

METHOD OF PRODUCING A
SEMICONDUCTOR DEVICE

BACKGROUND OF THE INVENTION

(Field of the Invention)

The present invention relates to a method of manufacturing a semiconductor device in which a copper (Cu) ball is brought into contact with an aluminum (Al) electrode pad within a predetermined time and the height of the squashed Cu ball is ruled.

A semiconductor device in which a copper fine wire (Cu wire) is used as a wire material and a die bonding material used for bonding a semiconductor chip on a die pad are described in a co-pending British application (publication No. GB 2238929) from which this application is divided.

(Description Related Art)

Fig. 1 is a cross sectional side view of a conventional semiconductor device. In the drawing, a semiconductor chip 1 is bonded onto a die pad 3 serving as a lead frame by an epoxy resin 4 serving as a die bonding material. An Al electrode pad 5 is provided on the surface of the semiconductor chip 1, the surface of the portion without the Al electrode pad 5 being covered with a SiO₂ glass coat for preventing Al wiring from corrosion by impurities in the molding resin of the chip 1. The Al electrode pad 5 and an inner lead 7 are electrically connected each other by a Cu wire 8. Silver plating 9 and 2 is plated on the surface of

the inner lead 7, and both the die pad 3 and the inner lead 7 are formed by using as material a copper alloy or an iron nickel alloy.

Fig. 2 is a cross sectional side view of another conventional semiconductor device which is the same as that shown in Fig. 1 except that Au-Si (gold-silicon) solder 10 is used as a die bonding material.

In the conventional semiconductor devices described above, it is generally necessary to select the suitable die bonding material. An unsuitable material causes the degradation of the semiconductor chip by the heating temperature in die bonding process and junction fault in wire bonding process. The details are described below.

When a die bonding material is the epoxy resin 4 (Fig. 1 case), the epoxy resin 4 is cured at a low temperature of 150°C to 250°C, which does not degrade the semiconductor chip 1. However, some problem occurs in the wire bonding process.

Figs. 3A and 3B are respectively a plan view and a cross sectional side view of the Al electrode pad 5 of the semiconductor chip 1 bonded on the die pad 3 with the epoxy resin 4, when the Al electrode pad 5 is etched by nitric acid (HNO₃) after a Cu ball has been bonded to the Al electrode pad 5. In these drawings, Al is excessively excluded to form an Al excluded portion 11, and a SiO₂ film

(13), which is an under layer of an Al film 12, is thus exposed. As a result, for example, the reliability of at a high temperature storage life test deteriorates, as described in Japanese Patent Laid-Open No. 1-143332. If ultrasonic energy which causes Al exclusion is decreased, a Cu-Al alloy layer does not make so large that the reliability at a high temperature storage test deteriorates either.

This reason is estimated that the wire bonding temperature is 250°C to 300°C and the glass transition temperature T_g of the epoxy resin is 110°C to 150°C, and the Cu ball is plastically deformed on the Al electrode pad 5 by with applying the greater ultrasonic vibration energy than that in the case of an Au ball, that is generally used. And more work hardening properties of the Cu ball is higher than that of the Au ball.

When a die bonding material is the Au-Si solder 10 (Fig. 2 case), the die bonding temperature is higher than 370°C which is the liquidus temperature of the Au-Si solder. This causes cracks in the glass coat 6 and degrades the semiconductor chip 1. The details are described below.

