SILICONE-PHOSPHOR ENCAPSULATION FOR HIGH POWER WHITE LEDS

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ABSTRACT

High-brightness Light Emitter Diodes (HB-LED) market has grown at an average rate of about 43% since the introduction of blue light wavelength die. HB-LEDs provide for a range of applications such as architectural lighting, signaling, entertainment lighting, automotive lights and LCD backlighting. The flexibility in color-changing properties, long life time, robustness, energy efficiency (lumens/watt) makes this technology very attractive. There are issues and challenges including the need to improve electronic drive circuit technology, total lumen output, "white light problem", color quality and reproducibility and cost efficiency. HB-LEDs are not a simple die, they need to be packaged in a complex structure as to maximize the effective intensity and prevent optical aberrations. HB-LEDs come in many packages, from single chip to sophisticated multi-directional aspheric lens designs. They include lenses, colored materials, and diffusers (one or two part silicone materials filled with phosphors) all of which can alter the spatial and spectral distribution relative to the basic light emitter die. Packages may include chips of different size, different types and different locations. Packages and chip locations may have different mechanical tolerances. Process for dispensing the fluids that constitute a large part of both, manufacturing and packaging of HB-LEDs need to be precise reliable and cost effective. Jetting technology offers a five fold faster process, and higher precision than traditional needle dispensing. The paper addresses some of the challenges in the LED packaging in particular jetting processes that lead to tighter distribution of the HB-LED color spectra (CIE, XYZ map) which in turn reduces the binning of LEDs and reduces the packaging cost of ownership.

Key word: LED, jetting, dispensing, YAG, CIE, volumetric accuracy.

INTRODUCTION

The introduction of blue LEDs as the base to obtain white light by means of packaging compounds, i.e., phosphors Yttrium-aluminum-garnet, YAG [1] and silicones/epoxies presents several dispensing challenges. No longer can a pure clear silicone compound with RGB source be used. Precise volumetric accuracy of the phosphors needs is required to assure minimum variation in the color. The white LEDs addressed in this paper are those built from a blue source with internal light sensitive layers which converts the blue wavelength to a variety of multiple wavelengths resulting in a white appearance. Typical optical radiation pattern for a packaged LED emission tends to be within an angle of about 20^0 from the direction of maximum intensity. Intensity of light is another parameter of importance, and has dependencies on the integrity of the packaging of the LED as well as on the volumetric accuracy of the fluid and its composition homogeneity. Large discrepancies (up to 50%) of photometric measurements of LED's are common in the industry. Various experiments were performed to address potential parameters responsible for LED performance variation. The CIE standard was used to quantify differences.

EXPERIMENTAL WORK

Test Objective

The main purpose of the present study is to isolate possible sources of variability associated with LED encapsulation with Phosphor-Silicone mixture. Specifically we expect to investigate the influence of phosphor loading, fluid volume, and time-based behaviors on the photometric properties of the devices. To determine the comparative performance differences of various dispensing processes including jetting[2] and traditional needle dispensing both, qualitative and quantitatively. The test strategy consisted in the initial characterization of high power (about 1 Watt) blue LEDs, see figure 1.

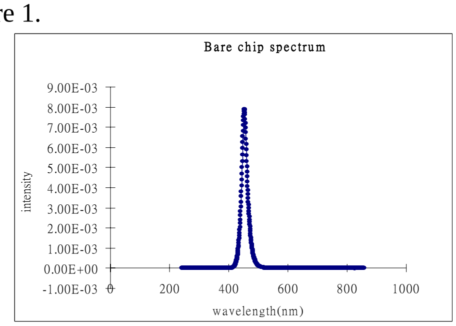


Figure1. HB-Blue die wavelength spectrum

The HB-LED package for this study consisting of the wire bonded die and fluid dispensed (two-part silicone matrix and phosphor, YAG), and not including the optical lens is evaluated for various optical characteristics. The metrology process for evaluation consisted mainly on standard photometry.

Experiment Cells

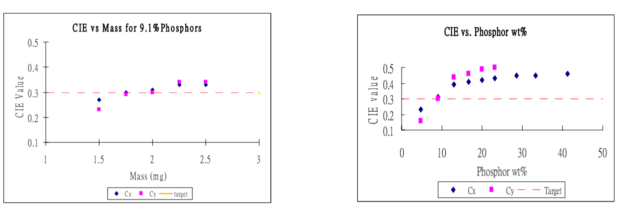
The bulk of the work reported here consisted of fluid dispensing processes with various methods that included traditional needle dispensing and jetting process. Dow Corning two part silicone material doped with YAG phosphor was used. The die used was a blue spectrum emitter diode from ELITE, 1mm^2 with mean wavelength of 460 nm (+/-2.5 nm); the die is wire bonded (1 mm high). Figure 2 Depicts the blue HB-LED cavity and wire bonded die prior to fluid dispensing prior to fluid dispensing and dicing

Figure2. HB-LED blue die showing the wire bonded die and the cavity prior to silicone and YAG dispensing.

