

METHOD FOR DETECTING THE SPLITTING OF A SUBSTRATE WEAKENED BY IMPLANTING ATOMIC SPECIES

5 **FIELD OF THE INVENTION**

The present invention relates to the detection of the splitting of a substrate weakened beforehand by implanting atomic species, and its application to the monitoring of a heat treatment applied to said substrate in order to cause said splitting.

10 **PRIOR ART**

The SmartCut™ process allows a layer to be transferred from a first substrate, called the donor substrate to a second substrate, called the receiver substrate.

To this end, the process comprises a step of implanting atomic species in the donor substrate, so as to form therein a weakened zone located at a depth corresponding to the
15 thickness of the layer to be transferred. Said atomic species are typically hydrogen and/or helium. In the weakened zone, the implanted species create defects that are referred to as “microcracks”, which take the form of cavities lying in a plane parallel to the main surface of the donor substrate.

The donor substrate is then bonded to the receiver substrate.

20 A thermal splitting step is then implemented, in which step the wafer resulting from the bonding of the donor substrate and receiver substrate is raised to a temperature that is sufficiently high to allow the microcracks to develop. To this end, the wafer is placed in an annealing furnace, the temperature of which is controlled. The anneal causes an increase in the pressure in the cavities, until the donor substrate splits along the weakened zone.
25 Once splitting has been initiated in one region of the weakened zone, the split propagates almost instantaneously along said zone. By almost instantaneously, what is meant is that the time taken for the splitting to occur is about 100 μs for a substrate of 300 mm diameter.

After splitting, the two portions of the wafer remain in contact with each other on either side of the splitting plane.

30 The wafer is unloaded from the annealing furnace with a view to separating the two portions of the wafer. The separation is for example achieved by inserting a blade between the two portions.

Generally, this process is implemented in batches, each batch comprising a plurality of wafers that are placed together in the annealing furnace.

35 Detection of splitting is an important parameter in the layer-transfer process.

Specifically, it is generally sought to minimize the thermal budget of the anneal by stopping the anneal once all of the wafers of the batch have been split, in order to avoid

damaging the wafers with an excessively high thermal budget, and to optimize the efficiency of the annealing furnace.

Moreover, it is possible, even if the intended thermal budget is applied, for one or more wafers of a given batch not to split. Such a situation may disrupt the realization of the separating step, which is generally automated, causing blockage of the separating machine. It is therefore desirable to be able to detect if a wafer has not been split, in order to be able to isolate the fabrication batch in question with a view to processing it manually and preventing the rest of the process from being disrupted.

To this end, document FR 2 902 926 proposes equipping the holder that holds the wafer in the annealing furnace with a piezoelectric sensor. During splitting, the vibration caused within the wafer is transmitted to the piezoelectric sensor and converted into an electrical signal that is recorded by a controller of the annealing furnace. Processing of this signal allows peaks that are characteristic of splitting to be detected.

However, use of such a piezoelectric sensor causes a certain number of problems.

On the one hand, it is indispensable to have a mechanical link between the wafer and the sensor for the latter to be able to detect splitting. However, depending on the type of equipment employed, it may be difficult to ensure such a mechanical link. Specifically, in certain furnaces, the cassettes containing the substrates are placed in direct contact with the wall of the furnace, which is liable to transmit vibrations generated by splitting but also by shocks related to its environment. These configurations are therefore unfavourable to the detection of splitting because they do not have a holder suitable for the piezoelectric sensors. Furthermore, the sensor can generally not be placed directly in the furnace itself in contact with the cassettes or substrates because of limitations as regards the temperature that it is able to withstand and contamination that it is liable to generate on the substrates.

Furthermore, a wafer may break or be damaged during splitting, this being liable to disrupt the separation. As in the case where splitting does not occur, it is necessary to isolate the batch in question in order to process it manually. However, a piezoelectric sensor is not suitable for detecting such an event. Specifically, the shock induced by breakage of a substrate depends on the size of the pieces and how they drop onto the holder, which are random factors.

Lastly, it has been shown that the characteristics of the substrate after splitting (in particular its roughness) largely depend on the mechanical energy released during splitting. It would therefore be advantageous to be able to evaluate this quantity.

However, the signal delivered by the piezoelectric sensor does not easily allow the splitting characteristics, for example splitting energy or duration, to be determined.

