A Ball Forming Process

The invention relates to a ball forming process, and especially a ball forming process for use with a wire bonder.

Recently, the use of copper wire for wire bonding during assembly and packaging of semiconductor devices has become attractive for manufacturers of central processor units (CPUs) to adopt. This is due to copper's faster conduction speed, better conductivity and lower heat accumulation than conventional gold wire.

However, one of the problems with using copper wire to form the wires on a packaged CPU is that there is a tendency for the copper wire not to bond properly to the contact pad of the die, or for the bonding process to cause cratering of the contact pad on the die.

These problems with using copper wire are mainly due to (i) the difference in hardness between the copper of the copper wire and the die pad of the device, and (ii) oxidation of the copper ball during the glow discharge which forms a ball of copper metal on the end of the wire which is then bonded to the die pad. The presence of an oxide layer on the ball reduces the quality of the bond between the copper ball and the contact pad of the device.

In accordance with a first aspect of the present invention, a ball forming process for forming a ball of metal on a metal wire in a wire bonder comprises

generating a glow discharge between an electrode and an end of the metal wire to form a ball of metal at the end of the wire, the ball being formed in a gaseous atmosphere comprising greater than 96% by volume of nitrogen and substantially no hydrogen.

Preferably, the gaseous atmosphere has a temperature of at least 55^0C. Typically, the gaseous atmosphere has a temperature in the range of substantially 50^0C to 250^0C.

The ball forming process is especially useful where the metal wire is not a precious metal. However, the invention can be used with any type of metal wire, such as copper, aluminium, gold or any other metal wire suitable for forming electrically conducting wires between a semiconductor die and a substrate on which the die is mounted.

In accordance with a second aspect of the present invention, a method of bonding an end of a metal wire to a contact surface of a semiconductor die comprises forming a ball of metal on the end of the wire using a ball forming process in accordance with the first aspect of the invention, contacting the ball formed with the contact surface of the semiconductor die and bonding the ball to the contact surface.

Preferably, the temperature of the gaseous atmosphere is such that the hardness of the metal forming the ball at that temperature matches, or is

approximately equal to, the hardness of the contact surface to which the ball is to be bonded.

Typically, the ball is bonded to the contact surface by an ultrasonic welding process.

Typically, the diameter of the wire on which the ball is formed may be in the range from substantially 0.5 mil (approximately 12.7μm) to 3 mils (approximately 76.2μm).

In accordance with a third aspect of the present invention, wire bonding apparatus comprises a ball forming region having a discharge electrode adapted to generate a glow discharge between the electrode and the end of a wire positioned in the ball forming region adjacent the electrode, a heating device adapted to be coupled to a gas source, to heat gas from the gas source to a temperature greater than 50^0C and to apply the heated gas to the ball forming region.

Preferably, the wire bonding apparatus further comprises a temperature sensor to sense the temperature of the gas applied to the ball forming region, the temperature sensor providing a feedback to a controller which controls the heating device in response to the temperature sensed by the temperature sensor.

Typically, the heating device may heat the gas to a temperature in the region of substantially 50^0C to 250^0C.

Typically, the heating device is adapted to be coupled to a source of nitrogen gas.

An example of method of wire bonding and wire bonding apparatus in accordance with the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of a wire bonder for bonding wires to a semiconductor device;

Figure 2 is a schematic view showing a ball formation system in accordance with the invention;

Figure 3 is a block diagram of closed loop temperature controller for use with the system shown in Figure 2;

Figure 4 is a perspective view showing a nitrogen heater assembly mounted on a bond head of the wire bonder shown in Figure 1;

Figure 5 is a graph showing shear strength versus nitrogen temperature for 70 μm bond pad pitch (BPP) bonding using copper wire;

Figure 6 is a graph showing ball lift versus nitrogen temperature for 70 μm BPP bonding using copper wire;

Figure 7 is a graph showing shear strength versus nitrogen temperature for 50 μm BPP bonding using copper wire; and

Figure 8 is a graph showing ball lift versus nitrogen temperature for

50 μm BPP bonding using copper wire.

