

Method for mounting a flip chip on a substrate

FIELD OF THE INVENTION

[0001] The invention concerns a method for mounting a flip chip on a substrate. A flip chip is a semiconductor chip that has a surface with so-called bumps over which the electrical connections to the substrate are made.

BACKGROUND OF THE INVENTION

[0002] Usually, when mounting semiconductor chips on a substrate, the substrate is presented on a horizontally orientated support surface and the semiconductor chips are presented on a wafer table whereby the electrical contact areas of the semiconductor chip point upwards. The semiconductor chip is removed from the wafer table by a bondhead of an assembly machine, a so-called Die Bonder, and placed onto the substrate. This assembly method is known in the trade as epoxy die bonding or softsolder die bonding depending on whether the semiconductor chip is glued to the substrate with epoxy or soldered to the substrate with solder. The flip chip method differs from this assembly method in that the electrical as well as the mechanical connection between the semiconductor chip and the substrate is made over the bumps. In order that the semiconductor chip with the bumps can be mounted, it has to be turned (flipped) by 180° after removal from the wafer table, hence the name flip chip.

[0003] With the flip chip method, the bumps on the semiconductor chip have to be brought into contact with the electrical connection areas of the substrate, the so-called pads. The demands on the placement accuracy are therefore somewhat greater with the flip chip method than with epoxy die bonding. Today, in order to be able to build such precise assembly machines, a lot of effort is put into the accuracy of the mechanical axes of motion. Such an assembly machine comprises for example a flip device that removes the semiconductor chip from the wafer table and turns it, a pick & place system with a bondhead that removes the flipped semiconductor chip from the flip device and places it on the substrate, and three cameras whereby the first camera makes an image of the semiconductor chip presented on the wafer table, the second camera makes an image of the already turned and picked up semiconductor chip - and therefore flip chip - by the bondhead, i.e. an image of the surface of the semiconductor chip with the bumps, and the third camera makes an image of the substrate with the pads. The images made by the second and third cameras are processed in order to determine the position of the flip chip and the position of the substrate in relation to the axes of motion of the bondhead so that the bondhead can place the flip chip positionally accurate onto the substrate. Temperature fluctuations cause linear expansion and have the effect that the position of the cameras changes relative to each other and to the axes of motion of the bondhead. In order to minimise the influence of temperature fluctuations on the placement accuracy, the distances between the second and third camera and the mechanical transport system are kept as short as possible. Hence an assembly machine is known for example with which the bondhead with the flip chip

is brought into a position above the substrate, then the second and third camera are swung in between the flip chip and the substrate, the bondhead is repositioned based on the images delivered by the second and third camera, the second and third cameras are swung out again and the bondhead lowered. With this assembly method however, maintaining the placement accuracy is done at the cost of the throughput.

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SUMMARY OF THE INVENTION

[0004] The object of the invention is to develop a method for mounting a flip chip that enables high placement accuracy and high throughput.

[0005] The invention therefore concerns a method for mounting a semiconductor chip with bumps on one surface onto a substrate location of a substrate whereby the bumps are brought into contact with
 10 corresponding pads on the substrate location. Positioning of the semiconductor chip over the substrate location is done by means of three axes of motion that correspond to two translatory and one rotary degree of freedom. The semiconductor chip is removed from a wafer table, turned by 180° about an axis parallel to the surface with the bumps and passed over to a bondhead. The bondhead contains a chip gripper that is rotatable on an axis. Parallel to this, the next substrate location is presented. The invention
 15 is characterized by the following steps:

- A) With a first camera (in technical jargon referred to as flipvision), making an image of the semiconductor chip, whereby the image contains the bumps on the semiconductor chip as well as reference marks placed on the bondhead, and whereby the three axes of motion are in first positions. Determining the position and orientation of the actual position of the semiconductor chip in relation to a system of coordinates defined by the reference marks and calculating a first correction vector v_1 that describes the deviation of the actual position of the semiconductor chip from its set position,
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- B) With a second camera (in technical jargon referred to as bondvision), making a first image, whereby the substrate location is visible in the image, determining the position and orientation of the substrate location in relation to the system of coordinates defined by the reference marks, whereby fictitious positions are used for the positions of the reference marks that they would take up if the three axes of motion had been moved from the first positions by a vector v to second positions, and calculating a second correction vector v_2 that describes the deviation of the actual position of the substrate location from its set position,
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- C) Calculating the positions to be approached by the three axes of motion under consideration of the vector v and the two correction vectors v_1 and v_2 ,
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- D) Moving the three axes of motion into these calculated positions,
- E) Making a second image with the second camera whereby the reference marks attached to the bondhead are visible in the image and determining the actual positions of the reference marks,
- F) Calculating a third correction vector v_3 , that describes the deviation of the actual positions of the reference marks from the used fictitious positions of the reference marks assumed in step B on
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evaluation of the first image made by the second camera,

G) Adapting the vector v to $v = v + v_3$,

H) If at least one component of the third correction vector v_3 is greater than a predetermined limit value, moving at least the axis of motion corresponding to this component to a new, corrected position,

5 I) Depositing the semiconductor chip onto the substrate location.

The reference marks are placed on the bondhead. This is to be understood in such a way that the reference marks are either located on the (not rotating) housing of the bondhead or on the chip gripper that is rotatable on the axis.

10 **[0006]** Steps A, B, C, D and I are always carried out. Steps E, F, G and H are carried out for mounting the first semiconductor chip that is mounted on starting production or after interrupting production in order to ensure that this semiconductor chip is placed at the correct location. Vector v describes the distance between the optical axes of the two cameras and the rotational position of the two cameras to one another. Vector v is updated each time by steps E, F, G and H. Vector v changes relatively slowly as the result of thermal influences. Steps E, F, G and H can be carried out on mounting every semiconductor chip by which very high placement accuracy is achieved. However, steps E, F, G and H can also only be
15 carried out sporadically, e.g. for each n th semiconductor chip or at predetermined time intervals. If necessary, steps E, F, G and H can be carried out several times in succession until all components of the third correction vector v_3 are less than the specified limit value.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

20 **[0007]** The accompanying drawings, which are incorporated into and constitute a part of this specification, illustrate one or more embodiments of the present invention and, together with the detailed description, serve to explain the principles and implementations of the invention. The figures are not to scale. In the drawings:

25 Fig. 1 shows the components of an assembly machine for mounting a semiconductor chips with bumps as a flip chip onto a substrate that are necessary for the understanding of the invention,

Figs. 2, 3 show geometrical presentations of mathematical relations, and

Figs. 4, 5 show examples of reference marks.

DETAILED DESCRIPTION OF THE INVENTION

30 **[0008]** Fig. 1 shows the basic idea of the invention based on a schematic presentation of the components of an assembly machine for mounting a semiconductor chip 2 with bumps 1, a so-called flip chip, onto a substrate location 3 of a substrate 4 that are necessary for the understanding of the invention. The

coordinates of a Cartesian system of coordinates are designated x, y and z whereby the x coordinate runs perpendicular to the plane of drawing. The assembly machine comprises a so-called pick & place system with a bondhead 6 that moves back and forth along an axis 5 running in y direction, and two cameras 7 and 8. The position of the bondhead 6 on the axis 5 is controlled by a generally known position measurement and control circuit that is not explained in more detail here. The substrates 4 are transported by a transport system in x direction to a bonding station 9 where each time the bondhead 6 places a semiconductor chip 2 onto a substrate location 3 that has electrical contact surfaces, so-called pads 10 assigned to the bumps 1. The bondhead 6 contains a chip gripper 11 that can be moved up and down in z direction and rotated on its longitudinal axis, i.e. here on the z-axis. In addition, the bondhead 6 has three reference marks 12, 13 and 14 arranged at intervals to one another (in Fig. 1 only the reference marks 12 and 13 are visible), the function of which is explained in detail in the following. With the embodiment shown in Fig. 1 the reference marks 12, 13 and 14 are arranged on the chip gripper 11, that forms part of the bondhead 6. Alternatively, the reference marks 12, 13 and 14 could be arranged on the housing of the bondhead 6. The semiconductor chips 2 are presented on a wafer table 15. The assembly machine further comprises a flip device 16 as well as a control and processing unit 17 that controls the assembly machine. With the sectional view shown in Fig. 1 five bumps 1 are visible arranged adjacent to one another in a row that correspond to five pads 10 lying adjacent to one another in a row on the substrate location 3.