Fig. 4A is a perspective view of the semiconductor chip 1 and the die pad 3, and Fig. 4B is a cross sectional side view taken along the line A-A in Fig. 4A. Fig. 5 is a plan view of the semiconductor ship 1 which is done the

structural analysis. In the drawings, Al wiring 14 is entirely covered with the glass coat 6. In the structural analysis after die bonded samples, there's found the crack in the glass coat 6 of the semiconductor chip 1 bonded on the die pad 3 with the Au-Si solder 10, which was immersed in a solution of 80 to 90°C phosphoric acid (H_3PO_4) for 20 minutes, and the Al wiring 14 under the glass coat 6 was etched. Then the resin mold chip deteriorates in the pressure cooker tests after resin mold deteriorates. This reason is estimated that the cracks 15 is caused by the concentration of stress in a certain portion of the glass coat 6 over the Al wiring 14, because the coefficients of thermal expansion of the glass coat 6 and the semiconductor chip 1 is different (SiO_2 of the glass coat: $0.65 \times 10^{-6}/^{\circ}C$, Si of the semiconductor chip: $3.5 \times 10^{-6}/^{\circ}C$). The reason why the die bonding materials is Au-Si solder 10 is that the wire bonding temperature should be raised to a higher temperature than that of an Au wire to progress the mutual diffusion between the Cu wire and the Al electrode.

In the above-described semiconductor device, when a die bonding material is the epoxy resin, the semiconductor chip is not bonded hardly because the heating temperature of wire bonding is higher than that of the glass transition temperature of the epoxy resin. In addition, the Cu ball is plastically deformed on the Al electrode pad with

applying the greater ultrasonic vibration energy than that of an Au ball, because the work hardening property of the Cu ball is higher than that of the Au ball. It causes Al excluding in the Al electrode pad, the SiO_2 under film is thus exposed, and the semiconductor device life deteriorates in a high temperature storage test.

When the Au-Si solder is used for the purpose of setting a heating temperature of wire bonding which is higher than that in the case of an Au wire, there occurs the cracks in the glass coat of the semiconductor chip at the heating temperature in die bonding, and thus the resin mold chip deteriorates in the pressure cooker test and more it has no economical merits.

SUMMARY OF THE INVENTION

The present invention has been achieved in order to solve the above-described problems, and it is an object of the present invention to provide a

Method of producing a semiconductor device which flames out at one end of a Cu wire, holds heat in a Cu ball, prevents a film oxide growing on the Cu ball surface and

increasing the hardness , and applies ultrasonic vibration in bonding to cause both Cu and Al atoms to vibrate efficiently without Al exclusion.

According to the present invention, there is provided a method of producing a semiconductor device comprising the steps of:

forming a copper ball by flaming out at one end of a copper fine wire;

lowering said copper ball and bringing it into contact with an aluminum electrode on a semiconductor chip within a time of 150 ms or less from the formation of said copper ball; and

pressuring said copper ball to said aluminium electrode pad so that the height of said copper ball is 25 μm or less.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1 and 2 are cross sectional side views of conventional semiconductor devices;

Figs. 3A and 3B are respectively a plane view and a cross sectional side view of the Al electrode pad of a conventional semiconductor device at which is done structural analysis;

Figs. 4A and 4B are respectively a perspective view and a cross sectional side view of a conventional semiconductor device after die bonding;

Fig. 5 is a plan view of the semiconductor chip at which is done the structural analysis of a glass coat crack when a semiconductor chip is die-bonded and which is immersed in a phosphoric acid solution;

Fig. 6 is a cross sectional side view of a semiconductor device manufactured according to one embodiment of the present invention;

Fig. 7 is a schematic view of the arrangement in a wire bonding step after forming a Cu ball;

Figs. 8 and 10 are cross sectional side views which show states wherein a Cu ball is bonded to an Al electrode pad;

Fig. 9 is a diagram which shows the relation between the height of a Cu ball and the time from Cu ball formation to the contact with an Al electrode pad;

Fig. 11 is a Weibull plot which shows the high temperature storage life test results of a semiconductor

device manufactured according to the present invention and a conventional semiconductor device;

Fig. 12 is a Weibull plot which shows the pressure cooker test results of a semiconductor device manufactured according to the present invention and a conventional semiconductor device;

Figs. 13A and 13B are respectively a plan view and a cross sectional side view of an Al electrode pad after etching of a Cu ball on it by nitric acid; and

Fig. 14 is a plan view of a semiconductor chip at which is done the structural analysis of a glass coat crack when the chip is die-bonded and which is immersed in a phosphoric acid solution.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

The present invention is more different from prior art in the first point that, in spite of the change of a wire material from Au to Cu, a problem to be solved is not clearly analyzed in the prior art, the prior art was not able to improve the device reliability and did not establish a mass-production technique. While, in an embodiment of the present invention, first, a solder-type die bonding material is selected in order to apply ultrasonic vibrations effectively to the Cu ball and the Al electrode pad because it is necessary to improve the plastic deformation of the Cu ball,

whose work hardening property is greater than that of the Au ball.

