Processing Guidelines For Photocurable Adhesives

Photocurable adhesives require specific handling and curing techniques to achieve optimum performance.

by Derek Wyatt, Ablestik Laboratories

Ultraviolet and visible (blue) light cure adhesives, collectively known as photocurable adhesives, are an integral part of the opto-electronic and medical sensor industries. These adhesives offer fast room temperature cure, low shrinkage and optical clarity with unfilled adhesives. Photocurable adhesives require specific handling and curing techniques to achieve optimum performance.

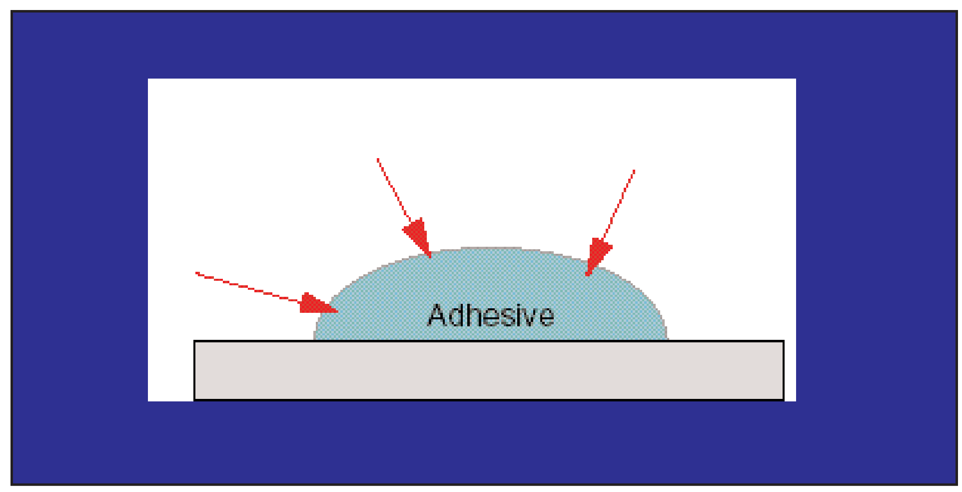

Figure 1. Oxygen inhibition.

How Light Curing Works

Visible (blue) and ultraviolet (UV) light, as it applies to photocurable adhesives, encompasses the region of electromagnetic radiation with wavelengths ranging from around 100 nm to 500 nm. Photocurable adhesives use photoinitiators to activate the cure. During the curing process, photons emitted from the light source strike the photoinitiator in the adhesive. After absorbing the incident light, the photoinitiators turn into reactive species that initiate polymerization. In acrylate-based photocurable adhesives such as Luxtrak7 adhesives, the polymerization is initiated by free radicals. In epoxy-based adhesives, another type of photoinitiator, an anion salt, is used to initiate the polymerization.

Adhesives can be formulated to respond at different wavelengths. The photoinitiators in the Luxtrak7 line of photocurable adhesives, for instance, are activated by wavelengths of 365 nm (UV) and 470 nm (visible blue).

In order to achieve a full cure, there must be a certain number of photons per unit area reaching the adhesive. This photon density is commonly referred to as the intensity of light. The minimum intensity of UV light needed to cure the adhesive is 50 mW/cm^2, while the minimum intensity for blue light is 100 mW/cm^2.

