INFLUENCE OF EPOXY VISCOSITY AND GOLD WIRE SIZE ON LED ENCAPSULATION PROCESS

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INFLUENCE OF EPOXY VISCOSITY AND GOLD WIRE SIZE ON LED ENCAPSULATION PROCESS

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LIST OF ABBREVIATIONS

LED	Light-emitting Diode
EMC	Epoxy Molding Compound
VOF	Volume of Fluid
FSI	Fluid Structure Interaction
PCB	Printed Circuit board
ID	Inner Diameter
OD	Outer Diameter
UDF	User-Defined Function
ESD	Electro Static Discharge
TEM	Transmission Electron Microscopy
FIB	Fused Ion Beam
MpCCI	Mesh-Based Parallel Code Coupling Interface
PBGA	Plastic Ball Grid Array
FEM	Finite Element Method
SEM	Scanning Electron Microscope
FD	Finite Difference
FE	Finite Element
FV	Finite Volume
MAC	Marker-and-Cell
CMM	Coordinate Measuring Machines
CIE	Commission Internationale de I'Elcairage

ABSTRAK

Terdapat pelbagai masalah yang dihadapi oleh aplikasi lampu LED berkuasa tinggi yang mampu mempengaruhi kebolehpercayaannya. Salah satu masalah kegagalan lampu LED yang paling umum adalah ubahbentuk wayar emas atau wayar emas terputus semasa proses enkapsulasi dan ini boleh mempengaruhi jangka hayatnya secara tidak langsung. Tujuan kajian ini ialah mengkajikan proses enkapsulasi lampu LED dan mengaitkan kesan kelikatan eposki (EMC) dan diameter ikatan wayar emas semasa proses enckapsulasi. ANSYS Fluent merupakan salah satu produk simulasi yang moden telah digunakan dalam kajian ini untuk mengenai interaksi struktur cecair (FSI) fenomena di antara ikatan wayar emas dan epoxy (EMC). Selain itu, isi pada epoksi yang diisikan ke dalam substrat lampu LED akan disimulasi dengan menggunakan kaedah isi padu cecair iaitu VOF dan fungsi yang ditentukan oleh pengguna iaitu UDF. Simulasi boleh dijalankan berulang kali dengan menukar kelikatan epoksi (0.248 kg/m.s, 0.448 kg/m.s, dan 0.648 kg/m.s) dan diameter ikatan wayar emas (0.025mm, 0.028mm, 0.030mm, 0.032mm dan 0.035mm). Parameter seperti kelajuan suntikan, masa suntikan, sudut hubungan masuk dan ketumpatan EMC akan dikekalkan dengan nilai yang tetap. Satu eksperimen akan dijalankan untuk mengesahkan struktur akhir hasil EMC yang diperolehi daripada simulasi dengan menggunakan keadaan yang serupa. Hasilnya, telah menunjukkan bahawa tekanan dan taburan yang diedarkan pada ikatan wayar emas meningkat secara tidak langsung dengan peningkatan kelikatan EMC. Seterusnya, terdapat juga bahawa kelikatan EMC yang tinggi akan menghasilkan tekanan dan taburan regangan pada ikatan wayar emas lebih tinggi daripada kelikatan EMC yang rendah. Kajian ini telah berjaya menunjukkan bahawa diameter wayar emas yang kecil akan menghasilkan tekanan dan taburan yang tinggi apabila jenis kelikatan EMC yang sama digunakan.

ABSTRACT

There are a few issues experienced in high-power LED applications that severely influence the reliability of the LEDs. One of the most problems of the LED failure is wire deformation or wire sweep during the encapsulation process that can indirectly affect the LED life expectancy. The goal of this study was to examine the encapsulation process of the LED and to correlate the impact of viscosity of the epoxy molding compound (EMC) and the gold wire bonding diameter during the LED encapsulation process. The advanced simulation tool, ANSYS Fluent is utilized to complete an investigation on the fluid-structure interaction (FSI) phenomena between the gold wire bonding and the EMC. The FSI modelling was used to measure the amount of stresses indirectly applied to the gold wire bonding during the encapsulation process. Besides, the volume of the EMC being dispense onto the LED substrate will be simulated by utilizing the volume of fluid (VOF) strategy and user-defined function (UDF) in the ANSYS Fluent. The simulation can be conducted repeatedly by changing the viscosity of the EMC (0.248 kg/m.s, 0.448 kg/m.s, and 0.648 kg/m.s) and the gold wire diameter (0.025mm, 0.028mm, 0.030mm, 0.032mm, and 0.035mm). Parameters such as injection speed, injection time, and inlet contact angle are fixed in this study. An experiment test was done to approve the final structure of the EMC results obtained from the simulation under similar setup conditions. The results demonstrated that the wire deformation, stress and strain distributed on the wire bonding increased with increasing viscosity of the EMC. The high viscosity of the EMC would yield higher deformation, stress and strain distributions of the gold wire bonding. The results also showed that the smaller the diameter of the gold wire, the larger the stress and strain distributions when the same type of viscosity of the EMC is applied.

CHAPTER 1

INTRODUCTION

1.1 Overview

Light-emitting diode (LED) is the most development innovation in lighting industry. Recently, light-emitting diodes (LEDs) were rapidly developed in various applications such as lighting hardware, traffic lights, camera glimmers and large area displays because of its high efficiency, low energy or power consumption and high strength (Wen, et al., 2017). Eventually, the theoretical viewpoint of LEDs is that they can work as thousands of hours as possible. However, with the rapid growth of the LEDs, the reliability of these high-power LEDs has become major challenge in this current scenario. For instance, material degradation, wire sweep, and structural destruction due to electrical, thermal and mechanical stress will prompt lumen debasement, shading variety just as early glitch of the LEDs gadget (Zhaohui, et al., 2011).

Encapsulation process is a process that adopted in the packaging of the LEDs. Epoxy resins, as elite thermosetting polymer materials have been broadly utilized for the current LEDs encapsulation process due to the benefits like high adhesion, extraordinary machinability and excellent resistance to chemicals (Shan & Chen, 2018). In fact, improper selection of the rheological properties of the epoxy resins such as viscosity can straightforwardly impact the wire deformation and the stress that acts on the wire structure during encapsulation process. Hence, the wire sweep issue can be occurred during the encapsulation process and this may lead to the failure of the LEDs. Besides, it is discovered that when the viscosity flow of the encapsulant and the pressure distribution are high, the gold wires are expected to have large deformation when contrasted with those at a low viscosity or pressure (Ramdan, et al., 2012).

