Method for Bonding Substrates

Specification

This invention relates to a method for bonding a first substrate with a second substrate.

The state of the art showcases a wide variety of processes, technologies, and systems with whose help different surfaces, in particular connecting surfaces, can be coated with liquids, in particular mixtures of viscous polymers with solvents.

Adhesives represent an important group of liquids. Adhesives are used to an increasing extent in the semiconductor industry in order to connect substrates to one another. In this case, a distinction is made between the temporary adhesives and the permanent adhesives.

A temporary adhesive is in most cases a thermoplast, which softens above a characteristic temperature, the so-called glass transition temperature. Substrates that were glued with the help of a thermoplast can be separated from one another again by heating the thermoplast above the glass transition temperature. Thermoplasts can be thermally cycled; therefore, they can be theoretically heated several times and cooled again, without them losing their physical and/or chemical properties. The reason lies in the fact that in contrast to duromers, thermoplasts do not cross-link. As a result, the polymer chains can be moved toward one another at correspondingly high temperatures, and the temporary adhesive remains moldable.

Even in the case of the spray coating, gas inclusions occur again and again, for example because of the roughness of the surfaces. This roughness is a direct result of the individual, agglomerating droplets on the surface of the substrate.

Embodiments of this invention indicate a method with which the bonding result is improved and which can be used universally.

According to an aspect, there is provided a method for bonding a first lower substrate with a second upper substrate by means of a connecting layer that is arranged between the substrates and that consists of a connecting material with the following steps, in particular with the following sequence: Applying at least one droplet of the connecting material to the second upper substrate in liquid form, and Distributing the connecting material between the substrates by bringing the substrates closer, wherein the distributing takes place automatically by capillary action of the liquid connecting material, wherein one of the substrates is released after contacting the at least one droplet with the first lower substrate , and as a result forming the shape of the connecting layer with a thickness t, wherein the connecting material is applied in an amount that is free of surplus.

All combinations of at least two of the features indicated in the specification, the claims and/or the figures also fall within the scope of the invention. In the indicated ranges of values, values as boundary values that lie within the above-mentioned limits are also to be considered as disclosed and can be claimed in any combination.

The basic idea of embodiments of this invention is to apply a connecting material as a liquid, in particular a polymer, even more preferably a permanent adhesive, between two substrates, in such a way that the liquid is distributed at least partially, preferably predominantly, automatically, in particular exclusively by linear movement of one or two substrates toward one another, between the substrates, in particular by concentric or radially symmetric propagation. An embodiment of the invention consists in particular in applying the connecting material in an amount that is free of excess. The embodiment that is disclosed is in particular self-regulating relative to

- A setting of the layer thickness and/or

- A wedge error compensation, and/or
- A liquid distribution.

Self-regulating means that no control is necessary for optimizing the above-mentioned parameters, in particular from the outside. A system according to embodiments of the invention, once left to itself, strives for the state with a maximally homogeneous layer thickness, a minimum wedge error and/or an optimum liquid distribution, in particular by gravitational action on the upper substrate and/or by capillary action between the two substrates.

Free of excess means that the amount of the applied connecting material is sufficient to form the complete connecting layer with a preset thickness t, in particular without connecting material overflowing a peripheral edge of at least one of the substrates.

The applied amount is preferably applied on a surface B that is small compared to the connecting surface A of the substrates. The ratio of surface B to A is preferably less than ½, even more preferably less than 1/3, even more preferably less than ¼, and even more preferably less than 1/5.

The liquid is automatically distributed in particular by the force of weight of one of the two substrates (in particular the upper substrate) and/or by capillary action of the liquid between the two substrates. One of the two substrates is released in particular after the liquids are brought into contact (in the case of an application on the two substrates) or the liquid is brought into contact with one of the substrates.

From the above, with minimal effort and expenditure of energy, there follows a defect-free, efficient, and material-conserving distribution of the connecting material and design of a connecting layer that consists of the connecting material between two substrates. The liquid is distributed in such a way that a mean thickness t of the hardened connecting layer is defined, and because of the homogeneous, bubble-free distribution, the total thickness of the stack that consists of the first substrate, second substrate, and the connecting layer is constant over the surface. In particular, the formation of an edge bead is also prevented. When using transparent substrates and liquids that can be hardened by electromagnetic radiation, in particular permanent adhesives, the liquid can be directly hardened by means of irradiation, in particular by means of UV light.

