

Wafer Dicing Apparatus And Wafer Dicing Method

FIELD OF INVENTION

The present invention relates to a laser cutting method and a vacuum chuck substrate holder for silicon wafers. In particular, it relates to a cutting method by laser cleavage and a vacuum chuck fixture for such method.

BACKGROUND TO THE INVENTION

When a silicon wafer is being parsed into its component dies through cleavage methods such as laser-induced thermal cracking, the silicon wafer is typically held on a chuck by a vacuum. However, when the silicon wafer is tightly held and fixed by the suction force from a vacuum chuck, the strong suction force leads to difficulty in the laser-induced thermal cracking. For example, the crack propagation may not separate the wafer from the cutting leading edge to the cutting trailing edge, particularly when forming the second-cut (as a 90⁰-cut to the first cut) after the first cut. Furthermore, defects such as localized surface recrystallization at the cutting trailing edge, "Y" cracking (i.e., two small cracks joining together at the cutting leading edge), or crack deviation in propagation at the cutting leading edge may appear at cross corners of the silicon die along the second cut. Examples of these defects are pictured in Figure 1, wherein Figure 1A depicts a defect of recrystallization at the cutting trailing edge corner, Figure 1B depicts a defect of failure of crack propagation, Figure 1C depicts a defect of "Y" cracking, and Figure 1D depicts a defect of crack deviation. Higher laser energy and slower scanning speed are required to compensate the issues mentioned above so as to achieve improved cutting for the second cut. However, such measures increase time of manufacture or power required.

Thus, there is a need for an improved method of cutting silicon wafers which eliminates the defects of current methods.

SUMMARY OF THE INVENTION

A laser cutting method and a substrate holder (vacuum chuck fixture) for silicon wafers is disclosed. The cutting method by laser cleavage introduces an external bending force during cutting to enhance the laser-induced thermal cracking process for laser cleavage of brittle substrates such as silicon wafers.

According to one aspect of the invention, there is provided a wafer dicing apparatus. The wafer dicing apparatus includes a grille, a vacuum suction unit and a cutter. The grille includes an alternating rib and slot arrangement for supporting a wafer, wherein one slot is between two adjacent ribs. The vacuum suction unit is in fluid communication with the grille and sucks air through at least one slot of the grille. The cutter dices the wafer, where either the grille, the cutter or both is configured to align the wafer to be diced along the rib of the grille.

As disclosed, there is provided a wafer dicing method. The method includes providing a wafer, stressing the wafer along a length that extends between two opposite points of the wafer perimeter, and dicing the wafer along the length where the wafer is stressed.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1, comprising Figures 1A to 1D, shows various defects resulting from conventional laser cutting of brittle substrates such as processed silicon wafers.

Figure 2, comprising Figures 2A to 2D, shows perspective views of a vacuum chuck for laser cleavage in accordance with the present embodiment. Figure 2A is a perspective view of an unassembled apparatus for cleavage including a porous chuck as a vacuum chuck and Figure 2B is a perspective view of the assembled apparatus. Figures 2C and 2D show the porous chuck, steel plate having a grille and wafer arrangement for laser cleavage.

Figure 3, comprising Figures 3A and 3B, show side planar views of the vacuum chuck arrangement of Figures 2C and 2D during cleavage in accordance with the present embodiment.

Figure 4 shows an enlarged view of a portion of the silicon wafer during laser cleavage in accordance with the present embodiment.

Figure 5, comprising Figures 5A to 5D, shows reduced defect results from laser cutting of brittle substrates such as processed silicon wafers in accordance with the present embodiment.

DEFINITIONS

The following provides sample, but not exhaustive, definitions for expressions used throughout various embodiments disclosed herein.

The term “wafer dicing apparatus” may mean a machine that is used to perform wafer dicing. In the context of a semiconductor (such as silicon) wafer, wafer dicing is the process by which a component die is separated from a wafer of semiconductors following the processing of the wafer. The dicing process can be accomplished by scribing and breaking, by mechanical sawing or by laser cutting.

