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Quantitative Analysis on Air-Dispensing Parameters for Manufacturing Dome Lenses of Chip-on-Board LED System

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*A COB(chip-on-board) LED(light emitting diode) system has advantages such as low cost and good heat dissipation. LED chips are bonded on PCB(printed circuit board) directly without packaging process in case of COB LED systems. Dome lenses made of polymeric resin are generally covered on the bonded LED chips by air dispensing for preventing mechanical damage and making white light. However, it is hard to control the shape of dome lenses precisely due to viscosity of the polymeric resin. We analyzed the relationship of the shape of dome lenses and experimental conditions of the air dispensing in this study. We introduced a new parameter, air pressure * dispensing time, whose physical meaning is impulse per unit area, and obtained much clear relationship of dispensing parameters and shape parameters of the dome lens. This relationship was similar to viscoelastic behavior. The aspect ratio (height over diameter) was increased as the new parameter increased, and was converged to a certain value. The maximum aspect ratio could be calculated by Young's equation of contact angle.*

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NOMENCLATURE

AR = Aspect ratio
d = diameter of a dome lens
h = height of a dome lens
γ^{lv} = liquid surface free energy
γ^{sl} = solid/liquid interfacial free energy
γ^{sv} = solid surface free energy
θ = contact angle

1. Introduction

Energy saving is recently a world-wide issue to prevent green-house effect and to save earth resources. General lightings and displays occupy high portion of energy consumption. The best way to save energy of lightings and displays is to use high efficient light sources, and LED (Light Emitting Diode) is the most promising light source which can meet the demand of the energy saving. Though LED systems have high energy efficiency, they have high cost and heat problems. COB (chip-on-board) technology is one of the candidate technologies to solve these demerits. The COB technology was used widely at semiconductor industries because better package having high density and good electrical characteristics.[1,2] The COB technology attaches LED chip on PCB (printed circuit board) directly, which can reduce cost[3] by decreasing the number of total processes and, enhance heat dissipation by decreasing the number of heat interfaces.[4,5] Therefore, COB LED systems are proper for high-power LED systems for general lightings and display.[5,6]

Encapsulation of polymeric resin covers the bonded LED chips[7] for preventing mechanical damage and making white light. Generally, air dispensing technology is used for manufacturing the encapsulation and the shape of the encapsulation is generally a dome lens. However, it is hard to control the shape of the dome lenses precisely due to viscosity of the polymeric resin.[8] We analyzed the quantitative relationship of air dispensing conditions and shape parameters of the dome lens, and suggested a new dispensing parameter to control the shape of the dome lens precisely in this study.

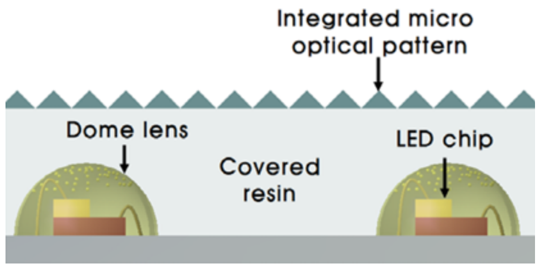

Fig. 1 A schematic diagram of hybrid LED package (modified from Ref. 9)

2. Experimental Methods

Based on author's previous research,[9] HLP (Hybrid LED Package) of Fig. 1 was verified to have highest efficiency when the HLP has dome lenses of 4 mm diameter and 1mm height. The dome lens was proved to increase light efficiency by reducing internal reflectance.[8] According to the results of the previous research, the target shape of the dome lenses was set to be 4 mm diameter and 1 mm height. Various dome lenses were manufactured under various pairs of air dispensing conditions (air pressure and dispensing time). Precise air dispenser (Super sigma X, Musashi Eng.) and UV curable polymeric resin (Loctite 3103) were used in this study. The Shore hardness and the refractive index of the resin are 51 and 1.5, respectively. Thermo-curable polymeric resins are more popular in LED industries. Generally, the dispensed dome lenses of thermo-curable resins are cured and hardened after at least more than several minutes after dispensing because the lenses should wait to be entered into oven. It takes more than one hour to be cured. The dispensed dome lenses are collapsed gradually before and during the curing. Special resins having much high thixotropy should be used in order to prevent the collapsing, however, it is too hard to dispense the resin having much high thixotropy. On the other hand, the dispensed dome lenses of UV curable resin can be cured and hardened by a UV lamp set aside the air dispenser before at most one minute after dispensing. Moreover, it takes just within ten seconds to be cured. Therefore, UV curable resin was used in this study.

