Chapter 15
Effect of Needle Size and Needle Height to Substrate in Encapsulation Process of LED Packaging

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Abstract The purpose of this study is to investigate the effect of needle size and substrate to needle height by measuring the droplet volume and epoxy covered area in encapsulation process of LED packaging. Five needle gages (16G, 18G, 21G, 22G, and 23G) were used in this experiment. Average volume of epoxy drops was determined for each size of needle. Experimental data shows that droplet volumes are directly related with the needle diameter. Optimum covered area by the epoxy encapsulation was found at the needle tip to substrate distance at 3.240 mm for the 16G needle. These findings are relevant and helpful for controlling the amount of epoxy, encapsulation area, and the encapsulant shape in encapsulation process of LED packaging.

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15.1 Introduction

LED encapsulation and lens formation are important to LED success. It has a significant impact on the light extraction performance of LED chips. The efficiency of light extraction is not only related to the phosphor coating but also closely related to the geometry of the interface and the lens shape [1, 2]. It is difficult to develop an encapsulation process that is cheap, dependable, and repeatable. Generally, permanent molds with cavities and compression molding systems are used in hemispherical lens forming. Then, the curing is performed in an oven and LEDs are separated from the cavities. The management of the tool's parasite adhesion on LEDs is a huge concern in these systems [3, 4]. The injection molding process can make several different forms of lens, but these molds are dedicated to a specific type and are not for rapid production. Developing a mold-free injection-based encapsulation process on large surfaces is very essential to establish the rapid industrial production. Many studies have been carried out to develop the moldless encapsulation. Researchers are trying to develop the best effective way [5, 6]. A needle-based dispensing system is convenient to perform the encapsulation process in laboratory-based research. Epoxy is dispensed over the substrate by a needle from a specific height to make the lens. Epoxy drops are needed to control to form a suitable shaped lens [7]. So it is very important to know the droplet size of epoxy and the epoxy covered area by a single drop. The droplet size delivered from different sized needles can be determined by many techniques. Droplets from different needles can be measured by means of measuring beaker and precision weigh scale. The weight of the certain drops of fluid can be recorded in milligrams, which is equivalent to volume in microliters, and the mean volume of an individual drop can be calculated [8].

The pendant drop method has been developed to measure the droplet volume of different drop configurations. Different sizes of needles, a camera, and a light source are required for this method. The image dimension can be measured based on resolution. By this way, the diameter of the droplet sphere is measured and the volume is calculated [9]. Recently, an open-sourced fully featured software written in the Python language named "Open Drop" is also used to measure droplet volumes [10]. The epoxy droplet is dispensed over the substrate for encapsulation. Several image-based methods are used to assess the maximum spreading of epoxy during encapsulation. The open-source image processing software image-J is commonly used in the scientific community [11, 12]. The objective of this work is to observe the effect of needle size and substrate to needle height in encapsulation process of LED packaging by measuring the droplet volume of the epoxy using different needle size and determination of covered area by epoxy for different needle tip to substrate distance. Another objective of this work is to find the optimal technical condition for the suitable dispensing height (needle tip to substrate distance) for this specific substrate.

15.2 Methodology

Five standard blunt needle gages—16G, 18G, 21G, 22G, and 23G were used in the experiment. These sizes were used as they are most commonly available in the market. The dimensions of the needles used in the experiment are shown in Table 15.1. These needles were well fit with the syringe. A goniometer was used to ensure accurate vertical positioning of the syringe with the experimental setup.

The experimental setup was constructed using a micrometer, syringe, light source, a laboratory stand, microscope, and a monitor to obtain standardized results with minimal error. A measuring beaker was placed vertically under the needle to measure the weights of epoxy drops. The same experimental setup was used to observe the epoxy covered area after dispensing over the substrate (shown in Fig. 15.1). The distance between needle tip and substrate is controlled by using a control knob.

The encapsulant used in the tests is a product of Penchem Technologies Sdn. Bhd, Malaysia. It has two parts. Part-A contains an epoxy ($C_{21}H_{25}ClO_5$) and part-B is the hardener (Alicyclic anhydrides). It is mandatory to mix part-A and part-B with equal volume % before application as encapsulant. This transparent epoxy system is especially suitable for LED encapsulation. This epoxy is needed to be cured at 120 °C/1 h and 125 °C/2 h. Part-A and B are taken in a beaker with the same volume % and mixed by a mechanical stirrer. The solution is then kept in a vacuum chamber to remove the bubbles inside. After that, it is taken into syringe for dispensing. Micrometer spindle was placed in such a way that every turn in thimble scale and main scale can create pressure on the plunger of the syringe. A certain plunger pressure is required to dispense the epoxy droplet.