For distribution of the connecting material, at least two substrates are used, whereby the connecting material is to remain for a certain time between the two substrates. According to the invention, temporary and permanent bonding methods are preferred.

The connecting material is in particular a permanent bonding adhesive. According to embodiments of the invention, however, the use of a temporary adhesive, a photoresist, a liquid, which is converted into an insulating layer in a later process, or a purification liquid would be conceivable. As connecting material, in particular all types of mixtures are defined, preferably adhesives, which are dissolved in solvents.

According to embodiments of the invention, the formation of defects, in particular the formation of bubbles, is also prevented in the case of connecting materials with high to very high viscosity. In addition, a liquid distribution with a very homogenous layer thickness t is achieved by the embodiment of the invention.

The substrates can have any shape, but are preferably circular. In particular, the substrates according to embodiments of the invention do not have any projections or edges that rise above the contact surfaces. The contact surface is designed as in particular completely flat. The diameter of the substrates is in particular industrially standardized. For wafers (preferred as substrates), in particular diameters of 1 inch, 2 inches, 3 inches, 4 inches, 5 inches, 6 inches, 8 inches, 12 inches and 18 inches are preferred. The embodiment of the invention can in principle handle any substrate, however, independently of its diameter. The embodiment of the invention is suitable in particular for the coating and the bonding of rectangular substrates, preferably glass substrates. In a first process step according to embodiments of the invention, a defined amount of liquid of the connecting material is deposited or applied on the first substrate and/or the second substrate. The liquid is preferably deposited/applied centrically and forms a puddle or a drop. The application is done in particular in such a way that a smooth and clean liquid surface is produced, whereby in particular the material selection and/or additional process conditions such as temperature and pressure are taken into consideration according to embodiments of the invention. An irregularity in the liquid surface can result in accidental inclusions.

In an embodiment of the invention, the liquid is not applied as drops but rather as a geometric pattern on the substrate surface. By the targeted deposition of a liquid pattern, the distribution of the liquid during the distribution process according to the invention can be influenced. This embodiment of the invention has particular advantages for the uniform distribution of the liquid on non-circular, in particular rectangular, for example quadratic, substrates. Rectangular substrates do not have any radial symmetry. The path to the corner of such a rectangular

substrate is therefore from the geometric mean of the substrate that consists of longer edges than the path to some of the edges. In general, the paths are therefore dependent upon the direction in which the liquid is distributed. Therefore, in order to distribute the liquid uniformly, in particular also at the same time, over the substrate surface, in particular more liquid is to be deposited according to embodiments of the invention in the direction of longer paths.

According to an embodiment of the invention, in particular by depositing the liquid in the shape of a cross, whereby the top corners show the rectangular substrate in the corners, an initial situation can be created, which in the distribution of the liquid according to embodiments of the invention leads to the fact that the liquid reaches each point of the rectangular substrate approximately simultaneously, and preferably exactly simultaneously. Analogous considerations apply for any shaped substrates, whereby the pattern of the liquid in each case is calculated individually for each form of substrate or is determined experimentally. In an embodiment of the invention, the pattern is to consist of lines and/or point combinations. In an embodiment of the invention, the line thicknesses of the lines of the pattern are varied during the deposition. By the production of such a pattern, it can also be ensured that a contact wave of the process according to embodiments of the invention begins to run from the correct contact point. By the production of such patterns, a faster and primarily more homogeneous coating is possible by the process according to embodiments of the invention. On the substrate surface of the second substrate, in turn there can be a deposited drop that is brought into contact with the pattern on the substrate surface of the first substrate.