[0009] In order that the bumps 1 on the semiconductor chip 2 can be placed positionally accurate onto the pads 3 on the substrate location so that the bumps 1 and the pads 10 come to lie on one another with the necessary accuracy, three degrees of freedom have to be brought into agreement, namely the translatory position, characterised by two coordinates, and the orientation (rotational position), characterised by an angle of rotation, of the semiconductor chip 2 in relation to the position and orientation (rotational position) of the substrate location 3. Each degree of freedom is assigned to at least one axis of motion. Each axis of motion is assigned to a drive so that the corresponding movement can be carried out. The three degrees of freedom can therefore be realised by means of the x-axis of the transport system for the substrate 4, the y-axis of the bondhead 6 and the angle of rotation θ of the chip gripper 11. However, it is of advantage to equip the assembly machine with a further axis of motion 18 that enables movement of the bondhead 6 in x direction whereby this axis of motion 18 can only carry out movements in the sub-millimetre range but significantly quicker than the transport system for the substrate 4.

[0010] In the ideal situation, i.e. when the semiconductor chip 2 picked up by the bondhead 6 is in its set position and when the substrate location 3 is also in its set position, in order to deposit the semiconductor chip 2 onto the substrate location 3 the bondhead 6 only has to be moved by a predetermined distance ΔY_0 in y direction from the location where the position of the semiconductor chip 2 is determined by means of the first camera 7.

[0011] Mounting the semiconductor chip 2 on the substrate 4 is done according to the following steps whereby with this example it is assumed that the axis of motion 18 is used (and not the transport system for transporting the substrate 4 in x direction) in order to position the semiconductor chip 2 correctly above the substrate location 3 in x direction.

[0012] With this example therefore, the axis of motion 18, the y-axis of the bondhead 6 and the angle of rotation θ of the chip gripper 11 present the three axes of motion that are assigned to the three degrees of freedom. In the following, their positions are designated X, Y and θ .

[0013] In a first phase, the semiconductor chip 2 is removed from the wafer table 15, turned by the flip device 16 and passed over to the bondhead 6. To carry out these steps, a construction of the assembly machine is particularly suitable with which the semiconductor chip 2 is removed from the wafer table 15 by the flip device 16, turned and then passed over to the bondhead 6 at a predetermined location. The first phase then takes place for example as follows:

- Moving the wafer table 15 so that the next semiconductor chip 2 is ready for picking up by the flip device 16.
- Making an image of the presented semiconductor chip 2 in order to check whether the semiconductor chip 2 is at the correct location and, if bad semiconductor chips are marked, check whether the semiconductor chip 2 is a good or bad semiconductor chip.
- If the semiconductor chip 2 is a good semiconductor chip, detaching the semiconductor chip 2 from the wafer table 15 and picking up the semiconductor chip 2 by the flip device 16.
- With the flip device 16, flipping the semiconductor chip 2, i.e. rotating the semiconductor chip by 180° about an axis parallel to the surface with the bumps,
- Turning the chip gripper 11 to a predetermined rotational position designated in the following as angle of rotation θ_1 .
- Moving the axis of motion 18 to a predetermined position designated in the following as X_1 .
- Passing over the semiconductor chip 2 from the flip device 16 to the bondhead 6.
- Presenting the substrate location 3 onto which the semiconductor chip 2 is to be mounted.
- Wetting the bumps 1 of the semiconductor chip 2 with flux. This step can be omitted when alternatively the pads 10 of the substrate 4 have flux or so-called tapes are used.
- Positioning the bondhead 6 in a predetermined y position so that the two reference marks 12, 13 and 14 and the semiconductor chip 2 are located in the field of view of the first camera 7. This y position is designated as Y_1 .