Optical and electrical measurements were performed using the Labsphere System. Experiments were partitioned into four cells. (I) To determine the appropriate mass mean value dispensed on the LEDs and appropriate silicon to YAG ratio as to meet specific CIE X and Y values by an iterative approach. (II) To determine correlation of material volume dispensed on the LED (Silicone and 9.1% by weight of phosphor) to various optical properties of the packaged HB-LED. (III) To determine correlation of phosphor/silicone mix ratio to various optical characteristics of packaged HB-LED. (IV) To determine correlation of material (silicone + 9.1% phosphor) pot life to various optical characteristics of the packaged HB-LED. (V) To determine the spread for time-pressure needle dispense and jetting for the optimum volume and silicon-to-phosphors ratio.

Experimental Results

For the first cell, optimization of volume and phosphors content for the HB-LED, it was determined that a mass of about 1.75mg with a 9.1% phosphors content will give the best results, i.e., acceptable brightness (>30 lm/W) and white color emission. We can see in figure 3 (a) the process of volume given 9.1% phosphors mixture, (b) the process of mixture ratio given a 2mg shot.



(a) (b)

Figure3. CIE target and results from silicone volume (a) and doping ratio (b) optimization weight of phosphors.

For this experiment the target was X=Y=0.3nm on the CIE map. This target was met by using the mixture of 1.75gm of silicone two part material and 9.1% YAG for each HB-LED.

Once the baseline, mass and silicone-to-phosphors ratio was established, CIE XY and brightness were evaluated as function of various other process parameters. The effect of volumetric accuracy was examined using jet dispensing and traditional time-pressure dispensing. Cell II experiments were carried by dispensing with both needle and jet. Phosphors content was kept constant at 9.1% per weight. Mass was varied from 1.2mg to 2.5 mg and CIE measurements were taken. Figure 4 depicts HB-LEDs with various amounts of material dispensed.

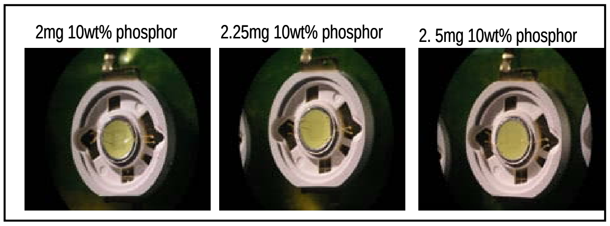


Figure4. HB-LED with various volume of silicone-YAG dispensed.

As the volume dispensed was increased so did the CIE X&Y values. For the case of jetting the correlation can be better established since its variation was tighter as depicted in figure 5. For the needle dispense (time-pressure), figure 6 the CIE XY to mass correlation although has similar trend as jetting, its correlation is not as high. This can be attributed to larger variation of the mass dispensed by needle.

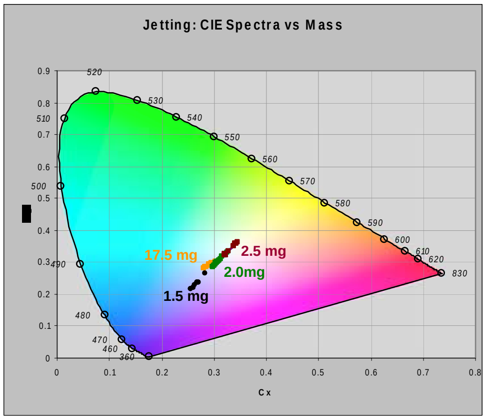


Figure5. CIE X-Y values for various volumes dispensed, by jetting process, 9.1% phosphors per weight.

Results from Cell II clearly show trends that are directly related to the spread of the CIE X-Y values and that influence the number of bins for a given LEDs class. Cell III experiments were performed to quantitatively determine the influence of silicone-to-phosphors ratio and CIE parameters. Blue light emitter die depend on the phosphors conglomerates to produce white light spectrum.