Consequently, full understanding of the effect of viscosity change of the encapsulation material is critical to be concerned in the present paper.

Other than that, wire bonding is also one of the critical packaging processes of the LEDs production, where the miniature measurement wires are precisely attached to the LED chip bond cushions as electrical connections. The most common material used in the industry are gold wires with ball bonded to the gold contact pad, because of their benefits of having great electrical conductivity and high corrosion resistance (Peng, et al., 2016). Currently, the dependability of the wire bond in ongoing LEDs production has fallen under review due to the demonstration of decreasing wire diameters to drive down the production costs. During the molding process, the stream front of the epoxy resins entering the shape cavity will has a force that will in general uproot the wire from their original position. The wires that are deformed or swept by the epoxy resins may have high possibility to break and causes a functional failure. Optimization of formulation of the epoxy resins and interaction boundaries have been contemplated and reported in numerous researches to minimize the wire sweep or deformation, yet investigation of the effect of the gold wire diameters on the LED package has not yet engaged as the element of LEDs failure.

There have been various attempts in academia and industry in attempting to comprehend the factor of failures due to wire sweep. However, there is an absence of a systematic approach to correlate the effect of the wire diameter and the phyi-rheological properties of the encapsulant materials used on LED encapsulation process. In this present paper, the influence of three different types of viscosity of the epoxy molding compound (EMC) and five gold wires with different diameters on LED encapsulation process will be studied, simulated as well as experimental study will be done to validate the results obtained via simulation. The ordinary construction of the high-power LED will be utilized in this study is semi-sphere as illustrated in Figure 1.1. The simulation of the LED encapsulation process is a common fluid-structure interaction (FSI) problem, which can be dealt with a coupled analysis of fluid flow and structural deformation using ANSYS Fluent. The results of the simulation are contrasted with the experimental result for justification.

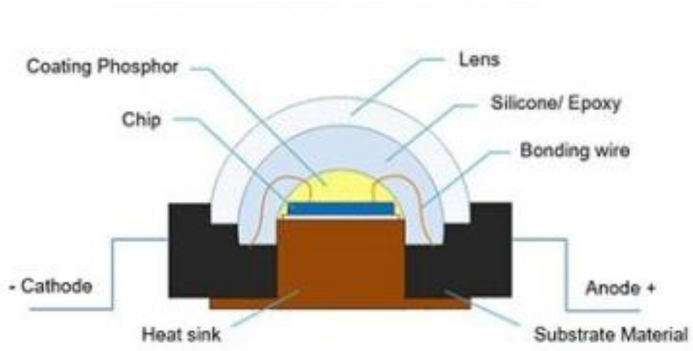

Figure 1.1: Typical LED encapsulant structure.

Source: (Taylor, 2017)

1.2 Project Background

A quality LED device should have superordinate characteristic, for instances, high efficiency, low power consumption, high reliability and high life expectancy. However, there are many possible factors that could affect the reliability and functionality of the LED device. In the industry, the standard percentage of failure for LED devices are around 3%. Many building owners yet experiencing failure rates up to 20% or even higher (Cloud, 2016). As such high failure rates occur for several reasons but can often be attributed to the following factors.

There are various issues that experienced in LED applications, which severely influence the life expectancy of the LEDs. Especially for white light with high-brightness LEDs, high-power LEDs and coordinated LED light sources that utilized in general lighting system (Cloud, 2016). The failures are mostly occurred at the packaging materials such as lead-frame, phosphors and encapsulation adhesive. For instance, heat generated by the chip of a LED and the external factors can cause staining and cracking of the LED packaging materials, which resulting in a change in colour and even a faulty LED. Figure 1.2 shows that the cracking phenomenon of the encapsulation materials of a LED lamp after long-term lighting aging test (Huanxiang, et al., 2020). For this analysis, Epoxy Molding Compound (EMC) is used as encapsulant because of the superior epoxy resin properties, excellent behaviour towards numerous solvents, chemical stability moistness resistance, good mechanical as well as electrical properties.

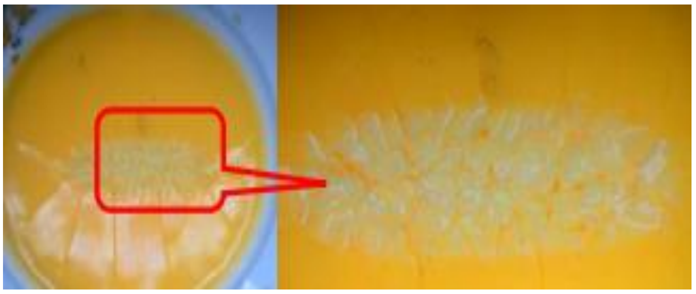

Figure 1.2: The appearance of encapsulation material after the LED aging test.

Source: (Huanxiang, et al., 2020)

Besides, wire deformation or sweep occurred during the encapsulation process. It is found that the effect of the viscosity of encapsulants can straightforwardly impact the wire displacement and drag force as well as stress that induced on the wire structure during the encapsulation process. The gold wire that encounters a high viscosity flow and high-pressure distribution will have large deformation when contrasted with low viscosity and pressure are utilized. The wires tend to break and cause failure to the LED device, when the stresses that act on the wire structure is too large (Ramdan, et al., 2012). Hence, the effect of rheological properties of the EMC will be studied in this present work. Moreover, the wire deformation or sweep can also be influenced by the wire diameter used during the encapsulation process. It is found that the wire sweep increases with decreasing wire diameter (Hian, et al., 2011). Hence, the effect of the gold wire bond diameter will also take into concern in this present work.

Wire attachment technique that used in this present paper is ball bonding. It only limited to gold and copper since it requires heat, pressure and ultrasonic energy to form the bond. Moreover, the ball bonding technique is suitable for making interconnection between LED and PCB since its restricted to small diameter of the wire. Other technique such as wedge bonding is not suitable for this type of bonding since it is essential larger diameter of wire or wire ribbon which used in power electronics application. Next, the LED package used in this study can be illustrated in Figure 1.3. The feature of this LED included white surface mounted diode (SMD) package, chip level conversion and many others more. The diameter of the expected EMC to fill is approximately 4.42mm, the chip level conversion size (1.267mm × 1.267mm × 0.139mm) and the gold wire diameters (0.025mm, 0.028mm, 0.030mm, 0.032mm, and 0.035mm) are the parameters used in this study.

