

Measurement Means and Method for Measuring Layer Thicknesses and Voids of a Wafer Stack

Specification

This invention relates to a measurement means for measuring and/or acquiring layer thicknesses and/or voids of one or more layers of a wafer stack on a plurality of measuring points which are distributed on the wafer stack. Furthermore this invention relates to a wafer processing device for processing a wafer stack and a method for measuring and/or acquiring layer thicknesses and/or voids of one or more layers of a wafer stack at a plurality of measuring points which are distributed on the wafer stack.

Development in the semiconductor industry is currently in the direction of wafer bonding processes becoming increasingly important. Thus for example novel functions such as motion sensors and/or orientation sensors in cell phones and other portable devices such as game consoles are leading to a rapidly increasing demand for microelectromechanical (MEMS) components which can detect acceleration and rotational speeds.

Another field with rapid growth is components which are produced as so-called 3D ICs. They include a chip system which consists of several layers with transistors ("active layers") which are connected among one another by means of contacts which lead through the silicon. These plated-through holes are called "through silicon vias" or abbreviated "TSVs" in the industry.

In order to produce these TSVs as economically as possible, as well as to be able to

implement other desired advantages such as a small overall packing size, it is necessary to thin the wafers to a suitable size before or after the TSV production or in the course of TSV production. Accordingly it is now distinguished between so-called via first, via middle and via last processes. With respect to thinning of the wafers, it has been found that the desired target thicknesses are no longer sufficient to be able to reliably move the wafer from one process step to the next since the mechanical stability of the wafer, especially in the currently conventional 300 mm wafer, is no longer extant.

Wafers are therefore advantageously temporarily mounted on a carrier so that reliable handling of the thin wafer which conventionally has a thickness $< 150\text{ }\mu\text{m}$, but usually $< 100\text{ }\mu\text{m}$ and often < 80 or even $< 50\text{ }\mu\text{m}$ is ensured. After completing the necessary process steps the wafer is again detached from the carrier. These two methods are called temporary bonding and debonding.

In a first process step the product wafer is bonded onto the carrier by means of suitable bonding technology which is known to one skilled in the art. This bonding step generally takes place such that the first main surface of the product wafer on which the chip structures are built up is oriented such that this surface comes into contact with the temporary adhesive and this adhesive layer subsequently produces the contact with the carrier wafer.

In almost all cases, within the framework of this rear side processing however mechanical thinning of the product wafer takes place. This includes especially grinding steps in which a defined thickness of the product wafer is removed by grinding. Conventionally, in this connection individual grinding steps with different grinding rates and/or grain sizes of the grinding wheels are used. Generally there are a first grinding step with a higher material removal rate (coarse grinding) and a second grinding step with a lower material removal rate (fine grinding).

In order to ensure the quality of the final chips and the integrity of the temporarily bonded wafer in conjunction with the rear side process steps, it is necessary for the temporary adhesive connection to satisfy certain quality criteria. In this connection there are a host of requirements for the adhesive material which are known to one skilled in the art. They relate among others to the capacity of the adhesive to be able to tolerate certain process conditions which can arise during rear side processing. They include among others temperature stability, compatibility with a vacuum environment (no outgassing), stability of the adhesive relative to chemicals such as solvents, acids, and bases, compatibility with diverse mechanical loads or electromagnetic waves (for example irradiation with light of a certain wavelength) and various combinations of these parameters. In addition to the demands on the adhesive material, there is also a host of parameters which relate to the geometrical and mechanical integrity of the adhesive layer. In particular it is of enormous importance for the success of rear side processing that the adhesive layer has a precisely defined and reproducible thickness, and no voids.

In contrast to thinning of an individual wafer however in the case of a temporarily bonded wafer the carrier wafer and the adhesive layer are located between the wafer support and the grinding means (grinding wheel, etc.). Thus the thickness of the carrier wafer and of the adhesive layer together influence the uniformity of the final thinned product wafer.

Therefore it can be stated in summary that it is necessary to be able to precisely control and monitor the uniformity of the thickness of the adhesive layer and generally also the absolute thickness value in a production process. For certain cases, depending on the control of the grinding process it can also be necessary to know the thickness of the carrier wafer - under certain circumstances also that of the entire temporarily bonded stack. In any case it is however necessary

to ensure a corresponding quality of the adhesive layer with respect to the uniformity of the thickness and optionally the absolute thickness value.

With respect to the voids it holds that during a grinding process and possible subsequent polishing process they would lead to the wafer being inadequately mechanically supported, and in this way damage of the wafer or at least nonuniformities of the wafer thickness which is desired during thinning can occur. This nonuniformity is caused by the mechanical flexibility of the base which is formed by these voids. In other words, the wafer would for example bend/sag into these voids during grinding and thus less substantial removal would take place at these sites; this would subsequently result in a locally elevated thickness of the thinned wafer. This effect would be stronger, the smaller the target thickness of the thinned wafer since it becomes more flexible with decreasing thickness. Ultimately this can even lead to fracture of the wafer during thinning. These fracture events constitute a major risk for grinding and/or polishing processes since the resulting relatively large material pieces can entail further damage to the entire wafer, but also of the grinding wheels and/or the polishing device. Aside from these problems, during grinding and/or polishing these voids can also lead to faults during the remaining rear side process steps. It should be noted here only as an example that gases enclosed in these voids during process steps which occur in vacuum chambers can lead to the thinned silicon wafers bursting during these process steps at these sites. In addition to the loss of the chip located at this site this would also result in further problems since the resulting particles would contaminate the system used in which the bursting took place, and under certain circumstances other production units and possibly would also entail quality problems on other wafers which have been processed on this unit.