The manufactured dome lenses were observed by an optical microscope attached to a contact angle measurement system. The some pairs of the air dispensing conditions were selected when the shape parameters (height and diameter) of the dome lenses were relatively similar to the target values. Air pressure had a range of 50 kPa to 550 kPa, and dispensing time had a range of 100 msec to 750 msec.

3. Results and Discussion

The height, the diameter and the aspect ratio (height over diameter) of the manufactured dome lenses under the selected dispensing conditions are presented in Fig. 2. The height and the diameter were generally proportional to the dispensing conditions since the two dispensing conditions are proportional to the volume of the dispensed resin. However, their relationship was much weak. The aspect ratio had vague relationship with the dispensing conditions. Therefore, a master curve to predict the shape of the dome lens could not be built if the dispensing conditions were used.

We created a new dispensing parameter (air pressure * dispensing time) to solve this problem. This new parameter physically means impulse per unit area acted on the dispensed resin according to Eq. (1). The projected area of the dispensed resin was always same in this study since the same needle was used for air dispensing. The impulse is same to the variation of momentum of the dispensed resin based on the impulse-momentum theorem. Since the final velocity of the dispensed resin was zero at all experiments, the new dispensing parameter could be regarded as an initial momentum of the dispensed resin.

$$P \times t = \left(\frac{F}{A}\right) \times t = \frac{(F \times t)}{A} = \frac{I}{A} \tag{1}$$

(P : air pressure, t : dispensing time, A : Area, I : Impulse)

Fig. 3 shows the height, the diameter and the aspect ratio (height over diameter) of the manufactured dome lenses varied by the new dispensing parameter. The height and the diameter had strong positive relationship with the new dispensing parameter. Fig. 3(a) had two stages (Stage I and Stage II) having different slopes. The slope of the 'Stage I' was larger than the slope of the 'Slope II'. These characteristics were same in the case of the diameter as shown in Fig. 3(b). These characteristics were similar to a viscoleastic creep curve based on Kelvin-Voight model as shown in Fig. 4 which is a one of the viscoelastic behavior models.[10] The curve shows high slope at the early stage and low slope at the late stage, and Fig. 3(a) and Fig. 3(b) can be fitted similarly by Kelvin-Voight model.

The x-axis parameters of Fig. 3(a), (b) and Fig. 4 are different, however, the two parameters include the same time term. The y-axis parameter of Fig. 4 is strain, which means varied length (final length - initial length) over initial length. If the initial length is same to all cases, the strain can be regarded as the final length qualitatively. The y-axis parameters of Fig. 3(a) and Fig. 3(b) are the height and the diameter, which mean the final length along vertical direction and horizontal direction, respectively. Thus, Fig. 3(a) and Fig. 3(b) can be compared qualitatively to Fig. 4. Moreover, the polymeric resin used in this study showed viscoelastic behavior because it had viscosity of 8,000 to 14,500cP which means medium viscosity. Therefore, the viscoelastic behavior of the polymeric resin induced the characteristics of the height and the diameter versus the new dispensing parameter.