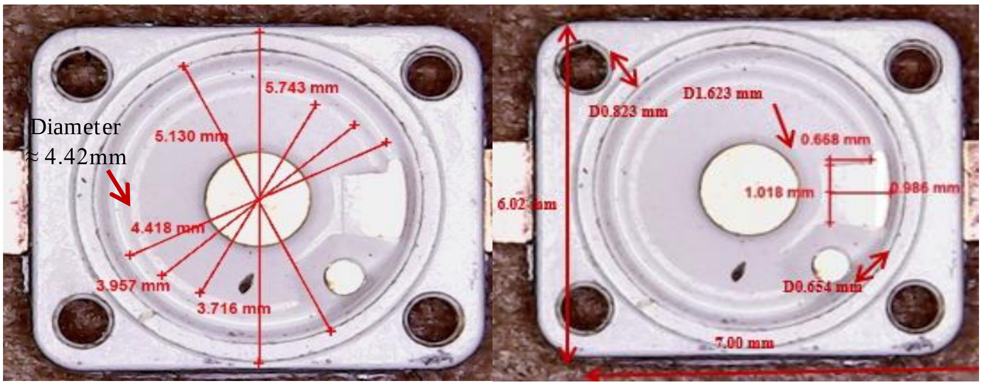

Figure 1.3: Top view of high-power LED package.

1.3 Problem Statement

The demand of LED lighting applications has considerably increased in recent years due to the benefits of high reliability, low power consumption and high efficiency. Nevertheless, there are still various issues observed in the LED lighting applications, that seriously influence the life expectancy and functionality of the LEDs. For instance, if the LED encapsulation process is not well-conducted, it would be resulting in the problems such as impurity, excessive EMC, insufficient EMC and damage or crack of the EMC. The excessive amount of EMC will induce more stress to the gold wire bond lead to the deformation of the wire bond increases. The wire will tend to break if the stress induced on the wire structure is too large. The lacking measure of EMC will prompt low quality of the light produced by the LED. Besides, the rheological properties of the encapsulant such as viscosity and the diameter of gold wire used can also be the main factors that might indirectly influence the wire deformation as well. This causes the failures mechanisms such as delamination, open circuit and cracks of these LEDs might appear in their use. Therefore, this study will focus on to study the influence of the EMC viscosity and the effect of gold wire size on LED during encapsulation process.

1.4 Objectives

The objectives of this present study are:

1. To study the influence of epoxy molding compound (EMC) viscosity and effect of the diameter of gold wire bond on LED during encapsulation process by using fluid structure interaction method (FSI).
2. To correlate the effect of viscosity of the EMC and the gold wire diameter during the LED encapsulation process.
3. To conduct an experiment that can validate the simulation results.

1.5 Scope of Work

The scope of work includes the study of the fluid-structure interaction (FSI) phenomena using the modern tool which is the ANSYS Fluent. This study is focused on simulation of the influence of the epoxy molding compound (EMC) viscosity dispense onto the LED and the effect of gold wire size during the LED encapsulation process. The volume of the EMC being dispense onto the LED mold cavity will be simulated by utilizing the User-Defined Function (UDF) in the ANSYS Fluent. Then, the interaction of the EMC with the gold wire bonding is studied by using the system coupling to determine the total stress being induced to the gold wire by the EMC. A 16G needle is used to dispense the EMC onto the LED which is set to be 3.240mm from the top surface of the LED substrate with the inner diameter (ID) of the needle tip is 1.1940mm. Finally, validation of the simulation results had been carried out by conducting an experiment. This is to make sure that simulation results are compatible in value and in tendency with the experimental results. The experiment will be conducted manually by using several apparatus and materials. The results will be collected and recorded by using a digital camera.

1.6 Thesis Outline

Chapter 1 begins with a general background relating to the high-power LED encapsulation process, project overview, problem statement, project objective and scope of work. Chapter 2 provides the literature analysis and useful insights reported pertaining to factors that related to the objectives of this study. The technique used to simulate the LED encapsulation process and experimental methodology are emphasized in Chapter 3. The demonstration of experimental and simulated results, parametric studies, optimization and case study of the LED encapsulation process will be discussed in Chapter 4. Lastly, Chapter 5 emphasizes the contributions of the thesis and provides suggestions for future investigations.

CHAPTER 2

LITERATURE REVIEW

2.1 Basic Structure of LED Packaging Modules and LED's Failure

A fundamental design of light-emitting diode (LED) comprises of at least one semiconductor chips that utilized as a lighting source, housing material utilized as a means of mechanical pressure protection and reflector, lead frame utilized as a medium for electrical connection, heat dissipation and light reflection and transparent or translucent encapsulation are utilized for stress buffering, colour variation as well as primary lens. Generally, there are many different types of LED packaging shapes have been intended in the market based on their requirements for heat dissemination and luminescence effectiveness of the LEDs in various applications (Luo & Hu, 2014). The LED packages can be isolated into the following types: Lamp-LED, TOP-LED, Side-LED, SMD-LED, High-Power LED, Flip Chip-LED and so on. Despite the fact there are various types of LED packages and technologies, yet the LED module can be classified into either a low-power or a high-power packaging design.

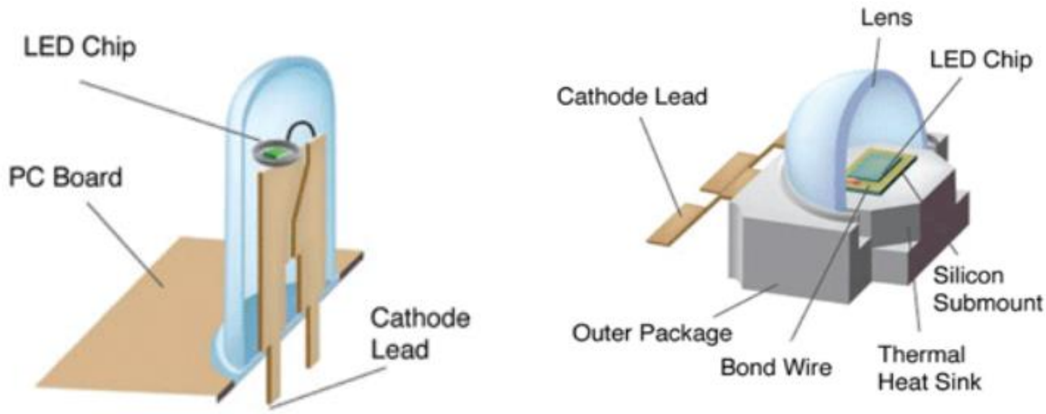

Figure 2.1: Typical low-power LED and high-power LED.

