INVESTIGATION ON INFLUENCE OF DIE SIZE AGAINST DIE-CRACK AT DIE ATTACH PROCESS

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Rapid cost down pressure in LED industry and shrinking size and thickness of mobile electronics goods has lead to LED players to develop thinner and smaller die. Having smaller and thinner die, compromise the mechanical strength of the die. At Die Attach (DA) process, crack die can occur when the die mechanical strength is compromised. In view of this, an investigation on two different die size of an AlInGaP on a germanium substrate with (111) lattice was carried out. The finding shows that the die with thinner and smaller outline has severe cracks as compared to larger counterpart. The crack length for the thinner and smaller die also relatively gets longer as the bond force increases. However, for both dies, micro-cracks start to appear at bond force 60gF onward. No crack was observed below 60gF. This finding confirms that smaller and thinner die has higher potential to have severe crack as compared to the larger one. Hence control of bond force below 60gF, is critical for Ge substrate based LED to avoid severe die-crack.

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1. Introduction

LED industry is going through rapid cost down pressure as seen in other semiconductor industries during last decade. Cost per lumen has become an important factor in the key performance of the LED manufacturer [1]. As a result of this cost down pressure, the LED industry is looking into many ways of reducing the cost. One of the learning from the other semiconductor industry that was having more functional dice by scaling down the chip size helps to reduce the chip cost [2]. Besides that, the LED industry is also going through a rapid expansion in many product applications. Mobile phone industry in particularly, evolving to thinner and wide variety of functions. This evolution, further shrank the LED product size and thickness to match application requirement. Hence, this directly requires thinner and smaller die [3, 4]. As a result of this, die mechanical strength is compromised [2]. In view of this, an investigation was carried out to see the correlation between two different die size and thickness toward crack formation at the die substrate. For this investigation Aluminium Indium Gallium Phosphate (AlInGaP) on germanium (Ge) die were used.

Prior work done by our group on AlInGaP on Ge die have exposed great deal of information on the Ge crack behaviour against bond force along the crystal plane of the Ge substrate [5]. However, this research work confined to one die size of 300µm wide by 300µm length and 150µm thickness. This die is relatively bigger as compared to the market expectation. In this investigation the die size that was investigated was 150µm by 150µm with 120µm thickness. A reference die used for this investigation was at 300µm by 300µm with thickness of 190µm.

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2. Theoretical background

Crack die occurs in DA process mainly due to ejector pin hitting the die substrate at certain stress level that exceed the inter-atomic strength of die substrate material. This stress applied on the die can be described by the Hertzian contact equation [6, 7]. Normal stress applied on the die substrate is expressed as:

$$\sigma = \frac{F}{A} \quad (1)$$

Where:
A is the area of ejector pin in contact. F is the load (force) which the ejector pin applies on the die. The ejector pin tip, which is semi-spherical in shape, is illustrated in figure 1. It is the standard ejector pin supplied for the LED industry by Micro-mechanics [8]. The ejector pin tip radius, R, for this research is 25µm. This radius was used because it is commonly used for the small die size. The ejector pin contact area can be derived as

$$A = \pi a^2 \quad (2)$$

Where, a is the ejector pin spherical surface contact length as illustrated in figure 1. Note that the Hertzian contact analysis is restricted to condition that the depth of penetration is small relative to the radius, R, of the sphere [7, 9].
Combining equation 2 to equation 1, the stress can be addressed as follows:

$$\sigma = \frac{F}{\pi a^2} \quad (3)$$

The stress applied to the die is directly proportional to the applied force; hence, higher the force applied to the die, the higher the stress will be absorbed by the die. On the other hand, the stress is inversely proportion to ejector pin tip contact area that is directly influenced by the ejector pin tip radius.

On the other hand, the bond force calculated using Newton's second law;

$$F = m϶, \quad (4)$$

Where m is the mass and ϶ is the acceleration of the ejector pin.

$$϶ = \frac{(v_2 - v_1)}{t} \quad (5)$$

$\mathcal{V}_2$ is the velocity of the ejector pin before hitting the back of the die (ejector pin speed). $\mathcal{V}_1$ is the velocity of ejector pin at datum. t is the time taken for the ejector pin to move from datum to the point of impact on die. The maximum bond force, F, can be addressed by combining equation 5 to equation 4 and by considering $\mathcal{V}_1$ = 0 at the datum.

$$F = m.\frac{\mathcal{V}_2}{t} \quad (6)$$

Henceforth, the maximum stress applied on the die can also be addressed as:

$$\sigma = \frac{m.\mathcal{V}_2}{\pi a^2.t} \quad (7)$$

The velocity the ejector pin travels before hitting the die is directly proportional to the stress applied on the die. Hence, the higher the ejector pin velocity, the higher the stress is at the chip substrate and this increases the possibilities to have crack die.