Embodiments of this invention optimize the quality criteria such as the absence

of voids, the reproducibility and uniformity of the adhesive thickness and to ensure as little scrap as possible in the production or processing of temporarily bonded wafer stacks.

According to a first aspect, there is provided a measurement means for measuring and/or acquiring layer thicknesses and voids of one or more layers of a wafer stack on a plurality of measuring points distributed on the wafer stack with the following features:

- a transmitter which can be moved relative to the wafer stack for emitting signals in the form of electromagnetic waves or ultrasonic waves,
- a receiver which can be moved with the transmitter relative to the wafer stack for receiving signals which have been sent by the transmitter and reflected on the wafer stack,
- an evaluation unit for evaluating the signals which have been received by the receiver, signals reflected by at least two transitions between layers of the wafer stack being distinguishable by the evaluation unit and their distances to one another and/or to a reference plane able to be determined, and the movement of the wafer stack and/or of the measurement means parallel to the reference plane and thus the position of each measuring point along the reference plane being detectable.

According to a second aspect, there is provided a wafer processing device for processing, especially grinding or bonding, preferably temporary bonding, or separating, of a wafer stack with:

- a measurement means for measuring and/or acquiring layer thicknesses and voids of one or more layers of a wafer stack on a plurality of measuring points distributed on the wafer stack with the following features:
- a transmitter which can be moved relative to the wafer stack for emitting signals in the form of electromagnetic waves or ultrasonic waves,

- a receiver which can be moved with the transmitter relative to the wafer stack for receiving signals which have been sent by the transmitter and reflected on the wafer stack,
- an evaluation unit for evaluating the signals which have been received by the receiver, signals reflected by at least two transitions between layers of the wafer stack being distinguishable by the evaluation unit and their distances to one another and/or to a reference plane able to be determined, and the movement of the wafer stack and/or of the measurement means parallel to the reference plane and thus the position of each measuring point along the reference plane being detectable and
- a mount for accommodating and fixing the wafer stack on one surface of the mount and for moving the fixed wafer stack parallel to the reference plane.

According to a third aspect, there is provided a method for measuring and/or acquiring layer thicknesses and/or voids of one or more layers of a wafer stack on a plurality of measuring points distributed on the wafer stack with the following steps, especially the following sequence:

- arrangement of a measurement means for measuring and/or acquiring the layer thicknesses and voids of the layers of the wafer stack at the measuring points relative to one flat side of the wafer stack,
- emission of signals in the form of electromagnetic waves or ultrasonic waves by a transmitter of the measurement means and reception of the signals which have been reflected by the wafer stack by a receiver of the measurement means,
- evaluation of the signals which have been received by the receiver by an evaluation unit, signals reflected by at least two transitions between layers of the wafer stack being distinguishable by the evaluation unit and their segment [sic] to a reference plane being determined, and the movement of the wafer stack and/or of the measurement means parallel

to the reference plane and thus the position of each measuring point along the reference plane being detectable.

All combinations of at least two of the features given in the specification, the claims and/or the figures also fall within the framework of the invention. At the given value ranges, values within the indicated limits will also be disclosed as boundary values and will be claimed in any combination.

Embodiments of this invention recognize, in the processing of wafers, deviations relative to the aforementioned quality criteria at a time as early as possible in order to minimize any loss of product wafers for this reason. This can be ensured especially in that the layer thickness and/or voids of individual layers of the wafer stack are measured/detected, and especially close in time before the wafer stack is ground. It is especially important to monitor the geometrical parameters of the carrier wafer since it is used for mechanical support of the product wafers and during the grinding process comes to rest between the wafer support which can be used as reference plane or reference surface, and the grinding wheel. Close in time in the aforementioned sense means that in the processing chain of wafer stacks there are as few wafer stacks as possible in the processing chain before the indicated wafer stack, therefore between the measurement step/detection step and including the grinding step, especially a maximum of five, preferably a maximum of three, even more preferably a maximum of one. It can be provided as per embodiments of the invention that the measurement step/detection step is carried out in a measurement/detection module (also metrology module) and the grinding step is carried out separately in space in an especially adjacent grinding module. The measurement step/detection step and the grinding step

take place in-line as per embodiments of the invention. It can also be that the examination of the wafer stack has been completed before the previous wafer has been completely ground, therefore is still in the grinding module. The measured wafer stack must then "wait" until it can advance.

On one especially advantageous embodiment the measurement step/detection step takes place close in time to the temporary bonding step. This results in that in the case of faults which occur in the temporary bonding step, the amount of misprocessed material is reduced. This offers the advantage that the amount of material, especially the number of bonded wafer stacks, which must be supplied to reworking can be reduced; this entails economical and logistical advantages. In this connection, close in time means that the measurement takes place in any case before grinding of the wafer. As already stated, the grinding process constitutes an irreversible process which can lead to catastrophic faults and especially to a total loss of individual bonded wafer stacks. But close in time advantageously means that a maximum of 10 further wafer stacks have been bonded before the inspection of a given wafer stack has taken place. It is still better if this number can be reduced to less than 7 or still better 5 or 3. These numbers relate to a process sequence in which all bonded wafer stacks after the temporary bonding process, especially directly after the temporary bonding step, are supplied to the measurement step/detection step as per embodiments of the invention. This just described reduction of these wafer stacks which are waiting for the inspection step in the process sequence can be advantageously achieved by means of a configuration of the production environment in which the device which executes the temporary bonding step is located as near as possible in space to the measurement device as per embodiments of the invention. In particular, this can be achieved by integrating the measurement device into a temporary bonding device. This integrated approach is conventionally called in-line integration or in-line metrology in industry. This can be