Source: (Canada, 2016)

The diagrammatic of an ordinary low-power LED package can be shown in Figure 2.1 (left). A low-power LED is mostly packaged with epoxy resin. The chip will be reinforced onto the lead frame by utilizing soldering or solder paste. At the highest point of the chip, it will be bonded with bonding wires on the other part of the lead frame (Luo & Hu, 2014). It has restricted attributes whereas the utmost driving current is limited to 20mA and accordingly the common forward voltage is just 3.2V. Hence, it restricts the LED power capacity to only 0.1W, and furthermore, the light produced is seldom surpassed the ranges from 2 to 3lm. Therefore, the low-power LED are usually utilized as an indicator.

Since low-power LEDs have restricted attributes, characteristics and cannot fulfill all application requirements, high-power LEDs have been developed and successfully manufactured to overcome the problems. In the Luxeon structure of the high-power LED, the chip will be reinforced onto the heat sink by using soldering or solder paste. The material used for the heat sink is usually copper since it has high thermal conductivity. Besides, the terminals of the chip are bonded to the lead frame through the bonding wires. To protect the chip as well as the bonding wires, silicone gel phosphor with a specific concentration will be dispersed within the lens and the molding compound. The high-power LEDs packaging will consistently have better heat dissipation, therefore the power produced can be in the excess of 10 times of the low-power LEDs packaging (YIlmaz, 2020).

In fact, there are still various problems that could be found in the LED applications, which severely influence the life expectancy and reliability of the LEDs. For instance, gold wire deformation might occur during the dispensing of the encapsulant to the LED substrate. If the deformation of the wire is simply too large, this could cause an open circuit due to wire breakage and henceforth affect the reliability and functionality of the LEDs. The extreme heat generated by the chip and the external environment can cause staining and fracture of the LED package material when poor material quality is utilized, resulting to a shift in color and even a faulty of the LED. Some reliability checking methods like thermal cycling, thermal shock or mechanical shock, high and low temperature running time check might be utilized to distinguish the performance of the LED applications. These methods can used to predict the failure mechanism and life expectancy of the LED by simulating the loading of manufacturing process and the working environment.

2.2 LED Failure Modes and Methods for Analysis

The defects occurring on the LEDs can be classified into three primary classes which are the chip, as the focal component, the internal and the external packaging. Due to the different assembly technologies, types of construction, and varying applications, an extended range of failure mechanisms can be illustrated (Pross, 2010). A sample of the high-power LED assembly technology and construction can be seen in Figure 2.2.

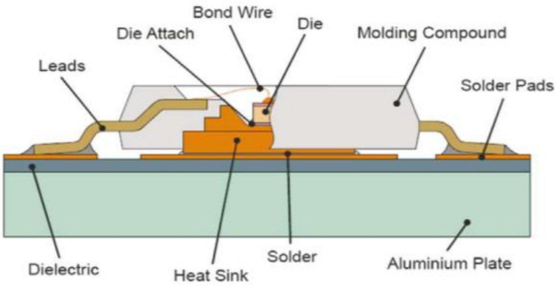

Figure 2.2: Example for a LED package on PCB.

Source: (Pross, 2010)

The optical performance of LEDs slowly diminishes can be brought by the growing deformities in the epitaxy layers, bringing about an increment of not radiating recombination and a reduction in the optical efficiency. There is normally a 30% to half diminish in optical performance is characterized as a defect while the expected working life is between 20,000 hours and 100,000 hours. A few unfavorable variables like inferior quality of epitaxy layers as well as an abundance intersection temperature due to insufficient thermal dissipation can be directly affecting the LEDs' optical performance. Other than that, penetration of humidity or other contaminants, latent Electro Static Discharge (ESD) damage, and a temperamental power supply can cause accelerating degradation of the epitaxy layers which can bring damage to the chip. Figure 2.3 shows that a catastrophic defect caused by ESD due to electrical over-burden resulting in a severe damage to the epitaxy layer.

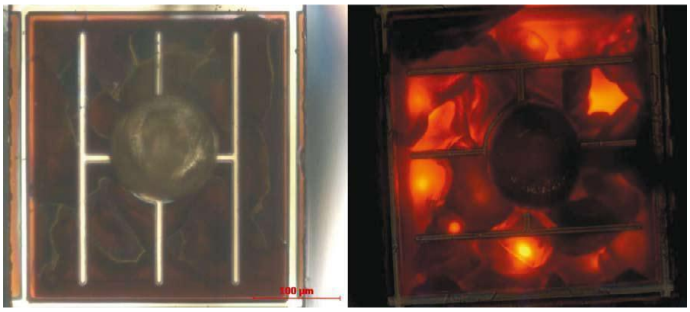

Figure 2.3: Reflected light and transmitted light microscope of a typical surface corrosion. Source: (Pross, 2010)

In the LED production process, LED interior construction is another common factor of the LED failure to be considered. The soldering process has ended up being particularly critical because thermal over-burden can cause cracks as well as separations along the boundary regions due to the different expansion rates of the materials. Broad capability tests and stable quality control will be an awesome way in controlling the soldering process during PC assembly are basics for a long lifetime. The encapsulation materials, for example, the silicone or epoxy resin are not airtight fixing and hence they are unable to give any assurance against humidity or other harmful materials. Furthermore, the mechanical pressure that is induced on the LED component can make a serious crack or detachment to the LED joint compound and allow the penetration of contaminants down to the chip or metal contact. For instance, bending the pins of 2-

pin-LEDs or thermal stress induced during the soldering process. This will bring about the modifications of the epitaxy layers and corrosions in the interfaces under unpleasant conditions. An X-ray microscopy picture of a broken bond wire can be observed in Figure 2.4.

Figure 2.4: An X-ray microscopy image of a broken bond wire.