The aspect ratio showed similar two stages. The aspect ratio was increased at 'Stage I', which meant the height is increased more than the diameter when the dispensing conditions were increased initially. However, the aspect ratio was converged to about 0.26 at 'Stage II'. This meant that the aspect ratio had an upper limit even if the air

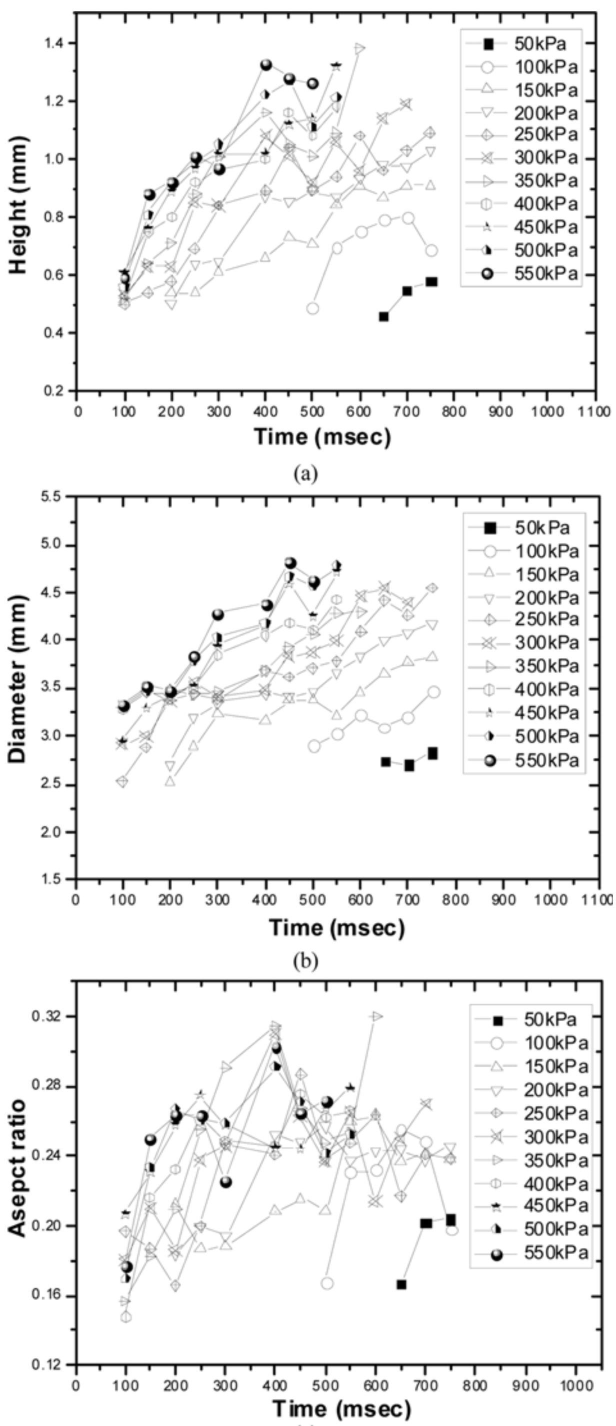

Fig. 2 Measured shape parameters ((a) height, (b) diameter and (c) aspect ratio) of dome lenses varied by dispensing conditions (air pressure and dispensing time)

