# LED Packaging Primer

## BACKGROUND:

With the explosion of LED packaging world wide, there are many young engineers rediscovering process problems associated with manufacturing LED products. This primer is an attempt to share many of the principles learned in this industry over the last 30+ years. We will look at some of the material and process issues that are being experienced today.

## LEADFRAME CHOICES:

In general, copper alloys have been the popular choice. Some manufacturers have tried mild steel, Kovar and Alloy 42. These three are iron based materials and have been used in semiconductor packaging because they are cheaper than copper. For LED Power Packaging, they have two major, short comings: thermal conductivity and corrosion/rust.

The thermal conductivity of copper is 385 W/m-K versus 17.3 W/m-K for Kovar and 10.5 W/m-K for Alloy 42. Mild steels are similar to Kovar and Alloy 42. This means that the iron based lead frames have 20 to 35 times higher thermal resistance. At a given power dissipation level, the iron based lead frame LEDs will cause a much higher junction temperature. That reduces the light output significantly, reduces the power rating of the LED, as well as the light output lifetime. Light output efficiency is everything in LED power products.

If that weren't bad enough, iron-based lead frames rust and suffer step-crack-corrosion. Some LED manufacturers have tried to ship mild steel-based lead frames. In time they begin to have returns for rusting and solderability issues. Manufacturers have tried to put an under plate of Nickel on the iron lead frames. Unfortunately, there are pin holes through that under plate. These pin holes are common in iron based materials and lead to rusting and corrosion problems.

Copper has a potential shortcoming. If copper migrates into the LED chip, the light output degrades. Fortunately, an under plate of Nickel does work as an effective barrier. This under plate does not have the pin hole problem that iron based alloys have. There are some manufacturers trying to die attach directly onto copper or onto silver plated copper. The light output degrades with time because of the diffusion of copper into the LED chip.

We have not covered ceramic or metal core board based LED products in this Primer. These packaging materials have higher thermal resistance and are more costly in high volume.

## DIE ATTACH MATERIALS:

For high power applications, thermal resistance is very important. It effects both the light output and the lifetime of the light output. These are discussed in detail in application notes AN-102 and AN-103. We recommend eutectic die attach rather than epoxy. The difference in thermal resistance is significant.

## ENCAPSULATION

**Epoxies** have been used for many years to encapsulate LEDs. For red, orange and yellow products, it is acceptable. For white, blue and green LEDs it is not. With time, the UV light from these products will cause the epoxy to darken. This will filter the light in an increasing rate over time and temperature. At rated conditions, the early white 5mm LEDs lost half of their light output by 10,000 hours. High powered white, blue and green LEDs lose light output even faster with epoxy encapsulation. With the industry promising 50-100,000 hours of useful light, epoxies are not a choice for encapsulation.

Some epoxy suppliers add UV inhibitors to minimize the darkening effect. They only push out the time and do not correct the darkening problem. With the industry promising 50-100,000 hours of useful light, epoxies are not a choice for encapsulation. In their place, manufacturers are using silicones. They are more expensive than epoxies but do not darken with time.

**Silicones** are messy to work with. They creep over surfaces and the work area requires constant cleaning to prevent accidents. It has been common in the past that the silicones creep across the work surface, down the legs of the workstation and out onto the work area floor. Operators loose their footing, slip, fall and incur body and head damage.

There are two problems with two part epoxy and silicone systems: air bubbles and adhesion. When the two parts are mixed either **air bubbles** are captured in the mixture; or, if mixed too quickly, vacuum bubbles are formed from cavitation. Either situation can cause optical unevenness. A method that has been used for many years is to vacuum degas the mixture prior to usage. This is used when the two parts are mixed away from the production area and brought in bulk to the dispensing station[s]. A second approach is to use a static mix head that mixes the two parts during dispensing.

**Adhesion** issues are almost always due to improper curing. The manufacturers of the epoxies and silicones recommend a two step cure: low temperature followed by a high temperature. Why? If the material is cured too quickly, the surface will cure first and trap the solvents and catalysts inside of the encapsulant. When the LED is turned on, the heat generated from the chip drives these agents towards the surface and breaks the adhesion to the package and lens. This is particularly true with silicone lenses. Belt ovens with multiple zones are an excellent way to assure that the proper curing cycle is followed. Box ovens lead to one step, high temperature curing.