Source: (Pross, 2010)

In addition, by integration the LEDs in an external assembly such as printed circuit board (PCB), more disappointment sources such as breakdowns of electrical joints due to poor soldering contacts should be thought of. The high-power LEDs will be encountered very critical effects on degradation due to thermal contact and heat dissipation. In order, to minimize or reduce these failures, the external assembly should ready to guarantee and ensure stable thermal contact during operation time. For example, in certain applications the LEDs will be covered by a defensive polish or an external joint compound.

Recently, the failure modes that are presented in the LEDs application can be approached by using various strategies for investigation (Pross, 2010). These strategies can be utilized to assign the noticed failure patterns to a potential root cause and give an approach to avoid them. The most straightforward method is by taking measurements whereas current-voltage curves, the intensity of light, frequency, and radiation characteristics can be resolved. For example, the radiation characteristics can be allocated the inhomogeneities of the light discharging region. Comparing the current-voltage curve between the malfunction and working LEDs can assist to differentiate the various causes of errors. Moreover, the other type of failure investigation such as non-damaging examination, destructive analysis, and physical analysis can be utilized to assign the LED failure modes. For non-destructive analysis, a visual light microscopy inspection can be used to provide information about the external construction, the external integrity of the LED package as well as the accessible parts of the interior construction. A general optical microscope can be observed in Figure 2.5. Other non-destructive procedures like separation of the wire bond on the LED chip can be identified by utilizing an X-ray microscope as shown in Figure 2.4.

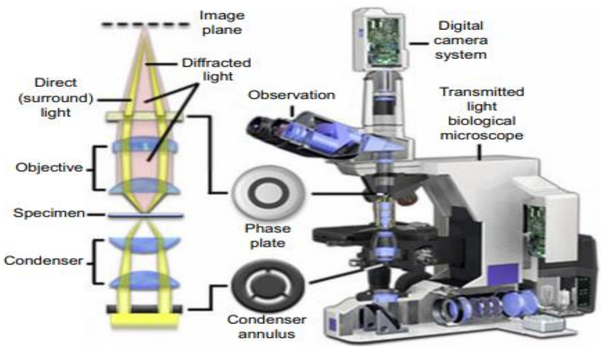

Figure 2.5: A light microscope.

Source: (Gianfrancesco, 2017)

In order, to confine the failures and direct admittance to the interior parts of the LED such as chip or bond interfaces, the destructive physical strategies can be used. The encapsulant materials can be eliminated by using chemical solvents and hence the internal structures of the LED are then available for the superior quality optical microscopy though the failures at the interfaces can be easily identified.

Last but not least, to confine the failures on the chip level, the strategies like dark spots or dark lines are often used to reveal the defective areas located on the chip. These strategies are usually founded on confined incitement of light emanation or current stream by an external electron beam or laser beam onto the chip. Other special strategies such as Transmission Electron Microscopy (TEM) and Fused Ion Beam (FIB) are accessible for the extensive analysis of failures in the epitaxy framework layer.

2.3 Effect of Rheology on Wire Sweep

The continuous miniaturization of chip size has significant impact in many modern electronic industries. For instance, the decreased chip size with increased I/O counts for the IC packages brings about a severe wire deformation and deflection during the transfer molding process which may causes some failure mechanisms (Ramdan, et al., 2012). Ramdan, et al. (2012) had successfully developed a 3D fluid-structure interaction (FSI) procedure and mesh-based parallel code coupling interface (MpCCI) for the perception of wire bond deformation and deflection for the microelectronics (PBGA) package during the encapsulation process. In their study, three different types of epoxy molding compound (EMC) with various rheology profiles have been utilized to observe and investigate the effect of the fluid flow inside the mold shape. The material properties and rheology profiles of the EMC can be illustrated in Table 2.1. Although this research paper is focused on the PBGA model, yet the FSI modelling techniques can be a good reference in this present study.

Table 2.1: EMC material properties(Ramdan, et al., 2012).

			Value		
		Unit	Case 1 [2]	Case 2 [22]	Case 3 [23]
Density	ρ	kg/m^3	1578	2000	1820
Tabulated thermal conductivity	T	°C	66.95	175	75
	k	W/m.K	0.74	0.97	0.669
Tabulated specific heat	T	°C	169.95	175	169.95
	C_p	J/kg.K	1078	1079	1205
Reactive I viscosity	N	—	0.7773	0.7773	0.28
	τ^*	Pa	0.0001	0.0001	2361
	B	Pa.s	0.04219	3.81×10^{-4}	0.416
	T_b	K	4810	5.23×10^3	2.091×10^3
	C_1	—	10.96	1.03	3.496
	C_2	—	0.00626	1.50	8.503
	α_g	—	0.6946	0.17	0.17
Reaction kinetics	H	J/kg	3.91×10^4	4.01×10^4	4.585×10^4
	m_1	—	0.4766	1.21	0.7241
	m_2	—	1.08	1.57	1.234
	A_1	1/s	0.1	33.53×10^3	8475
	A_2	1/s	5.926×10^5	30.54×10^6	9.715×10^6
	E_1	K	2×10^4	7161	7216
	E_2	K	7501	8589	8585

A VOF model in ANSYS Fluent was utilized to simulate and investigate the processes. Moreover, the viscosity Castro-Macosko modelling techniques has been applied in to track the melt front. A meshed wire produced by Ramdan, et al. (2012) can be illustrated in Figure 2.6, where all the boundary and initial conditions requirements were set for the simulation in ABAQUS.

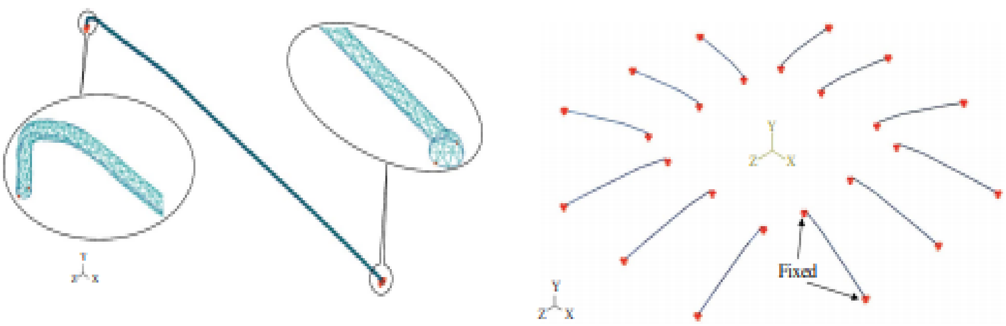

Figure 2.6: Meshed wire and boundary condition of wire in ABAQUS.