The three axes of motion therefore have the positions X_1 , Y_1 and θ_1 .

[0014] Now, in a second phase, the steps follow that distinguish the method in accordance with the invention.

[0015] A) With the first camera 7, making an image of the semiconductor chip 2 whereby the image contains the bumps 1 of the semiconductor chip 2 as well as the reference marks 12, 13 and 14 attached to the bondhead 6, determining the actual position of the semiconductor chip 2 in relation to a system of coordinates defined by the three reference marks 12, 13 and 14 and calculating a first correction vector v_1 that describes the deviation of the actual position of the semiconductor chip 2 from its set position. Determining the actual position of the semiconductor chip 2 is done either by means of evaluating the position of the bumps 1 or the position of reference marks, so-called fiducials, attached to the semiconductor chip 2.

[0016] The deviation of the actual position of the semiconductor chip 2 from its set position is characterised by three quantities Δx_1 , Δy_1 and $\Delta \theta_1$ whereby Δx_1 and Δy_1 designate the shifting of a reference point P of the semiconductor chip 2 in x direction or y direction and $\Delta \theta_1$ the rotation of the semiconductor chip 2 about the reference point P. The correction vector v_1 is therefore given by $v_1 = (\Delta x_1, \Delta y_1, \Delta \theta_1)$. In the example, the reference point P is the centre point of the set position of the semiconductor chip 2.

[0017] Fig. 2 illustrates this situation. The reference marks 12, 13 and 14 define a local system of coordinates with two Cartesian coordinate axes, i.e. coordinate axes x and y lying perpendicular to one another. Fig. 2 shows the set position presented with a dashed rectangle 19 and the actual position of the semiconductor chip 2 presented with a continuous rectangle 20 as well as the three reference marks 12, 13 and 14. The correction vector v_1 indicates the value by which the axes of motion have to be moved so that the actual position of the semiconductor chip 2 coincides with its set position. The axes of the rectangle 19 run preferably parallel to the coordinate axes x and y and its centre is located for example in the centre of a rectangle formed by the three reference marks 12, 13 and 14.

[0018] B) With the second camera 8, making an image of the substrate 4, determining the actual position of the substrate location in relation to the system of coordinates defined by the three reference marks 12, 13 and 14 whereby for the position of the three reference marks 12, 13 and 14 their position R_0 is used that they take up when the axes of motion are in position $(X_1 + \Delta x, Y_1 + \Delta y, \theta_1 + \Delta \theta)$, and calculating a second correction vector v_2 that describes the deviation of the actual position of the substrate location from its set position. (For this reason, the reference marks that are actually not present in Fig. 1 are nevertheless presented in grey as reference marks 12', 13'). The significance of the values Δx , Δy and $\Delta \theta$ is explained further below. Determining the actual position, i.e. the translatory position and the orientation of the substrate location 3 is done either by evaluating the position of its pads 10 or by evaluating the position of reference marks arranged on the substrate 4.

[0019] The deviation of the actual position of the substrate location 3 from its set position is

characterised by three quantities Δx_2 , Δy_2 and $\Delta \theta_2$, whereby Δx_2 and Δy_2 designate the shifting of a reference point S of the substrate location 3 in x direction or y direction and $\Delta \theta_2$ the rotation of the substrate location 3 about the reference point S. The second correction vector v_2 is therefore given by $v_2 = (\Delta x_2, \Delta y_2, \Delta \theta_2)$. In the example, the reference point S is the centre point of the set position of the substrate location 3.

[0020] Fig. 3 illustrates this situation. Fig. 3 shows the set position of the substrate location 3 as a broken rectangle 21 and the actual position as a continuous rectangle 22 as well as the position of the three reference marks 12, 13 and 14 calculated on the assumption that the axes of motion are in position $(X_1 + \Delta x, Y_1 + \Delta Y_0 + \Delta y, \theta_1 + \Delta \theta)$ (the reference marks 12, 13 and 14 are not contained in the image made by the camera 8). Corresponding to the set position of the semiconductor chip 2, the set position of the substrate location 3 is characterised in that the centre point M of the substrate location 3 lies in the centre of a rectangle defined by the three reference marks 12, 13 and 14 and that the pads 10 of the substrate location 3 are arranged parallel to the x or y axis. The correction vector v_2 indicates the values by which the axes of motion have to be moved so that the actual position of the substrate location 3 coincides with its set position.