At the present time, this energy is determined very indirectly by attempting to correlate the characteristics of the split surface with an energy. However this is complex to do,

because it depends on the substrate and many parameters that are not necessarily controlled or known.

A more direct way of estimating the energy released during splitting is to measure the time at which splitting occurs using a piezoelectric sensor such as the aforementioned. It is assumed that the energy released only depends on the thermal budget received by the wafer. However, this assumption is true only to a first approximation. Specifically, wafers may split at the same time but on so doing release different amounts of energy because of differing initiation mechanisms.

10 **DISCLOSURE OF THE INVENTION**

One aim of the invention is to remedy the problems mentioned and to provide a method allowing the time at which splitting of a substrate occurs to be detected with precision, and for this to be done for each substrate of a batch present in an annealing furnace.

15 This method must also make it possible to detect whether a substrate of the batch has not split or whether a substrate has broken during splitting.

To this end, the invention provides a method for monitoring a heat treatment applied to a substrate comprising a weakened zone formed by implanting atomic species with a view to splitting said substrate along said weakened zone, the substrate being arranged in a heating chamber, characterized in that it comprises recording sound in the interior or in the vicinity of the heating chamber and detecting, in said recording, a sound emitted by the substrate during the splitting thereof along its weakened zone.

20 By "vicinity of the heating chamber" is meant a zone that is sufficiently close to the chamber so that the sound emitted during the splitting can be recorded. The size and location of said zone may depend on the environment of the furnace, but the skilled person is able, based on a few audio recordings made previously, to make sure that at the intended location the audio recording is of sufficiently good quality so that the sound of the fracture may be detected therein.

25 The advantage of this audio recording is that the sound emitted by the substrate during the splitting thereof is very specific and cannot be confused with the sound produced during another event in the environment of the annealing furnace.

Moreover, apart from simple determination of the time at which splitting occurred, the recorded sound lends itself to an analysis (for example frequency spectrum, duration, intensity, etc.) that allows quantities characteristic of the splitting, for example the energy released, splitting speed, the occurrence of a breakage, etc. to be determined.

35 According to a first embodiment, said recording is made with a microphone arranged in the interior of the heating chamber.

According to a second embodiment, said recording is made with a microphone arranged on an exterior wall of an annealing furnace containing said heating chamber.

According to a third embodiment, said recording is made with a microphone arranged between a thermal screen and a door of an annealing furnace allowing access to the heating
5 chamber.

According to a fourth embodiment, said recording is made with a microphone arranged in a tube that opens onto the interior of the heating chamber.

Advantageously, said method further comprises, from the recording of the sound in the interior or in the vicinity of the heating chamber, detecting a breakage of the substrate.

10 In one application of said method, a batch of substrates to be split is loaded into the heating chamber, said method comprising detecting, in the audio recording, the sound emitted by each substrate during the splitting thereof.

According to one form of execution, the method comprises recording sound in the interior or in the vicinity of the heating chamber by means of two microphones that are
15 located at a distance from each other, and, on the basis of a time shift between the sounds of the splitting of a substrate detected in the recording of each of said microphones, locating within the batch the substrate for which splitting has occurred.

Preferably, said microphones are arranged in opposite regions of the heating chamber.

20 Advantageously, the heat treatment is stopped once each substrate of the batch has been detected to have split.

If, after a preset length of time, the number of substrates detected to have split is lower than the number of substrates, the batch is unloaded with a view to separating the split substrates manually.

25 Advantageously, a vibration frequency of a substrate during splitting is determined from a maximum frequency of the sound generated by the splitting of the substrate, and a splitting speed of the substrate is determined from said vibration frequency.

Moreover, an energy released during the splitting of a substrate may be determined from the intensity of the sound generated by said splitting.

30 It is also possible to determine the speed of a splitting wave propagating through a substrate from the maximum frequency corresponding to the peak sound intensity.

Preferably, the substrate comprises at least one semiconductor material.

Another subject of the invention relates to a device for the heat treatment of a batch of substrates to be split.

35 Said device comprises an annealing furnace comprising a heating chamber intended to simultaneously receive the whole of said batch, at least one microphone configured to record sounds in the interior or in the vicinity of the heating chamber, and a processing

system configured to detect, in an audio recording produced by said microphone, a sound emitted when a substrate splits.

According to one embodiment, the microphone is arranged in a tube that opens onto the interior of the heating chamber.

5 Particularly advantageously, the device comprises at least two microphones that are located at distance from one another.

