Comparison of the copper and gold wire bonding processes for LED packaging*

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Abstract: Wire bonding is one of the main processes of the LED packaging which provides electrical interconnection between the LED chip and lead frame. The gold wire bonding process has been widely used in LED packaging industry currently. However, due to the high cost of gold wire, copper wire bonding is a good substitute for the gold wire bonding which can lead to significant cost saving. In this paper, the copper and gold wire bonding processes on the high power LED chip are compared and analyzed with finite element simulation. This modeling work may provide guidelines for the parameter optimization of copper wire bonding process on the high power LED packaging.

Key words: LED packaging; wire bonding; copper wire; FEM
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1. Introduction

Solid state lighting, in terms of high power LEDs will be the fourth illumination source to substitute the incandescent lamp, fluorescent lamp and high pressure sodium lamp[1]. LEDs have superior characteristics such as high efficiency, low power consumption, high reliability and long life[2]. Currently, high power LEDs have found applications in outdoor and indoor illumination, automotive front lighting, backlighting for large LCD displays and city improvement engineering[3−5].

Wire bonding is one of the main processes of the LED packaging which provides electrical interconnection between the LED chip and lead frame, or other substrates. The gold wire bonding process has been widely used in LED packaging industry currently. However, due to the high cost of gold wire, copper wire bonding may be a good substitute for the gold wire bonding which can lead to significant cost saving. Wire bonding using copper wire also has many other advantages over the gold wire. Copper wire has better thermal and electrical properties, excellent ball neck strength and high-loop stability and better looping control[6]. But copper wire has higher hardness and stiffness than gold wire which may induce higher stress and strain in the electrode structure. Inappropriate copper wire bonding parameters may lead to the reliability problems such as bond pad cratering, peeling and cracking below the bond pad.

In this paper, numerical simulations are carried out by a couple thermal mechanical transient dynamic finite element methods to investigate the stress, strain and temperature evolution of the electrode structure of the high power LEDs during the impact and ultrasonic vibration stages of wire bonding process with copper and gold wire. The plastic and friction heating effects are considered in these models. The copper and gold wire bonding processes on the high power LEDs are compared and discussed in terms of bond force, stress and strain distribution of the bond pad and the metal layers under bond pad and the temperature evolution during the bonding process.

2. Physical model of wire bonding process

The schematic diagram of wire bonding on the high power LEDs is shown in Fig. 1. It involves the capillary, the free air ball (FAB), the heat affected zone (HAZ), the bond pad, GaN layer and the sapphire substrate. A local model is taken in our numerical studies. The thicknesses of GaN layer and sapphire substrate are 3 μm and 50 μm respectively. The length of GaN and the sapphire substrate is 200 μm. The electrode structure of LED chip consists of the indium tin oxide (ITO) and titanium layers as the ohmic contact layers which are covered by the gold bond pad. The ITO layer and Ti layer are both thin films with thickness of 0.1 μm. The ITO and Ti thin film are

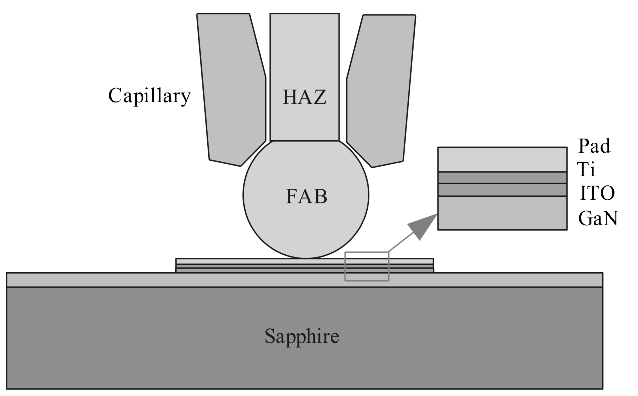

Fig. 1. Wire bonding system on the high power LEDs.

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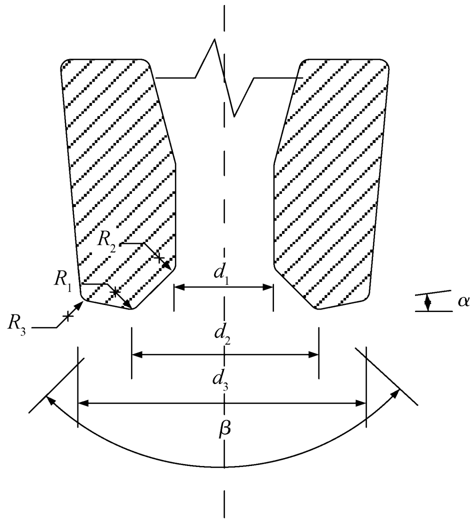

Fig. 2. Geometry of capillary.