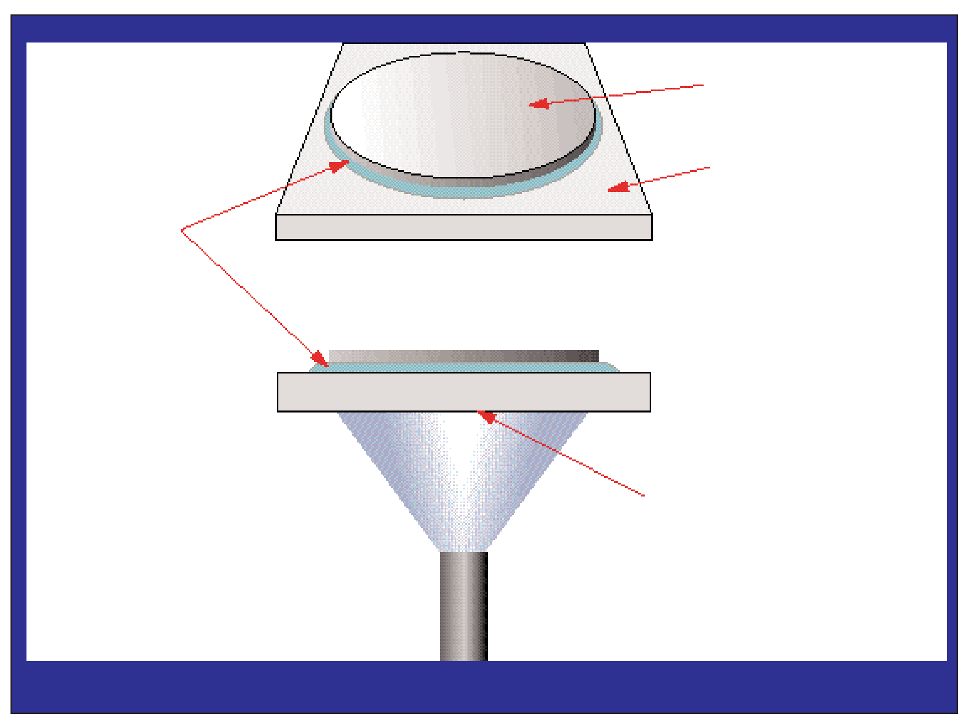

Figure 2. Bonding a steel disk to an alumina substrate.

Blue Versus Ultraviolet

Each type of cure has its own advantages and disadvantages. Depending on the application, *i.e.*, size and shape of the bonding parts and adhesive thickness, one type of cure will usually be more suitable than the other.

Blue light offers numerous advantages over UV light for photocuring. Blue light is safer than UV and does not generally require safety shielding on the curing equipment. Blue light

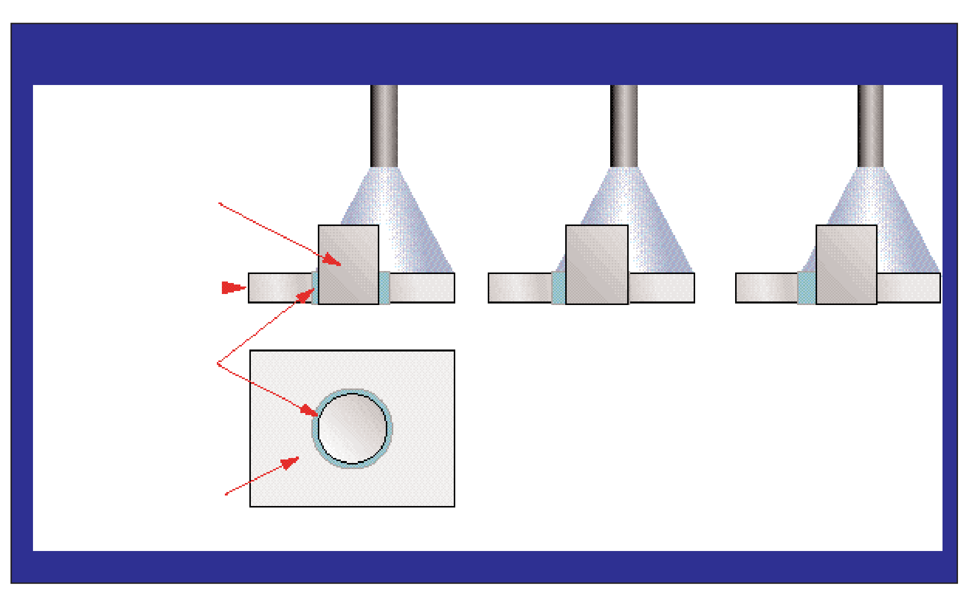

Figure 3. An example of uneven curing.