According to one form of execution, the processing system is configured, on the basis of a time shift between the sounds of the splitting of a substrate detected in the recording of each of said microphones, to locate within the batch the substrate for which splitting has
10 occurred.

Advantageously, the device further comprises a system for controlling the furnace, configured to stop the heat treatment once all the substrates of the batch have been detected to have split.

15 DESCRIPTION OF THE FIGURES

Other features and advantages of the invention will emerge from the detailed description which follows, with reference to the appended drawings in which:

- Figure 1 is a representation of the acoustic signature of the splitting of a silicon substrate;
- 20 - Figure 2 is a schematic of installation of a microphone according to a first embodiment in the interior of the annealing furnace;
- Figure 3 is a schematic of installation of a microphone according to a second embodiment on the exterior wall of the annealing furnace;
- Figure 4 is a schematic of installation of a microphone according to a third
25 embodiment between the door and the thermal screen of the annealing furnace;
- Figure 5 is a schematic of installation of a microphone according to a fourth embodiment, in a tube in fluidic connection with the interior of the annealing furnace;
- Figure 6 is a schematic of installation of two microphones according to a fifth embodiment, in two opposite locations in the annealing furnace;
- 30 - Figure 7 is a calibration curve showing the relationship between the frequency of the vibrations emitted during splitting (in Hz) and the speed of the splitting (in m/s).

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

35 The present invention is based on the fact that the splitting of a substrate, in particular a semiconductor substrate, along a weakened zone formed beforehand by implanting atomic species has a specific acoustic signature, which may therefore be detected within an audio recording in or in the vicinity of the heat-treatment furnace in which said substrate is located. The substrate may be alone or bonded to another substrate. The latter case in

particular applies when it is desired to transfer a layer of said substrate to the other substrate via the SmartCut™ process.

Figure 1 illustrates the acoustic signature of the splitting of a silicon substrate, i.e. the audio intensity as a function of time detected in the furnace following the splitting of the substrate. The unit of the time axis is seconds. This signature takes the form of an abrupt increase in sound intensity then a rapid exponential decrease over a time of 1 to 2 s.

Such a signature is specific to splitting, and cannot be confused with the signature of other events liable to occur in or in the vicinity of the annealing furnace.

This signature may be obtained with any microphone sensitive to frequencies of a few tens of kHz, optionally suitable for operating at high temperature depending on its intended location.

The detection of the splitting delivers at least one piece of information on the splitting process that is qualitative (splitting or not of a substrate) or even quantitative as will be explained in more detail below.

Thus, the inventors have gone against the teaching of document FR 2 902 926 according to which an audio recording is not suitable for detecting the splitting of a substrate, and have in contrast demonstrated that it is possible to extract from an audio spectrum more information than from the signal of a piezoelectric sensor in contact with the substrate.

In particular, surprisingly, even though the splitting is almost instantaneous (of about 100 μ s), the sound caused by the splitting has a much longer duration, of about 1 to 2 s. This effect seems to be explained by an induced oscillation of the substrate on either side of the splitting plane, under the effect of a difference between the pressure generated within the microcracks and the gas pressure surrounding the substrate.

Although the audio spectrum is relatively complex (composed of several frequencies), it has a signature that is characteristic of splitting and that may be detected by processing the signal.

Figures 2 to 6 illustrate various embodiments of the invention.

In each of these figures, the structure of the furnace is identical and will therefore be described only once here. If a given reference sign is used in more than one figure it means that the elements referred to are identical or perform the same function. To make the figures clearer, the various elements are not necessarily shown to scale.

The furnace 1 has a tubular general shape that extends along a horizontal axis. The interior wall 10 of the furnace defines a heating chamber 11 in which the substrates S to be split are placed. In general, the heat treatment is not carried out on a single substrate but on a batch of substrates. To this end, the substrates are arranged in vertical position in one or more cassettes 2 that are placed side-by-side in the furnace. The cassettes are introduced via a door 12 that is located at one end of the tube. The door 12 is thermally insulated from the heating chamber 11 by a thermal screen 13. The end of the tube opposite

to the door is usually blind. Heating elements 14 are arranged around the wall of the furnace in order to raise the heating chamber to the temperature desired for the splitting. For example, the temperature applied to split silicon substrates is generally about from 100 to 500°C, preferably from 300 to 500°C.

5 Those skilled in the art will naturally be able to adapt the teaching provided below to any other type of furnace.

The star surrounded by circles symbolizes the occurrence of splitting in a substrate and the propagation of sound that results therefrom.