Source: (Ramdan, et al., 2012)

Based on the simulation results obtained, it was found that the least deformation of the wire or wire sweep was obtained from the case 2, where the viscosity of the EMC used was the lowest as compared to case 1 and case 3. The impact of the viscosity on pressure was discovered to be straightforwardly affected on the wire displacement as well as the drag force or stresses induced on the wire bond structure during the encapsulant filling process. The wires that experienced a high viscosity flow and high-pressure distribution were expected to have large deformation when contrasted to those experienced at a low viscosity and low-pressure distribution. The simulation results from this research paper where the percentage of wire sweep against each wire graph for the three different cases can be observed in Figure 2.7.

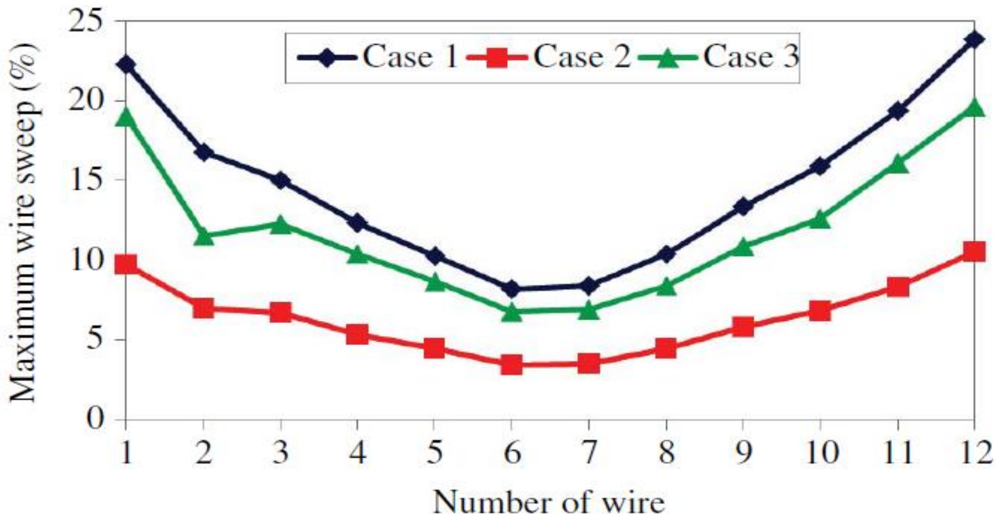

Figure 2.7: Percentage of maximum wire sweep of each case.

Source: (Ramdan, et al., 2012)

Finally, Ramdan, et al. (2012) had carried out the experiment to validate the simulation results by utilizing similar PBGA size, working condition as well as material properties of EMC in the simulation study. It was found that the average discrepancy of the most extreme and least of wire sweeps between the present FSI predictions technique and the experimental results is approximately 8%. Hence, this demonstrated that the reasonable forecasts of FSI technique made were found in good agreement with those experimental test results. The limitation of this research paper is that the model used was not LED package, however the FSI technique and simulation results obtained can be used as a good reference for this present study to determine the influence of viscosity or rheological profiles of the EMC on the LED package during encapsulation process.

2.4 Fatigue Life Evaluation of Wire Bonds in LED Packages

Thermal shock test is one of the dependability tests for the LED packages, where the most widely recognized failure mode is wire neck breakage. However, to evaluate the wire bonding dependability of the LED packages, the thermal shock tests can be very time-consuming (Zhang & Lee, 2014). In this research study, a numerical analysis for the wire bonding dependability on the LED packages was proposed. A wire bonding lifetime model for the thermal shock test was created by Sung-Uk Zhang et. al (2014), which is based on Coffin-Manson fatigue law to estimate the number of cycles to failure by utilizing the numerical simulation. Besides, a finite element method (FEM) was utilized to calculate the plastic strain of the wire bond under the test conditions. To identify the relationship between the wire loop and the accumulated plastic strain, a response surface methodology is used as well in this present research paper.

The wire bonding lifetime model which is based on Coffin-Manson fatigue law is illustrated as follows. The N_f can be analysed by using Weilbull investigation based on the failure data of the thermal shock tests, while $\Delta\varepsilon_p$ is computed by using FEM examination based on the prescribed test conditions.

$$N_f = a(\Delta\varepsilon_p)^b$$

where

N_f = mean number of cycles to failure

$\Delta\varepsilon_p$ = increment of volume averaging accumulated plastic strain between first and second thermal cycle

a and b = coefficients that calibrated by using linear regression

Table 2.2: LED package and test conditions for thermal shock tests in this research paper.

Number of DP	Size	Kind of silicone	Wire diameter (μm)	Wire height (μm)	Wire length (μm)	Wire loop
1	Large	A	25.0	190	1000	L1
2	Large	A	25.0	230	1000	L1
3	Large	A	25.0	190	1000	L2
4	Large	A	25.0	230	1000	L2
5	Small	B	30.0	200	650	L2
6	Small	B	30.0	300	650	L2
7	Small	B	30.0	200	920	L2
8	Small	B	30.0	300	920	L2
9	Medium	A	25.0	280	1100	L3

A few thermal shock tests were carried out based on the data point conditions as shown in Table 2.2. These data points were simulated in the finite element models to compute the plastic strains accumulated during the temperature cycle. In order, to reduce geometry discrepancy, a scanning electron microscope (SEM) was utilized to capture the wire shape in detail as shown in Figure 2.8. The simulation results obtained show that the data point 3 has the largest increment while data point 5 has the smallest one among the all the data points. This indicated that wire types, wire height, wire length, wire loop as well as wire diameter can affect the reliability performance of the LED applications. Thus, it is important to select the correct size of the wire bond for the LED package. This research paper can be a good reference when the effect of the diameter of wire is concern in this present work.

