

Ultrasonic wire bonder with a sensor for the control of the bond force

The invention concerns an ultrasonic wire bonder with a sensor for controlling the bond force of the type named in the preamble of claim 1.

5 An ultrasonic wire bonder for producing wire connections of the type named in the preamble of claim 1 is known from the European Patent Specification EP 340 506. The ultrasonic bonder has a rotatable rocker rotating on a horizontal rotational axis with a horn on the tip of which the capillary guiding the bond wire is clamped. Four piezo sensors are arranged on the rocker. As soon as the tip of the capillary impacts on the semiconductor chip, the force exerted by the semiconductor chip on the capillary and transmitted to the horn and the rocker leads to forces acting upon the piezo sensors. The signals
10 delivered from the piezo sensors are used to control the force to be exerted by the capillary on the semiconductor chip. The piezo sensors are relatively heavy which has a detrimental effect on the production rate of the ultrasonic bonder.

An ultrasonic wire bonder with a force sensor formed from foil strain gauges and a piezoelectric force sensor which are attached to the horn is known from the European Patent Specification EP 275 877. The
15 disadvantage is that these sensors have an uncontrolled affect on the characteristics of the horn and therefore the ultrasonic oscillations of the capillary.

A further ultrasonic wire bonder with a force sensor is known from the US Patent Specification US 5 230 458. The pick-up of the force sensor takes place but at an unfavourable location so that the signal delivered by the force sensor during the fast sequence of the bond process reproduces the time
20 characteristics of the force exerted by the semiconductor chip on the capillary as delayed and distorted.

It is also known to dispense with a force sensor and to derive the force exerted by the semiconductor chip on the capillary from the current which flows through the motor driving the rocker. The dynamic motor current is however dependent on further process parameters such as the rigidity of the substrate.

Furthermore, monitoring of the quality of the bonded connections is known from the European Patent
25 Applications EP 368 533 and EP 540 189 and the German Patent Application DE 43 37 837. For this purpose, a distance sensor is foreseen which registers the deformation of the bonded connection.

The object of the invention is to suggest a more suitable sensor for the control of the bond force.

The named task is solved in accordance with the invention by means of the characteristics of Claim 1.

Embodiments of the invention are explained in more detail below based on the drawing.

30 It is shown in:

Fig. 1 The parts of an ultrasonic wire bonder necessary for understanding the invention,
and

Fig. 2 - 6 Sensors and their arrangement on the ultrasonic bonder.

Fig. 1 shows an ultrasonic wire bonder 1 for the production of wire connections with a rocker 3 rotatable
5 on a horizontal axis 2. A motor 4 is foreseen for the rotating movement of the rocker 3. On the rocker 3,
a horn 5 is attached at the tip 6 of which a capillary 8 is clamped which guides the wire 7. The tip 6 of
the horn 5 must be understood as being the front part of the horn 5 in front of and behind the location
where the capillary 8 is clamped. The rocker 3 also has a wire clamp 9 arranged above the capillary 8. A
10 sensor 10 is arranged on the rocker 3 for the contactless measurement of the deflection of the tip 6 of the
horn 5 in relation to the tip of the rocker 3. The sensor 10 can work for example as optical, inductive or
capacitive. The rocker 3 is constructed in the known way and a linear motor is preferably foreseen as the
motor 4 so that large accelerations of the capillary 8 are possible in vertical direction. A position
measuring system 11 is foreseen for acquisition of the actual rotational position of the rocker 3 in
relation to the axis 2. The sensor 10 delivers a signal U_s which is supplied to a control unit 18 which
15 controls the motor 4.

The signal U_s is excellently suited for controlling the force acting upon the semiconductor chip or the
substrate during bonding. The method of working is now described in more detail with the example of
attaching the wire 7 to a semiconductor chip 12. For the formation of a so-called ball bond, the end of
the wire protruding out of the tip of the capillary 8 is first shaped into a ball. Afterwards, the capillary 8
20 is lowered by means of rotating the rocker 3 on the axis 2. As soon as the tip of the capillary 8 touches
the surface of the semiconductor chip 12, a force is built up, the so-called bond force. Because the rocker
3 continues to be rotated by the motor 4, but the capillary 8 rests on the semiconductor chip 12, the horn
5 bends: The tip 6 of the horn 5 is deflected in relation to the tip of the rocker 3 where the sensor 10 is
located and on which no force is exerted.

