Vibration characteristic researching of capillary of ultrasonic wire bonding

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Abstract

Wire bonding, a process of the connection between a semiconductor chip and a lead frame by a thin metal wire, is one of the important processes of electronic packaging. Vibration characteristic and friction behaviour of capillary of Microelectronic Packaging ultrasonic bonding system are studied. A dynamic contact model of capillary was built by finite element method to gain bonding mechanism of wire bonding system. Vibration response and contact friction property of the capillary are calculated. The effects of the loading frequency and static compressive force to the vibration response and contact friction stress were obtained, and the relationships between the loading frequency, the static compressive force and the vibration response were given. The researching conclusions can be used as references for having a better understanding of the bonding mechanism and the study of fault diagnose techniques for bonding process.

Keywords: ultrasonic wire bonding, contact analysis, finite element, capillary

1 Introduction

Wire bonding is a process for connection between a semiconductor chip and a lead frame by a thin metal wire [1-3]. For every error bonding point will cause the IC circuit failure entirely, thorough researches about bonding mechanism and the effect factor of bonding quality are indispensable. Capillary is a key device of bonder, so the research on its dynamic characteristic and contact friction behaviour will help to master bonding mechanism well. For capillary's high-speed and non-linear vibrate characteristic, it is very difficult to study bonding mechanism through routine methods. In this paper finite element method is presented to investigate the vibration characteristic of capillary. First, the mode of capillary is analysed and first nature frequency is got, second a dynamic contact model is built and referring to the parameter, got from mode analysis, the load to capillary is confirmed. The effect factor of contact friction stress is acquired in bonding process. The result can be used as references for having a better understanding of the bonding mechanism and the study of fault diagnose techniques for bonding process [4-8].

2 Ultrasonic wire bonding system introduction

Ultrasonic wire bonder (shown as Figure 1) by and large consists of a phase-locked-loop (PLL) ultrasonic generator, an ultrasonic transducer system (a piezoelectric driver, a barrel, a concentrator and a capillary), a work holder to support the materials to be bonded, and means for applying a static compressive force to the materials being bonded [1]. The ultrasonic, generated from PPL ultrasonic signal generator, is transformed into high frequency mechanical vibration energy through piezoelectric transducer. Over the years, various models have been postulated in describing the possible mechanism involved in ultrasonic wire bonding [7, 9].

For quality control purposes, it is convenient to model the mechanism as follows: the materials being bonded are first brought into contact under an external static compressive force, producing some initial deformation but no adhesion due to the presence of surface films or oxides. Energy is then introduced via the transducer, which vibrates at ultrasonic frequency, thus it results in oscillatory forces parallel to the wire-pad interface. The wire softens upon absorption of energy and flows under loading, breaking up the surface oxides and exposing a fresh surface of both the wire and the boding pad. Interfacial movement is progressively restricted by the formation of multiple micro welds in the peripheral area of the contact zone. Continued application of cyclic stresses produces plastic deformation of wire [1].

Figure 1 shows that the system is a strong coupling connection with tribology and dynamics. Bonding process is a very short time, especially for high-speed bonder. Capillary is a key device of wire bonder, so in this paper its dynamics characteristic and bonding mechanism are studied through finite element method.

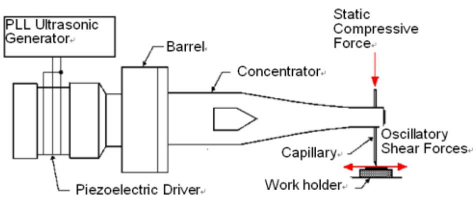

FIGURE 1 Structure of an ultrasonic wire-bonding system

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3 Model of capillary

In order to accurately reflect bonding system properties and simultaneously simplify system model, only a model of capillary is built here. Vibration energy, imputed from concentrator, is loaded to the tail end (7.73 mm to 11.1 mm) of capillary through a function as Equation (1) (see Figure 2). A work holder is built under the capillary to study contact friction behaviour between capillary and work holder [2].

