax products excel in different ways, depending on formulation specifics. Product Data Sheets provide some guidance in this area. However, each application is unique and there is no substitute for real-life test results on actual parts subjected to the stress conditions that the parts will see over their expected lifetime.

Step 4. Cure Requirements. The cure requirements of the material should be considered. Most importantly, the question of whether shadow areas are present should be taken into account. If shadow areas are present, there are three options:

- Eliminate shadow areas by:
  1) Choosing a viscosity and/or dispensing system that keeps the LCM out of shadows or,
  2) Changing the substrates so that they do not block light
- Employ a secondary cure mechanism, i.e., heat or activator.
- Choose an adhesive system other than one that cures with light.



Surviving harsh environments

Bonding difficult substrates

Step 5. Specifications. Industry specifications or requirements may be a make-or-break consideration. For example, USP Class VI or ISO 10993 designation for medical grade adhesives, IPC 830 qualification for conformal coatings, or UL94 V-0 designation for consumer electronics may be required. Where these standards apply, information is provided on product selector guides and data sheets.

What Curing Equipment Should I Consider for My Process?

Dymax offers a full range of standard curing equipment and LCMs that are matched for optimum curing efficiency. Your curing equipment choice should be based on the requirements of the application, the LCM and the desired process parameters. Because Dymax manufactures both LCMs and curing equipment, Sales Representatives and Applications Engineers are available to consult with you on the best match of curing equipment and LCM.

Factors influencing curing equipment selection:

- Batch or continuous processing
- Size of curing area
- Desired process speed
- Surface exposure to O_2
- Depth of cure
- Cure chemistry of the resin
- Adaptation to an existing production line

There are a number of basic types of UV systems to meet most processing requirements. Each offers a different combination of three main features - spectral output, intensity or dose and light shape to affect cure. Spectral output and its importance to UV curing resins have already been discussed. Intensity or irradiance is the power arriving over a unit of area in any given instant. Intensity or irradiance is normally expressed in W/cm^2 or mW/cm^2. Generally speaking, intensity is important because the higher the intensity the faster the cure of the adhesive or coating. Establishing the minimum intensity needed to cure a resin in a specified time is critical to a successful UV curing process.

Cure time or the length of the exposure of the adhesive or coating at a given intensity is also a critical curing parameter. The product of intensity and cure time is called radiant energy or dose, and is the amount of energy that has arrived at a surface over a period of time. This is measured in Joules per square centimeter or J/cm^2.

As discussed earlier, the light used to cure LCMs spans a range of wavelengths. Both intensity and dose are normally expressed in terms of a particular band of radiant energy. For example, a light source that emits UVA and Visible light may yield light intensity of 20 W/cm^2 in the UVA range and 20 W/cm^2 in the Visible range for a total of 40 W/cm^2 of radiant energy.

Finally the shape and size of the light bear upon its usefulness for a particular application. Typical shapes include small spots of light typically 6 mm in diameter, flood lamps that produce a large square of light or "foot print" and focused beam lights that produce a high intensity beam that is typically 2,5 cm x 15 cm. Dymax offers curing systems in all three configurations.

- UV Spot Systems
- Flood Curing Chambers
- Flood Systems Mounted on Conveyors or Indexing Tables

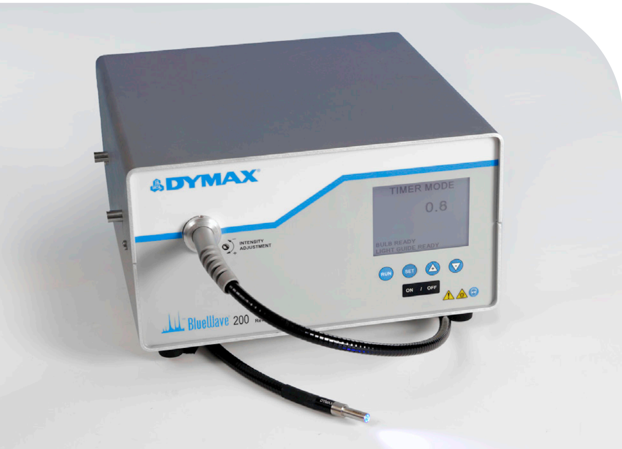
Spot Curing Systems

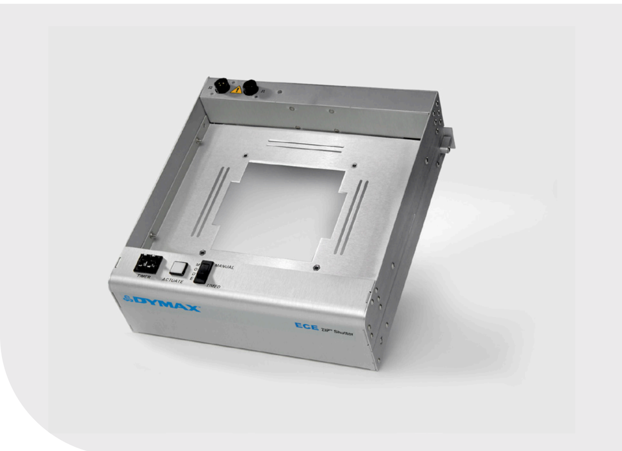
Spot curing systems have evolved significantly over the last 20 years. Bulbs (lamps) last longer. Current systems have more power, more closely match the photoinitiators used in most LCMs, and incorporate a number of other features for more reliable processing. Spot intensities range from 4.000-20.000 mW/cm^2 at the lightguide tip (measured between 320-390 nm). A variety of accessories and attachments are available from multi-pole lightguides to rod lenses where cure area can be expanded to as much as 25 cm^2 in some cases.

Dymax offers several spot-curing models, including the BlueWave® 200 and BlueWave® MX-150. A large number of accessories are available for use with these systems.