## PHOSPHORS FOR WHITE LIGHT

This is an important topic and many problems can occur: A few of these are:

- Patent law suits
- Uneven color temperature
- Color rings around the outside of the light pattern
- Too many white color bins
- Color rendering

There have been two types of **patent law suits**: material and process. Most of the major LED manufacturers have filed lawsuits against one another and against smaller companies. This issue can not be taken likely. The early semiconductor industry experienced similar law suits and eventually most manufacturers cross licensed one another or obtained licenses from the patent holders. The LED industry is beginning to do the same. Our recommendation is to get a license or cross license if you have intellectual property to exchange.

There are three types of **uneven color temperature**. The first is the radial where the color temperature changes radially away from the center. The second is uneven in areas. The third is the color ring around the periphery of the light pattern and will be covered below.

Radial effects are generally caused from the silicone-phosphor layer varying in thickness. The thicker the layer the more blue light conversion to white. If the center is lower in color temperature [yellowish] than the periphery, the silicone may be too viscous and forming a dome over the LED chip. If the center has higher color temperature [bluish], the silicone may have low viscosity and most of the silicone coating flows around the outside of the LED chip. The side emitted light from the LED chip will have more blue conversion and therefore lower color temperature. Another cause could be that the phosphors settle in the silicone coating after dispensing. The coating should be cured immediately after dispensing. YAG phosphors are very heavy compounds and settle quickly. The less viscous the silicone the faster they settle.

Uneven effects can be caused from insufficient mixing. In some rare situations, a round cavity around a square LED chip may have four, peripheral areas that are lower color temperature. A square cavity can correct this. However, generally process issues are the cause.

**Color rings** around the periphery of the emitted light are either bluish or yellow. Generally this is a process problem. There are several reasons for seeing a color ring. If the color ring is yellow in color, the different causes are:

- The dispensed phosphors are not cured shortly after being dispensed
- The viscosity of the silicone that the phosphors are mixed into is too low. The phosphors will settle too fast and have a higher concentration around the side of the LED chip than on top of the chip.

If the ring is on the outside and blue, then there would be other causes. This would mean that there are more phosphors on top of the LED chip than on the side. Consequently, there is more blue light converted over the chip than on the side. There are several causes for that.

- The viscosity is too low and there is no coverage on the sides of the LED chip
- The viscosity is too high and only the top of the LED chip is coated

If none of these are effective, then the phosphor coating can be moved off from the LED chip and placed above it. One option is to put it on the bottom of the lens.

Too many **white color bins** is the result of process variation. Why is this important to control. The customers do not want any bins. They would like to receive product with consistent color temperature. That is what they get when they buy or use incandescent, halogen and fluorescent light bulbs. General Electric holds their process to 3 % variation for light output and even tighter for color temperature.

That having been said, lets look at what needs to be controlled. The silicone and phosphor mixture must be continually stirred to keep the phosphors evenly mixed and to prevent settling. YAG phosphors in particular, as noted above, are very heavy compounds and will settle in the silicone if left alone. The viscosity of the silicone must be chosen so that a uniform thickness is over the top of the LED chip and around the sides of the chip. This is a difficult task because the chip sits up and it is difficult to control the flow down the sides of the chip and out to the side.

One way to overcome these variations is to move the phosphor layer off from the chip. The Lighting

Research Center at Rensselaer Polytechnic Institute has published some preliminary results that this will improve the efficiency of white LEDs. There is a United States Patent 6319425 by Asahi Rubber for a silicone sheet with phosphors imbedded in it. Our evaluation says that this will produce white LEDs with no binning. We recommend that you read their Patent. It is full of engineering information on how to develop a film. One possible location can be on the bottom of the lens. By putting it there, each batch of products can be specifically set for the required color temperature at the end of the assembly process.

**Color rendering** is in reference to trying to approximate sun light. A measure is CRI, or color rendering index. The early YAG phosphors produced white light that varied between blue-white and yellow-white. Increasing the amount of YAG phosphor lowers the color temperature and the LED efficiency. A short coming of the single YAG phosphor approach is that the white light produced is missing some of the color spectrum. An illustration of this is shown in the set of pictures below. A group of floral displays is illuminated by white LEDs where the color temperature has been varied by changing the amount of the YAG phosphors. These pictures demonstrate the short coming of a single phosphor approach. There are some phosphor vendors that supply multiple phosphors so the color rendering is greatly improved. Not all applications require a high CRI and the single phosphor is sufficient. For general purpose lighting, multiple phosphors must be used.