In the LED packaging industry DA process, the optimum bond force varies. It is influenced by the equipment, die size and the type of mylar on which the dies were mounted.

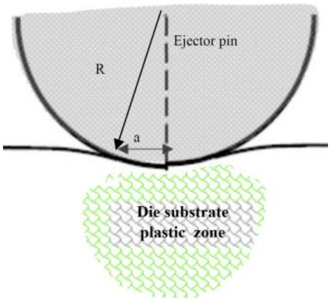


Fig. 1. Ejector pin contact to surface of substrate [13]

3. Evaluation methodology

The investigation was carried out using Tosok die bonding equipment to create the cracks. This is mainly to replicate the actual condition of LED die bonding process. Hence, the data comes out of this research is directly applicable for the LED packaging industry. The samples were prepared following the process steps as illustrated in Fig. 2.

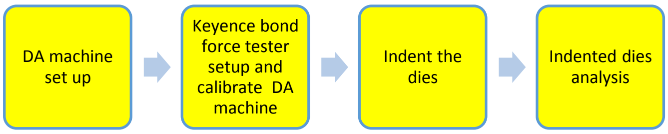


Fig. 2. Sample preparation process flow

The dice were carefully selected. There are without any mechanical defect. All the dice were serialized in a mylar tape for traceability purpose. DA equipment was set up by checking the ejector pin and bond head alignment and bonding stability.

Die-crack occur when the ejector pin hit the bottom of the die during die bonding process. This is illustrated in figure 3, where the die bonding sequence shows the maximum stress applied on the die substrate. The die bond sequence marked in the red box is where the die goes through highest stress. This is further illustrated in detail in figure 4. Here the ejector pin already pushed the die up from the mylar tape and the bond head picked up the die. The force acting on the die will be at the highest point. The bond force is controlled using the die attach equipment pick up force parameter. To increase or to lower the bond force, this parameter was changed accordingly.

In order to confirm the bond force setting at the die bonder is accurate, Keyence bond force tester was used to measure the bond force. It was installed on the bonder as illustrated in figure 5a. Several bonding trials were carried out to check the bonding consistency. Final confirmation of the bonding consistency was carried out by using a hand held force tester - Correx Tension Gauge [10] as shown in figure 5b. This is to counter confirm the Keyence bond force tester measurement accuracy before commencing the experiment. The experiment commenced with indenting 40gF (as control) and continued with 60gf, 80gF, 100gF, 120gF, and 140gf respectively. Each bond force cell, 100pcs of dice were indented and they were serialized on a mylar tape.

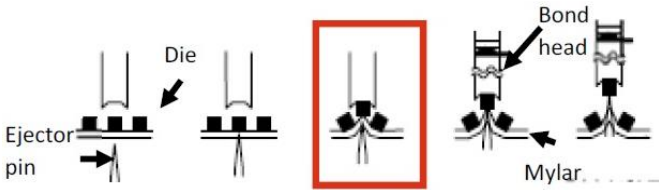


Fig. 3. Die bonding sequence [11].

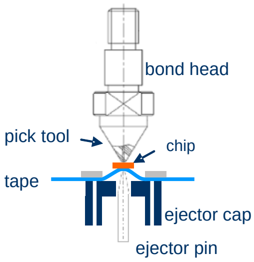


Fig. 4. Shows the detail view of the bond head, chip and ejector pin as illustrated in the box in fig. 2.

a. Keyence - Compression Load Cells installed on DA equipment

b. Correx hand held bond force gauge to confirm the DA force on DA equipment.

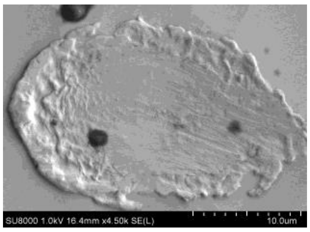
Fig. 5. Keyence bond force sensor mounted on DA equipment.