Answers To Frequently Asked Questions

Q1. Can an acrylate-based light curable adhesive with secondary thermal cure capability be cured with heat alone?

Yes! Because of the relatively slow kinetics of thermal initiation, oxygen inhibition has a more profound effect with thermal-only cures. For this reason, the adhesive must be cured under nitrogen. Because of the long cure times needed, this type of cure is generally not recommended.

In applications where the initial cure is achieved with light, a protective skin is formed on the adhesive's surface, preventing any in-diffusion of oxygen from the atmosphere. This allows any remaining adhesive shadowed from the light to be thermally cured (100° C for 1 hour or 80° C for two hours) without the need for nitrogen.

Q2. Will heating the material during cure affect its cured physical properties?

Yes! Heating the adhesive during cure is an effective way of changing its glass transition temperature (T_g) and modulus. Earlier work has shown that it is possible to increase the T_g and modulus of an adhesive by increasing its temperature before cure. Care should be taken when heating the uncured adhesive. For every 10° C increase in temperature, the viscosity will drop by approximately 50 percent. This reduction in viscosity may cause variability in dispensing.

Q3. Placing the light wand directly over the adhesive does not cure the material. Is the adhesive working properly?

There are many other factors that could inhibit the cure of the adhesive, such as the distance of the light source from the adhesive, package geometry, absorbance by intervening substrates, the use of an inappropriate light source or even the use of a bulb past its work life.

Typically, the incomplete cure of an adhesive can be attributed to insufficient intensity of light at the bondline. The most common factor causing insufficient intensity is too large a distance between the light source and the adhesive. The light intensity can decrease by as much as 75 percent (depending on the source used) for each doubling of the distance between the tip of the light wand and the adhesive bondline. For this reason, the light wand should be kept as close to the adhesive as possible and fixed in position. This is more of a problem with blue light cures, since they usually require twice the intensity of light than their UV counterparts. To achieve a full cure, a minimum intensity of 100 mW/cm^2 for blue and 50 mW/cm^2 for UV light should be maintained at the bondline.

It is also important to understand how package geometry can affect the intensity of light at the adhesive layer. Some simple questions provide guidance. Does the light need to pass through a substrate? If so, how transparent is the substrate to UV (365 nm) and blue light (470 nm)? Optical clarity does not necessarily translate to light transparency at the wavelengths used for curing. Similarly, a material that is visibly opaque is not necessarily completely opaque to UV or blue light. If the substrate is translucent to these wavelengths, then how much light will be reflected off the surface? What is the intensity of light at the adhesive's surface? Using a radiometer, the intensity of light that has passed through the substrate can be easily measured before curing.

Another factor that can drastically affect cure of the adhesive is the bulb life. As a bulb ages, the intensity of light at the effective wavelengths can decrease substantially. The usual misconception is that if a bulb is emitting light, the adhesive should cure. This is not always the case. Testing the bulb's output with a radiometer is the best way to determine if the bulb should be replaced.

Q4. How will the adhesive properties differ if cured using a UV-light versus a blue light?

In most cases, UV light sources emit a significant amount of infrared radiation. As a result, the adhesive can be exposed to high temperatures (higher intensity lamps generally produce higher quantities of infrared). The temperature exposure will affect both T_g and the modulus of the adhesive. Earlier work has shown that it is possible to increase the T_g and modulus of an adhesive by increasing its temperature before cure. However, because of the quick cure times, the increase in temperature of the uncured adhesive prior to cure will probably be negligible.

Q5. After curing a light-curable encapsulant, a tacky surface is observed. Is the adhesive cured?

