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Application of a Force Sensor in Wire Bonding Process

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Abstract: Wire bonder is important equipment in semiconductor end-package. The benefits of using force sensor are precisely force control and earlier contact detection. In this paper, we introduced an application of a force sensor in the wire bonding process. We proposed the control strategy of the whole bonding process with the force sensor. In the bonding process, it's very important to make sure the safety before switching between the force control and position control. A contact detection method in force mode was introduced to get a smooth switch from position control to force control. Before switching from the force control to position control, a two-steps method was proposed to prevent vibrations. The experiments results show that a good bonding performance was achieved by applying with the force sensor. *Copyright © 2013 IFSA.*

Keywords: Wire bonder, Force sensor, Force control, Contact detection, Impact force.

1. Introduction

Wire bonder [1] is important equipment in semiconductor end-package. It bonds a wire which supplies a current path between the pad on silicon wafer and the lead on lead frame. The thermosonic ball bonding is the most popular process used in auto gold wire bonder. It uses ultrasonic energy, high temperature and bond force during the bond formation. The energy, temperature and pressure are technological parameters to make a good bond formation. The Z-axis of wire bonder is called bond head as shown in Fig. 1. The assembling of bond head contains the motor, the transducer and the capillary. The capillary is hollow therefore the wire can across it.

There are two bond points to bond a wire, the first bond point and the second bond point. Fig. 2 illustrated the process to bond the first bond point. Firstly, the capillary move to the search height with high speed and turn to constant speed motion with a low speed to detect whether the ball is contact with the pad. When contact, the control of Z-axis is turned to force control mode from position control mode. Then, the ultrasonic energy and pressure are added to finish the bond formation. After bond formation, the energy and pressure are released and control mode of Z-axis is turned to position mode. The process to bond the second bond point is the similar. The microslip model of the bonding process was introduced by Hu [2, 3].

We see there are two control mode used in the process, the position control and the force control. For the sake of lower cost, sensor-less force control are usually used in the force control. However, open loop control usually loses precision. To achieve precisely force control, a force sensor is needed. Hybrid force/position control is widely used in

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manipulator control system [4, 5]. Also, faster and more correct contact detection can be get with a force sensor [6, 7]. Kim [8] introduced an algorithm to compensate impact force using a piezo force sensor. However, the control approach of bonding process is rarely introduced.

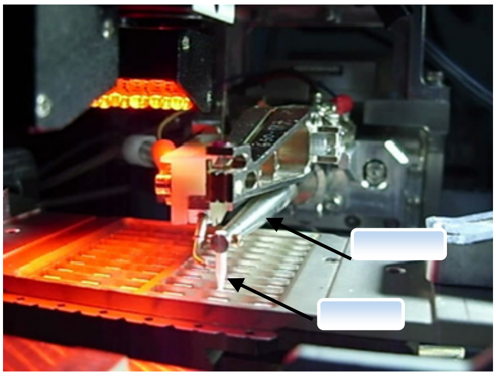

Fig. 1. Front view of bonding area.

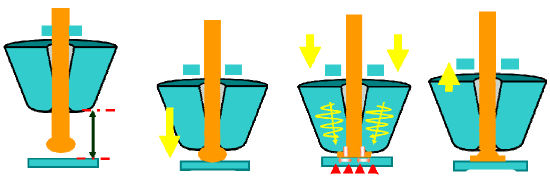

Fig. 2. Process of first bond.

In this paper, we introduce an application of force sensor in the control wire bonding process. With the force sensor, a closed force control loop can be used and precisely pressure can be achieved. The contact detection can be performed in the force mode. Then, the contact can be detected earlier before the impact force is larger than the bond force. The benefit is that the impact force on the pad is reduced and the quality of fine pitch wire bonding is improved [8]. We firstly introduce the sensor assembling and calibration. Then we illustrated the control structure of position control and force control. To get the contact detection in force mode, the force control algorithm is introduced in the following. The experiment will show the bonding result using our proposed method.

2. The Force Sensor

The force sensor used in wire bonder is a SlimLine quartz sensor produced by Kistler. It produces an electric charge directly proportional to the force. The charge is measured by an electrode and fed to the charge amplifier via the integral cable. The precision can be less than 0.1 gf (gram force). The output of amplifier is an analog voltage between 0 V to 10 V. The sensor looks like a ring. It's easily mounted under the nut of bond head as shown in Fig. 3. The measured force is not the pressure on the tip of capillary but it's proportional to the pressure. Therefore, after mounting in the wire bonder, the amplifier must be set in the measuring range and the sensor must be calibrated.

The calibration of force sensor needs another setup of calibrated force sensor. In the process of calibration, the tip of capillary should contact the surface of calibrated sensor with a pressure. The measured forces of calibrated and un-calibrated sensors can be read out from the amplifier. Then, we can get a relationship between the measured voltage and pressure of the capillary. The result is 33 gf/mv.