Figure 1 shows a wire bonder 20 which has a bond head 21 mounted on an XY table 22 which is movable in an X direction 23 and a Y direction 24. Attached to the bond head 21 are an optical system 25, a wire clamp 8 and an ultrasonic transducer 9. The ultrasonic transducer 9 has a bonding tool, commonly known as a capillary 10, mounted at the opposite end from the bond head 21. The wire bonder also includes a wire tensioner 34. In use, a wire 26, such as a copper wire, extends through the wire tensioner 34, the wire clamp 8 and a through bore in the capillary 10 and terminates in a wire tail 5.

The wire bonder 20 is used to bond wires between contact pads 27 on a semiconductor device 28 and a contact area 29 on a substrate 30 on which the semiconductor device 28 is mounted. During the wire bonding operation, the substrate 30 and device 28 are supported on a top plate 31 on the wire bonder 20.

Prior to ultrasonically bonding the free end of the tail 5 to a contact pad 27, the free end of the wire tail 5 is formed into an approximately spherical ball of metal 32 by generating a glow discharge 11 between the free end of the wire tail 5 and an electrode 4 on the wire bonder 20, as shown in Figure 2. During formation of the ball 32, the transducer 9 and the wire clamp 8 are displaced vertically upwards from the top plate 31 in a Z direction 33 so that the wire tail 5 is adjacent the electrode 4, as shown in Figure 2.

The ball formation system, as shown in Figure 2 includes a high voltage generator 1 which has a negative terminal 41 electrically coupled to the electrode 4 and a positive terminal 42 electrically coupled to the wire clamp 8. The electrode 4 is supported by a stainless steel bar 3. When the wire clamp 8 clamps the wire 26, the wire 26 is in electrical contact with the positive terminal 42. Therefore, when a sufficiently high potential (typically 3kV to 5kV) is applied between the terminals 41 and 42, a glow discharge 11 is formed between the end of the electrode 4 and the wire tail 5. The glow discharge 11 heats the wire tail 5 and causes the metal at the free end of the wire tail 5 to melt and surface tension effects cause the molten metal to form the ball 32.

However, there are problems associated with the formation of the ball 32. In particular, if the metal of the wire 26 is not gold or platinum, during the ball formation process, the surface of the molten metal is prone to oxidation which results in an oxide layer on the surface of the ball 32. This oxide layer reduces the quality of the bond when the ball 32 is bonded to the pad 27, as the oxide layer forms an interface between the pad and the ball 32 and reduces the integrity of the bond. This can lead to subsequent bond failure, such as by the ball 32 lifting off the pad 27 after the bonding process, or by shear failure of the bond between the ball 32 and the pad 27.

In addition, if the metal of the wire 26 has a different hardness to that of the metal of the contact pad 27, or the contact area 29, this can also affect the quality of the bond. This is especially so where the metal of the wire 26 is

harder than that of the metal of the pad 27, as this may cause wear or cratering of the pad 27.

However, the inventors have found that these problems can be mitigated if the ball 32 is heated during the ball formation process and/or the ball 32 is formed in an atmosphere of nitrogen.

Figure 2 shows a combined heater/blower 6 which is coupled at an inlet 43 to a source of nitrogen gas 7. The nitrogen gas 7 is heated by a heater 44 (see Figure 3) within the heater/blower 6 and expelled from the heater/blower 6 through an outlet 45 which directs the heated nitrogen gas to the ball forming region of the wire bonder where the wire tail 5 and electrode 4 are located during the glow discharge 11. The heater/blower 6 also includes a temperature sensor 46 which senses the temperature of the heated nitrogen 47 expelled from the outlet 45. The sensor 46 outputs a signal corresponding to the sensed temperature to an amplifier 47 which amplifies the signal. The amplified signal is output to a signal converter 48. The output from the signal converter 48 is fed to a comparator 49 which compares the output from the signal converter 48 with a preset temperature Tinput and outputs the result of the comparison to a controller 2. In response to the output from the comparator 49, the controller 2 controls the output temperature Toutput of the nitrogen heater 44 to maintain the heated nitrogen gas 47 at the preset temperature Tinput.

Figure 4 shows a perspective view of the heater/blower 6 mounted on the bonding head 21 so that the output 45 is directed towards and adjacent to the free end of the capillary 10 which is mounted on the transducer 9.