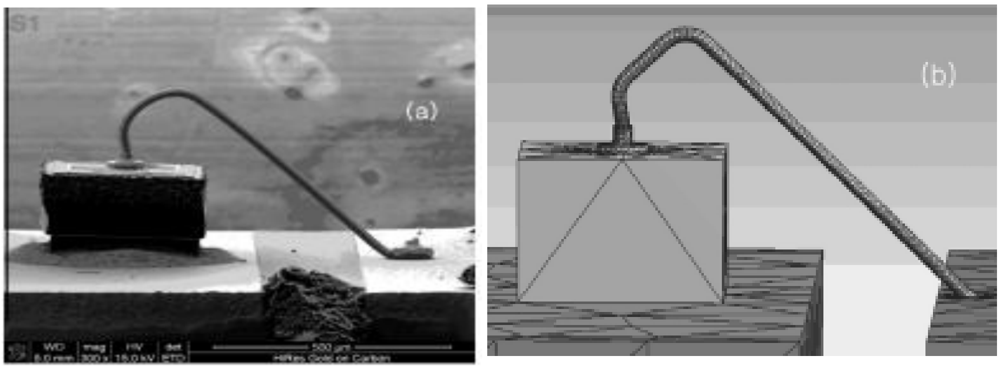

Figure 2.8: A wire shape (a) SEM picture and (b) finite element model created.

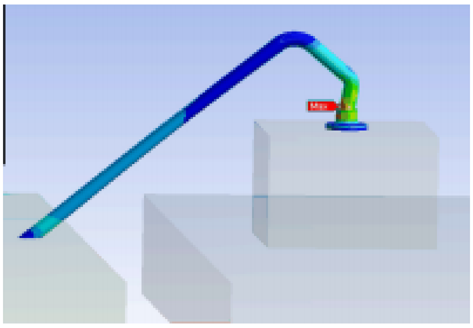

Figure 2.9: Equivalent plastic strain distribution on the gold wire.

Source: (Zhang & Lee, 2014)

2.5 Effects of Ball Bond Diameter on Wire Bond Reliability

HuiYuen Peng et. al (2016) had sucessfully studied the effect of interfacial corruption on the three different wire bond test samples after isothermal aging for the automative application. An experiment was carried out and a model of the wire bond was developed and simulated by utilizing COMSOL Multiphysics simulation software to understand the thermal stress distribution induced in the wire bond during isothermal aging. This research paper is mainly centered around the effect of wire bond diameter and ball bond diameter during isothermal aging process. Although different simulation method is used in this research paper, yet the results studied are very important as a reference for this present study.

Three 99% unadulterated gold wire with various diameters of 2mm, 1.5mm and 1mm are used in their research study. The gold wires used are bond onto the LED chip bond pad and the three different average ball bond diameters produced are recorded and tabulated with 157μm, 121μm and 94μm respectively. The samples were then exposed to isothermal aging at 200°C inside a research centre oven for intervals of 30, 100, and 500 hours to access the wire bond dependability under high-temperature environment and the ball shear test was done on each sample at the end of the experiments. The results obtained by HuiYuen Peng et. al that the ball shear forces decrease with increasing isothermal aging duration as shown in Figure 2.10. Hence, the wire bond interfacial attachment will corrupts significantly after isothermal aing, while the ball bond sample with smaller diameter was more significantly influenced based on the results obtained.

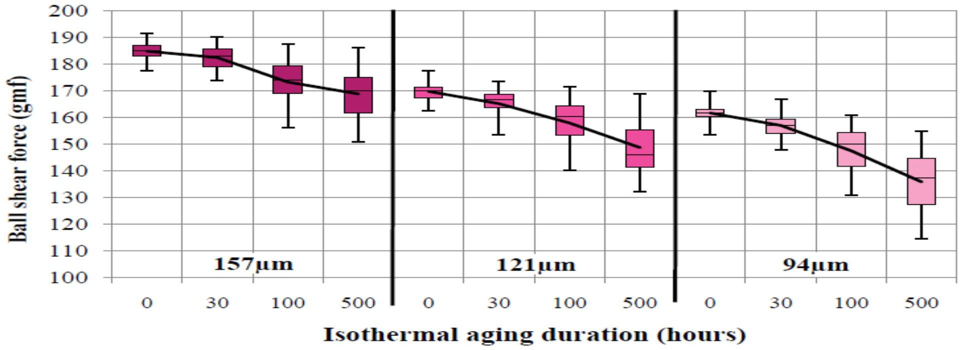

Figure 2.10: Ball shear strength result for isothermal aging at high temperature of 200°C.

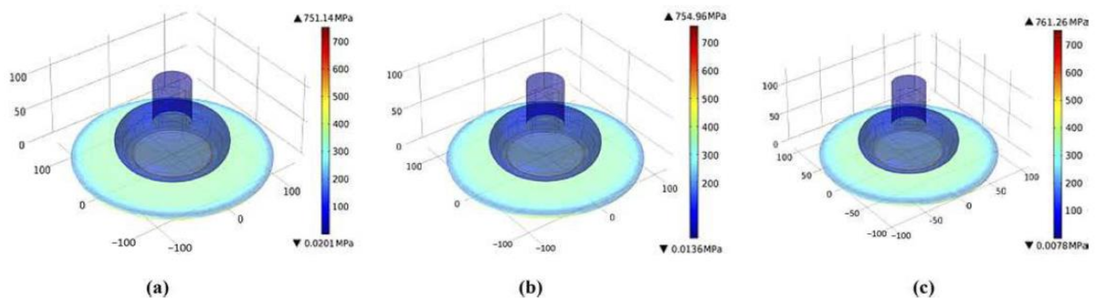

Figure 2.11: Von Mises stress of the overall wire bond model having diameter of (a) 157μm, (b) 121μm, and (c) 94μm.

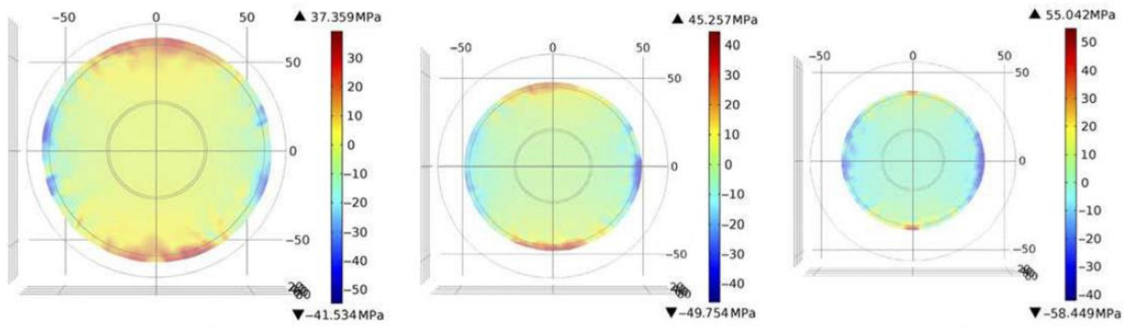

Figure 2.12: Tensor stress distribution of the bonding interface for ball bond (a) 157µm, (b) 121µm, and (c) 94µm.