10 Whatever the location of the microphone, the latter transmits data recorded in real time to a control station comprising a computer (designated by the reference 4 in Figure 6) allowing the recordings to be processed by implementation of a suitable software package for processing the signal. The data may be transmitted by wire or wirelessly, using any suitable protocol.

15 Said control station is advantageously configured, depending on the results of the processing of the data, to trigger stoppage of the furnace, or to generate a warning for the attention of an operator tasked with monitoring the furnace.

Figure 2 illustrates a first embodiment, in which a microphone 3 is arranged directly in the heating chamber 11. For this application, a microphone suitable for high temperatures, i.e. tolerating temperatures of as high as 300°C, or even 850°C, which type of microphone 20 is commercially available, is chosen. Thus, the microphone is as close as possible to the substrates and is less sensitive to noises made outside of the furnace.

Advantageously, the microphone is placed on the wall opposite the door 12.

Figure 3 illustrates a second embodiment in which a microphone 3 is arranged on an exterior wall of the furnace, for example opposite the door 12. The audio detection is less 25 effective but sufficient for the detection of the splitting of a substrate. Moreover, this variant of execution makes it possible to not require a microphone suitable for high temperatures.

Figure 4 illustrates a third embodiment, in which the microphone 3 is arranged between the door 12 and the thermal screen 13 of the furnace. With respect to the first embodiment the microphone is subjected to lower temperatures, but it is naturally 30 necessary to choose one suitable for these temperatures.

Figure 5 illustrates a fifth embodiment, comprising a particular mount for the microphone 3. This mount comprises a tube 30 of small diameter, substantially corresponding to the size of the microphone 3, and for example of about 1 to 5 mm. The length of the tube is typically about 1 to 10 cm. Said tube 30 opens onto the heating chamber 35 11 through a hole drilled in the wall of the furnace, for example the wall opposite the door 12. Thus, even if the microphone makes contact with the atmosphere of the furnace, the thermal dissipation that occurs along the tube is sufficient to guarantee a temperature

compatible with the operation of the microphone, even if the latter is not especially suitable for high temperatures.

Figure 6 illustrates a fifth embodiment, in which two microphones 3 are arranged in the furnace, each in the vicinity of one end of the tube. Each microphone records the sounds that are produced within the heating chamber 11. During the processing of the recordings transmitted by each microphone, the time shift of the acoustic signatures of a given event allows the location, within the batch, of the substrate in which splitting took place to be estimated. It is thus possible to determine the substrate that has split.

Naturally, the various embodiments described above may be combined.

10 The exploitation of the detection of the splitting of a substrate may take various forms.

On the one hand, counting the number of substrates detected to have split and comparing this number with the number of substrates present in the furnace makes it possible to verify whether each substrate has indeed split. In this case, it may be advantageous to trigger stoppage of the heat treatment once the number of substrates detected to have split reaches the number of substrates, since the heat treatment then becomes pointless. It is thus possible to optimize cycle time, minimize the thermal budget applied to the substrates and decrease power consumption.

15 In contrast, if at the end of a preset duration of heat treatment, the number of substrates detected to have split is lower than the number of substrates, it is possible to deduce that one or more substrates have not split. In such a case, it is preferable to not send this batch to an automated separating machine, because the presence of an un-split substrate will possibly cause untimely stoppage of the machine. The batch in question is therefore unloaded with a view to separating the split substrates manually.

Breakage of a substrate does not necessarily result in a specific signature. Specifically, the sound produced during a breakage may be related to how the pieces of the substrate fall or indeed to how the substrate breaks and may therefore have variable characteristics. However, insofar as the sound produced by the splitting of a substrate is well identified, any other sound produced in the chamber may be related to a breakage. In this case, it is advantageous to take the batch out of the furnace with a view to processing it manually, in order to prevent a broken substrate from disrupting the operation of the automatic separating machine. Advantageously, the interior of the furnace is cleaned before a new batch of substrates to be split is introduced.

Moreover, apart from the qualitative exploitation that has just been described, the inventors have demonstrated a correlation between the maximum audio frequency corresponding to the peak intensity and the speed of the splitting wave that propagates through the substrate. This correlation is schematically shown in Figure 7, which shows the relationship between the frequency of the emitted vibrations (in Hz) and the speed of the splitting wave (in m/s). By virtue of such a curve, which is constructed beforehand for a

given type of substrate and determined implantation conditions, it is possible to determine, from the audio recording of each substrate, the speed of the corresponding splitting. It is then possible to verify the uniformity of the splitting characteristics within the batch.