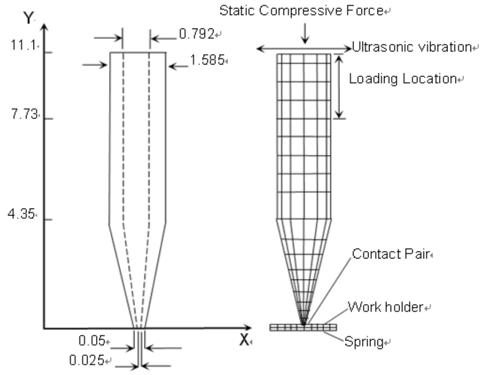


FIGURE 2 Size and model of capillary/mm

Capillary is a high-density and high hardness ceramic material. Solid 45 is selected for capillary and work holder and Combine 14 for spring. Refined mesh is generated at the tip of capillary to accurately reckon its deformation. Target element and contact element are selected Target 169 and Contact 171 respectively [5]. In order to simulate real movement and restraint of capillary, only x direction freedom vibration of capillary's top (7.73 mm to 11.1 mm) is allowed. The equation is:

$$F = 1 \times 10^{-6} \times \sin(2\pi\omega t)\,, \tag{1}$$

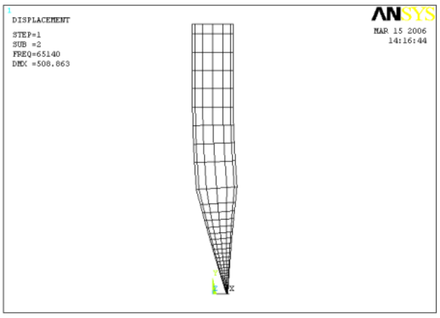
Frequency range from 60 kHz to 68 kHz, size of static pressure is from 0.02 N to 0.2 N, and computation time is 10ms at a time interval of 2×10^{-3} ms. Beside y direction freedom of work holder, others are restrained.

4 Vibration response of capillary

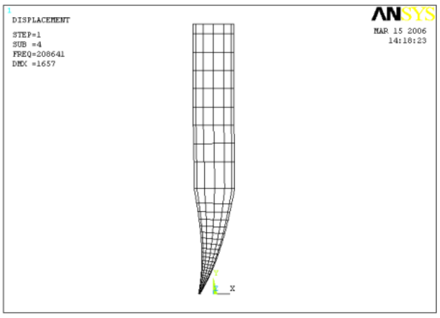
4.1 FREE VIBRATION ANALYSIS OF CAPILLARY

Capillary is multi-DOF cantilever structure. It is difficult to extract the intrinsic mode through theoretical or experimental methods. In this paper inherent modal are calculated and extracted by the finite element method. Finite element analysis software, ANSYS80, is used to calculate its mode and dynamic response. Here, we are more interested to extract the mode range from 0 to 300 kHz. Table 2 shows the other order mode of capillary. We may see that mode of capillary about x axis and y axis is same as the structure of capillary is symmetry.

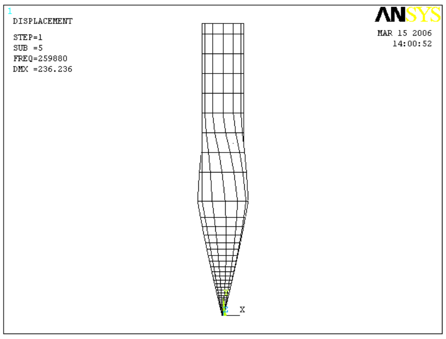
Mode deformations of capillary are shown in Figure 3. Figures 3a, 3b, and 3c show the deformations of first order, second order and torsion respectively. The first order nature frequency about x-axis is 65,140 Hz. It is very adjacent with work frequency of capillary. The mode of only x-axis or y-axis direction is inspired for concentrator's horizontal vibration.



a) First order mode



b) Second order mode



c) Torsion mode

FIGURE 3 Mode deformation of capillary

4.2 SELECTING FRICTION MODEL OF CONTACT ANALYSIS

Bonding process is a flexible contact process, which is still pending further study. So far, there is still no universally agreed specific solution. For a long time, many dynamicity and mathematicians have been working hard to solve the contact problem. With the development of computer science, numerical-based and similar-deal approach are rapidly developed. Finite element method is the main tool among them. Here, a contact pairs must be defined where contact might occur during the deformation of model. Once potential contact surfaces are identified, we can define them as target and contact elements, which will the track the kinematics of the deformation process. Target and contact elements make up a contact pair are associated with each other via a shared real constant set (Figure 4).