In most cases the adhesive is cured. The tacky surface that is observed is due to oxygen inhibition. In acrylate-based adhesive systems, oxygen is known to inhibit polymerization giving rise to the term "oxygen inhibition." In the bulk of the material, once the finite level of oxygen is depleted (by exposure to light), the polymerization will initiate. At the adhesive's surface, however, depleted oxygen is continuously replenished by oxygen molecules in the atmosphere (Figure 1), which results in continuous inhibition of the polymerization. The end result is a tacky surface, composed of a combination of lower molecular weight polymers and uncured material.

When bonding two surfaces together, oxygen inhibition is generally not observed. In most cases, oxygen inhibition is seen when a package geometry allows a portion of the adhesive to be directly exposed to the atmosphere during cure. Oxygen inhibition can be overcome by curing the material under nitrogen.

Q6. Can a light-curable adhesive be over-cured?

No! Additional light exposure will not promote further conversion. It is quite possible to overheat the adhesive if a UV-light source is used. UV light sources often emit a significant amount of infrared radiation, resulting in an increase in the adhesive's temperature (higher intensity lamps generally produce more infrared). In some cases a slight discoloration may be noticed. The extent of the discoloration will depend on the intensity, time and temperature the adhesive experiences. If this happens, the light wand should be moved back to reduce the intensity of light on the adhesive and the effect on cure determined (cure time may need to be increased, cured properties may change).

Q7. What are the storage conditions for photocurable adhesives?

For the Luxtrak7 family of photocurable adhesives, the storage life is three months at 25° C or six months at 5° C. The storage life for some materials may vary. Be sure to consult the data sheet for the specific material. These adhesives should never be stored below 0° C unless specifically stated on the technical data sheet.

Q8. How does the viscosity change with temperature?

Like many other materials, the viscosity of these adhesives will decrease as the temperature increases. A simple rule-of-thumb is that for every 10° C increase in temperature, the viscosity will drop by approximately 50%.

can penetrate through many materials, such as white ceramic and many plastics, which UV light does not penetrate. Blue light offers increased depths of cure in the adhesive, typically 10 to 12 mm for unfilled grades and 5 to 6 mm for filled material.

On the other hand, UV light offers the advantage of completely curing the adhesive in as little as 10 seconds, while blue light cures typically require more time (<60 seconds). For applications that involve using small volumes of adhesive or thin coatings exposed to the atmosphere, UV light has the ability to overcome oxygen inhibition more so than blue light.

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Processing Shadowed Areas

In some applications, package geometry may not allow for complete exposure of the adhesive to light. To address such applications, some light cure adhesives have been formulated with a secondary thermal cure initiator. This thermal initiator will allow shadowed areas of the adhesive to reach a com-