implemented according to embodiments of this invention in combination with any temporary bonding approaches which are known from the prior art. For example, it is also conceivable to integrate the measurement device into a temporary bonding unit for thermoplastic or UV-curable adhesives, these units conventionally containing one or more coating modules for the application of the adhesive and one or more bond modules between which the wafers to be processed are moved by means of an automatic wafer handling device which is especially part of the unit. Depending on the type of adhesive used, heating modules can also be additionally integrated in the system and are used to drive the solvent out of the adhesive layer. It is also advantageously conventional to integrate suitable alignment devices known to one skilled in the art for aligning the wafers into these systems.

In addition one embodiment of the invention consists in detecting voids in the adhesive layer and the adhesive layer thickness and possible fluctuations of this adhesive layer thickness.

Another embodiment of the invention is that the acquired values can be automatically evaluated as data in order to automatically make a decision about further processing or removal of the wafer from the process chain.

Another embodiment of the invention consists in integrating the subject matter of the invention into an automatic processing device for the temporary bonding of product wafers. In this way an analysis as complete as possible of each product wafer will be enabled without reducing the productivity rate of the processing device. Detection/measurement thus takes place "in-line", therefore as "in-line metrology". Accordingly it is provided according to one embodiment of the measurement means as per embodiments of the invention that it can be used in a wafer processing system, especially in-line.

Here according to the subject matter per embodiments of the invention there is a module-like structure of the process modules which are located in-line for the process sequence or the process chain. Use in conjunction with the following modules in a wafer processing system is especially advantageous:

- a painting module for at least partial painting of the wafer stack, especially with an adhesive, advantageously with a temporary adhesive,
- a bond module for connecting the wafer layers of the wafer stack,
- a measurement means as per embodiments of the invention in an inspection module,
- a handling means, especially with one or more robot arms, for transport of each wafer stack within the wafer processing system from one module to the next and
- optionally a heating means for driving out the solvent.

If deviations are detected in this connection especially before rethinning of the product wafer, it is possible to subject the product wafer or the wafer stack to a rework. This is constituted especially such that the product wafer would be again detached from the carrier and the entire temporary bonding process could be carried out again. For this detachment step systems which are intended specifically for this purpose or in-line modules can be used. In particular debonding systems are especially suitable for this purpose and they are conventionally used for detaching the thin product wafer from the carrier. Optionally process parameters designed for this purpose for this debonding system can be adapted to the requirements of debonding of a product wafer which has not been thinned or which has not been completely thinned. This rework process is of great importance for purposes of cost-effective production. In particular product wafers or wafer stacks which have a very high degree of complexity, which can be expected for these 3D IC wafer stacks, have a very considerable value in this stage since they have already progressed far in the production

flow. The value of these wafer stacks generally exceeds 1000 euros, in part even 10,000 euros. Therefore it is decisive as per embodiments of the invention to detect in time or as early as possible so-called catastrophic faults which would lead to a total loss of the wafer stack and to supply them to a rework process before the wafer stacks pass through a process step after which this rework process would no longer be possible. In this connection the grinding of the wafer stack for reducing the thickness can be regarded in any case as a step after which this rework process would no longer be possible and otherwise would threaten a total loss of the product wafer.

To the extent the measurement means is made to work without mechanical action on the wafer stack, especially with a distance H from the wafer stack, the measurement/detection can take place especially carefully by the measurement means, especially without contact. When using ultrasonic waves, the contact necessary for propagation of the ultrasonic waves takes place between the wafer stack and the measurement means via a fluid agent which is provided on the wafer stack and which is suitable for transmission of ultrasonic waves. In this case, according to one preferred version it can be provided that between the fluid agent and the wafer stack there is a separator, especially a membrane, for shielding of the wafer stack from the liquid. The separator must be suitable for transmission of ultrasonic waves. The space underneath the membrane can preferably be evacuated so that the membrane rests as uniformly and flat as possible on the wafer stack. The use of a negative pressure is indispensable since only the ambient pressure provides for the membrane to completely cling to the wafer stack 8. If this were not so, air-filled cavities could adulterate the measurement result since air would at least largely reflect acoustic waves.

According to one advantageous embodiment of the invention it is provided that the measurement means, especially the transmitter and receiver, can be used at the same time for

detecting layer thicknesses and voids, especially with a layer resolution of $< 10\text{ }\mu\text{m}$, preferably $< 1\text{ }\mu\text{m}$, even more preferably $< 0.1\text{ }\mu\text{m}$. As per embodiments of the invention it is moreover conceivable to use several transmitter/receiver units at the same time, especially located next to one another, in order to be able to scan the surface correspondingly more quickly. The layer resolution is meant in the transverse direction to the reference plane R, therefore depth resolution or vertical resolution or thickness resolution.

The diameter D of the measurement signal is advantageously between $1\text{ }\mu\text{m}$ and $100\text{ }\mu\text{m}$, especially between $5\text{ }\mu\text{m}$ and $50\text{ }\mu\text{m}$, preferably between $10\text{ }\mu\text{m}$ and $30\text{ }\mu\text{m}$. For a laser beam the aforementioned diameter D corresponds for example to the diameter of the laser beam.