In particular, the amount of deposited/applied liquid is determined, in particular calculated, relative to the desired thickness t at the end of the method, i.e., in particular after the hardening of the liquid. Assuming a homogeneous distribution of the liquid between the substrates, a 100% incompressible liquid with constant density and a corresponding preset substrate surface, the amount of liquid to be deposited is calculated in particular as follows. The volume V of the connecting layer with the thickness t over the basic surface A (connecting surface of the first and/or second substrate) after the process according to embodiments of the invention is concluded is:

$$V = t * A$$

In the case of circular substrates, the surface area A is equal to the square of the radius of the circle (or half the diameter) times the number π, i.e.,

$$V = t * r^2 * \pi = t * \left(\frac{d}{2}\right)^2 * \pi$$

In the case of an incompressible liquid, the volume is independent of the pressure. In particular, the amount of liquid of the connecting material is deposited/applied by a volume control, whereby in the case of the preset substrate surface area A and the desired or set layer thickness t, the amount of volume to be deposited is to be dispensed, in particular adjusted by a shrinkage caused by the hardening. The shrinkage, in which in particular a polymerization shrinkage is involved, is indicated by the shrinkage parameter s. A polymerization shrinkage is defined as the reduction of the volume or the compacting of a polymer by the advancing cross-linking of the polymer chains below one another. This irreversible process takes place primarily in the permanent bonding adhesives. Another reason for the reduction of the volume would be the outgassing of

liquid components. In embodiments of the invention, outgassing of a liquid would be difficult or not possible at all, since the distributed liquid is located between two, in general gas-tight, substrates. The outgassing would be possible only via the relatively narrow area between the peripheral contours of the two substrates. Hereinafter, therefore, this type of shrinkage will not be discussed in any further detail. The shrinkage parameter s is defined as

the difference of 1 and the ratio of the volume V after the shrinkage to volume V_0 before the shrinkage, therefore:

$$s = 1 - \frac{V}{V_o}$$

The shrinkage is less than 0.2, preferably less than 0.1, even more preferably less than 0.01, most preferably less than 0.001, and with the utmost preference 0.

As an alternative, the amount of liquid is deposited/applied in particular by a mass control system, whereby the calculated volume is multiplied with the (in particular constant) density of the connecting material.

$$m = \rho * V = \rho * t * r^2 * \pi = \rho * t * \left(\frac{d}{2}\right)^2 * \pi$$

In this case, according to embodiments of the invention, care must be taken in particular that the density of the liquid is a function of temperature. A smallest possible thickness t of the connecting layer is preferably sought in order to optimize the transmission of electromagnetic radiation through the connecting layer, i.e., to reduce the absorption.

By way of example, but not in a limiting manner, the amount of liquid to be deposited for different layer thicknesses for a specified diameter of a substrate is presented in the form of a table. The density is in this case selected as 1 g/cm^3, whereby this is a realistic value for the density of polymers according to embodiments of the invention. The real density of a thermoplast, in particular a thermoplast that is dissolved in a solvent, can deviate therefrom.

Tabular depiction of a series of amounts of liquid to be deposited with volume V (or correspondingly converted mass m) for a 200 mm substrate and different thicknesses t.

Radius r m	Surface Area A m^2	Density ρ g/cm^3	Thickness t µm	Volume V m^3	Mass m kg
0.1	0.031416	1	1	3.14159E-08	3.14159E-05
0.1	0.031416	1	2	6.28319E-08	6.28319E-05
0.1	0.031416	1	5	1.5708E-07	0.00015708
0.1	0.031416	1	10	3.14159E-07	0.000314159
0.1	0.031416	1	50	1.5708E-06	0.001570796
0.1	0.031416	1	100	3.14159E-06	0.003141593

The thickness t according to embodiments of the invention of the connecting layer lies in particular between 100 µm and 0.001 µm, preferably between 75 µm and 0.01 µm, even more preferably between 50 µm and 0.1 µm, most preferably between 25 µm and 1 µm, and with the utmost preference between 10 µm and 1 µm.

In another, in particular second, process step, the approach of the two substrates toward one another is carried out. Before and/or during the approach, a wedge error compensation can be performed in particular between the substrates. The two substrates are preferably quickly brought closer up to a first position in order to accelerate the

process sequence. In this approach process up to the first position, the relative speed of approach of the two substrates toward one another is in particular greater than 0.01 mm/s, preferably greater than 0.1 mm/s, even more preferably greater than 1 mm/s, and most preferably greater than 10 mm/s. The embodiment of the invention has the advantage, however, that the correction of the wedge error can be completely eliminated in most cases. The wedge error is automatically compensated for completely or at least to a large extent by the self-distributing liquid between the two substrates.