Three approaches are applied to determine the mean drop volume for each size needle (shown in Fig. 15.2). For measuring through a measuring beaker, twenty drops are taken in the beaker which was previously been tared on a weighing scale and it was calculated the average droplet volume. Droplet images were taken by microscope for each type of needle, and image processing system was used manually to calculate the droplet volume. An open-source software—“Open Drop” was applied to calculate

Table 15.1 The dimensions of different needles used in experiments

Needle size	OD (mm)	ID (mm)	Needle length (mm)
16G	1.62	1.19	12.5
18G	1.28	0.84	12.5
21G	0.81	0.51	12.5
22G	0.71	0.41	12.5
23G	0.63	0.33	12.5

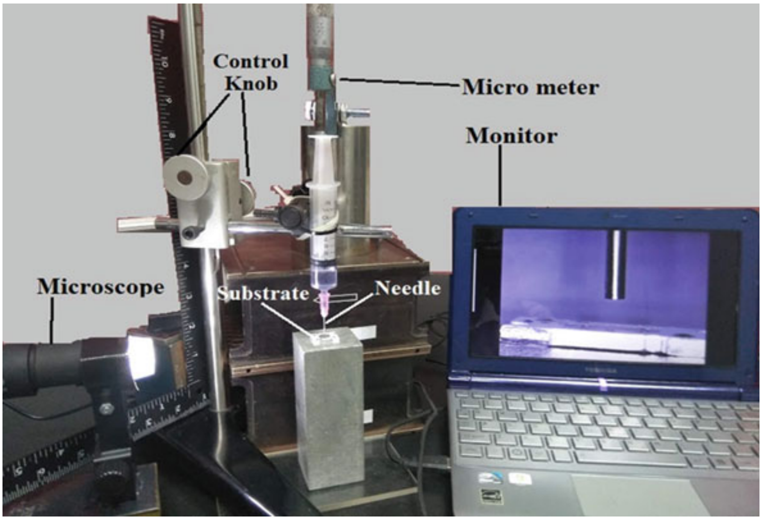

Fig. 15.1 Experimental setup for dispensing the epoxy

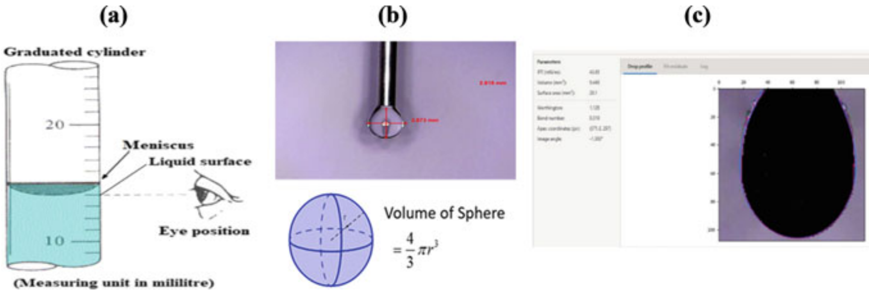

Fig. 15.2 Different approach of measuring droplet volume—**a** measuring cylinder, **b** image system (manually), and **c** open drop software

the droplet volume depending on the image taken for each drop. After calculating the maximum droplet volume, the suitable needle size was chosen. The droplet of epoxy was dispensed from five different height to substrate (1.620, 2.430, 3.240, 4.050 and 4.860 mm) for the specific needle. All the experiments before curing were maintained at room temperature. The curing was then performed at 120 °C for one hour and then checking the sample once, the curing was been continued for 2 h at 125 °C. The best epoxy covered area was determined after curing the epoxy over substrate by the open-sourced software "Image-J".

15.3 Results and Discussion

The mean droplet volume of 20 drops dispensed from blunt needles of five needle sizes was measured by three approaches. Maximum value of droplet volumes was found by measuring cylinder method for 16G, 18G, 21G, 22G, and 23G were 17.241, 13.333, 11.364, 10.417, and 9.524 mm^3, respectively. There was a significant correlation between needle gage and drop volume with larger needles dispensing larger drop volumes. The volume measuring by the manual image system and open drop software are not significantly different compared to the measuring cylinder. The average drop volumes are shown as graph in Fig. 15.3. Comparing results from repeated testing of individual needle gages documented little variation with no correlation found in drop volume. According to the data found from the experiment, the 16G needle dispenses the highest droplet volume and the lowest is from 23G. From the graph, it is observed that the droplet volume is directly related to the needle size at normal temperature and pressure.

Epoxy dispensing from different height was observed. 16G needle was used in this approach. The needle was vertically hold to the stand and ensured that the droplet was falling to the target position of the substrate. The substrate was kept over a flat type of vice and maintained on a perfect horizontal plane. Uniform pressure was applied over the syringe plunger to maintain equivalent droplet size. For each height, 20 samples were taken and cured at oven at 120 °C for 1 h and later again at 125 °C for 2 h. The epoxy covered area for five different height was measured for each sample. Image-J software was used to measure the area. The randomly taken images of epoxy covered area (green colored) over the substrate for each height are shown in Fig. 15.4.