Source: (Peng, et al., 2016)

To further observe the effect of the diameter of wire bond, HuiYuen Peng et. al (2016) carried out the 3D model of the wire bond by using COMSOL Multiphysics simulation software. The Von Mises stress of the overall wire bond model and the Tensor stress of the different ball bond diameter bonding interfaces with the boundary condition at 200°C have been simulated as shown in Figure 2.11 and Figure 2.12. The Von Mises stress is referring as the thermal stress reading induced in the wire bond model. The findings showed that the Von Mises stress for smaller ball bond is higher as compared to the other two samples. This explained that the ball shear force degradation was fastened for smaller ball bond due to more induced thermal stress to the outer edge of the bonding interface. For tensor stress, it is a stress reading for analyzing ball bond deformation. The results showed that the smallest diameter of ball bond have the highest differences between the alternating positive and negative readings, and this cause the degradation of this ball bond was fastened when compare to the other ball bond diameters.

2.6 Simulation Modelling Methods

The computing capabilities such as speed, reliability, adaptability and accuracy that would have been unrealizable a few years ago has awakened an interest in simulation modelling. Recently, simulation modelling plays an important role in many engineering industries such as automotive, aerospace, biomedical and many more. By using simulation modelling technique, the prediction of the outcome can be easily obtained and achieved by various modelling tools. During the LED encapsulation process, the interaction between the fluid (EMC) and structures such as gold wires, chip and solder bumps can be occurred. Since, the fluid structure interaction (FSI) phenomenon is very difficult to visualize in the actual packaging process, hence the simulation modelling technique is very useful to model the FSI in the moulded packaging of LED.

The appropriate selection of the viscosity model in simulation modelling is very important to obtain the optimum predictions of the EMC behaviour over the LED structures such as gold wires and microchip. There are many different types of viscosity models have been utilized by researchers, such as power law model, Cross viscosity model, Castro-Macosko model, and Herschel-Bulkley model (Khor & Abdullah, 2012). Yet, it was found that the Castro-Macosko model can provides more reliable predictions on the flow rheology compared to the other models. Therefore, the most suitable Castro-Macosko model is selected for the optimum prediction outputs during the LED encapsulation process.

Besides, the volume of fluid model is used to utilize the free surface modelling for tracking the movement and interface of the fluid (EMC) during the encapsulation process. There are variety of discretizing methods can be found for solving the VOF equations, such as finite difference (FD), finite element (FE) as well as finite volume

(FV) (Abdul Aziz et al., 2015). This technique is based on the Marker-and-Cell (MAC) which required high computational and storage requirements. However, there are few restrictions that applied to the VOF model in the Fluent. All the control volumes must be filled with either a single fluid phase or a multiphase of fluids. Moreover, the solver available for this method was only pressure-based and it can be only applied to one phase which is compressible. Other restriction is species mixing and reacting flow are not able to model when the VOF model is being applied in the Fluent. Lastly, the second-order implicit time-stepping formulation as well as the shell conduction model for walls are not applicable with the VOF model (Inc, 2003).

2.7 Epoxy Molding Compound (EMC) Properties

Epoxy Molding Compounds (EMC) have been widely used for numerous applications in the electrical and automotive industry due to their excellent electrical properties, good chemical resistance and high mechanical properties. The typical properties of the EMC or thermosetting materials are mainly based on their molecular structure (Buchmann, 2016). The thermosetting materials typically show a 3-dimensional cross-linked structure. The structure of melted thermosetting (left) and cured thermosetting (right) materials are both shown in Figure 2.13. In order, to cross linked the melted thermosetting structure, polyaddition mechanism usually applied for the EMC by simple bonding or curing without any waste of the products.

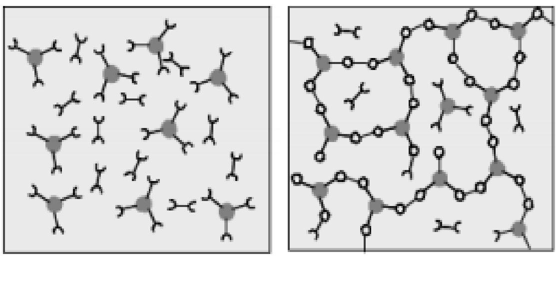

Figure 2.13: Molecular structure of the thermosetting materials.

Source: (Franck, 2016)

Basically, the cross linking of the molecules or thermosetting materials have different temperature over time behaviour as compared to the thermoplastic materials. For the thermoplastic materials, the viscosity drops when the temperature increases. However, there are two competing effects accumulated in the thermosetting materials. For instance, in melting and curing processes of the thermosetting materials, the viscosity tends to reduce over time due to increasing temperature. Moreover, the viscosity of the thermosetting materials can be increased as well during the curing process. Figure 2.14 shows the resulting viscosity of thermosetting materials during melting and curing.

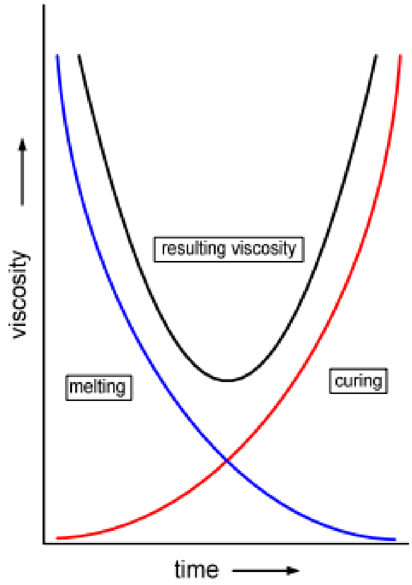

Figure 2.14: Viscosity of the thermosets over time.

Source: (Buchmann, 2016)

Epoxy molding compound (EMC) is comprised of a polymer matrix that is epoxy resins, hardeners and accelerators. This polymer matrix is compounded with fillers, reinforcing materials, pigments, and release agents to form into solid powder or granulates. Since EMC reacts according to the addition polymerization reaction, no by-products are formed during the molding process. Despite the thickness of the wall, the