Secondarily, a liquidus temperature of a die bonding material is selected such as Pb-5% Sn solder, which generally shows many achievements, or the like, of 370°C or less because it is required to prevent glass coat cracking at the heating temperature of the semiconductor chip.

Lastly, the time from the Cu ball forming to the contact with the Al electrode pad is set to 150 ms or less because the longer it takes, the more the film oxide on the Cu ball surface grows, and the worse makes the plastic deformation property of the Cu ball, and the less is the heat energy in the Cu ball itself. Further, the height of the squashed Cu ball after pressing is ruled as small as possible, i.e., 25 μ m or less.

An embodiment of the present invention will be described in detail below with reference to the drawings. Fig. 6 is a cross sectional side view of an embodiment of the present invention in which reference numerals 1 to 3 and 5 to 9 denote the same as those in the conventional semiconductor device. For example, a Ti-Ni-Au layer is provided as an Au-metallized layer 16 on the rear side of the semiconductor chip 1, and Pb-5% Sn solder is situated as a solder 17 between the metallized layer 16 and the silver plating 2 on

the die pad 3 in order to bond the semiconductor chip 1 on the die pad 3.

Fig. 7 is a schematic view of the arrangement in a wire bonding step after forming a Cu ball. In the drawing, a capillary chip 18 is stayed above the semiconductor chip 1 to press the Cu ball 8a on the Al electrode pad 5, and a heat block 19 for heating the die pad 3 is placed under the die pad 3.

In the above mentioned semiconductor device, the Cu ball 8a is downward moved together with the capillary chip 18 onto the Al electrode pad 5, as shown in Fig. 8, and the force about 150 g is loaded on the Al electrode pad 5 and the ultrasonic vibration energy is supplied through the capillary chip 18 and the heat energy (about 280°C) is supplied from the heat block 19.

In order to understand the quantitative value of the Cu ball 8a plastic deformation, the Cu ball 8a was bonded to the Al electrode pad 5 by applying the same amount of ultrasonic vibration energy through the capillary chip 18, the height h of the Cu ball 8a (squashed) was measured while changing the time t from the Cu ball 8a formation to the contact with the Al electrode pad 5.

The results of the measurements are shown in Fig. 9. It is found from the drawing that in the time t of less than 150 ms the height of the Cu ball 8a is almost constant,

while in the time of over 150 ms the height of the Cu ball 8a is not kept constant and widely varies. It is therefore found that the plastic deformation of the Cu ball 8a is stable as the time t is decreasing, and that also judging from the viewpoint of the mechanical limit of the production equipment used, the time of less than 150 ms is the best condition. In addition, the time t of less than 120 ms is preferable, and the time from 150 ms to 100 ms exhibits excellent results.

If the height of the Cu ball 8a squashed is 25 μm or less, a Cu-Al alloy can be produced safely without making damage to the semiconductor chip 1, while if over 25 μm , an alloy cannot be produced sufficient without making damage to the semiconductor chip 1, this may induce the deterioration in the device reliability. In the case of the capillary chip 18a shown in Fig. 10, the height h of the Cu ball 8a (squashed) is defined as the shortest distance between the recess 8b of the Cu ball 8a and the Al electrode pad 5. In Fig. 9, the curve A shows the results obtained when the Cu ball 8a sphere formed had a small diameter, and the curve B shows the results obtained when the Cu ball 8a sphere formed had a large diameter. Generally, the diameter of the Cu wire 8 is about 25 μm , and the diameter of the Cu ball 8a (squashed) is 100 μm or less.