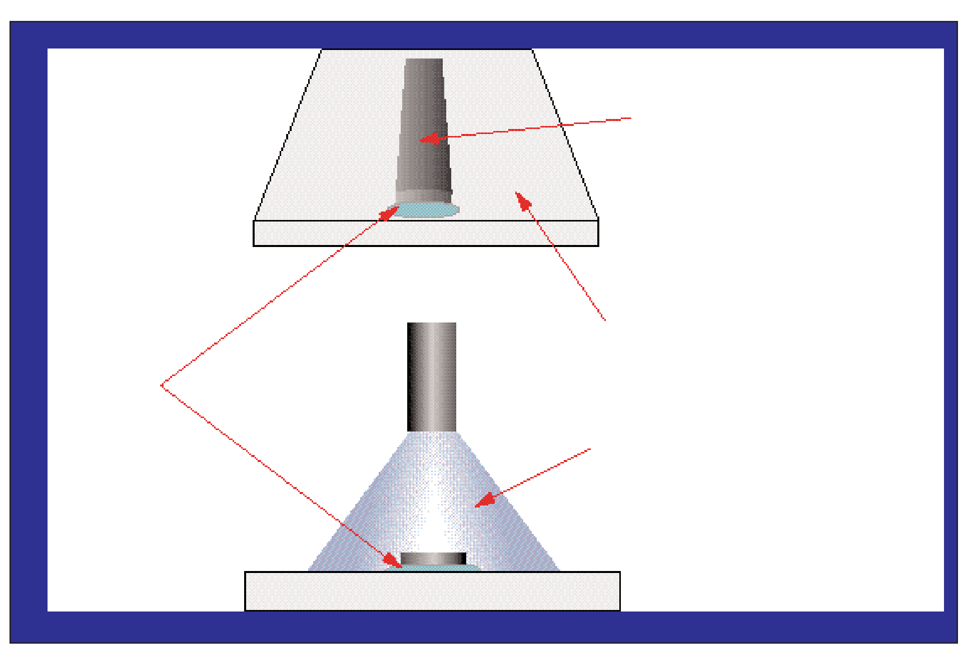

Figure 4. Bonding a polyimide strip to a stainless steel substrate.

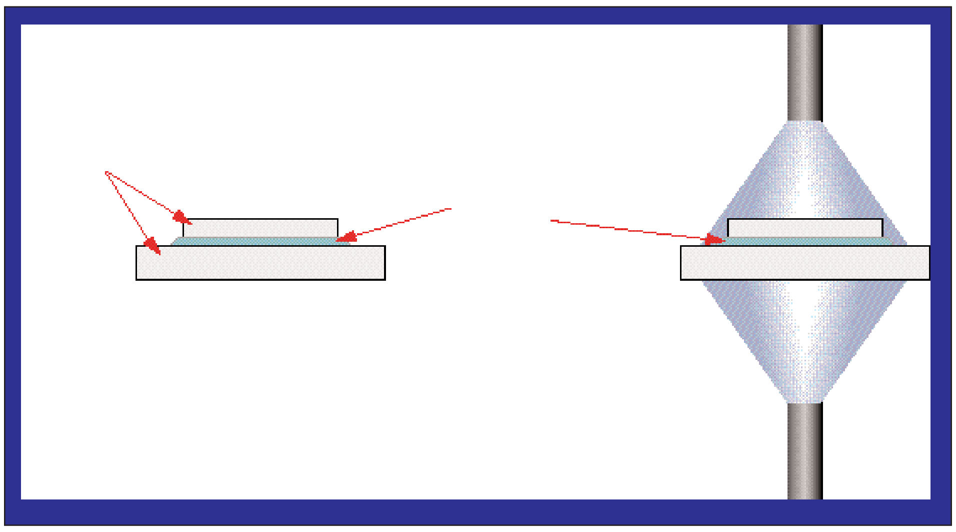

Figure 5. Bonding glass to glass, with a perpendicular cure.