In another advantageous embodiment of the invention it is provided that adjacent measuring points can be measured by the measurement means within a grid with a distance X and Y of less than 5 mm , preferably less than 3 mm , even more preferably less than 1 mm , most preferably less than 0.5 mm . Therefore blanket, grid-like sensing of the entire wafer stack takes place so that essentially all voids can be detected as seamlessly as possible.

Width resolution of the measurement signal in the lateral direction, therefore parallel to the reference plane R is advantageously between $0.1\text{ }\mu\text{m}$ and $50\text{ }\mu\text{m}$, especially between $1\text{ }\mu\text{m}$ and $30\text{ }\mu\text{m}$, preferably between $10\text{ }\mu\text{m}$ and $20\text{ }\mu\text{m}$. A laser beam is intended to measure for example at a certain measuring point. It will however not hit the measuring point exactly, but will deviate by $\Delta X/\Delta Y$. Here ΔX and ΔY correspond to the width resolution. With width resolution especially the extension, therefore width or diameter of a void, is acquired. The better the width resolution, the more measurements must be taken. Therefore as much as possible an optimum must be set between rapid measurement and detection of as many voids as possible. The thinner the

target thickness of the wafer or wafer stack, the more critical small voids already are.

According to one preferred embodiment of the invention it is provided that the measurement/detection is two-stage, especially by a first high-speed and coarse measurement means and an optional second, very precise measurement means. Only wafer stacks which have been rated as possibly critical in the first measurement means pass through the second measurement means. The second measurement means is not provided in-line so that as much as possible the process flow is not disrupted. A wafer stack which is possibly rated as critical in the first measurement means by the evaluation unit is therefore at least temporarily separated from the process sequence.

The relationship between the point grid distance, the diameter D of the measurement signal and the width resolution is shown in Figure 9.

This method can be used in situ and/or in-line. In-situ means the use of the method during a technological / physical / chemical processing step. Here for example the rethinning of a structure wafer or the edge zone etching in a chemical bath should be named.

In-line is defined as the use of the method in a process module which is upstream or downstream of another process module. The first module can be a bonding station in one embodiment as per embodiments of the invention. The following module would then in this case in a typical embodiment be the measurement means which has been described here in order to measure a wafer stack. While a wafer stack is bonded in the bonding station, in the measurement station one of the wafer stacks bonded beforehand, advantageously a wafer stack which was bonded beforehand as close in time as possible, according to the aforementioned explanations for the term close in time, especially a wafer stack bonded immediately beforehand, is measured/sensed. In-line therefore

differs from in-situ in that a separation of the method as per embodiments of the invention takes place into its own module which however has been system-integrated into a processing chain with other processing steps.

Advantageously it is furthermore provided that the measurement means as per embodiments of the invention is provided with a preferably fixed interferometer which is mechanically coupled especially to the transmitter and the receiver, especially white light interferometer, for measuring its distance to one surface on at least one of the measuring points.

The aforementioned features which have been described for the measurement means apply accordingly to the device as per embodiments of the invention and the method as per embodiments of the invention.

Other advantages, features and details of the invention will become apparent from the following description of preferred exemplary embodiments and using the drawings.

Figure 1 shows a measurement means as claimed in the invention in a first embodiment,

Figure 2 shows a measurement means as claimed in the invention in a second embodiment,

Figure 3 shows a measurement means as claimed in the invention in a third embodiment,

Figure 4 shows a measurement means as claimed in the invention in a fourth embodiment,

Figure 5 shows an illustration of possible quality defects of a wafer stack,

Figures 6a - 6c show different method sequences as claimed in the invention for measuring/sensing several measuring points,

Figure 7a shows a photograph of a wafer stack which has been sensed by infrared signals with the measurement means as claimed in the invention,

Figure 7b shows a diagram of measurement/sensing of a wafer surface as claimed in the invention,

Figure 8 shows a schematic of a device as claimed in the invention for processing of a wafer stack,

Figure 9 shows a schematic of the detection of a void of a wafer stack,

Figure 10 shows a photograph of a wafer stack which has been sensed by ultrasonic signals with the measurement means as claimed in the invention,

Figure 11 shows a schematic of a device as claimed in the invention for processing of a wafer stack and

Figure 12 shows a measurement means as claimed in the invention in a fifth embodiment.

The same components and parts with the same action are identified with the same reference numbers in the figures.

Figure 8 shows a wafer processing device as claimed in the invention for processing of a wafer stack 8 which consists of one structure wafer 1, one connecting layer 2 and one wafer 3. The structure wafer 1 at a transition 15 between the structure wafer 1 and the connecting layer 2 has contacts 14 which have been introduced into the surface of the structure wafer 1 and bumps 13 which project from the surface and which can consist of metal alloys. The structure wafer 1 can also be made without structures, in the same way as the wafer 3 can be made with structures.

The wafer stack 8 is fixed its flat side opposite the surface of the structure wafer 1 on a surface 16 of a mount 12, here a chuck [sic]. Fixing takes place via vacuum paths 17 of the mount 12.

The connecting layer 2 is made as temporary adhesive and by means of the latter the structure wafer 1 is temporarily bonded onto the wafer 3. A further transition 18 is accordingly between the connecting layer 2 and the wafer 3.

The device furthermore has a measurement means 11 which can move relative to the wafer stack 8 along a reference plane R. The performance of relative motion is decisive so that a movement of the wafer stack 8, especially by moving the mount 12, is likewise conceivable. Here it is decisive that the relative motion between the measurement means 11 and the wafer stack 8 can be sensed, for example in a X-Y coordinate system which spans the reference plane R.