The term “grille” may mean a grating having a frame with a window that has a series of members that extend across the window. The phrase “alternating rib and slot arrangement” may refer to the manner in which the members extend across the window, i.e. “rib” may refer to the member that extends across the window, while “slot” may refer to the cavity or space that is between two of the members. The rib may be straight or curved or has both straight and curved portions, which in turn defines the shape of the adjacent slot.

The term "cutter" may mean a device that performs wafer dicing and may be a mechanical based component such as a dicing saw or a contactless based component such as a laser.

The phrase "align the wafer to be diced along the rib of the grille" may mean that during the dicing of a wafer, the grille, the cutter or both are continuously moved so that partitioning of the wafer occurs at the portion of the wafer that is in contact with the rib of the grille.

DETAILED DESCRIPTION

A vacuum chuck fixture in accordance with a present embodiment can introduce external bending forces instantly in order to guide crack propagation in order to enhance a laser-induced thermal cracking process for cleavage separation of silicon wafers or other brittle substrates. In accordance with the present embodiment, ribs (for example, a thin stainless steel sheet with alternating ribs and slots) are utilized on the top surface of a vacuum chuck. The ribs support the silicon wafer and are aligned with a second-cutting line (i.e., the cutting line is along the rib and aligned with the central line of the rib). There is a slot which forms a cavity between every two ribs.

Figure 2A shows a wafer dicing apparatus 100 in accordance with an embodiment of the invention. The wafer dicing apparatus 100 comprises a grille 102 and a vacuum suction unit 106 to realise the above mentioned vacuum chuck fixture. The wafer dicing apparatus 100 also includes a cutter 122.

The grille 102 comprises an alternating rib and slot arrangement 112. The alternating rib and slot arrangement 112 is a frame 126 with slots 108 and ribs 110, wherein one slot 108 is between two adjacent ribs 110. The grille is for supporting a wafer 104 across the alternating rib and slot arrangement 112. Figure 2A shows that the wafer 104 is provided on an optional layer of UV (ultraviolet) tape 124.

The vacuum suction unit 106 is in fluid communication with the grille 102, wherein the vacuum suction unit 106 sucks air through at least one slot 108 of the grille 102. When the suction vacuum is on, the suction force at two sides of a rib 110 of the alternating rib and slot arrangement 112 will vertically pull downward the wafer 104 and bend the wafer 104 evenly along the rib 110, to establish a dicing line (see Figure 3). Meanwhile, because of the bending feature along the rib 110, the maximum bending stress line will be aligned with the dicing line, which helps guide crack propagation.

The cutter 122 is for dicing the wafer 104. During dicing of the wafer 104, either the grille 102, the cutter 122 or both is configured to align the wafer 104 to be diced along the rib 110 of the grille 102. Thus, the wafer dicing apparatus 100 is provided with means (not shown) that move either the grille 102, the cutter 122 or both to establish the required dicing lines that partition the wafer 104 into its constituent component dies. Accordingly, in one embodiment, only the grille 102 moves during the dicing of the wafer 104. In another embodiment, only the cutter 122 moves during the dicing of the wafer 104. In yet another embodiment, it may be both the grille 102 and the cutter 122 that move during the dicing of the wafer 104. In a further embodiment, it may be the wafer dicing apparatus 100 is provided with means (not shown) that move any one or more of the grille 102, the cutter 122 or the wafer 104 with the vacuum chuck fixture to establish the required dicing lines that partition the wafer 104 into its constituent component dies. The wafer 104 may be diced in a first orientation 128, followed by a second orientation 130.

The wafer dicing apparatus 100 may include a porous chuck 120, which is optional, as the grille 102 is sufficient to support the wafer 104 during dicing of the wafer 104. The grille may be provided on a surface of the porous chuck 120 which faces the cutter 122. However, in another embodiment (not shown), the grille may be fabricated on the surface of the porous chuck. In this other embodiment, the grille forms part of the porous chuck.