Moreover, the energy released during splitting is directly proportional to the detected maximum sound intensity. Therefore, the relative variation in the maximum sound intensity and its comparison to the average value detected on identical substrates allows the energy released during the splitting of a substrate, which is an indicator of the quality of the splitting, to be estimated.

10 REFERENCES

FR 2 902 926

CLAIMS

1. Method for monitoring a heat treatment applied to a substrate comprising a weakened zone formed by implanting atomic species with a view to splitting said substrate
5 along said weakened zone, the substrate (S) being arranged in a heating chamber (11), characterized in that it comprises recording sound in the interior or in the vicinity of the heating chamber (11) and detecting, in said recording, a sound emitted by the substrate during the splitting thereof along the weakened zone.
- 10 2. Method according to claim 1, wherein said recording is made with a microphone (3) arranged in the interior of the heating chamber (11).
3. Method according to claim 1, wherein said recording is made with a microphone
15 (3) arranged on an exterior wall of an annealing furnace (1) containing said heating chamber (11).
4. Method according to claim 1, wherein said recording is made with a microphone
20 (3) arranged between a thermal screen (13) and a door (12) of an annealing furnace (1) allowing access to the heating chamber (11).
5. Method according to claim 1, wherein said recording is made with a microphone
(3) arranged in a tube (30) that opens onto the interior of the heating chamber (11).
- 25 6. Method according to one of claims 1 to 5, further comprising, from the recording of the sound in the interior or in the vicinity of the heating chamber (11), detecting a breakage of the substrate.
7. Method according to one of claims 1 to 6, wherein a batch of substrates to be
30 split is loaded into the heating chamber, said method comprising detecting, in the audio recording, the sound emitted by each substrate during the splitting thereof.
8. Method according to claim 7, comprising recording sound in the interior or in the
35 vicinity of the heating chamber (11) by means of two microphones (3) that are located at distance from each other, and, on the basis of a time shift between the sounds of the splitting of a substrate detected in the recording of each of said microphones, locating within the batch the substrate for which splitting has occurred.

9. Method according to claim 8, wherein the microphones (3) are arranged in opposite regions of the heating chamber (11).

10. Method according to one of claims 7 to 9, wherein the heat treatment is stopped
5 once each substrate has been detected to have split.

11. Method according to one of claims 7 to 9, wherein, after a preset length of time, the number of substrates detected to have split is lower than the number of substrates, and the batch is unloaded with a view to separating the split substrates manually.
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12. Method according to one of claims 1 to 11, wherein a vibration frequency of a substrate during splitting is determined from a maximum frequency of the sound generated by the splitting of the substrate, and a splitting speed of the substrate is determined from said vibration frequency.
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13. Method according to one of claims 1 to 12, wherein an energy released during the splitting of a substrate is determined from the intensity of the sound generated by said splitting.

14. Method according to one of claims 1 to 13, wherein the speed of a splitting wave propagating through a substrate is determined from the maximum frequency corresponding to the peak sound intensity.
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15. Method according to one of claims 1 to 14, wherein each substrate comprises
25 at least one semiconductor material.

16. Device for the heat treatment of a batch of substrates each comprising a weakened zone formed by implanting atomic species with a view to splitting said substrate along said weakened zone, comprising an annealing furnace (1) comprising a heating
30 chamber (11) configured to simultaneously receive the whole of said batch, at least one microphone (3) configured to record sounds in the interior or in the vicinity of the heating chamber, and a processing system (4) configured to detect, in an audio recording produced by said microphone, a sound emitted when a substrate splits along the weakened zone.

17. Device according to claim 16, wherein the microphone (3) is arranged in a tube
35 (30) that opens onto the interior of the heating chamber (11).

18. Device according to either of claims 16 and 17, comprising at least two microphones (3) that are located at distance from one another.

5 19. Device according to claim 18, wherein the processing system (4) is configured, on the basis of a time shift between the sounds of the splitting of a substrate detected in the recording of each of said microphones, to locate within the batch the substrate for which splitting has occurred.

10 20. Device according to one of claims 16 to 19, further comprising a system for controlling the furnace, configured to stop the heat treatment once all the substrates of the batch have been detected to have split.