In the basic Coulomb friction model, two contacting surfaces can bear shear stresses up to a certain magnitude across their interface before they start sliding relative to each other. This state is known as sticking. The Coulomb friction model defines an equivalent shear stress τ, at which sliding on the surface begins as a fraction of the contact pressure p ($\tau = \mu p + COHE$, where μ is the friction coefficient and COHE specifies the cohesion sliding resistance). Once the shear stress is exceeded, the two surfaces will slide relative to each other. This state is known as sliding. The sticking/sliding calculations determine when a point transitions from sticking to sliding or vice versa [5].

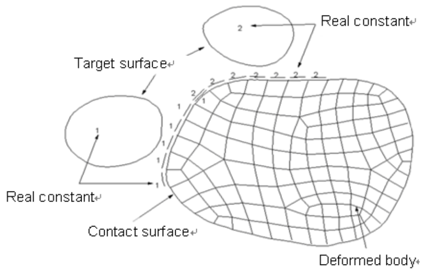


FIGURE 4 Localized contact zones

5 Result of calculation

According to vibration theory, case 1, amplitude response of capillary's tip will be changed at different loading frequencies. Amplitude response of capillary's tip is the biggest under natural frequency. Considering energy point, the system energy inspired will be the biggest when loading frequency is natural frequency. Case 2, when the static pressure is changed, amplitude response of capillary's tip will also be changed. The reason is that bonding system is a damping system and friction change will affect damping coefficient. With damping increasing, the amplitude response will reduce, vice versa. Much static pressure will be carried in order to improve bonding quality, but over high static pressure will also arouse destruction. In this paper, the effect relations between the amplitude response and frequencies or static pressure are studied. The deformation of capillary under loading is shown as Figure 5.

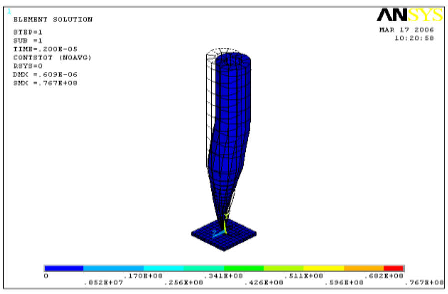


FIGURE 5 Vibration deformation of capillary

5.1 AMPLITUDE RESPONSE WITH DIFFERENT FREQUENCIES

Here, we have more interests about the amplitude response of capillary tip and its friction situation. So some nodes at the capillary tip are selected to study bonding mechanism. The amplitude response of capillary tip with loading frequencies from 63,140 Hz to 67,140 Hz (where static pressure is 0.02 N, frequency interval of 1,000 Hz) is shown in Figure 6. We can see from the figure that the amplitude response increase straight until it become stable under natural frequency, while there are continuous wave when loading frequencies are deviated with natural frequency. Furthermore, with the incensement of deviating, the amplitude response will be gradually reduced.