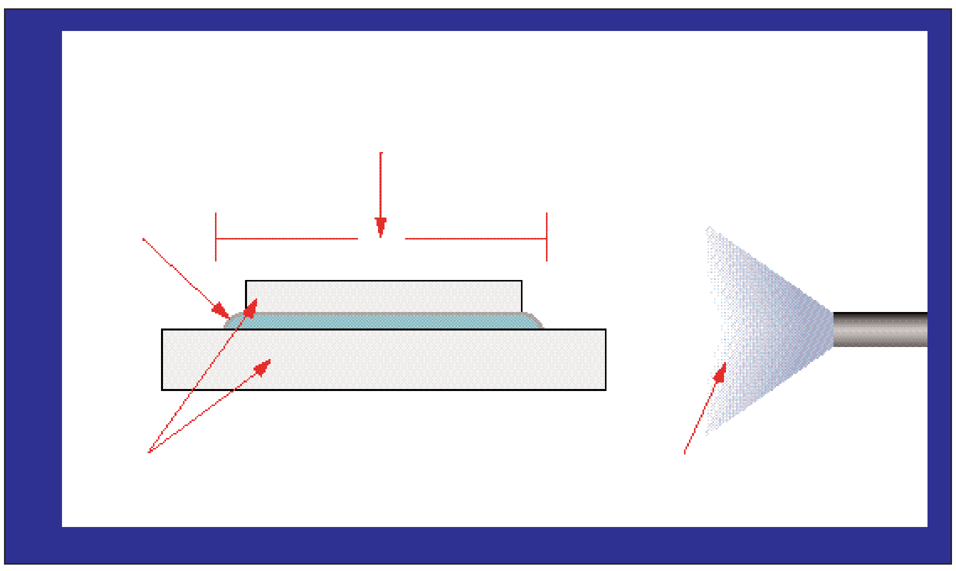

Figure 6. Bonding glass to glass, with a parallel cure.

plete cure after exposure to heat. Typical thermal cure profiles for these adhesives are 1 hour at 100° C or 2 hours at 80° C.

First, the non-shadowed adhesive is exposed to the proper intensity of light prior to heat exposure. This causes a protective skin to form on the adhesive's surface, which "tacks" the part in place and prevents any in-diffusion of oxygen from the atmosphere, allowing the remaining adhesive shadowed by the light to be thermally cured at 100° C for 1 hour or 80° C for two hours. Although generally not recommended, it is possible to thermally cure these adhesives under nitrogen without initially using light.

Application Examples

Example 1. Many opto-electronics applications involve the use of white ceramic. In this example, a steel disk is being bonded to an alumina substrate. Several different approaches can be taken to achieve a complete cure with either a UV or a visible light-curable adhesive. The best approach involves using blue light. Although alumina is non-transparent to UV, it is transparent to blue light. By placing the light source directly underneath the substrate, a complete cure can be achieved. As light passes through the substrate, the intensity will be significantly reduced. If the intensity is reduced too much, the adhesive may not cure properly. The best way to know if enough light is passing through the substrate is to measure its intensity on the opposite side of the substrate with a radiometer. This curing approach is illustrated in Figure 2.

If blue light is not available, then a second approach must be used. This method involves exposing the adhesive fillet to UV-light from above, followed by a secondary thermal cure. Curing the adhesive fillet evenly is important. An uneven cure could result in the bonded part shifting due to the adhesive's uneven shrinkage, as seen in Figure 3. This is particularly important in applications that require precise optical alignment. When using a UV spot cure system, if the dimensions of the package are larger than the UV "spot" and consequently do not allow for the entire fillet to be exposed to a sufficient intensity of UV light at the same time, a uniform cure can be achieved by either using multiple UV spot sources arranged to illuminate the entire adhesive fillet or by the use of an area-cure UV light source designed to illuminate the entire area. After exposure to UV light, the adhesive underneath the disk can be fully cured by subsequent thermal curing.

Example 2. The second application involves bonding a narrow polyimide strip to a stainless steel substrate. Polyimide and stainless steel do not transmit UV blue light. For this application, curing can be achieved in two steps. First, fixture the polyimide strip to the substrate by curing the surrounding fillets with light. Second, cure the shadowed area with a secondary thermal cure. This application is illustrated in Figure 4.

Example 3. The third example involves two glass pieces being bonded together for an optical switch application. Because the substrates are transparent to both UV and blue light, the choice of which light source to use should be based on convenience. The best method of curing the adhesive is to position the light source perpendicular to the adhesive plane as shown in Figure 5. This will ensure even curing.

The adhesive could also be cured by positioning the light source parallel to the adhesive plane, as shown in Figure 6. In this configuration, the ratio between the part length and the cure depth of the adhesive becomes an important issue. A good rule-of-thumb for curing bondlines such as this is, if the part length exceeds 50 percent of the cure depth of the adhesive, multiple light sources must be used around the perimeter of the part to ensure complete coverage of the bondline with light. Blue light typically provides a maximum cure depth of 10 to 12 mm for an unfilled material and 5 to 6 mm for a filled material. UV light cures are roughly half as deep as blue light cures and as such, are typically not recommended for applications requiring deep cures.

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