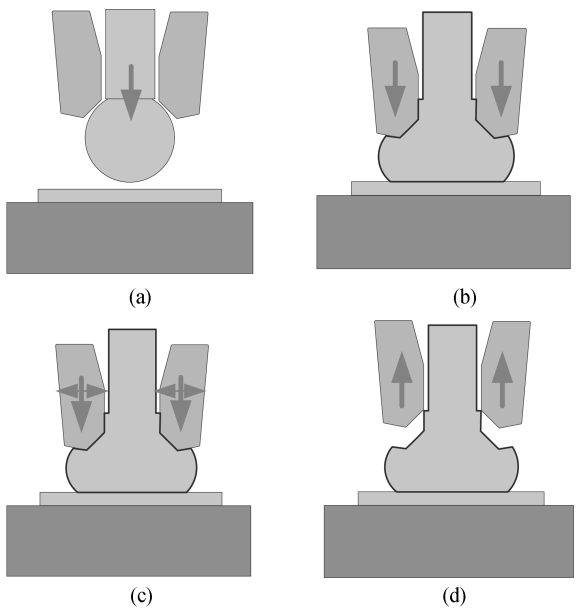

Fig. 3. Schematic diagram of wire bonding. (a) FAB generation and vertical motion. (b) Impact stage. (c) Horizontal ultrasonic vibration and compression stage. (d) Move up of capillary.

deposited by the electron beam evaporation. The thickness of the gold bond pad is 1.5 μm and the length of the electrode structure is 120 μm in our model.

The geometry of capillary is shown in Fig. 2. A specific set of parameters d_1 = 30 μm, d_2 = 60 μm, d_3 = 100 μm, α = 3°, β = 90°, R_1 = R_2 = 3 μm, R_3 = 5 μm are applied. The diameter of bonding wire is 25 μm. Generally the diameter of the FAB will be 1.5–4 times bigger than that of the bonding wire. The diameter of the FAB is chosen to be 70 μm in present work.

Typically the whole wire bonding process consists of five stages. As shown in Fig. 3, they are the generation of FAB by heating up the bonding wire tip, vertical motion of the capillary and FAB, impact of FAB with bond pad, input of the ultrasonic vibration energy and move up of the capillary. Usually, after the initial impact of FAB on the bond pad, the ultrasonic vibration and the compression of capillary are conducted during the same period of time till the final smashed ball is formed.

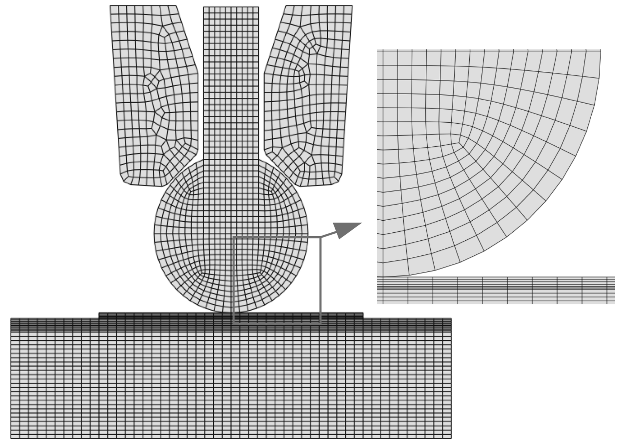

Fig. 4. 2D finite element model.

In our models, the whole wire bonding process on high power LEDs is simplified to consist of the impact and ultrasonic vibration stages, as shown in Figs. 3(b) and 3(c). The heating effects of the heated pedestal, plastic deformation and the friction are considered in the simulation. But the heating effect by absorbing the energy of ultrasonic vibration is not included at present due to lack of the some critical material parameters such as the amplitude absorption coefficient.

3. Finite element model of wire bonding process

A coupled thermal mechanical transient dynamic finite element framework for the wire bonding process is developed, which considers the thermal heating effects of plastic deformation and friction. The calculation is carried out with an explicit algorithm on a general FEM code Abaqus 6.8. Figure 4 shows a 2D finite element model in the present numerical study. Linear CPE4RT elements are applied in the simulation. The elements with enhanced hourglass control in the contact regions between the capillary and the FAB to prevent the hourglass effect. The mesh in the multilayer electrode structure is refined to improve the accuracy of calculation. The capillary/FAB contact pair and FAB/bond pad contact pair are the nonlinear kinematic contact pairs with consideration of the dynamic friction. The surface to surface contact pairs are defined between interfaces of the FAB/bond pad and the capillary/FAB. The friction coefficient of both contact pairs is assumed as 0.4. The bottom of sapphire is fixed in all degrees of freedom.

