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 ~~according to Claim 1~~. Furthermore this invention relates to a wafer processing device for processing a wafer stack ~~according to Claim 8~~ 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 ~~according to Claim 10~~.

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

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~~The object~~ of this invention ~~is therefore to~~ 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.

~~This object is achieved with the features of Claims 1, 8 and 10. Advantageous developments of the invention are given in the dependent claims.~~ 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~~The basic idea~~ of this invention ~~is on the one hand to~~ 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 claimed in~~ 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 ~~claimed in~~ 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 ~~claimed in~~ 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~~claimed in~~ 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~~basic idea~~ 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~~aspect~~ 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~~central aspect~~ 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 ~~claimed in~~ 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 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 a adhesive, advantageously with a temporary adhesive,
- a bond module for connecting the wafer layers of the wafer stack,
- a measurement means as ~~claimed in~~ 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 ~~claimed in~~ 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 μm, preferably < 1 μm, even more preferably < 0.1μm. As ~~claimed in~~ 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 μm and 100 μm, especially between 5 μm and 50 μm, preferably between 10 μm and 30 μm. 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 μm and 50 μm, especially between 1 μm and 30 μm, preferably between 10 μm and 20 μm. 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 deltaX/deltaY. Here deltaX and deltaY 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 ~~claimed in~~ 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 ~~claimed in~~ 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~~claimed in~~ 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 ~~claimed in~~ per embodiments of the invention and the method as ~~claimed in~~ 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,