High temperature of 200°C storage tests were done to evaluate the semiconductor device life and the Weibull plot of Fig. 11 is obtained. As seen from this, the life (denoted by the curve C) of the present invention semiconductor device is much improved as compared with the life (denoted by the curve D) of the conventional semiconductor device. Pressure cooker tests at 121°C and 100% RH were done to evaluate the semiconductor device life and the Weibull plot of Fig. 12 is obtained. As seen from this, the life (denoted by the curve E) of the present invention semiconductor device is much improved as compared with the life (denoted by the curve F) of the conventional semiconductor device. These excellent results are also supported by the structural analysis of this semiconductor chip. Namely, Figs. 13A and 13B are respectively a plane view and a cross sectional side view of the Al electrode pad after the Cu ball 8a was etched by nitric acid (HNO_3). As seen from the drawings, although Al is slightly excluded to form an Al excluded portion 11, the SiO_2 film 13 which is an under layer of the Al film is not exposed. Further, as shown in Fig. 14, when the die bonded semiconductor chip 1 was immersed in a phosphoric acid (H_3PO_4) solution at 80 to 90°C for 20 minutes, no corrosion was found in the Al wiring and no crack occurs in the glass coat.

Although the above-described embodiment employs the Pb-5% Sn solder as a soldering material, any other solders, which liquidus temperatures is 370°C or less, are able to use in the same manner as that described above. For example, solder composed of Pb-Sn (5% or more of Sn), Pb-Ag, Pb-In, Sn-Ag, Pb-Ag-Sn, Pb-Ag-In and the like can be used. In addition, although the Ti-Ni-Au layer is used as the metallized layer 16, the surface of the layer may be metallized by Au or Ag, for example, an Ag-metallized layer such as Cr-Ag layer or the like, may be used as the metallized layer.

Further, this invention is also adapted to a transistor chip which is not a planar type IC without any glass coat and any insulating film such as a SiO₂ film. A semiconductor made of a compound such as GaAs or the like other than Si may be used as a substrate. The under layer of the Al film of the Al electrode pad 5 is not limited to the SiO₂ film, and other materials may be good.

As described above, the present invention is able to prevent the glass coat from cracking and able to bond firmly the whole of the semiconductor chip on the die pad by solder situated between the silver plating on the die pad and the Au-metallized layer formed on the rear side of the semiconductor chip. The present invention is also able to decrease the work hardening property of the Cu ball and thus

prevent Al from being excluded when the Cu ball is bonded on the Al electrode pad. Further, it is good state for the Cu ball plastic deformation to make alloys with the Al electrode pad. It is also possible not to make the Al exclusion by certainly applying ultrasonic vibrations to both the Cu ball and the Al electrode pad. But the greatest advantage of the present invention is that, the same bonding process employed in an Au wire can be performed as the Cu wire bonding process without big change, and so it realize the practical use reliability for the semiconductor device.



CLAIMS:

1. A method of producing a semiconductor device comprising the steps of:

forming a copper ball by flaming out at one end of a copper fine wire;

lowering said copper ball and bringing it into contact with an aluminum electrode on a semiconductor chip within a time of 150 ms or less from the formation of said copper ball; and

pressuring said copper ball to said aluminium electrode pad so that the height of said copper ball is 25 μm or less.

2. A method according to Claim 1, wherein, before said copper ball is formed, said semiconductor chip is bonded to a die pad by using a solder which is used for bonding a semiconductor chip to a die pad and which has a liquidus temperature which does not allow the occurrence of cracks due to the difference in thermal expansion between the glass coat of said semiconductor chip and said semiconductor chip (Si).

3. A method according to Claim 2, wherein said liquidus temperature is 370°C or less.

4. A method of producing a semiconductor device, substantially as herein described with reference to Figures 6 to 9 of the accompanying drawings.