The first position preferably ends with bringing the liquids into contact (with application on the two substrates) or bringing the liquid into contact with one of the two substrates.

The relative speed of approach is in particular reduced when reaching the first position and is in particular less than 1 mm/s, preferably less than 0.1 mm/s, even more preferably less than 0.01 mm/s, and most preferably less than 0.001 mm/s. In an especially preferred embodiment, the process according to the invention accordingly is performed in a previously-described two-stage process.

In another, in particular third, process step according to embodiments of the invention, one of the substrates, in particular the second substrate, is detached from its securing device (receiving device). In the case of horizontal storage of the two substrates, gravitational force and capillary force, which acts via the liquid between the two substrates, pulls the upper substrate in the direction of the lower substrate. By the pressure distribution, thus produced, within the liquid, the liquid is automatically distributed along the boundary surface. The propagating liquid wave in this case pushes the air ahead of it and removes all types of gases from the substrate boundary surface. The distribution of the liquid is

carried out in particular uniformly, even more preferably radially symmetrically, and preferably concentrically. In the case of corresponding storage and selection of a viscosity of the liquid, which is high enough to prevent the liquid from running from the substrate in the event that the substrates are positioned crosswise or vertically, a crosswise or vertical positioning of the substrates is also conceivable. In such an embodiment of the invention, exclusively the capillary action would ensure the automatic approach of the substrates toward one another as well as the liquid distribution between the substrates.

In another, in particular fourth, step according to embodiments of the invention, the liquid reaches the edge of the two substrates, and, based on the preset amount and the lack of capillary action, the distribution is automatically ended. The liquid (connecting material) has in particular a viscosity that is low enough to be able to be distributed between the two substrates, but is high enough not to be able to leave the substrates held together by the surface tension present on the edge. The viscosity is a physical property, which is greatly temperature-dependent. The viscosity of liquids, in particular of polymers, in general decreases with increasing temperature. At room temperature, the viscosity of the connecting material according to embodiments of the invention is in particular between 10^6 Pa*s and 1 Pa*s, preferably between 10^5 Pa*s and 1 Pa*s, even more preferably between 10^4 Pa*s and 1 Pa*s, and most preferably between 10^3 Pa*s and 1 Pa*s.

The processes according to embodiments of the invention work in principle with any hydrophilicity values of the substrate surfaces. The hydrophilicity values of the substrate surfaces can, in particular by using different substrate materials and/or different surface treatment processes, also be different. If a rough distinction is thus made between

hydrophobic and hydrophilic, in principle the following combinations for the first and second substrates are possible:

- Hydrophobic-hydrophobic
- Hydrophilic-hydrophilic
- Hydrophobic-hydrophilic
- Hydrophilic-hydrophobic

Hydrophilic substrate surfaces are used according to embodiments of the invention primarily when a corresponding wetting and thus a higher contact surface and a correspondingly higher adhesive strength between the liquid and the substrate surface are to be produced. In particular, substrates, on whose bottom side liquids in the form of a drop should be deposited, have a correspondingly high hydrophilicity.

According to embodiments of the invention, however, hydrophobic surfaces are used primarily for producing a point contact between a deposited liquid and the substrate surface. Such point contacts can be used primarily in those embodiments of the invention in which the liquid is deposited only at the hydrophilic bottom side of the upper substrate, while the top side of the hydrophobic lower substrate when making contact makes only point contact with the convex drop. The force of the weight of the upper substrate then spreads the drops between the two substrate surfaces starting from this point-like contact.

The hydrophilicity is determined using the contact angle method. In this case, the angle between the tangent to a liquid drop and the wetted surface is measured using an optical device. The method is known to one skilled in the art. The measured angle is acute in the case of higher hydrophilicity and obtuse in the case of higher hydrophobicity.