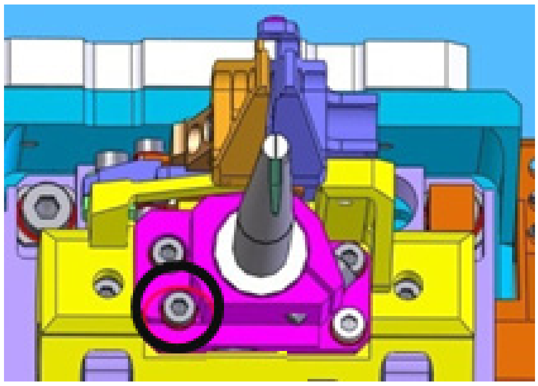

Fig. 3. Mounting of the force sensor.

The measured force reflects the reaction force acting on the Z-axis. If the bond tip contact with the bonding surface, i.e., if the Z-axis is stopped, the reaction force is proportional to the pressure of bond tip. If Z-axis is in free motion, the reaction force is proportional to the acceleration or deceleration of Z-axis. Therefore, the measured force is a combination of driven force of Z-axis and pressure. Typically, both of them do not occur simultaneously. Fig. 4 illustrates a measured signal from the force sensor during Z-axis motion. A point to point motion is firstly accelerated and then decelerated motion. The measured force has the same profile as the acceleration.

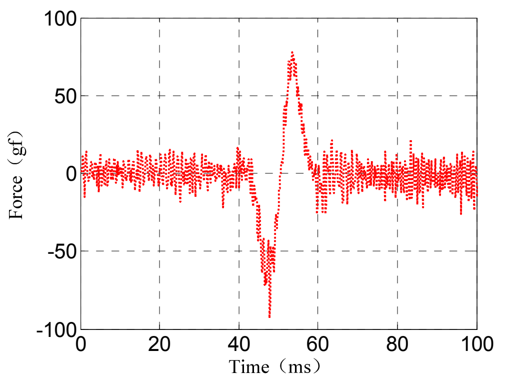

Fig. 4. Profile of measured force during Z-axis motion.

3. Control Law of Bond Head

The bearing of bond head is a spring bearing. The spring bearing is also called leaf bearing or elastic bearing. It has spring force which would cause steady state error in both position control and force control. We have proposed a spring force compensation algorithm to simplify the control problem [9].

3.1. Position Control

The motor of bond head is driven by a servo drive which works at current control mode. The position and velocity loop are realized in a motion controller. The model of the motor with spring bearing is equation (1),

$$G_p(s) = \frac{1}{Js^2 + k_s} \ , \quad (1)$$

where J is the inertia of motor and K_s is the elastic coefficient.

The model of the drive is modeled as a first order filter with a time delay,

$$G_i(s) = \frac{e^{-Ls}}{1 + T_i s} \ , \quad (2)$$

where T_i is the time constant and L is the time delay.

The velocity loop controller is a PI-controller with integration constant T_v and proportional constant K_v. The position loop control is a P-controller with proportional constant K_p. This controller also called PPI control. The control structure is shown in Fig. 5, K_{so} is the elastic coefficient used in spring force compensation.

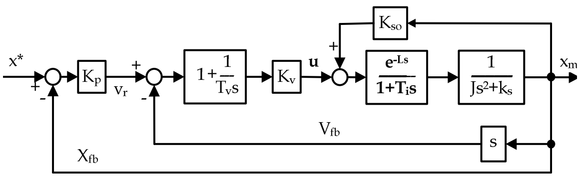

Fig. 5. Position control structure.

3.2. Force Control

There are many form of force control. In this paper, we used a closed loop force controller with an inner position loop. The force controller is a P-controller with proportional coefficient fK_p. The control structure is shown in Fig. 6. The constant K_{fb} is the calibrated force coefficient of force sensor.

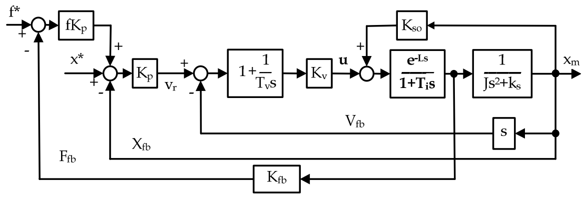

Fig. 6. Force control structure.

It's obvious that the force controller adjusts the motor's output force via the position controller. When perform on force control, the parameters of inner position loop controller should be lower than them during in position control mode. It can be understand as the position loop performs a coarse tuning and the force loop performs a fine turning.

4. Force/position Control Loop Switching

As previously described, the control mode of bond head should be changed twice to finish a bond point. If the switching is incorrect, the bond will be failed. Even worse, the die would be destroyed. Therefore, it's very important to make sure the safety before switching.