Figure 2A shows the wafer dicing apparatus 100 in its unassembled form, while Figure 2B shows the wafer dicing apparatus 100 in its assembled form. In Figure 2B, the alternating rib and slot arrangement 112 of Figure 1A is hidden from view by the wafer 104 that is provided on the grille 102.

Figure 2C shows one manner in which the wafer 104 may be cut in the first orientation 128 during a dicing operation using a laser-induced thermal cracking process, where the grille 102 and the porous chuck 120 are separate components. For the purposes of simplicity, the cutter 122 (shown in Figures 2A and 2B) are not shown. The grille 102 is placed on top of the porous chuck 120 and the wafer 104 is placed on top of the grille 102 for laser cleavage. The wafer 104 is provided on the tape 124. However, the wafer dicing apparatus 100 is not limited to dicing wafers, such as semiconductor silicon wafers, but is also suitable to dice other substrates, such as brittle substance substrates (e.g. crystal sapphire substrates, glass substrates and ceramic substrates). The porous chuck 120 may also be selected from chucks that are adapted for the laser-induced thermal cracking process.

A vacuum is provided on the other side (i.e. the side that is opposite to the surface that faces the grille 102) of the porous chuck 120 to hold the wafer 104 and the grille 102 on the porous chuck 120. As shown in Figure 2D, in order to dice the wafer 104 (i.e. dicing semiconductor dies when the wafer 104 is a silicon wafer), first cuts are made perpendicular to the ribs 110 of the grille 102. Second cuts are made parallel to the ribs 110 and over the slots 108 in the grille 102 in order to introduce a bending force to assist the laser-induced thermal cracking process.

With reference to Figure 2B, either the grille 102, the cutter 122 or both is configured to align the wafer 104 to be diced in a direction that is misaligned with respect to the rib 110 of the grille 102 to produce a cut in a first orientation 128 (i.e. the first cut). Either the grille 102, the cutter 122 or both is then configured to

rotate the wafer 104 to align the wafer 104 to be diced along the rib 110 of the grille 102 to produce a cut in a second orientation 130 (i.e., the second cut).

For the cut in the first orientation 128, the misalignment with respect to the rib 110 of the grille 102 may mean that the rotation angle between the cut of the first orientation 128 and the cut of the second orientation 130 is up to 90°. Thus, the first cut is not necessarily perpendicular to the second cut. Further, either the grille 102, the cutter 122 or both is configured to align the wafer 104 to be preferably diced along a central longitudinal length of the rib 110 of the grille 102.

When bending a beam or a rectangular strip at a uniformly distributed load, the maximum bending deflection and bending stress can be calculated approximately as:

- Bending Stress: $\sigma_{max} = \frac{3pL^2}{4bh^2}$
- Bending Deflection: $\delta_{max} = \frac{5pL^4}{384E} \frac{12}{bh^3}$

p	Uniform load of intensity; suction force per unit length introduced to wafer strip piece
E	Elastic modulus; Young's modulus of silicon
σ	Bending stress
L	Distance between two supporting points; width between the ribs (or the width of the slots)
b	Width of the wafer strip piece
h	Thickness of the wafer strip piece

The bending stress σ_{max} is controllable through control of the size of the ribs 110 of the grille 102 at the porous chuck 120 surface and the vacuum suction pressure. The preferred size of the rib 110 is flexible and may be determined in response to the cutting die size, i.e. the width of each rib 110 of the alternating rib and slot arrangement 112 is determined by the size of a die of the wafer. Further, the size of the ribs 110 (and consequently the size of the slots 108) should provide a bending force sufficient to assist the laser-induced thermal cracking dicing in accordance with the present embodiment.