The first stage of the wire bonding process includes the contact impact with strain hardening and the second stage deals with the horizontal ultrasonic vibration and the compression of capillary. In the impact stage, the capillary is supposed to move down a certain distance of –23 μm within duration of 0.2 ms. In the ultrasonic vibration stage, the amplitude of horizontal movement cycle of the capillary is assumed as 1 μm and the frequency is set to be 130 kHz. During the ultrasonic vibration stage, the vertical displacement of capillary is supposed to be –2 μm to exert a bonding force to the copper ball within some period of time, typically 20–30 ms, which is about 2000–3000 cycles of ultrasonic vibration. This is very hard for the simula-

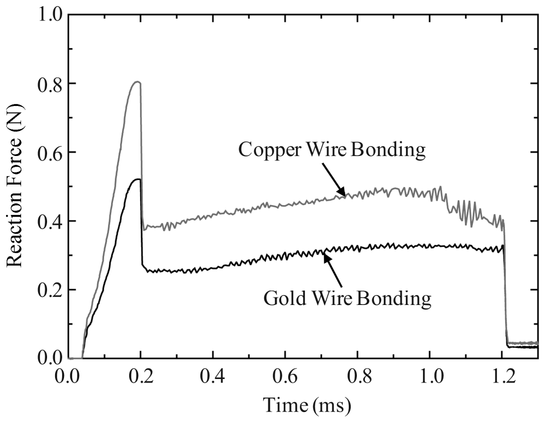

Fig. 5. Reaction force evolution of capillary during the copper and gold wire bonding process.

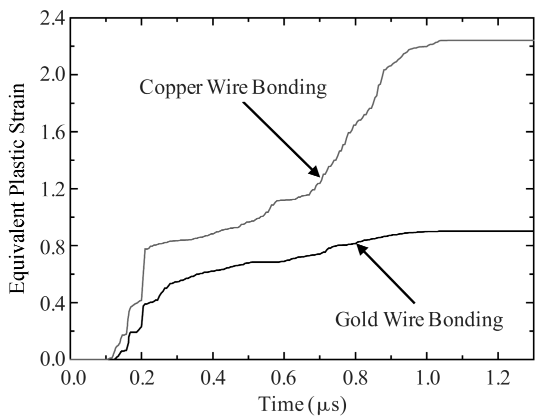

Fig. 6. Equivalent plastic strain evolution at the edge of FAB and bond pad contact pair during the copper and gold wire bonding process.

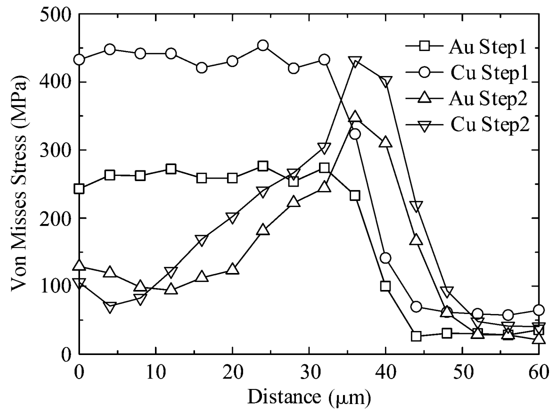

Fig. 7. Distribution of von Mises stress in ITO layer from center to right edge of the copper and gold wire bonding processes.

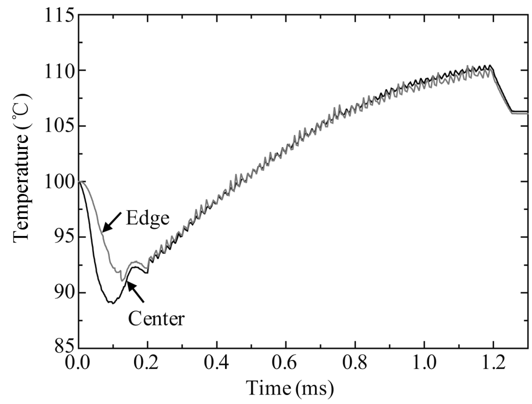

Fig. 8. Temperature evolution at the center and edge of the FAB/bond pad contact pair during the gold wire bonding process.

tion to run so many cycles, therefore in this paper, the duration of ultrasonic vibration considered for the simulation is 1 ms. And then after that the capillary is moved up by some distance within 0.1 ms.