4.1. Switch from Position to Force Control

As shown in the bonding process, the bond head starts contact detecting after it reached the search height. Contact is the necessary condition to perform control mode switching from position mode to force mode.

There are three signals can help to detect the contact, the position, the velocity and the force. The position signal is the slowest and the force signal is the fastest. If the contact is detected earlier, the impact force will be smaller. Since there are many disturbances will cause a failing detect [7]. Therefore, a filter is needed to avoid the disturbances. Since there are low pass filters embedded in the charge amplifier, we just use a Hamming window as an infinite impulse response filter as in equation (3),

$$f(k) = (f(k-1) + f(k-2) + f(k-3))/3 \quad (3)$$

The flow chart of contact detection is shown in Fig. 7. F_c is the threshold for judgment of contact. If bond surface detected, the control mode can be switch to force mode immediately.

We say that the control parameters of position loop will be changed smaller after switched into force mode. If the spring force was not correctly compensated, there will be fluctuations in both force sensor and velocity as shown in Fig. 8. If it is correct, the switch process will be smooth as shown in Fig. 9.

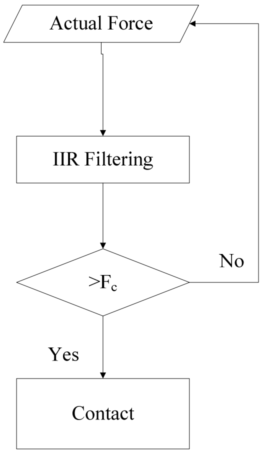

Fig. 7. Flow chart of contact detection.

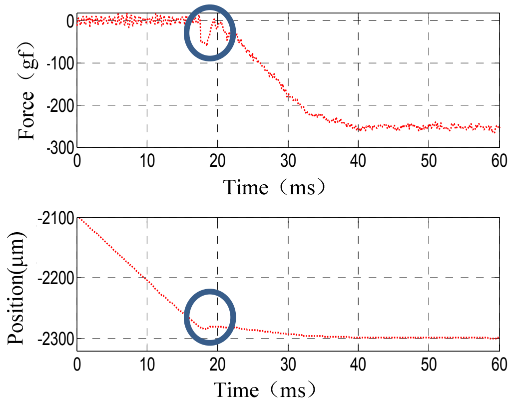

Fig. 8. Force and position fluctuation with incorrect spring force compensation.

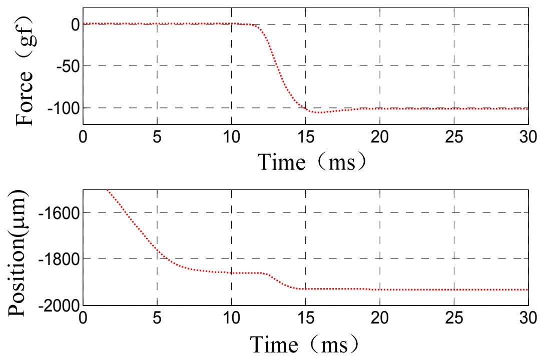

Fig. 9. Force and position profile with incorrect spring force compensation.

4.2. Switch from Force to Position Control

After the bond formation finished, the bond head should move up and turn into the next process. When switching into position mode, the control parameters will be change. There will be jump in the control signal if the position loop has tracking errors. Then, big fluctuations will happened in the bond head as shown in Fig. 10 and Fig. 11.

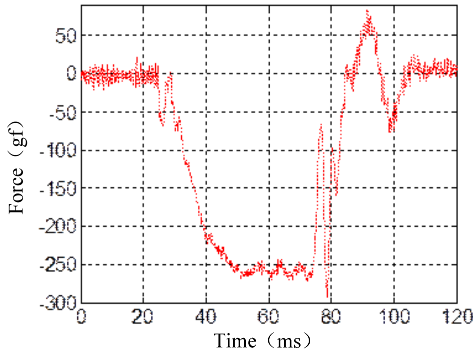

Fig. 10. Force fluctuation with incorrect switching.

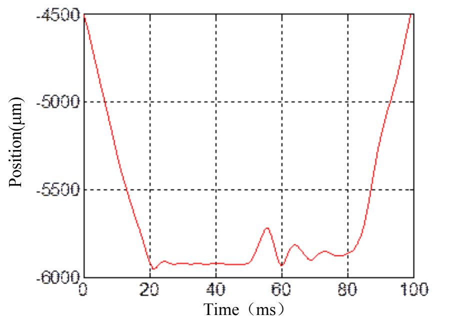

Fig. 11. Position fluctuation with incorrect switching.

Here, we introduce a two-steps method to make sure the switching safety. Firstly, the bond force should be released in one sampling time. At this time, there will be tracking errors in the position loop. We use the spring force compensation interface to add more control signal to synchronize the reference position and actual position. At the time of tracking error equals to zero, we perform the switching immediately. The profiles of force and position with correct switching are illustrated in Fig. 12, there is no fluctuation occurs.