The operation of the measurement means 11 is shown in different versions in Figures 1 to 4. Figure 5 shows the possible problems which can arise in the joining of wafers. For example the connecting layer 2 can have a nonuniform layer thickness. In the ideal case the wafers 1, 3 would be equally thick everywhere. Figure 5 shows that the wafers 1, 3 can also have a nonuniform thickness distribution. Furthermore the wafers can have so-called “voids” 4.

According to Figure 1 the measurement means 11 consists of a housing 5 in which on its bottom there are a transmitter 9 and a receiver 10. They are aligned in the direction of the wafer stack 8, especially parallel to the reference plane R. The measurement is based on waves being injected into the bonded wafer stack 8 by means of the transmitter 9 and on the reflections on the individual transitions 15, 18 between the different materials being acquired with the receiver 10. The receiver 10 is made as a signal detector for detection of the signals in the form of electromagnetic waves or ultrasonic waves.

In particular electromagnetic waves with a suitable wavelength at which there is sufficient transparency of the wafers 1, 3 used and of the adhesive material of the connecting layer 2 are suitable as signal waves. For silicon wafers this can be for example light in the infrared range or x-radiation. For glass wafers light in the visible range and when using suitable glasses also in the UV range would be suitable.

The signal source for the electromagnetic radiation can be located especially in the housing 5, especially integrated in the transmitter 9. Alternatively to electromagnetic waves acoustic waves are suitable, especially waves in the ultrasonic range from 100 kHz to 800 MHz, preferably 100 MHz to 400 MHz.

The use of a light source with electromagnetic radiation in the infrared range, especially 1050 nm to 10 μ m, preferably 1300 nm light wavelength, is preferred. The optics of the measurement means is designed such that the beam of electromagnetic waves can be focussed and routed onto the wafer stack 8.

To the extent the transmitter 9 and the receiver 10 or the housing 5, as in the exemplary embodiments according to Figures 2, 3 and 4, are in direct contact with the wafer stack 8 or a liquid 7 which has been applied to the wafer stack 8, measurement/sensing takes place by contact coupling. This type of contact coupling takes place as claimed in the invention mainly when ultrasonic waves are used.

When using electromagnetic waves there is a distance H between the transmitter-receiver unit and the wafer stack 8.

In the case of the ultrasonic measurement shown in Figure 3 by means of the liquid 7, it is applied to the wafer stack 8 before the measurement and the housing 5 with the ultrasonic transmitter is immersed into the liquid 7 in order to transmit the ultrasonic waves to the wafer stack 8 and to enable a measurement by the transmitter 9 and the receiver 10. The transmitter 9 can be made here as an ultrasonic transmitter. The liquid 7 is generally applied through the housing 5. The housing 5 has a feed line 25 via which the especially continuous inflow of liquid 7 from a liquid reservoir takes place.

In the embodiment according to Figure 4 it is moreover provided that between the liquid 7 and the wafer stack 8 there is a membrane 6 to protect the wafer stack 8 from the liquid 7. The membrane 6 is so elastic that it can be matched to the topography of the surface of the wafer stack 8. The liquid 7 is applied to the surface of the membrane 6. The measurement signal is then injected through the liquid and through the membrane 6 into the wafer stack 8. The space underneath the membrane 6 can preferably be evacuated and is evacuated before the measurement takes place. Evacuation has the advantage that the air pressure on the side of the housing 5 presses the membrane 6 onto the surface of the wafer 3. This ensures that the membrane covers the surface of the wafer 3 without forming cavities and thus signal injection takes place only via solids and/or liquids, especially without a gaseous phase.

In one especially advantageous version of the embodiment according to Figure 4 the membrane 6 is used as a liquid reservoir by a trough-shaped liquid reservoir 27 being formed by a peripheral membrane wall 26. In this special embodiment it is therefore conceivable as claimed in the invention for there to be a closed circuit between the liquid reservoir 27 and the feed line 25. In this way a very clean execution of the measurement/sensing is possible.

In one especially preferred embodiment it is also conceivable for the device to contain only the trough-shaped liquid reservoir 27 with respect to liquid handling and for a circuit for the liquid to be completely omitted, especially at least during the measurement process. The feed and drainage of the liquid to/from the liquid reservoir 27, which drainage is intended optionally, in particular for facilitating maintenance efforts, take place in this case by suitable means which are not shown in the figures for liquid supply and liquid discharge.

The signals reflected on the transitions 15, 18 and on the mount surface 16 in the form of

electromagnetic waves or ultrasonic waves are evaluated by means of one suitable receiver 10 at a time and with consideration of the propagation velocity of the waves in the various materials of the structure wafer 1, the connecting layer 2 and the wafer 3 allow a precise conclusion about the material thicknesses d_1 of the wafer 3 or d_2 of the connecting layer 2 and d_3 of the structure wafer 1. Thus precise detection of the thicknesses and the thickness uniformity of the layers of the wafer stack 8, therefore of the structure wafer 1, the connecting wafer 2 and of the wafer 3 is possible. By moving the measurement means over the entire wafer stack 8 parallel or along the reference plane R the layer thicknesses can be determined at the corresponding measuring points with local resolution.

As described above, for measuring/sensing of the wafer stack 8 motion relative to the transmitter 9 and the receiver 10 takes place. This can be achieved either by moving the wafer stack 8 or the transmitter-receiver unit or a combination of the two movement possibilities. Preferably an arrangement is chosen in which as few axes as possible are required, especially by a travelling means for moving the wafer stack along one X and one Y-axis, therefore parallel to the reference plane R. The measurement means is preferably rigidly mounted.