[0021] The values Δx , Δy and $\Delta \theta$ represent a vector v . The first semiconductor chip 2 of a production batch can be mounted on the assumption that $\Delta x = 0$, $\Delta y = 0$ and $\Delta \theta = 0$, as any error caused by this is eliminated during the course of the method.

[0022] C) Calculating the positions to be approached by the three axes of motion under consideration of the two correction vectors v_1 and v_2 , as well as the vector v as $(X_1 + \Delta x_1 + \Delta x_2 + \Delta x, Y_1 + \Delta Y_0 + \Delta y_1 + \Delta y_2 + \Delta y, \theta_1 + \Delta \theta_1 + \Delta \theta_2 + \Delta \theta)$, i.e. as $X_1 + \Delta x_1 + \Delta x_2 + \Delta x$ for the position of the bondhead 6 along the x axis, in the example for the axis of motion 18, $Y_1 + \Delta Y_0 + \Delta y_1 + \Delta y_2 + \Delta y$ for the position of the bondhead 6 along the y axis, and $\theta_1 + \Delta \theta_1 + \Delta \theta_2 + \Delta \theta$ for the angle of rotation of the chip gripper 11.

[0023] D) Moving the three axes of motion to these calculated positions.

[0024] E) With the second camera 8, making an image whereby the image now contains the reference marks 12, 13 and 14 attached to the bondhead 6, and determining the actual position R_1 of the three reference marks 12, 13 and 14.

[0025] F) Calculating a third correction vector $v_3 = (\Delta x_3, \Delta y_3, \Delta \theta_3)$ that describes the deviation of the actual position R_1 of the reference marks 12, 13 and 14 from their position R_0 used for determining the second correction vector v_2 .

[0026] G) If at least one component of the third correction vector v_3 is greater than a specified limit value, moving the corresponding axis of motion to a new position corrected by the corresponding component of the correction vector v_3 or moving all three axes of motion to new positions corrected by the third correction vector v_3 . In the latter case therefore to the positions $(X_1 + \Delta x_1 + \Delta x_2 + \Delta x_3 + \Delta x,$
 5 $Y_1 + \Delta y_0 + \Delta y_1 + \Delta y_2 + \Delta y_3 + \Delta y, \theta_1 + \Delta \theta_1 + \Delta \theta_2 + \Delta \theta_3 + \Delta \theta).$

[0027] H) Adapting the vector v to $v = v + v_3$.

[0028] I) Depositing the semiconductor chip 2 onto the substrate location 3.

[0029] The correction vectors v_1 and v_2 characterise possible positioning errors of the semiconductor chip 2 or the substrate location 3. The vector v characterises the total accumulated positional
 10 displacement of the individual components of the assembly machine as a result of thermal influences. The third correction vector v_3 characterises the changes occurring as a result of thermal influences. On the one hand, the method described therefore guarantees that the first semiconductor chip of a production batch is already mounted correctly and, on the other hand, that thermal positional displacements are continuously compensated without the axes of motion having to be perpetually recalibrated.

15 [0030] The described order of the method steps can, under certain circumstances, deviate from the given order as certain steps can be carried out in parallel or in the reverse order.

[0031] Steps A, B, C, D and I are always carried out. Steps E, F, G and H are carried out whenever the vector v is not yet known with the required accuracy or when it can be expected that the vector v could have changed. If necessary, steps E, F, G and H can be carried out several times in succession until all
 20 components of the third correction vector v_3 are less than a specified limit value.