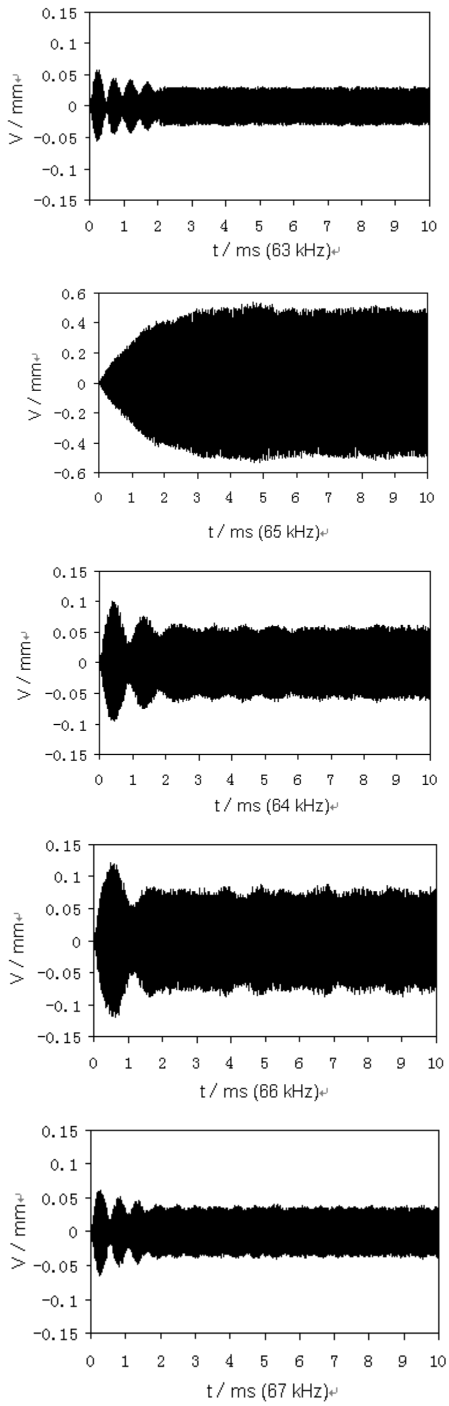
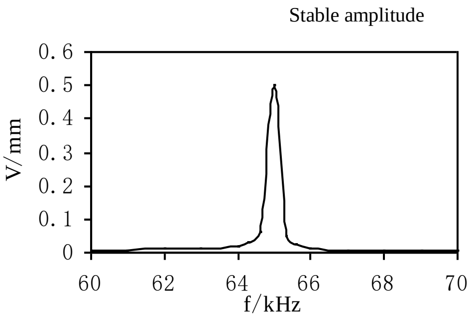


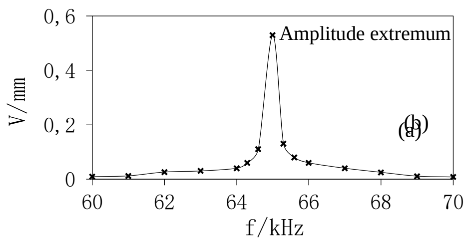
FIGURE 6 Applications response of capillary's tip

The curves between amplitude response and loading frequencies are shown in Figure 7. Figure 7a denotes the change that the amplitude response reach stable, Figure 7b is the biggest of amplitude response with different loading frequencies. As expected, there is a peak-amplitude at the 65 kHz and it is showed in the harmonic response analysis. The stable amplitude is same with the amplitude extremum under the natural frequency, while the earlier is smaller than latter under the others frequencies. Furthermore, the amplitude fluctuant are severe when run at non-natural frequency. It will affect bonding quality seriously.

The contact friction stresses are also different when different loading frequencies are adopted. The curve between maximum contact friction stresses and different loading frequencies (where the same static pressure is used as 0.02 N) is shown in Figure 8. We can see from Figure 8 that the maximum contact stress appears at the natural frequency. When the loading frequencies are increased or reduced, contact stresses are smaller than that under natural frequency. Bonding process is carried out to use friction stress mainly, so it is expected that the work frequency should be most close to the natural frequency.



a)



b)

FIGURE 7 Applications response versus frequencies

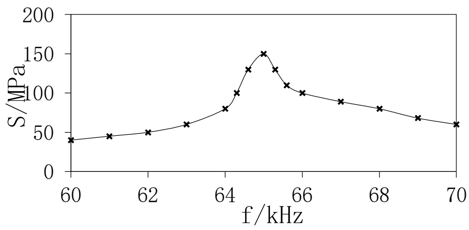


FIGURE 8 Maximum contact stress versus frequencies (bonding force=0.2 N)

5.2 AMPLITUDE RESPONSES WITH DIFFERENT PRESSURES

Contact stress and amplitude response of capillary tip are changed under the static pressure is different. Insufficient static pressure will result in shortage of contact stress, at the same time, exorbitant one cannot be achieved fairly good results. Figure 9 shows the curves between loading pressure and amplitude response of capillary tip (where there are five curves, they denote five different loading frequencies, respectively). Amplitude responses of capillary tip are reduced with bonding force increasing. The minimum amplitude of natural frequency is bigger than the maximum amplitude of other frequencies.