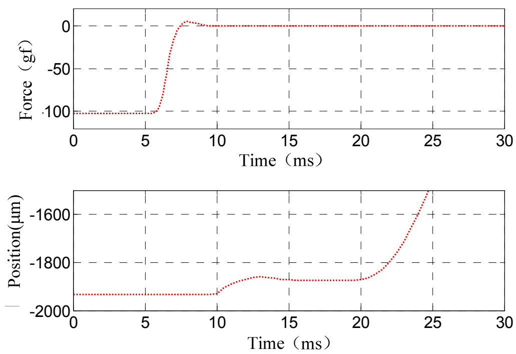

Fig. 12. Force and position profile with correct switching.

5. Experiments

After applied a force sensor, the contact detection will be faster than other mode. The impact force will also be decreased. Fig. 13 illustrates a test result of impact force with different velocity. The impact force is detected by the same force sensor as used in calibration. The impact force is very small different with the impact force is 1 time larger than the bond force before they used a force sensor as show in reference [8]. It indicates that a nearly flat-top impact force [7] is achieved.

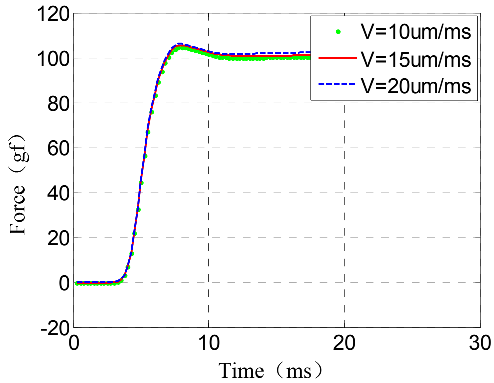

Fig. 13. Impact force with different velocity.

Fig. 14 illustrated a series of signals from the force sensor mounted in the wire bonder. The bond head act the first point bond circularly. It indicates two points. There are no fluctuations in the switching between both position and force control mode. Also, the bond force is precisely controlled.

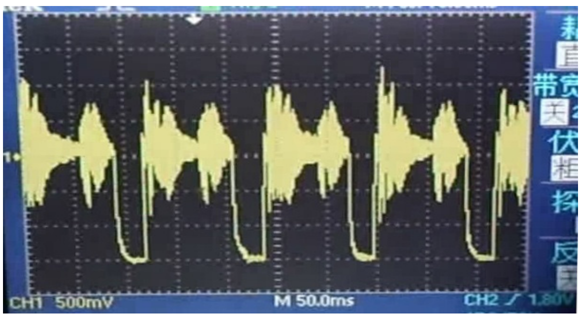

Fig. 14. Force profile of bonding test.

After integrating all the modules of wire bonder, we finished the wire bonder operating system and performed the truly bonding process. Fig. 15 is a lead frame and Fig. 16 is a unit without bonding. Fig. 17 illustrates a unit of die after bonding. The bond formation is good.

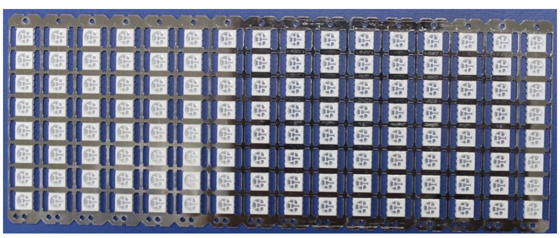

Fig. 15. A view of leadframe.

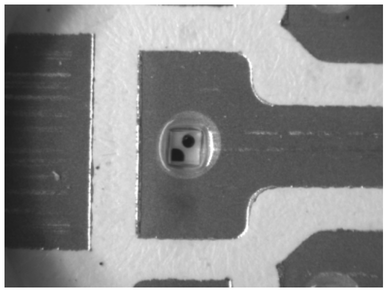

Fig. 16. A unit of die in the leadframe without bonding.

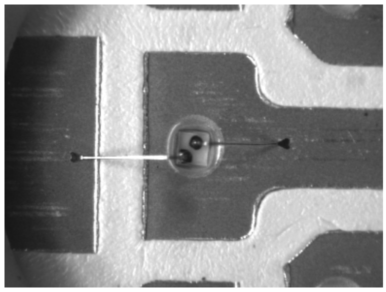

Fig. 17. A unit of die in the leadframe after bonding.

6. Conclusions

In this paper, we introduced an application of a force sensor in bonding process to get a good bonding performance. We introduce the mounting and calibration of the force sensor and proposed the control strategy of the bonding process with the force sensor. Applied with the force sensor, the impact force is decreased and a nearly flat-top impact force is achieved. A precisely force control also can be realized. Then, a good bond formation can be achieved.

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