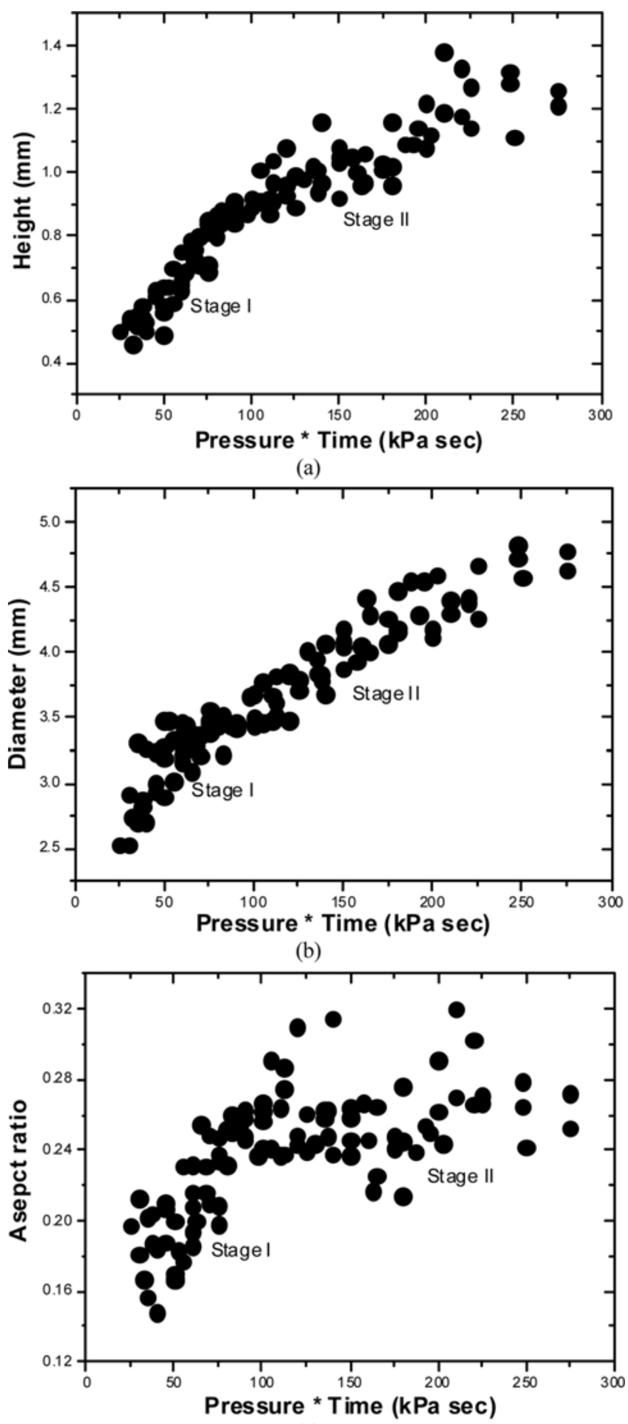

Fig. 3 Measured shape parameters ((a) height, (b) diameter and (c) aspect ratio) of dome lenses varied by a new dispensing parameter (air pressure * dispensing time)

pressure and the dispensing time were increased consistently, and that the height and the diameter were increased with a same rate after they reached a certain value. This phenomenon can be explained by Young's equation[11-13] of a contact angle shown in Eq. (2).

$$\gamma^{sv} = \gamma^{sl} + \gamma^{lv}\cos\theta \tag{2}$$

(γ^{sv} : solid surface free energy, γ^{sl} : solid/liquid interfacial free energy, γ^{lv} : liquid surface free energy)

The same resin (liquid) and the same PCB (solid) were used in this study, thus, the three free energies are constant and the contact angle had a unique value. If the dome lens manufactured in this study is a part of a sphere, the contact angle can be calculated by Eq. (3) based on the geometrical relationship as shown in Fig. 5. The contact angle is a one-to-one function of the aspect ratio of the dome. One of the