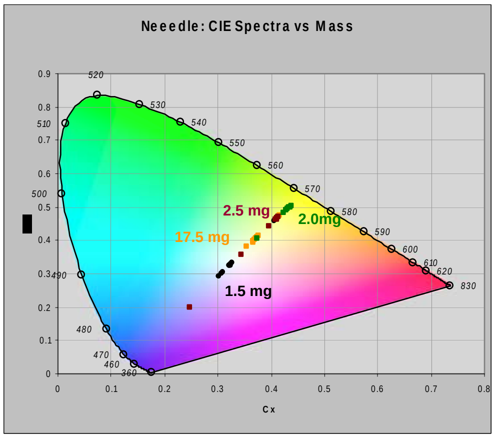


Figure6. CIE X-Y values for various volumes dispensed, with needle, time-pressure process, 9.1% phosphors per weight.

Hence, the distribution and amount of phosphors in the silicone mixture is a very important parameter to control. Scarcity of the phosphors results in blue wavelength emission, excessive amounts of the phosphors although may induce higher brightness, it also carries a yellowish color emission. Figure 7 shows direct correlation of phosphors content to the CIE chromaticity. The range for phosphors-to-silicone mix varied from 5% to 90% per weight.

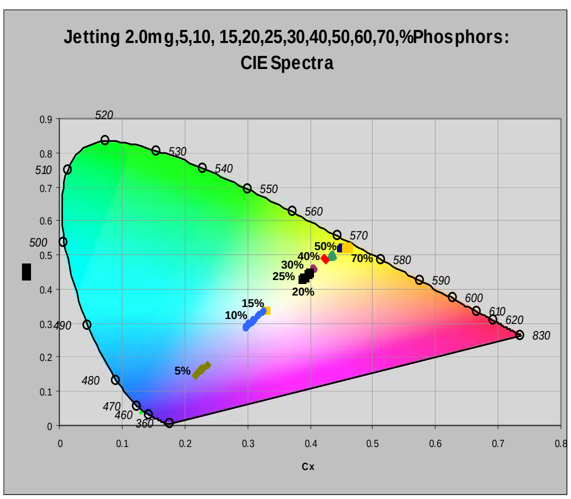


Figure7. Plot of the CIE vs phosphors content in the silicone matrix base, total mass dispensed was 2.0mg.

Clearly phosphor content ratio to silicone cause a large variation in the CIE XY values, thereby increasing the number of bins for the same die.

Cell IV experiments consisted of examining the phenomenon of phosphors settling in the silicone mixture over time and its influence on HB-LEDs optical characteristics. Given the properties of the mix, the phosphors conglomerates have negative buoyancy in the silicone fluid and settling occurs. For a dispensing system the presence of stagnation zones and their locations in the path of the fluid flow will dictate the phosphors-to-silicone ratio being dispensed and thereby determining the CIE XY values. Viscosity of the silicone has a direct correlation with the time for this settling to occur, lower viscosities causes faster settling. At the early stages of dispensing a good mixture ratio yields good white color, however over time the phosphors settling in various places (depending on the fluid path geometry,) yields corresponding variations in the color map. Eventually, the phosphors settling, either dispenses (yielding yellow rich spectra), or will permanently reside on stagnation zones and low phosphors-to-silicon ratio will be dispensed resulting in a blue spectra LED .This time dependence can be depicted in figure 8.

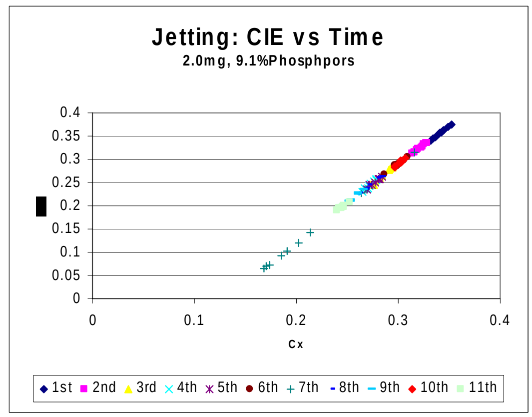


Figure8. C_X, C_Y map for different time after initial mixing of YAG and silicone.

Above plot can be incorporated in the CIE map and thereby obtaining the corresponding variation and bin distribution. Figure 9 shows this mapping.