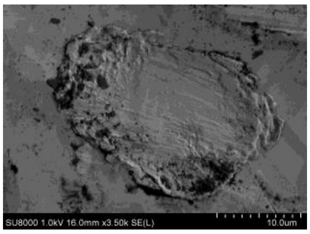
The indented dies were analysed by using Hitachi SU8020 Scanning Electron Microscope (SEM) for surface crack formation. Some dies were cross-section using Focused Ion Beam (FIB) to see the crack propagation inside the die substrate. On the other end, the crack length was measured using high power scope. For each bond force cell, 30pcs of dice were measured and average crack length was calculated. These average crack length was computed into a line chart to see the correlation between die size, bond force and crack length.

4. Results and discussion

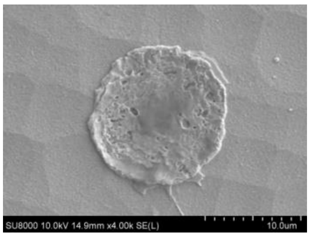
4.1. Crack formation analysis of difference die size.

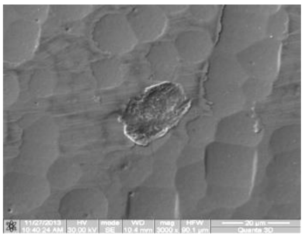
The crack formations were illustrated in figure 6. No crack seen at 40gF. The crack began to occur at 60gF force onward as illustrated in figure 5c and d. Small micro crack was observed at this bond force.



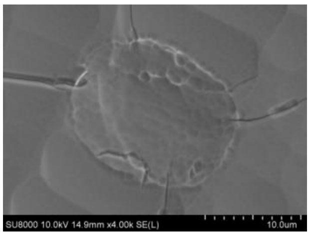


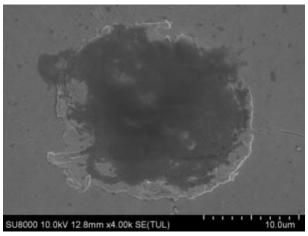
a. Small die indented at 40gF. *b. Big die indented at 40gF.*



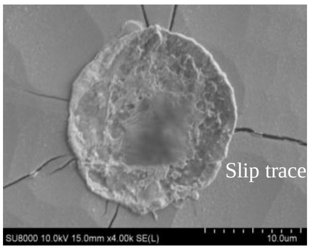


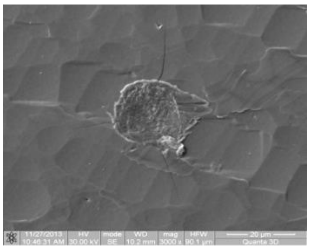
c. Small die indented at 60gF. *d. Big die indented at 60gF.*





e. Small die indented at 100gF. *f. Big die indented at 100gF.*





g. Small die indented at 140gF. *h. Big die indented at 140gF*

Fig. 6. Crack formation comparison between small and big dies over different bond forces.

Plastic deformation and material pile up at small die is more severe than the big die. Crack at 100gF bond force for small die is much bigger and severe compare to big die. Plastic deformation was more severe in the small die. Slip trace also very visible after 100gF on both die sizes. Same observations were seen for 140gF bond force. However, crack much more severe in small die compare to big die. This clearly indicates that small die easily crack with small bond force. This finding is in agreement with findings by Desmond Y.R et.al. [2]. Their finding shows that an increasing in trend of the die breaking load with the die thickness and size. This was expected as larger load is needed to cause die crack in a die with a greater volume (size times with thickness).

This crack phenomenon also justify to the Griffith energy balance criterion, where, the force asserted is in proportional to stress, that determines the material deformation and crack formation on it [6, 9]. This was clearly observed in this investigation as shown in Figure 6a, b and c, when the force was increased gradually from 60gF to 140gF, the crack severity increased proportionally.

4.2. Correlation of Die Size and Crack Length

The crack length increased relatively to the bond force and die size. This is illustrated in Fig. 7. As the bond force increases, the energy asserted to the Ge atomic bond increased proportionally and more bonds were broken and crack length also increased relatively. As the bond force increases, the slip traces get more visible in the indented area. Zone in the immediate vicinity of the imprint is strongly strained. Also very visible here are the micro-cracks and major cracks increasing relative to bond force.

Crack occurs due to stress at which the bond rapture takes place. The stress at which this bond rapture takes place is also called ideal strength, (δ) which is described in equation 8 [12]:

$$\delta \approx E/15 \tag{8}$$

Here E is the Modulus of Elasticity, whose valued for Ge is 103GPa [13]. The ideal strength of Ge will be roughly 6.87GPa.