Figures 3A and 3B each show a side planar view of the implementation of a wafer dicing method for laser-induced thermal cracking dicing of silicon wafers in accordance with the embodiment shown in Figures 2C and 2D.

The wafer dicing method comprises providing a wafer 104, as shown in Figure 3A. Turning to Figure 3B, the wafer 104 is stressed along a length that extends between two opposite points 302 and 304 of the wafer 104 perimeter. The wafer 104 is then diced along the length where the wafer 104 is stressed. This length runs along a plane that is perpendicular to cross-sectional view shown in Figure 3B.

The dicing of the wafer 104 along the length where the wafer is stressed produces a cut in a second orientation, whereby this cut in the second orientation is performed after the wafer 104 is cut in a first orientation. An exemplary method to produce the cut in the first orientation is as follows.

Prior to stressing the wafer 104 along the length that extends between the two opposite points 302 and 304 of the wafer 104 perimeter (i.e. after the wafer 104 is provided as shown in Figure 3A), the wafer 104 may be diced along a length that extends between two different opposite points (not shown) of the wafer 104 perimeter to produce the cut in the first orientation. These two different opposite points are not the same as the two opposite points 302 and 304 along which dicing

shown in Figure 3B is performed to produce the cut in the second orientation. Further, dicing of the wafer 104 to produce the cut in the first orientation is preferably performed under vacuum suction, although such vacuum suction is not essential.

The wafer 104 may then be rotated (not shown) to perform the steps of the wafer dicing method described with respect to Figure 3B. In more detail, the stressing of the wafer 104 along the length that extends between the two opposite points 302 and 304 of the wafer 104 perimeter is performed. Dicing of the wafer 104 along the length where the wafer is stressed produces the cut in the second orientation that is misaligned to the cut of the first orientation.

Stressing of the wafer 104 is achieved by providing the wafer 104 across an alternating rib and slot arrangement 112 of a grille 102, the alternating rib and slot arrangement 112 comprising one slot 108 between two adjacent ribs 110, and sucking air through at least one slot 108 of the grille 102 to stress the wafer 104 along the rib 110 of the grille 102. The cut in the first orientation is thus in a direction that is misaligned with respect to the rib 110 of the grille 102 (and is preferably perpendicular to the rib 110 of the grille 102), while the cut in the second orientation is along the rib 110 of the grille 102.

A vacuum (represented using the reference numeral 306) is turned on, before a laser beam forms a crack dicing line aligned along the supporting ribs 110, to increase tensile stress at the crack dicing line from the vacuum-induced bending in the wafer 104, at portions 330 located adjacent to slots 108 between two respective supporting ribs 110. The crack dicing line is typically aligned with the central line of the supporting rib 110, with the central line producing a line where there is maximum bending stress. Preferably, the ribs 110, applied on the porous chuck 120 top surface, are fabricated from stainless steel, i.e. the grille 102 may be a stainless steel piece having slots 108 and ribs 110. While stainless steel is preferred because of its ease of machining and low cost, other materials of

sufficient tensile strength may be used to form the ribbed slotted structure of the grille 102 applied on the porous chuck 120 top surface in accordance with the present embodiment. The size of the ribs 110 is preferably 1 to 2 mm in width and 100 to 500 μm in height/depth/thickness. The slot 108 width is preferably 2 to 3 mm for a 5 mm square die piece.

Figure 4 shows an enlarged view of the bending 330 over the ribs (not shown) which enables improved crack propagation in accordance with the present embodiment. The change in the slot size is dependent on the silicon die size and, while the depth/height of the slots and ribs is preferably from 100 μm to 500 μm , it has been found that slot depth/height from 50 μm to 2 mm will work well for laser dicing. In addition, for crack propagation, one or more of the following cross-section shapes are possible for the slots of the alternating rib and slot arrangement described in the above embodiments: a V-grooved structure or a U-grooved structure. Further, from a perspective top view, the slots of the alternating rib and slot arrangement described in the above embodiments may have one or more of the following shapes that also facilitate crack propagation: rectangular, wave, curvilinear or any other similar shaped channel structure. These shapes are equally applicable to the ribs of the alternating rib and slot arrangement described in the above embodiments, since the shape of each rib is determined by the shape of its adjacent slot.