Flood Curing Chambers

Flood systems are used to cure relatively large areas and are especially adaptable to conveyors. Flood systems are available with dimensions of 20 cm x 20 cm at intensities of 30-70 mW/cm^2 and 12.5 cm x 12.5 cm with intensity range of 150-225 mW/cm^2. The choice of curing system will depend on the size of the area to be cured and the speed at which cure must be achieved. Flood systems can be mounted in chambers or workstations, on conveyors or integrated into customized systems. Many curing options are available. Please contact your Dymax representative for more detailed information.





What are My Options for Material Application (Dispensing)?

Depending on the application and the adhesive or coating, LCMs can be applied in many ways: dispense, spray, roll coat, screen print, stencil print, brush, etc. Dymax adhesives and coatings are formulated to meet most dispensing equipment requirements and are available in package sizes ranging from 3 mL syringes to 200-liter drums. The most common package sizes are:

- Syringes 10 mL, 30 mL
- Cartridges 170 mL, 300 mL, 550 mL
- Bottles 250 mL, 1 liter
- Pails 15 liters
- Drums 200 liters

For more information on a material application method appropriate for your application, contact your Dymax representative.

How Do I Maintain Process Consistency?

Process variations can be the result of changing environmental conditions, changes in parts, the presence of contaminants, the condition of the curing system, and lot to lot variability in the LCM. The following is a review of common process variables and the effect these may have with respect to performance realized. These variables apply to all adhesive and coating systems, not just those supplied by Dymax.

Environmental Conditions. Temperature changes may impact material viscosity. Viscosity decreases as temperature increases. To avoid variables in dispensing, particularly the quantity applied and the rate of material flow after application, store Dymax materials under relatively constant temperatures (10ºC-32ºC). If this is not possible, make sure the materials equilibrate to a relatively consistent temperature prior to use.

Changes in Your Parts. Incoming inspection should assure that parts conform to specifications and exhibit minimum variability. Automated production systems rely on precise timing. Variability in part dimensions can significantly impact the ratio of material applied to the area to be covered. Even more important, variability in the surface characteristics of a part can dramatically affect the adhesion of a Dymax (or any other supplier's) material to the part.

Contamination. As with all coatings and adhesives, adhesion (and performance) can be significantly compromised by surface contamination, e.g., fingerprints (oils), machine oils, release agents, dust/dirt, etc. While Dymax products are exceptionally forgiving with respect to contaminants, efforts should be taken to minimize surface contamination whenever practical. Isopropyl alcohol, IPA, is recommended for cleaning contaminated surfaces. Acetone and MEK are not recommended cleaning solvents.

Curing System Maintenance. The bulbs (lamps) used in most curing systems, including all spot systems, gradually degrade over time. The result is lower light intensity with the age of the bulb. Bulb degradation is a function of the bulb, the number of times the bulb is powered on and off, and the temperature at which the bulb operates. Maximum bulb life, in terms of operating-hours, is achieved by minimizing the number of times a bulb is powered on and off. At a minimum, leave a lamp on if it will be used within two hours. Additional guidelines for maintaining curing equipment and bulbs (lamps) are available from Dymax.

It is essential that bulb intensities are monitored regularly and maintained within limits established for each application that are known to produce satisfactory parts. A radiometer is essential for this task. Once bulb intensities drop below a predetermined level, the bulb should be changed, or the exposure should be lengthened to compensate for lower bulb intensity.

ACCU-CAL™ 50 radiometer can measure the intensity of spot, flood and conveyor curing systems.

Consistency of curing is maintained by following these simple steps:

1. Establish the lower limit intensity needed for cure in your specified time frame.
2. Choose a curing system with a maximum intensity level at least 3 to 5 (or more) times the lower limit.
3. Monitor the lamps with a radiometer and change the bulbs when the measured intensity is 50% above the lower limit.

For example, if you determine that an intensity of 20 mW/cm^2 is required over 10 seconds to give satisfactory cure, choose a system that will provide a 100 mW/cm^2 of intensity. Change the bulb when the intensity drops to 30 mW/cm^2.

LCM Lot to Lot Variability. All adhesives and coatings, being formulated chemical products, vary slightly in properties from lot to lot. An important property that does vary and can affect your process is viscosity. Process validation should take viscosity variability into account.

Safety and Handling Procedures

Dymax recommends that all safety and handling procedures be considered and implemented in accordance with local and federal regulations.

Materials. Dymax LCMs are non-flammable, contain no solvents (100% reactive), and are considered non-hazardous for shipping purposes. When using Dymax materials, impervious gloves are recommended. Contact Dymax for specific glove recommendations. Unused material should be disposed of in a manner consistent with local regulations. Cured Dymax products are considered non-hazardous. In many production environments, special ventilation systems are not needed. Where large quantities of light curing materials are being dispensed and/or cured, forced air ventilation should be employed to minimize worker exposure to vapor.

UV and Visible Light. Dymax materials cure with UVA, and in some cases, blue light. While these bands of light are relatively safe, precautions should be taken to shield workers from direct, intense exposure. Dymax supplies UV eye protection gear, which satisfies OSHA regulations for eye protection. Dymax offers UV curing equipment in chambers with shielding to block worker exposure from the light. A radiometer is invaluable in assessing exposure level and maintaining process control. For more information on this subject, contact Dymax Applications Engineering.

Shelf Life and Product Storage

With few exceptions, Dymax LCMs have a one-year shelf life when stored below 32°C (90°F) in an unopened container. Dymax light-curable materials are packaged inside UV and visible light blocking containers.

Some Dymax products carry shorter shelf lives, or require refrigerated storage. Some require mixing prior to use. Specific storage and handling guidelines are provided on the back of Product Data Sheets.