For hydrophilic substrate surfaces according to embodiments of the invention, the preferred contact angle between the liquid connecting material and the connecting surfaces (contact surfaces) is in particular less than 90°, preferably less than 70°, even more preferably less than 50°, and most preferably less than 30°. For the hydrophobic substrate surfaces according to embodiments of the invention, the preferred contact angle between the liquid connecting material and the connecting surfaces (contact surfaces) is in particular greater than 90°, preferably greater than 125°, even more preferably greater than 150°, and most preferably greater than 175°.

Should it be necessary to convert a hydrophobic substrate surface into a hydrophilic substrate surface (or a hydrophilic substrate surface into a hydrophobic substrate surface), this can be performed with the known technique before performing the process according to embodiments of the invention.

Plasma treatments, surface etchings, chemical treatments, coatings, sputtering, increasing surface roughness, etc., would be conceivable.

Hereinafter, the two substrate surfaces are assumed to be hydrophilic (preferred embodiment).

In order to ensure the distribution of the liquid and primarily the optimal wetting of the connecting surfaces, the surface of the substrates is preferably hydrophilic. If the deposition/application of a drop is carried out in particular on the upper/second substrate, a hydrophobicity that is too high (i.e., a hydrophilicity that is too low) can have a disadvantageous effect on the adhesive behavior between the liquid and the substrate surface. The hydrophilicity (i.e., the adhesive force) between the liquid and the substrate surface is preferably at least so high that the liquid is not drawn from the substrate surface by the gravitational force. In this case, a hydrophilicity is therefore selected in which the

contact angle is at least larger than 0, in particular larger than 10°, and preferably larger than 20°.

Another physical parameter that is relevant according to embodiments of the invention is the adhesion between the connecting layer and the substrates. The adhesion is preferably defined by the energy per unit of surface area, which is necessary in order to separate from one another two surfaces that are connected to one another. In this case, the energy is indicated in J/m^2. The connecting layer and the substrates are selected in particular in such a way that the energy per unit of surface area is less than 2.5 J/m^2, preferably less than 0.1 J/m^2, more preferably less than 0.01 J/m^2, most preferably less than 0.001 J/m^2, with utmost preference less than 0.0001 J/m^2, and most preferably less than 0.00001 J/m^2. A preferred, in particular empirically determined, mean of the energy per unit of surface area between a coating material, applied in particular on at least one of the substrates, and a polymer as connecting material lies at approximately 0.1 J/m^2. A typical, empirically measured mean of the energy per unit of surface area, between pure silicon and the same polymer, lies at approximately 1.2 J/m^2. Corresponding values can fluctuate depending on coating material, substrate material and contamination, in this case a polymer. In the future, much more efficient coating materials can also be expected.

In an embodiment of the invention, the connecting surfaces, in particular in front of a coating of the surfaces according to embodiments of the invention, can be treated and/or can be coated with a plasma in order to change or to specially set the surface properties, in particular the hydrophilicity or hydrophobicity.

The usable types of plasma are preferably

- Inductive plasma

- Capacitive plasma
- Remote plasma

The contact angle or the desired adhesion is set by the selection of the parameters of the plasma.

According to an advantageous embodiment of the invention, the method is performed by the deposition of the exact amount of liquid of the connecting material and/or by the knowledge of the density, the viscosity and/or the surface properties of the connecting material in such a way that the liquid does not leave the peripheral edge of the two substrates. It is thus prevented that the unit in which the process according to embodiments of the invention is performed is contaminated by the liquid.

According to a preferred embodiment of the invention, the connection of the two substrates is carried out via the collection of the connecting material applied on the lower/first substrate with the connecting material applied on the upper/second substrate, in particular in the form of a drop (English: droplet). The drop in this case can be deposited by, for example, a unit for depositing liquids against the direction of gravity, as it is described in the publication DE102013113241.3. The drop can in particular also be applied manually. This embodiment of the invention is especially preferred since the drop at the connecting surface (contact surface) of the second, upper substrate has a perfect convex shape because of gravitation acting on the drop. In contrast to this, the liquid on the connecting surface of the first, lower substrate can have concave areas, in particular when it was poorly deposited. The concave areas primarily, but not exclusively, are produced by a "repeated deposition" of liquid on different, in particular