No cracks were observed for both die size at 40gF bond force.

This is mainly due to the stress induced by the ejector pin is smaller than the ideal strength of the Ge substrate. The ejector stress induced by the ejector pin is calculated using equation 2, with a= 5µm (measured value) is only at 5GPa, is far lower than the ideal strength of Ge substrate that was at 6.87GPa. This finding is quite similar to findings of Bradby et.al [14], where defects along the (111) planes and plastic deformation on Ge was found under 50mN indentation load at room temperature. No crack was found at this load. Similar finding also reported by Oliver et.al [15], where plastic deformation on Ge was observed upon indented on the Ge substrate at 60mN load.

Cracks were observed for both die size at 60gF onward. The stress applied to the Ge substrate through the ejector pin at 60gF was estimated using equation (2) roughly 7.49GPa. This is larger than the ideal strength of Ge substrate that was at 6.87GPa. This crack or separation occurs when stress applied to the Ge substrate is sufficient to exceed the maximum inter atomic force per bond [16].

If compare between both die sizes, the smaller die size crack length is much longer and wider compare to the bigger die size. This was expected as mentioned earlier, where the bigger and thicker die has larger volume and it takes greater load before it cracks [2].

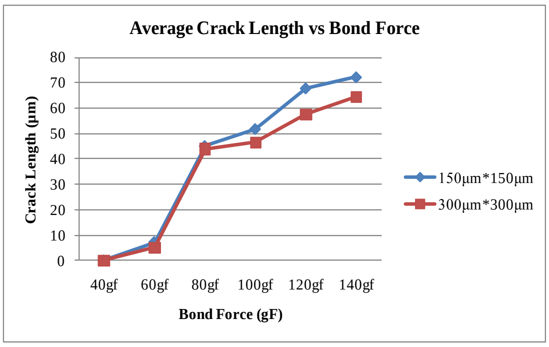
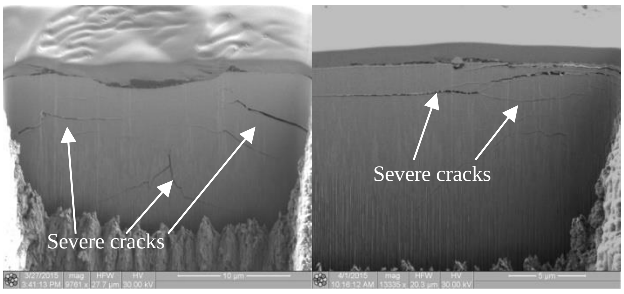


Fig. 7 Crack length comparison between small and big dies.

4.3 Cross Section Analysis of Die-crack

The dice were cross-sectioned using FIB cut. The illustration in figure 8a and b, clearly show that severity of stress induced at 140gF impacted the smaller die is more severe compare to bigger die. This is due to the ability of the die to absorb the stresses. In bigger size die has larger volume and it’s able to absorb more energy [2]. Hence, distribute the energy into the entire atomic chain in its mass. This as a result bigger die has less severe crack. On the other hand, the smaller die has more crack, they were larger and more severe. This clearly shown in Focus Ion Beam (FIB) section photo as illustrated in figure 7a and b, where many cracks were observed beneath the impact crater of the small die compare to big one.



a. Small die indented at 140gF b. Big die indented at 140gF.

Fig. 8. FIB cross-section of small and big die at 140gF.

Both die cracked only at surface level and far away from the active layer. Hence poses no impact to the electro-optical properties of the die at non stressful application condition. However, such crack may propagate when subject to harsh thermo-mechanical stresses [17, 18].

5. Conclusions

The investigation on two different die size of AlInGaP on Ge substrate has provided an important information on the impact of the die size toward crack formation and propagation. The finding showed crack severity propotional to bond force for both die size. The smaller die has larger crack length and more severe cracks are. This is also supported by Griffith energy blance criterion, where force asserted is in propotion to stress, determinies the material deformation the crack formation.

This finding also shows minor cracks start to form for both die at 60gF onward, regardless of the die size. However, as bond force increases crack length and severity of crack in small die is worse then the bigger die. Hence, it is important that small die (AlInGaP on Ge) must be handled carefully. Based on this experiment, we found, bond force below 60gF posses no crack at this Ge substrate, if use the ejector pin of 25um radius.

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