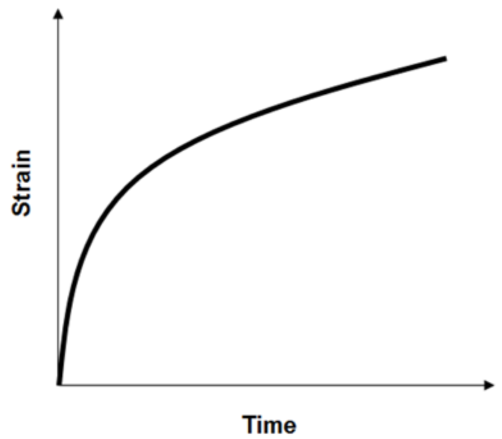

Fig. 4 A viscoelastic creep curve based on Kelvin-Voight model

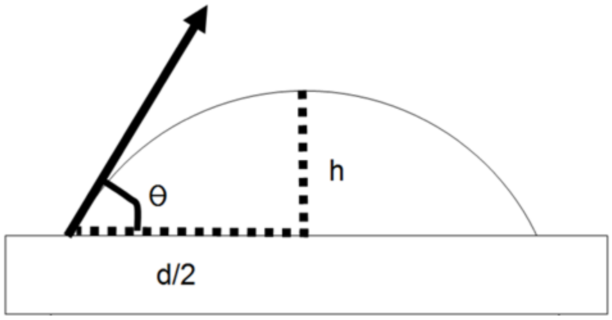

Fig. 5 A schematic diagram of contact angle of dome lens

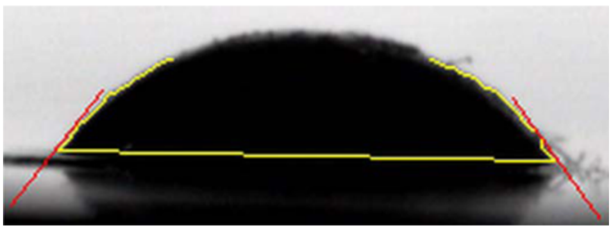

Fig. 6 Contact angle measurement of a dome lens (diameter : 3.997 mm, height : 0.989 mm)

manufactured dome lenses in Fig. 6 was measured by a contact angle measurement system, and its contact angle was 52.9°, which was almost same to the calculated contact angle 52.7° from Eq. (3). The other measured contact angles of various aspect ratios were also almost same to the calculated contact angles as shown in Fig. 7. Thus, the dome lens can be assumed hemispherical and the upper limit of aspect ratio is determined by the contact angle of Young's equation.

$$\theta(°) = 90 - \frac{180}{\pi}\left(\tan^{-1}\left(\frac{d}{4h} - \frac{h}{d}\right)\right) = 90 - \frac{180}{\pi}\left(\tan^{-1}\left(\frac{1}{4} \times \frac{1}{AR} - AR\right)\right) \quad (3)$$

(AR : aspect ratio)

The new dispensing parameter had strong relationship with the height, the diameter and the aspect ratio of the manufactured dome lenses. Moreover, the characteristics of their relationship could be

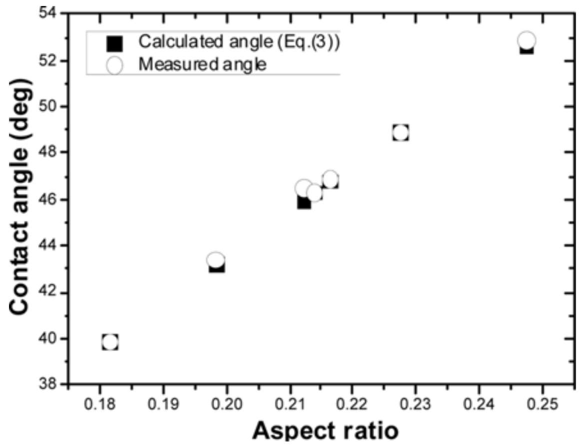

Fig. 7 Comparison of calculated contact angles (Eq. (3)) and measured contact angles

explained by viscoelastic behavior and contact angle theory. Therefore, the new dispensing parameter can be used to predict the shape of the dome lenses for COB LED systems manufactured by air dispensing technology.

4. Conclusions

We analyzed the relationship of dispensing conditions (air pressure and dispensing time) and shape parameters of a dome lens (diameter and height) quantitatively when dome lenses for COB LED systems were manufactured by air dispensing technology. We made the following conclusions:

(1) Dispensing conditions had weak relationship with the shape parameters of dome lenses.

(2) On the other hand, a new dispensing parameter (air pressure * dispensing time) showed strongly positive relationship with the shape parameters of the dome lenses. The new dispensing parameter physically means impulse per unit area and initial momentum of the dispensed resin.

(3) The variation of the two shape parameters was similar to viscoelastic creep curve when it was fitted by the new dispensing parameter, which was induced by viscoelastic behavior of the dispensed polymeric resin.

(4) The variation of the aspect ratio (height over diameter) had an upper limit when fitted by the new dispensing parameter, which could be explained by contact angle theory of free energies of resin and PCB.

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