In Figures 6a to 6c the most important scanning methods for sensing the entire wafer stack 8 are shown, in Figure 6a sensing taking place in a meander form. Meandering scans have the advantage that the sensing distance can be very quickly traversed, adverse effects on the recording [sic]. Another type of scanning is a line scan according to Figure 6b. This type of scan can be accomplished by a linear drive, possible play of translation units of the linear drive, especially reverse play, being minimized. This version is particularly advantageous especially in the above described two-stage measurement method, particularly in the second measurement means. Another alternative consists in constant advance of the housing 5 with the wafer stack 8 rotating toward the

center of the wafer stack 8. This yields helical sensing. It is common to the aforementioned scan methods that the scanning takes place continuously. The continuous measurement signals of the individual measuring points are converted and evaluated accordingly by an evaluation unit. The time for scanning of one wafer stack, especially for in-line, integrated measurement means as claimed in the invention is less than 180 seconds, preferably less than 100 seconds, more preferably less than 60 seconds. For measurement means which are not integrated in-line and which are provided especially in addition to a measurement means which is integrated in-line, especially measurement means which are used for detailed inspection of especially separated wafer stacks, the inspection times can also be much longer. It is quite conceivable for these measurement processes to last longer than 10 minutes, in many cases even longer than 20 minutes or 30 minutes.

If there are voids 4 in the adhesive layer 2 (Figure 7a), within this void 4 relaying the injected wave is either not possible at all or is only possible with a differing propagation velocity. In the case of acoustic waves their propagation in voids 4 is as well as completely prevented so that conclusions can be very clearly drawn about the fault 4 using the reflected waves (Figure 10).

In the case of the electromagnetic waves and especially infrared light, the measurement device detects the various transitions or intersection planes 15, 16, 18 by interference and can thus draw conclusions about the layer thicknesses d_1 , d_2 , d_3 . The determination of layer thicknesses d_1 , d_2 , d_3 takes place indirectly via the detection of peaks at the transitions 15, 16, 18 by interference. Based on the difference of these peaks the thickness of the respective layer which is limited by the transitions 15, 16, 18 can be computed. The evaluation unit automatically performs this computation. Here it must be watched that the measured layer thickness is linearly dependent on the index of refraction of the layer. This is because the electromagnetic waves propagate at different

speeds in different materials, and the signal transit time through the layers linearly influences the location / the interval of the peaks which have been detected by the receiver. In one preferred embodiment, without corresponding correction the layer thickness measured for one layer seems higher for layers with higher index (n) of refraction by the factor of the index (n) of refraction.

For example, the measured layer thickness for an adhesive layer with a thickness d_2 in the region of the adhesive would be $d_2 \cdot n$, while the measured layer thickness in the region of possible voids which are located in the adhesive layer would be $d_2 \cdot 1$. This is based on the fact that air and vacuum have an index of refraction of roughly 1. The index of refraction (n) for different materials can be determined with methods which are known to one skilled in the art. Conventionally these values are also dependent on the wavelength of the electromagnetic signal used. For IR light with a wavelength of 1300 nm the index of refraction for current thermoplastic adhesives can be for example in the range between 1.2 and 2.5, but mostly between 1.3 and 2, but even more typically between 1.4 and 1.9.

In the measurement result for the adhesive layer thickness the above described effects lead to an abrupt drop of the measured layer thickness (Figure 7b, Figure 7c) in the region of a void; this allows a conclusion about the void 4 by means of suitable evaluation algorithms. The X-axis of the figures/diagrams from Figures 7a to 7c constitutes the respective distance to the left edge of the wafer stack.

One example of the execution of an evaluation algorithm is shown by Figure 7c. The evaluation unit is designed such that a freely definable window monitors a monitoring region 21 within the measurement region. If signals enter the monitoring region 21, a corresponding action is set. This is explained using one example. Figure 7c constitutes the layer thickness d_2 (thickness) of

the connecting layer 2 as a function of the distance along the wafer stack 8. Apparently the layer thickness of the connecting layer 2 in this example varies between 37 and 42 μm . This thickness value in this case represents the value measured for the adhesive thickness without correction by the index of refraction. This means that the real adhesive thickness could be computed in this case by division of the illustrated thickness value by the index of refraction. In special embodiments it can be distinguished between bumps, dices, voids, bubbles, etc. They should be characterized by different depth / thickness / signal deviations. Here all corresponding algorithms are intended which can detect a signal deviation from the thickness. Advantageously these evaluation algorithms are also combined with suitable algorithms which for example also consider the superficial extension of these voids. The superficial extension of the voids can be determined by an evaluation of all collected thickness values in the X / Y coordinate system according to the just described evaluation techniques. Possible intermediate values which have not been measured can advantageously be determined by interpolation.

For infrared measurement or ultrasonic measurement the measurement / acquisition takes place independently of the distance H of the transmitter 9 / receiver 10 from the wafer stack 8 since the measured values for the thicknesses of the individual layers take place by difference calculation based on the reflections on the individual transitions.

In order to be able to determine the thickness distribution of the individual layers to be measured over the entire wafer, it is necessary to accommodate a plurality of measuring points distributed over the wafer. Advantageously the measuring points are arranged in a suitable coordinate system (see Figure 10); this later facilitates the analysis and data processing. Advantageously the coordinate system for measuring point acquisition corresponds to a local

coordinate system which has been assigned to the wafer which is to be inspected. Suitable coordinate systems would for example be a Cartesian coordinate system or a polar coordinate system. Advantageously the measuring points are placed close enough to one another to detect defects (voids) which can be typically expected with appropriate reliability. In particular it is desirable to detect defects of a size which would result in the above described catastrophic fault cases in the subsequent processing. The layer resolution should preferably be better than $10\text{ }\mu\text{m}$, even more preferably better than $1\text{ }\mu\text{m}$, most preferably better than $0.1\text{ }\mu\text{m}$.