25 The signal U_s delivered by the sensor 10 is dependent on the deflection of the tip 6 of the horn 5 in
relation to the wire clamp 9 but should be used for controlling the bond force. By means of a calibration
procedure, the relationship between the signal U_s of the sensor 10 and the bond force can therefore be
determined. This calibration procedure takes place in two steps:

Step 1: The tip 6 of the horn 5 is loaded with a calibration part of predetermined weight, therefore with a
30 predetermined force F_1 and then the current I_{M1} is measured which the motor 4 has to deliver so that the
rocker 3 does not rotate. For this purpose, the current through the motor 4 is controlled until the position
measuring system 11 indicates that the rocker 3 no longer rotates so that, from this, the variable
 $k_M = F_1 / I_{M1}$ is calculated. The calibration part is then removed.

Step 2: Current I_{M1} is applied to the motor 4 so that the capillary 8 now presses on the support with force F_1 and the signal U_{S1} delivered by the sensor 10 is determined. Afterwards, the variable

$$k_s = \frac{F_1}{U_{S1}} = \frac{k_M * I_{M1}}{U_{S1}} \text{ is calculated.}$$

The calibration procedure is now completed. During operation of the ultrasonic bonder, the actual bond force $F(t)$ results from the sensor signal $U_S(t)$ according to the equation

$$F(t) = k_s * U_S(t). \quad (1)$$

With the dynamic sensor signal $U_S(t)$ the current $I(t)$ of the motor 4 can therefore be controlled in such a way that the bond force $F(t)$ follows a preset time profile.

The deflection of the tip 6 of the horn 5 is not only dependent on the bond force but also on further influencing variables, in particular the temperature of the surroundings. Therefore, it is preferably foreseen to recalibrate the relationship between the deflection of the tip 6 of the horn 5 and the bond force during operation of the ultrasonic bonder. If necessary, recalibration can be carried out during each bonding procedure and takes place as follows: During a bonding procedure, as soon as the desired bond force is adjusted, ie, the actual signal U_{S2} and the actual current I_{M2} through the motor 4 have achieved stable values, the variable k_{Sn} is calculated as

$$k_{Sn} = \frac{k_M * I_{M2}}{U_{S2}}.$$

Variable k_{Sn} designates the currently valid value for variable k_s . It is however recommended not to recalibrate the variable k_s based on a single measurement but to draw upon, for example, 10 or 20 successive measurements of k_{Sn} . The variable k_s is preferably corrected as a floating average over a predetermined number of measurements of k_{Sn} and thereby continually adapting the control of the bond force to the actual nominal conditions in accordance with equation (1).

Calibration and recalibration can also take place in different ways.

The invention offers the following advantages:

- The bond force is measured directly there where it occurs, namely at the capillary 8. The measurement takes place without time delay.
- The measurement is contactless. The propagation of the ultrasonic waves in the horn 5 is not affected.
- The point in time at which the capillary 8 impacts on the semiconductor chip 12 can be recognised practically without delay with the sensor 10 so that the rocker 3 can be immediately braked before too large a bond force is built up. In addition, control of the bond force is applied immediately after the impact of the capillary 8 and is totally effective because of the high acceleration possibilities of the rocker 3. In this way, the impact speed of the capillary 8 and the desired impact force can be optimally

synchronized to one another.

- The bond force very quickly reaches its set value and ultrasonics can be applied to the horn 5 correspondingly early. In this way, the bond time for producing the bonded connections is reduced and the production rate of the ultrasonic bonder is increased.