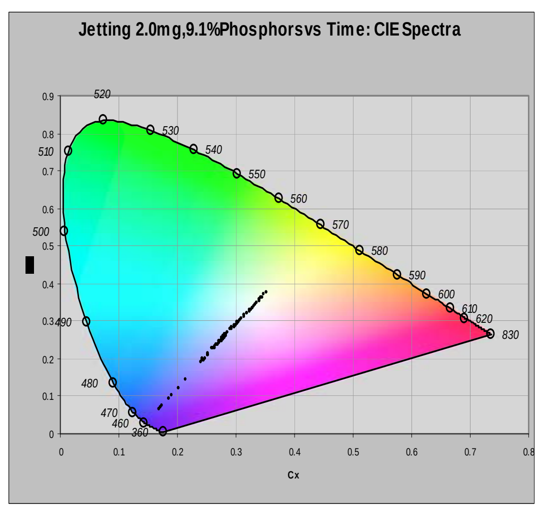
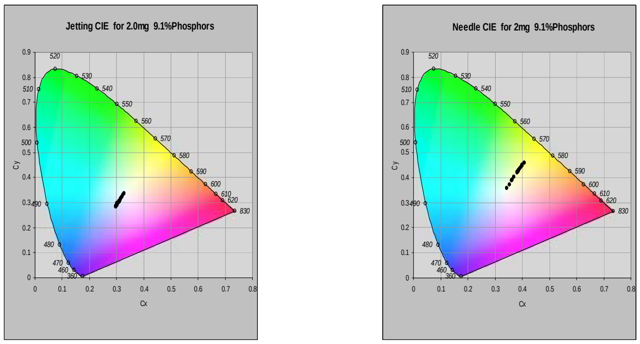


Figure9. CIE diagram of chromaticity as function of phosphors settling in the silicone over time.

Cell V addresses various dispensing processes namely needle and jetting. Determination of correlations often requires precise dispensing systems capable of resolving small variations. This was accomplished by jetting processes since it was determined that the volume accuracy was better than that of needle. A targeted of 2.0mg of silicone-YAG mixed (9.1% phosphors per weight was dispensed on HB-LEDs. For the needle a time-pressure valve was used. For the jetting a DJ-9000 DispenseJet from Asymtek was used. Figure 10 shows the results; there one can observe a larger spread in the needle dispensing process. This is inherently a problem facing time-pressure dispensing today, and will most likely worsen for small volumes.



(a) (b)

Figure10. (a) CIE map for jetting dispense of silicone and YAG mix. (b) CIE map corresponding to traditional time-pressure needle dispense.

The brightness of the HB-LED and its wavelength Spectrum are plotted in figure 11. Jetting yielded high brightness.

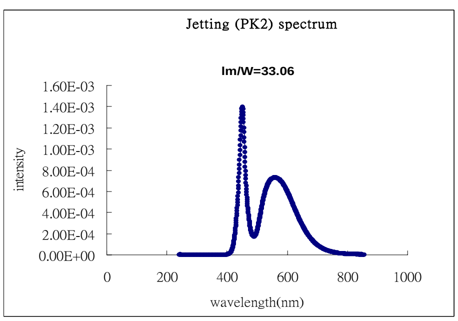


Figure11. LED wavelength spectrum after encapsulation

During the HB-LED dispensing process it was observed that the needed z-motion retraction for traditional needle dispensing resulted in longer dispensing times compare to jetting. Experiments simulating production runs showed a difference of about 5X, the jet having higher throughput.

CONCLUSIONS

The CIE chromaticity spread is very much dependent on the quality of the dispensing process. The volumetric accuracy is directly related to the spread of the CIE map, i.e., the binning of LEDs. Phosphors doping variation yields spread of the CIE XY values and increased binning. Phosphor settling occurs over time. This settling results in variations of the silicone-to-phosphors ratio and thereby increasing binning as well. Jetting dispensing will result in less binning compared to that of the needle. The HB-LED brightness for jetting process exceeded target. Jetting materials for LED packages provides a dispensing method contact free and volumetrically consistent. Jetting being exercised at dispense gaps noticeably higher than those used by the traditional needle dispensing, makes it surface topology free as well as damage proof on the parts. Asymtek jetting valve DJ9000 is a proven technology: used extensively in the underfill process and optoelectronics including several LED fluid dispensing. Jetting shows quality improvement over the traditional needle dispensing. Jetting process throughput about 3X to 8X higher than the needle process.

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REFERENCES

[1] Japanese Patent Application No. 10-194156 (194156, 1998) filed on Jul. 9, 1998, Japanese Patent Application No. 10-316169(316169/1998) filed on Nov. 6, 1998 and Japanese Patent Application No. 10-321605(321605/1998) filed on Nov. 12, 1998.

[2] H. Quinones, A. Babiarz, L. Fang (EMAP, Taiwan, October 2002) Jetting Technology: A Way of the Future in Dispensing.