The diameter D of the measurement signal according to Figure 10 is advantageously between $1\text{ }\mu\text{m}$ and $100\text{ }\mu\text{m}$, especially between $5\text{ }\mu\text{m}$ and $50\text{ }\mu\text{m}$, preferably between $10\text{ }\mu\text{m}$ and $30\text{ }\mu\text{m}$. For a laser beam the aforementioned diameter D corresponds for example to the diameter of the laser beam.

The width resolution of the measurement signal in the lateral direction, therefore parallel to the reference plane R , is between $0.1\text{ }\mu\text{m}$ and $50\text{ }\mu\text{m}$, especially between $1\text{ }\mu\text{m}$ and $30\text{ }\mu\text{m}$, preferably between $10\text{ }\mu\text{m}$ and $20\text{ }\mu\text{m}$.

Analogously to the procedure with respect to voids the wavelengths of the thickness fluctuation which typically occur are advantageously taken into account when the measuring point grid is fixed. Based on the above described considerations it has proven advantageous to set one measuring point roughly every 1 to 3 mm . In order to be able to more reliably recognize voids, it is even more ideal to set one measuring point every 0.8 mm or every 0.5 mm or even better every 0.25 mm . For especially sensitive applications with very small target wafer thicknesses it can also be advantageous to set one measuring point every 0.1 mm .

It is very often such that certain electromagnetic rays such as for example infrared are not

able to penetrate the structure wafer 1 since it is either metal-coated, doped or bumped. Metal coatings can be present for example through contacts 14 on the wafer surface or within the wafer. The bumps 13 consist of metal coatings which are likewise opaque to IR. Furthermore the wafer can be doped. Doping almost always occurs mainly in structure wafers and reduces the infrared transparency.

By means of an interferometer 19 which is integrated in addition to the measurement means 11 or into the measurement means 11 the surface 16 of the mount 12 can be measured before the wafer stack 8 is deposited on the mount. In Figure 8 a surface unevenness of the mount surface 16 is represented by warpage. The irregularity of the surface can however have any other shape. This is measured with the white light interferometer 19. After measuring the distance profile by the white light interferometer 19 the wafer stack 8 is placed on the mount 12. Then the measurement is repeated by the white light interferometer 19 so that a second distance profile, specifically that of the entire wafer stack 8, is obtained. The difference of the two distance profiles corresponds to the total height of the wafer stack 8.

Thus, in combination with the above described measurement/ detection of the transitions 15, 18 by corresponding computation, the layer thickness d_3' can also be determined according to Figure 8 by the layer thicknesses d_1' of the wafer 3 and d_2' of the connecting layer 2 being subtracted from the total thickness of the wafer stack 8.

Another advantage arises by using the white light interferometer as a scanner during the scan process by means of infrared or ultrasound. The white light interferometer scanner is moved only along one line beyond the edge of the wafer stack. Here it continuously measures the distance to the surface of the wafer stack 8 when it is located over it, or the distance to the mount surface 16

when it goes beyond the wafer stack 8. If at this point the height of the entire system changes during the actual infrared or ultrasonic scan, for example due to thermal fluctuations, the white light interferometer scanner detects this based on the fluctuation of the height since absolute distance can be determined. In contrast to the infrared scanner which measures by means of interference only the peaks which arise by interference on the interfaces 15, 16 and 18 [sic]. The infrared scanner is therefore able to measure relative distances, therefore thicknesses. It always requires at least two signals from whose difference the thickness of the respective layer can be computed. The infrared scanner is therefore insensitive to "vibrations" and thermal fluctuations. The white light interferometer scanner conversely measures the distance to the transmitter-receiver unit. If its scan frequency over an entire scan line is much faster than the change in the height of the entire system, the change in the height of the entire system can be acquired as a function of time.

Figure 7a shows a wafer stack 8 which is measured with a measurement means as claimed in the invention, with a diameter of 300 mm in which several voids 4 with a depth represented in color have been found. A two-dimensional evaluation of the wafer stack 8 according to Figure 7a is done in Figure 7b in the form of a diagram by the evaluation unit, the line corresponding the diagram [sic] being drawn in Figure 7a. It can be recognized in Figure 7b how the void 4 in the middle of the wafer stack appears in cross section.

In another embodiment the edge zone B of the wafer stack 8 is measured in-situ by means of the above described measurement means during a chemical treatment process. Preferably the measurement method from Figure 6c is used. While chemicals 22 dissolve an edge zone adhesive 28 of the connecting layer 2, the progress in the detachment process can be continuously measured by the measurement means 11. Advantageously the method is applied to wafer stacks 8 which bond

the structure wafer and the carrier wafer only on the edge. These techniques are known to one skilled in the art in this field.

According to another embodiment which is shown in Figure 12, voids 4 in a layer, especially a mold 24, which covers electronic components 23, especially dices, can be detected by means of one of the above described measurement means.

Doping elements which are preferred as claimed in the invention are elements of the third main group such as boron, indium, aluminum or gallium or elements of the fifth main group such as phosphorus, arsenic or antimony.