Shear strength and ball lift were tested for a number of wire bonds versus nitrogen temperature for bonding using 50 μm BPP copper wire and bonding using 70 μm diameter BPP copper wire. Results of the tests are shown in Figures 5 to 8. Figure 5 shows shear strength in ($g/\mu m^2$) versus nitrogen temperature in (^0C) and shows that the maximum shear strength 50 is obtained at a nitrogen temperature of approximately 120^0C. Figure 6 shows a graph of ball lift, as a percentage of bonds which lifted, versus nitrogen temperature (^0C) for bonding using the 70 μm BPP copper wire and shows that at approximately 80^0C 51 and above, the ball lift is zero percent. Therefore, these results indicate that for bonding using the 70μm BPP copper wire, maximum bond strength is achieved when the ball 32 is formed in a nitrogen atmosphere with a temperature of approximately 120^0C.

Figures 7 shows shear strength ($g/\mu m^2$) as a function of nitrogen temperature in (^0C) for bonding using the 50/μm BPP copper wire and Figure 8 shows ball lift, as a percentage of the total bonds, versus nitrogen temperature (^0C) for bonding using the 50μm BPP copper wire. Figures 7 and 8 show that the maximum shear strength 55 and the minimum ball lift percentage 56 were obtained at a temperature of approximately 140^0C. Therefore, these results indicate that for bonding using the 50μm BPP copper wire, the maximum bond

strength is achieved when the ball 32 is formed in a nitrogen atmosphere at temperature of 140^0C.

The advantage of forming the ball in an atmosphere of nitrogen is that this reduces the oxidation of the surface of the ball 32. The advantage of heating the ball 32 during the ball formation process is that the ball 32 can be heated to a temperature at which the hardness of the metal from which the wire 26 is formed corresponds more closely to the hardness of the metal of the pad 27 or contact surface 29.

CLAIMS

1. A ball forming process for forming a ball of metal on a metal wire in a wire bonder, the process comprising generating a glow discharge between an electrode and an end of the metal wire to form a ball of metal at the end of the wire, the ball being formed in a gaseous atmosphere comprising greater than 96% by volume of nitrogen and substantially no hydrogen.

2. A process according to claim 1, wherein the gaseous atmosphere has a temperature of at least 55^0C.

3. A process according to claim 2, wherein the gaseous atmosphere has a temperature in the range of substantially 50^0C to 250^0C.

4. A process according to any of the preceding claims, wherein metal wire not a precious metal wire.

5. A process according to claim 4, wherein the metal wire is copper wire.

6. A process according to any of the preceding claims, wherein the diameter of the metal wire is in the range from substantially 0.5 mil (12.7μm) to 3 mils (76.2μm).

7. A method of bonding an end of a metal wire to a contact surface of a semiconductor die, the method comprising forming a ball of metal on the end of

the wire using a ball forming process according to any of the preceding claims, contacting the ball formed with the contact surface of the semiconductor die and bonding the ball to the contact surface.

8. A method according to claim 7, wherein the temperature of the gaseous atmosphere is such that the hardness of the metal forming the ball at that temperature matches, or is approximately equal to, the hardness of the contact surface to which the ball is to be bonded.

9. A method according to claim 7 or claim 8, wherein the ball is bonded to the contact surface by an ultrasonic welding process.

10. Wire bonding apparatus comprising a ball forming region having a discharge electrode adapted to generate a glow discharge between the electrode and the end of a wire positioned in the ball forming region adjacent the electrode, a heating device adapted to be coupled to a gas source, to heat gas from the gas source to a temperature greater than 50^0C and to apply the heated gas to the ball forming region.

11. Apparatus according to claim 10, further comprising a temperature sensor to sense the temperature of the gas applied to the ball forming region, the temperature sensor providing a feedback to a controller which controls the heating device in response to the temperature sensed by the temperature sensor.

12. Apparatus according to claim 10 or claim 11, wherein the heating device heats the gas to a temperature in the region of substantially 50^0C to 250^0C.

13. Apparatus according to any of claims 10 to 12, wherein the heating device is adapted to be coupled to a source of nitrogen gas.