4. Comparisons of bonding process of copper and gold wire

The copper and gold wire bonding processes on the high power LEDs are compared with numerical simulation in this section. The results are shown in Figs. 5–9.

The evolution of reaction force of capillary during the copper and gold wire bonding processes is shown in Fig. 5. It can be seen that the reaction force of capillary in the copper wire bonding is larger than that of gold wire bonding. In the copper wire bonding, the reaction force of capillary increases rapidly from 0 to 0.8 N with the vertical motion of capillary during the impact stage and the reaction force of capillary remains at about 0.4–0.5 N at the ultrasonic vibration stage. In the gold wire bonding, the reaction force of capillary during the impact and ultrasonic vibration are about 0.52 N and 0.28 N respectively.

The equivalent plastic strain evolution of the FAB and bond pad contact pair edge during copper and gold wire bonding process is shown in Fig. 6. The equivalent plastic strain of FAB and bond pad contact pair edge in the copper wire bonding is larger than that of gold wire bonding. The equivalent plastic strains of the copper and gold wire bonding are 2.24 and 0.9 respectively.

Figure 7 shows the von Mises stress distribution in the ITO layer under a bond pad of copper and gold wire bonding. The maximum von Mises stresses in the ITO layer at the end of impact and vibration stages are 273 MPa and 347 MPa respectively of gold wire bonding. While the maximum von Mises stresses are 453 MPa and 431 MPa respectively of copper wire bonding. The stress level of the copper wire bonding process is much higher than that of the gold wire bonding process which is due to the fact that the copper FAB is stiffer than the gold FAB. The elastic modulus of the copper FAB is 80 GPa in present simulation, while the elastic modulus of the gold FAB is only 30 GPa.

Figure 8 shows the temperature evolution at the center and edge of the FAB/bond pad contact pair of the gold wire bonding process. The contact pair is cooling down by the capillary during the impact stage which is the same as the situation in the copper wire bonding shown in Fig. 9. The temperatures of the contact pair center and edge decrease from 100 to 89 and 92 °C respectively. The temperatures of the contact pair center and edge increase to about 110 °C during the ultrasonic vibration stage which is due to the friction heating effect and some plastic deformation heating effect. From Fig. 9, it can be found that the temperature increase of the copper wire bonding process is higher than the gold wire bonding process which is the

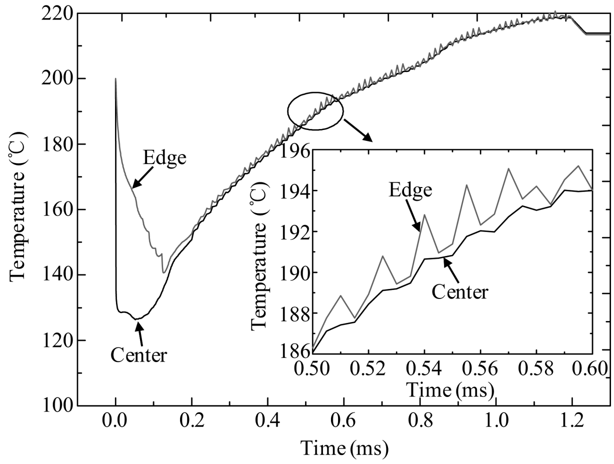

Fig. 9. Temperature evolution at the center and edge of the FAB/bond pad contact pair during the copper wire bonding process.

result of that copper which needs more wire bonding power to form the final smashed ball bonding.

From the comparison, it can be found that the copper wire bonding process will induce much higher stress and strain in the bond pad and ohmic contact layers under bond pad. The process parameters copper wire bonding should be controlled more carefully than the gold wire bonding. More work is needed to accept cooper wire as a working candidate.

5. Conclusion

Copper and gold wire bonding processes which are simplified to consist of impact and ultrasonic vibration stages on high power LEDs have been studied by using a couple thermal mechanical transient dynamic finite element frameworks in this paper. The copper wire bonding will induce much higher stress and strain to the electrode structure compared to the gold wire bonding process, which is due to the fact that copper FAB is stiffer than the gold FAB. The process parameters for copper wire bonding should be controlled more carefully than the gold wire bonding. The plastic and friction heating effect of copper wire bonding is more significant than the gold wire bonding as that copper wire bonding needs more bonding force and power.

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