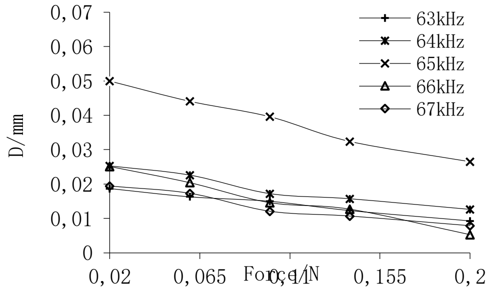


FIGURE 9 Applications response versus bonding force (where five curves denote five different frequencies, respectively)

However, the amplitude response will be quite unstable under exorbitant bonding force. Figure 10 shows amplitude response of capillary tip versus loading times under exorbitant bonding force of 2 N. We may see that amplitude response of capillary tip is mostly near to zero sometime. As expected, the capillary tip cannot move due to too high friction.

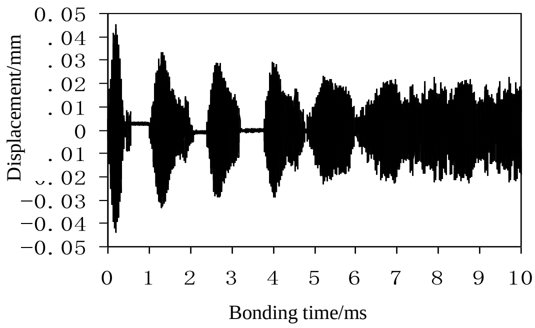


FIGURE 10 Amplitude response versus bonding time (bonding force=2N).

The contact friction stress curve and its spectrum when bonding force is 2 N are shown in Figure 11. Contact stress is increased or reduced periodically. Its trend is very close to Figure 10. There is a peak-amplitude at 120 kHz from frequency spectrum curve. The main reason is that there are two contacts occurring within every vibration cycle.

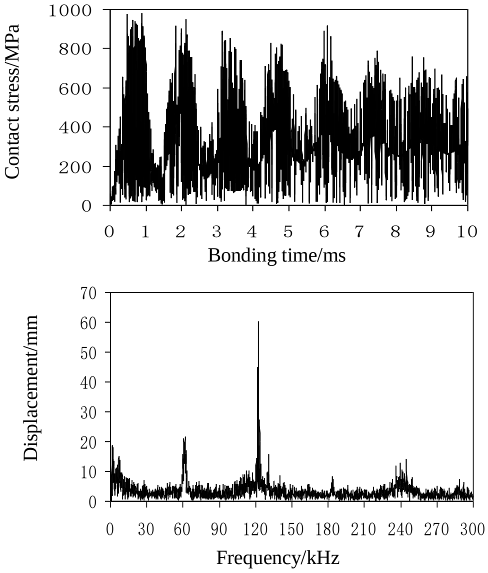


FIGURE 11 Contact stress and frequency spectrum (bonding force=2N).

6 Conclusions

In this paper, the dynamic characteristics and contact friction behaviour of capillary are studied. A dynamic contact model of capillary was built by finite element method to master wire bonding system bonding mechanism. Vibration response and contact friction property of the capillary are calculated. The effects of the loading frequency and static compressive force to the vibration response and contact friction stress were obtained. From above researching works, the following conclusions may be gained: First, amplitude response of capillary relatives with the loading frequencies. Under non-natural loading frequency, amplitude response wave severely. Second, a suitable bonding force must be selected in bonding process. Excess high or low bonding force will affect bonding quality seriously. Third, times to reach stabilization of amplitude response are different under various bonding force. The bigger bonding force, the shorter bonding stable times, vice versa.

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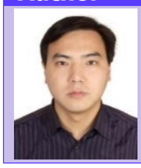

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