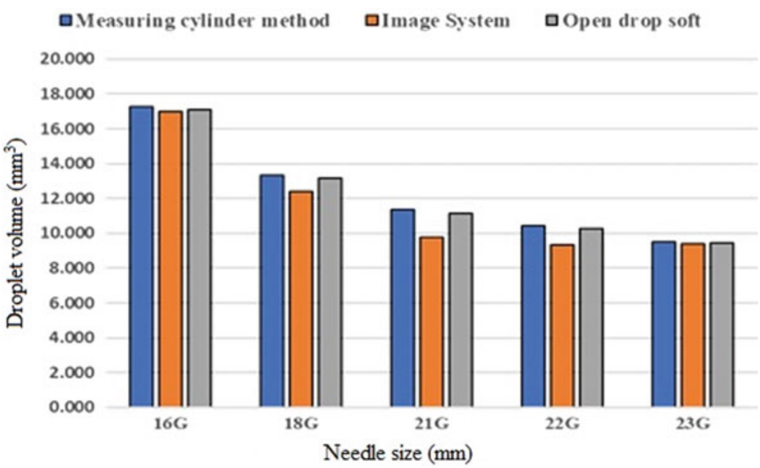

Fig. 15.3 Needle size versus droplet volume graph

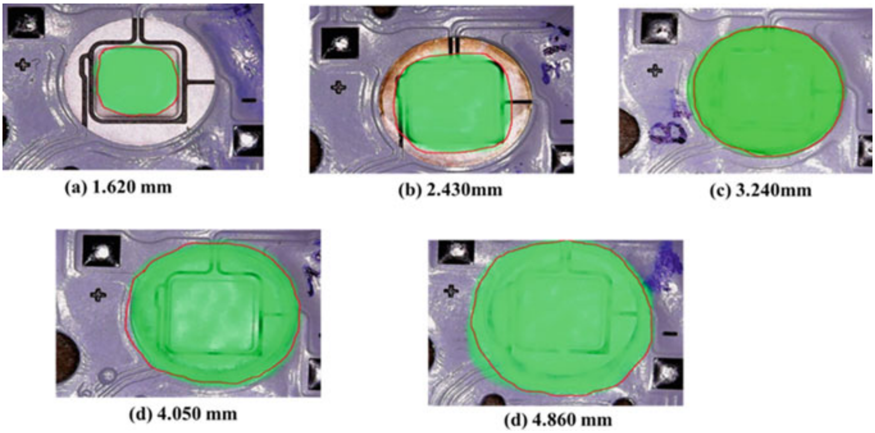

Fig. 15.4 Covered area measurement by Image-J software for different dispensing height

The average area was taken for each height, which is shown as graph in Fig. 15.5. The focusing area over the substrate is circular of 50.24 mm^2. For the dispensing height 1.620, 2.430, 3.240, 4.050, and 4.860 mm, the average covered area for 16G needle are 20.69, 41.31, 52.45, 55.75, and 61.74 mm^2, respectively.

From the data, we can determine that 41.18% of target area is covered by 1.620 mm height. Furthermore, 82.20%, 104.40%, 110.97%, and 122.89% area are covered by 2.430, 3.240, 4.050, and 4.860 mm dispensing height, respectively. We note that this study examined the effect of needle size on drop volume as well as encapsulation covered area. In this study, the shape of encapsulation is not considered. For the single drop of epoxy spreading over the substrate at normal temperature and pressure was observed. It is observed that the 16G needle is dispensing maximum droplet volume

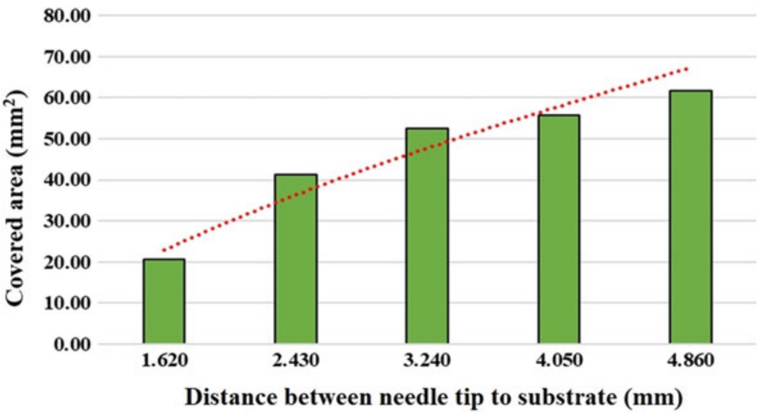

Fig. 15.5 Trendline with increase of encapsulation area with increase in distance between needle tip and substrate

and with this needle the optimum epoxy covered area is found for the 3.240 mm dispensing height.

15.4 Conclusion

The needle size significantly affects epoxy drop volume. The smallest volume is dispensed by the smallest gage needle 23G. Highest droplet volume was found with the needle of biggest diameter. Needle size 16G on 3.240 mm distance from substrate provides optimum epoxy covered area by single drop of epoxy. The described study shows that it is possible to perform the encapsulation process without the help of a mold. It will be easy to maintain proper shape of encapsulation by the right amount of epoxy dispensing from calculated height. This study will be helpful to adjust the automatic equipment of encapsulation process in LED packaging.

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