[0032] The reference marks 12, 13 and 14 are preferably placed on a plate made of glass in the form of structured markings in chrome. Glass is transparent so that the reference marks 12, 13 and 14 can be seen by both cameras 7 and 8. Preferably, a glass is chosen the coefficient of thermal expansion of which is as low as possible. The dimensions of the plate are selected greater than the dimensions of the largest
 25 semiconductor chip to be mounted and the reference marks 12, 13 and 14 placed close to the edge so that the reference marks 12, 13 and 14 are visible to both cameras 7 and 8 independently of the size of the semiconductor chip.

[0033] The function of the reference marks 12, 13 and 14 lies in the definition of a local system of coordinates in relation to which the set position of the semiconductor chip as well as the set position of
 30 the substrate location are defined. As reference marks, in the sense of the invention, other solutions are also valid that fulfil this function. Instead of the three reference marks 12, 13 and 14 for example two reference marks 12 and 13 can be foreseen that are formed by two lines aligned orthogonal to one

another as is shown in Fig. 4. The reference mark 12 defines the position of the x-axis, the reference mark 13 defines the position of the y-axis of the local Cartesian system of coordinates. A further solution is shown in Fig. 5. Here, two reference marks 12 and 13 define the position of the x-axis of the local Cartesian system of coordinates. The y-axis of the local Cartesian system of coordinates is defined in that
5 it runs perpendicular to the x-axis and straight through the reference mark 12.

[0034] While embodiments and applications of this invention have been shown and described, it would be apparent to those skilled in the art having the benefit of this disclosure that many more modifications than mentioned above are possible without departing from the inventive concepts herein. The invention, therefore, is not to be restricted except in the spirit of the appended claims and their equivalents.

CLAIMS

1. Method for mounting a semiconductor chip (2) having a surface with bumps (1) onto a substrate location of a substrate (4) whereby the bumps (1) are brought into contact with corresponding pads (10) on the substrate location whereby the positioning of the semiconductor chip (2) over the substrate location is done by means of three axes of motion, the method comprising
 - 5 picking the semiconductor chip (2) from a wafer table (15),
 - turning the semiconductor chip (2) by 180° about an axis parallel to the surface with the bumps (1),
 - passing the semiconductor chip (2) over to a bondhead (6),
 - presenting the substrate location (3),
 - 10 the method further comprising the steps
 - A) with a first camera (7), making an image of the semiconductor chip (2) whereby the image contains the bumps (1) of the semiconductor chip (2) as well as reference marks (12 - 14) attached to the bondhead (6), whereby the three axes of motion are in first positions, and determining the position and orientation of the actual position of the semiconductor chip (2) in relation to a system of
 - 15 coordinates defined by the reference marks (12 - 14) and calculating a first correction vector v_1 that describes the deviation of the actual position of the semiconductor chip (2) from its set position,
 - B) with a second camera (8), making a first image whereby the substrate location (3) is visible in the image, determining the position and orientation of the substrate location (3) in relation to the system of coordinates defined by the reference marks (12 - 14), whereby fictitious positions are used for the
 - 20 positions of the reference marks (12 - 14) that they would take up if the three axes of motion had been moved from the first positions by a vector v to second positions, and calculating a second correction vector v_2 that describes the deviation of the actual position of the substrate location (3) from its set position,
 - C) calculating the positions to be approached by the three axes of motion under consideration of the
 - 25 vector v and the two correction vectors v_1 and v_2 ,
 - D) moving the three axes of motion to these calculated positions, and
 - E) depositing the semiconductor chip (2) onto the substrate location (3).
2. Method according to claim 1, **characterised in that** after step D the following steps are carried out:
 - with the second camera (8), making a second image whereby the reference marks (12 - 14) attached to the bondhead (6) are visible in the second image, and determining the actual positions of the reference
 - 30 marks (12 - 14),
 - calculating a third correction vector v_3 that describes the deviation of the actual positions of the reference marks (12 - 14) from the used fictitious positions of the reference marks (12 - 14) assumed in step B on evaluation of the first image made by the second camera (8),
 - 35 - adapting the vector v to $v = v + v_3$,

- if at least one component of the third correction vector v_3 is greater than a specified limit value, moving at least the axis of motion corresponding to this component to a new, corrected position.