Reference number list

- 1 structure wafer
- 2 connecting layer
- 3 wafer
- 4 voids
- 5 housing
- 6 membrane
- 7 liquid
- 8 wafer stack
- 9 transmitter
- 10 receiver
- 11 measurement means
- 12 mount
- 13 bumps
- 14 contacts
- 15 transition
- 16 mount surface
- 17 vacuum paths
- 18 transition
- 19 interferometer
- 20 measurement signal
- 21 monitoring region

22	chemicals
23	electronic components
24	layer
25	feed line
26	membrane wall
27	liquid reservoir
28	edge zone adhesive
R	reference plane
d1, d1'	layer thickness
d2, d2'	layer thickness
d3, d3'	layer thickness
H	distance
B	edge zone

Claims

1. Measurement means for measuring and/or acquiring layer thicknesses and voids of one or more layers of a wafer stack (8) on a plurality of measuring points distributed on the wafer stack (8) with the following features:

- a transmitter (9) which can be moved relative to the wafer stack (8) for emitting signals in the form of electromagnetic waves or ultrasonic waves,
- a receiver (10) which can be moved with the transmitter (9) relative to the wafer stack (8) for receiving signals which have been sent by the transmitter (9) and reflected on the wafer stack (8),
- an evaluation unit for evaluating the signals which have been received by the receiver, signals reflected by at least two transitions (15, 18) between layers of the wafer stack (8) being distinguishable by the evaluation unit and their distances to one another and/or to a reference plane (R) able to be determined, and the movement of the wafer stack (8) and/or of the measurement means (11) parallel to the reference plane (R) and thus the position of each measuring point along the reference plane (R) being detectable.

2. Measurement means as claimed in Claim 1, wherein the measurement means (11) can be used in a wafer processing device, especially in-line.

3. Measurement means as claimed in one of the preceding claims, wherein the measurement means (11) is made to work without mechanical action on the wafer stack (8), especially with a distance (H) from the wafer stack (8).

4. Measurement means as claimed in one of the preceding claims, wherein the measurement

means (11), especially the transmitter (9) and receiver (10), can be used at the same time for detecting layer thicknesses and voids, especially with a layer resolution of $< 10\text{ }\mu\text{m}$, preferably $< 1\text{ }\mu\text{m}$, even more preferably $< 0.1\text{ }\mu\text{m}$.

5. Measurement means as claimed in one of the preceding claims, wherein adjacent measuring points with a distance less than 5 mm, preferably less than 3 mm, even more preferably less than 1 mm can be measured by the measurement means (11).

6. Measurement means as claimed in one of the preceding claims, wherein the measurement means is suitable for in-situ measurement, especially during a grinding process or a separating process.

7. Measurement means as claimed in one of the preceding claims, wherein with a interferometer, especially one which is mechanically coupled preferably fixed to the transmitter (9) and the receiver (10), especially a white light interferometer, for measuring its distance to one surface, especially a mount surface (16) of a mount (12), on at least one of the measuring points.

8. Measurement means as claimed in one of the preceding claims, wherein the transmitter (9) and the receiver (10) are located in a housing (5).

9. Wafer processing device for processing, especially grinding or bonding, preferably temporary bonding, or separating, of a wafer stack 8 with:

- a measurement means for measuring and/or acquiring layer thicknesses and voids of one or more layers of a wafer stack (8) on a plurality of measuring points distributed on the wafer stack (8) with the following features:
- a transmitter (9) which can be moved relative to the wafer stack (8) for emitting signals in the form of electromagnetic waves or ultrasonic waves,

- a receiver (10) which can be moved with the transmitter (9) relative to the wafer stack (8) for receiving signals which have been sent by the transmitter (9) and reflected on the wafer stack (8),
- an evaluation unit for evaluating the signals which have been received by the receiver, signals reflected by at least two transitions (15, 18) between layers of the wafer stack (8) being distinguishable by the evaluation unit and their distances to one another and/or to a reference plane (R) able to be determined, and the movement of the wafer stack (8) and/or of the measurement means (11) parallel to the reference plane (R) and thus the position of each measuring point along the reference plane (R) being detectable and
- a mount for accommodating and fixing the wafer stack (8) on one surface (16) of the mount (12) and for moving the fixed wafer stack (8) parallel to the reference plane (R).

10. Wafer processing device as claimed in Claim 9 as in-line system with a painting module for at least partial painting of the wafer stack 8, an inspection module and a bond module.

11. Method for measuring and/or acquiring layer thicknesses and/or voids of one or more layers of a wafer stack on a plurality of measuring points distributed on the wafer stack with the following steps, especially the following sequence:

- arrangement of a measurement means for measuring and/or acquiring the layer thicknesses and voids of the layers of the wafer stack at the measuring points relative to one flat side of the wafer stack,
- emission of signals in the form of electromagnetic waves or ultrasonic waves by a transmitter of the measurement means and reception of the signals which have been reflected by the wafer stack by a receiver of the measurement means,

- evaluation of the signals which have been received by the receiver by an evaluation unit, signals reflected by at least two transitions between layers of the wafer stack being distinguishable by the evaluation unit and their segment [sic] to a reference plane (R) being determined, and the movement of the wafer stack and/or of the measurement means parallel to the reference plane (R) and thus the position of each measuring point along the reference plane being detectable.

**Measurement Means and Method for Measuring
Layer Thicknesses and Voids of a Wafer Stack**

Abstract

The invention relates to a measurement means and a method for measuring and/or acquiring layer thicknesses and/or voids of one or more layers of a wafer stack on a plurality of measuring points distributed on the wafer stack and a corresponding wafer processing device.

Figure 8