non-centric, positions of the first lower substrate. Because these "repeated depositions" can be minimized to a large extent by correspondingly correctly calibrated depositing units, the embodiments of concave areas that take place in the submillimeter or submicrometer range are the ones of primary importance. It happens that the liquid surface forms local, very small (barely visible to the naked eye) concave areas by local surface tension changes (for example, by fat particles, dust particles, ions, organic molecules, etc.), which areas can act as germinal points for the formation of defects or bubbles. Independently of the cause for the forming of an imperfect convex liquid surface, this embodiment of the process can prevent flaws from forming. By virtue of this embodiment, the collection of drops takes place at the connecting surface of the second, upper substrate with the liquid, having in particular concave areas, at the connecting surface of the first lower substrate. Because of the continuous, in particular slow, approach, enough time remains that defects, in particular gas inclusions, are pushed outside.

In another embodiment of the invention, the liquid was deposited by a coating technique, in particular by centrifugal enameling or spray enameling, on the substrate surface of a substrate, in particular the lower/first substrate. In turn, the connecting material is applied as drops on the substrate surface of the upper/second substrate.

In another embodiment of the invention, the connecting material is applied on the lower/first substrate in the form of a pattern. In this case, the pattern is selected in such a way that in the case of the distribution of the connecting material according to embodiments of the invention, an optimal, quick and primarily simultaneous wetting of the

substrate surfaces is carried out. This type of distribution is preferred in particular for non-circular, in particular rectangular, substrates, since the length of the path, which the connecting material covers from the center to the edge, depends on the direction. Therefore, a deposition of the connecting material, matched to the geometry of the substrate, in particular on the lower/first substrate, is advantageous. On the upper/second substrate, in this case in particular a drop of the connecting material is to be deposited in order to promote the contact according to embodiments of the invention.

In an embodiment, it is conceivable to deposit/apply geometric figures, in particular one (or several, preferably crossed) rectangle(s) instead of a drop and/or a puddle. In this connection, the distribution process of the liquid according to embodiments of the invention is accelerated between the two substrates because of the better predistribution and the thus increased capillary action.

Because of the specifically deposited geometric figures, the liquid was already predistributed over a long distance (for example: line) or several longer distances (for example: cross). The deposited geometric figures preferably accelerate the liquid wave that is caused and promoted by the capillary forces, so that the distribution process of the liquid according to the invention is completed more quickly.

In another embodiment of the invention, the dispensing of the liquid to the lower/first substrate is eliminated. Only a dispensing of an, in particular individual, drop on the connecting surface/contact surface of the second/upper substrate is carried out. Especially for the production of extremely thin liquid layers, the amount of liquid of the one drop on the connecting surface of the second upper substrate is preferred according to embodiments of the invention. The gravitation on the

drop acts by the dispensing of the drop on the connecting surface of the second, upper substrate, so that this drop has a perfect concave shape and does not have any concave areas. The point-like contact of the drop with the connecting surface of the first, lower substrate is correspondingly exact. In the case of this embodiment, it must be dispensed only once, by which time and expense are saved.

The distribution of the liquid connecting material (liquid) at room temperature is the preferred embodiment of the invention. Alternatively, the tempering of the first and/or second substrate is conceivable according to embodiments of the invention. By the tempering of the first and/or second substrate, the viscosity of the liquid can be set specifically, and thus the flowing behavior can be regulated. The first/upper substrate and/or the second/lower substrate is/are in this case tempered depending upon the desired viscosity of the liquid. In this case, the temperature range according to embodiments of the invention is in particular between -100°C and 300°C, preferably between -50°C and 300°C, even more preferably between 0°C and 300°C, most preferably between 50°C and 300°C, and even more preferably between 100°C and 300°C. In particular, still no permanent cross-linking of the liquid takes place in the temperature range of the tempering of the first and/or second substrate.

The connecting material that is to be distributed between the two substrates according to an embodiment of the process of the invention is preferably hardened (English: cured), in particular during and/or after the distribution of the connecting material between the substrates. The hardening is done either using electromagnetic radiation and/or by means of heat. The electromagnetic radiation in this case has in particular a wavelength in the