Thus, in accordance with any embodiment of the invention, defects such as localized surface recrystallization at a cutting trailing edge, "Y" cracking (two small cracks joining together at the cutting leading edge), or crack deviation in propagation at the cutting leading edge appearing at a cross corner of a silicon die in the second-cut can be resolved and/or significantly reduced. Furthermore, the dicing speed can be increased by a factor of greater than 25%. Figure 5, including Figures 5A, 5B, 5C and 5D, shows the typical results obtained when using the laser cleavage method in accordance with the embodiment shown in Figures 2C and 2D.

Instead of using ribs made from metal sheets or other types of thin substrates such as thin stainless steel, shallow trench cavities fabricated on a vacuum chuck surface (having a grille with an alternating rib and slot arrangement as described above) can also take the role of the ribs to introduce the bending force for assisting the laser-induced thermal cracking dicing of silicon wafer pieces. Such shallow trenches may be realised, for example, by having a portion of the slots of the alternating rib and slot arrangement having a depth contained within the thickness of the grille where the alternating rib and slot arrangement is fabricated. On the other hand, the slots of the alternating rib and slot arrangement may have a depth that extends the thickness of the grille where the alternating rib and slot arrangement is fabricated (i.e. such slots are through holes/cavities). It is also possible that the porous chuck has a portion of slots or trenches formed directly on the top surface of the porous chuck and having a depth contained within the thickness of the porous chuck, the depth of the trenches substantially similar to the thickness of the grille such that the trenches are cavities which substitute for the grille. In addition, the above embodiments can be applied not only to laser wafer dicing but also to other brittle substrates to be cleaved (or cut or separated) with laser cleavage techniques.

The dicing process is carried out by the use of laser-induced thermal cracking. The wafer is separated automatically under a single scan of the laser beam, thereby providing a simple and elegant process that exhibits a number of advantages. Some of these advantages are no debris and avoiding the use of assist gas, flowing water, protective film and post-secondary mechanical external force. Conventionally, assistant media are used to remove debris and the cut kerf is a few tens of micrometers.

In accordance with the present embodiment, the assistance of the bending stress introduced to the silicon die piece and the guiding of the crack propagation help resolve many current laser cleavage defects such as localized surface

recrystallization at the cutting trailing edge, "Y" cracking, and crack deviation in propagation at the cutting leading edge which appear at cross corners of silicon die in a second-cut. Also, the dicing speed can be increased because of the assistance of the bending stress. As there is no material removal, the separated wafer edges are debris-free. The kerf width is minimal and merely that of the cracking line. The side sidewall surface is smooth due to the brittle fracture mode. And the reduced energy requirement to effect cracking allows high-speed wafer separation.

Possible implementations may include a wafer cutting system using a pulsed fiber laser or a pulsed solid-state laser source (with a wavelength in the range of 1064 nm to 1550 nm) and including an optical isolator, a laser pulse modulator, a beam expander (2X to 8X), full beam reflection optics, a laser beam focal lens, a wafer holding and moving setup, a vacuum suction device, stainless steel sheets with slots (where the ribs of the slots are 100 to 500 μm in height/depth and 0.5 to 3 mm in width). The stainless steel slots are placed on top of the vacuum chuck, or instead of the slots, trenches are fabricated on the vacuum chuck surface. A bend/suction force from the slots and vacuum pressure are applied the substrates to be cut during laser scanning. The suction force is controlled by the size of the trench cavities or slots, together with the vacuum pressure. The silicon wafer is then placed on the ribs and the laser dicing line is aligned with the central line of the rib. An irradiation belt is formed in the silicon wafer surface by laser irradiation at a laser power density below the vaporization threshold of material ablation and below the melting point of the silicon wafers no flow assistant gas is required. A laser-induced thermal cracking process occurs on the silicon wafer surface by a single pass beam scanning the wafer surface, the silicon wafer having a thickness up to 1500 μm and the silicon wafer being automatically separated by the crack propagation with beam scanning without using a post-secondary mechanical external force to assist to wafer separation.