5 Fig. 2 shows a first embodiment of the sensor 10 and its arrangement on the rocker 3. The sensor 10 has a light sender 13 and a light receiver 14 which form a light barrier 15 and which are arranged in a U-shaped housing 16. The housing 16 is attached next to the wire clamp 9 close to the tip 6 of the horn 5 on the rocker 3. The light sender 13 and light receiver 14 are located one on each side of the horn 5 and in such a way that the upper edge of the horn 5 is always located in the light barrier 15. If the horn 5 is
10 now deflected in relation to the rocker 3, then the shadowing of the light barrier 15 increases because of the horn 5 and the signal U_s of the sensor 10 decreases corresponding to the degree of shadowing.

Fig. 3 shows a second embodiment of the sensor 10. With this sensor 10, two light senders 13a, 13b and two light receivers 14a, 14b are foreseen to form two light barriers 15a and 15b. The first light barrier 15a is arranged as for the first embodiment, the second light barrier 15b is arranged parallel to the first
15 light barrier 15a, however in such a way that the lower edge of the horn 5 is always located in the second light barrier 15b. If the horn 5 is now deflected in relation to the rocker 3, then the shadowing of the first light barrier 15a is increased because of the horn 5 and the shadowing of the second light barrier 15b decreases. The differential signal of the two light receivers 14a and 14b serves as signal U_s of the sensor 10. The advantages of this embodiment exist in a higher sensitivity of the signal U_s as well as in a lower
20 dependency of the signal U_s on the temperature.

Fig. 4 shows a third embodiment of the sensor 10 with a reflective working light barrier 15 with which the light emitted by the light sender 13 is partially reflected on the upper surface of the horn 5 and directed to the light receiver 14.

Fig. 5 shows a fourth embodiment of the sensor 10 with a reflective working light barrier 15 with which
25 the light emitted by the light sender 13 is directed via a fibre-optic cable 17 to the upper surface of the horn 5 where it is partially reflected and directed back to the light receiver 14 via the fibre-optic cable 17.

It is also possible to attach coils or capacitor plates in the housing 16 instead of the optical elements and to measure the deflection of the horn 5 by inductance or capacitance. Such an embodiment with
30 inductive distance measurement is presented in Fig. 6. A coil serves as the sensor 10, for example a coil with ferrite core or a flat coil which is arranged on the rocker 3 above the tip of the horn 5. An alternating current is applied to the coil and the ohmic resistance and/or inductance of the coil is measured. The ohmic resistance and/or the inductance of the coil changes when the distance to the horn

5 changes.

The sensor 10 can also be used to determine the quality of the adhesion of the bonded wire 7. To do so, after production of the wire connection, the wire 7 (Fig. 1) is clamped by the wire clamp 9 and then the rocker 3 is raised. In doing so, the piece of wire is tensioned between the bond connection and the wire clamp 9 and an increasing force is built up which prevents the wire clamp 9 from following the rotating movement of the rocker 3. As a result, the wire clamp 9 is bent in relation to the tip 6 of the horn 5 on which no force is exerted so that the distance between the wire clamp 9 and the horn 5 reduces. In this way, that deflection of the wire clamp 9 in relation to the horn 5 can be determined with which the wire breaks. With a calibration procedure, the relationship between the deflection of the wire clamp 9 in relation to the horn 5 can be determined as a function of the force working on the wire clamp 9. In this way, the force necessary in order to break off the wire 7 can be determined with high accuracy.

The sensor 10 is furthermore suitable for recognition of oscillations of the horn 5 in relation to the rocker 3 which therefore indicate that the horn 5 is inadequately secured to the rocker 3.

PATENT CLAIMS

1. Ultrasonic wire bonder (1) for the production of wire connections with a rotating rocker (3) rotatable on a horizontal axis (2) onto which a horn (5) is attached at the tip (6) of which a capillary (8) which guides the wire (7) is clamped and with a sensor (10) for controlling the force which acts on the capillary (8) during bonding, **characterized in that** the sensor (10) is arranged on the rocker (3) in the area of the tip (6) of the horn (5) and that the sensor (10) contactlessly measures the deflection of the tip (6) of the horn (5) in relation to the rocker (3).
2. Ultrasonic wire bonder in accordance with claim 1, **characterized in that** the sensor (10) is an optical sensor.
- 10 3. Ultrasonic wire bonder in accordance with claim 1, **characterized in that** the sensor (10) is an inductive sensor.