Thus, an apparatus and method in accordance with the present embodiment has been shown and described which provides commercial potential for high speed dicing of silicon wafers in the semiconductor and solar industries. Although the description provided above has been largely directed toward cutting silicon wafer, the methods described are also generally applicable to other semiconductors that may be used as the wafer substrate for work pieces, such as GaAs, SiC, SiN, or indium phosphide, and other brittle ceramic and glass substrates.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the embodiments without departing from a spirit or scope of the invention as broadly described. The embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A wafer dicing apparatus comprising
a grille comprising an alternating rib and slot arrangement, wherein one slot is between two adjacent ribs, the grille for supporting a wafer across the alternating rib and slot arrangement;
a vacuum suction unit in fluid communication with the grille, the vacuum suction unit for sucking air through at least one slot of the grille; and
a cutter for dicing the wafer, wherein either the grille, the cutter or both is configured to align the wafer to be diced along the rib of the grille.
2. A wafer dicing apparatus according to claim 1, further comprising a porous chuck, wherein the grille is provided on a surface of the chuck which faces the cutter.
3. A wafer dicing apparatus according to claim 2, wherein the grille is fabricated on the surface of the porous chuck.
4. A wafer dicing apparatus according to claim 1 or 2, wherein the grille is fabricated from any one or more of the following materials: stainless steel, aluminum alloy, or other metal or ceramic.
5. A wafer dicing apparatus according to any one of the preceding claims, wherein a portion of the slots of the alternating rib and slot arrangement has a depth that extends the thickness of the grille.
6. A wafer dicing apparatus according to any one of the preceding claims, wherein a portion of the slots the alternating rib and slot arrangement comprises trenches, each formed from slots that have a depth contained within the thickness of the grille.

7. A wafer dicing apparatus according to any one of the preceding claims, wherein each slot of the alternating rib and slot arrangement has any one of following shapes: rectangular, wave or curvilinear.
8. A wafer dicing apparatus according to any one of the preceding claims, wherein each slot of the alternating rib and slot arrangement has a cross-section having any one of the following shapes: V-groove or a U-groove.
9. A wafer dicing apparatus according to any one of the preceding claims, wherein the width of each rib of the alternating rib and slot arrangement is determined by the size of a die of the wafer.
10. A wafer dicing apparatus according to any one of the preceding claims, wherein the width of each rib of the alternating rib and slot arrangement is around 1 to 2 mm.
11. A wafer dicing apparatus according to any one of the preceding claims, wherein the width of each slot of the alternating rib and slot arrangement is around 2 to 3 mm.
12. A wafer dicing apparatus according to any one of the preceding claims, wherein a thickness of the grille is around 100 to 500 μm .
13. A wafer dicing apparatus according to any one of the preceding claims, wherein either the grille, the cutter or both is configured to align the wafer to be diced along a central longitudinal length of the rib of the grille.

14. A wafer dicing apparatus according to any one of the preceding claims, wherein either the grille, the cutter or both is further configured to:

align the wafer to be diced in a direction that is misaligned with respect to the rib of the grille to produce a cut in a first orientation; and

to rotate the wafer to align the wafer to be diced along the rib of the grille to produce a cut in a second orientation.

15. A wafer dicing apparatus according to claim 14, wherein the rotation angle between the first orientation and the second orientation is up to 90° .

16. A wafer dicing apparatus according to any one of the preceding claims, wherein the cutter comprises any one or more of the following devices: saw or laser.