

ANNULAR GRINDSTONE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to an annular grindstone mounted to a cutting apparatus.

Description of the Related Art

A device chip to be mounted on an electronic apparatus is formed, for example, by cutting a disk-shaped wafer including a semiconductor. A plurality of intersecting streets is set on a surface of the wafer, and a device such as an integrated circuit (IC) including the semiconductor is formed in each of regions partitioned by the streets. Then, the wafer is divided along the streets, whereby individual device chips are formed. For the division of the wafer, a cutting apparatus having a cutting unit in which an annular grindstone (cutting blade) is mounted is used. In cutting a workpiece such as a wafer by the cutting apparatus to divide the workpiece, the annular grindstone is made to cut into the workpiece while rotating the annular grindstone in a plane perpendicular to an upper surface of the workpiece. The annular grindstone has a grindstone section including abrasive grains and a binder in which

the abrasive grains are dispersed and fixed, and the abrasive grains exposed appropriately from the binder make contact with the workpiece, whereby the workpiece is cut. Although the abrasive grains are consumed as the cutting of the workpiece progresses, the binder is also consumed and new abrasive grains are successively exposed from the binder, so that the cutting performance of the annular grindstone is maintained. Such an action of the annular grindstone is called self-sharpening.

In recent years, power devices have been drawing attention as a semiconductor device higher in voltage resistance and controlling electrical signals of larger currents as compared to devices formed from a silicon wafer. The power device is used, for example, in power source circuits for electric cars, hybrid cars and air conditioners. For manufacture of the power device, a silicon carbide (SiC) wafer better than the silicon wafer in electric characteristics is used. Since the SiC wafer is a hard material, cutting the SiC wafer to divide the SiC wafer has been conducted by using, for example, an annular grindstone in which the binder is formed of nickel (Ni). However, since the binder formed from nickel is hardly consumed, there have been cases where the self-sharpening action would not be generated at a sufficient

level. Therefore, when an SiC wafer is cut by the annular grindstone, the cutting performance of the annular grindstone is lowered, so that defects called chipping or the like may often be generated at side surfaces of the device chips formed.

In view of this, as a method by which an SiC wafer can be divided with high processing quality, there has been known a method in which a laser beam is applied to the SiC wafer along streets, to form shield tunnels including an amorphous phase in the SiC wafer (see Japanese Patent Laid-open No. 2014-221483). In addition, there has been known a method in which an SiC wafer is cut while applying ultrasonic waves to an annular grindstone (see Japanese Patent Laid-open No. 2014-13812).

SUMMARY OF THE INVENTION

Since the laser processing apparatus and the cutting apparatus applying ultrasonic waves to an annular grindstone are expensive, processing by use of these apparatuses is high in cost. In view of this, development of an annular grindstone by which a hard material such as SiC wafer can be cut with high quality is desired. If a hard material can be cut with high quality by mounting the annular grindstone to an existing cutting apparatus,

it is unnecessary to incorporate a special configuration into the cutting apparatus, and therefore, processing cost can be suppressed. Further, since a new use is given to an existing cutting apparatus, the value of the existing cutting apparatus is enhanced.

It is an object of the present invention to provide an annular grindstone cutting a hard material such as SiC wafer with high quality.

In accordance with an aspect of the present invention, there is provided an annular grindstone including a grindstone section that includes a binder and abrasive grains dispersed and fixed in the binder, in which the binder includes a tin-nickel alloy.

Preferably, a content of tin in the tin-nickel alloy is equal to or more than 57 wt% and less than 75 wt%.

In addition, preferably, the annular grindstone consists of the grindstone section.

Alternatively, preferably, the annular grindstone further includes an annular base having a grip section, and the grindstone section is exposed to an outer peripheral edge of the annular base.

The annular grindstone according to the described mode of the present invention includes the grindstone

section that includes the binder and the abrasive grains dispersed and fixed in the binder. Besides, the binder includes the tin-nickel alloy. The annular grindstone ensures that the binder is largely consumed when a hard material such as SiC wafer is cut, and a self-sharpening action is generated suitably, so that the cutting performance of the annular grindstone is maintained. Therefore, during the cutting of the hard material, processing quality is not lowered. In addition, since the annular grindstone can be mounted to an existing cutting apparatus, processing cost is suppressed.

Therefore, according to the described mode of the present invention, there is provided an annular grindstone cutting a hard material such as SiC wafer with high quality.

The above and other objects, features and advantages of the present invention and the manner of realizing them will become more apparent, and the invention itself will best be understood from a study of the following description and appended claims with reference to the attached drawings showing a preferred embodiment of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a perspective view schematically depicting an annular grindstone consisting of a grindstone section;

FIG. 1B is a perspective view schematically depicting a grindstone including an annular base and a grindstone section;

FIG. 2 is a sectional view schematically depicting a manufacturing process for an annular grindstone consisting of a grindstone section;

FIG. 3A is a sectional view schematically depicting a plating layer formed;

FIG. 3B is a sectional view schematically depicting removal of the base;

FIG. 4 is a sectional view schematically depicting a manufacturing process for an annular grindstone including a grindstone section and an annular base;

FIG. 5A is a sectional view schematically depicting a plating layer formed;

FIG. 5B is a sectional view schematically depicting partial removal of the base; and

FIG. 6 is a graph depicting the status of generation of chipping when an SiC wafer is cut by use of an annular grindstone in which a binder is formed of nickel and an annular grindstone in which a binder is

formed of a tin-nickel alloy.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

An embodiment of the present technology will be described. FIG. 1A is a perspective view schematically depicting an annular grindstone consisting of a grindstone section, as an example of an annular grindstone (cutting blade) according to the present embodiment. The annular grindstone 1a illustrated in FIG. 1A is an annular grindstone of a what is called washer type. The annular grindstone 1a includes a circular annular grindstone section 3a having a through-hole in its center. The annular grindstone 1a is mounted to a cutting unit of a cutting apparatus. In this instance, a spindle possessed by the cutting unit is passed through the through-hole. When cutting a workpiece, the spindle is rotated, whereby the annular grindstone 1a is rotated in a plane perpendicular to the extending direction of the through-hole. When the grindstone section 3a of the annular grindstone 1a in rotation is brought into contact with the workpiece, the workpiece is cut. In addition, FIG. 1B is a perspective view schematically depicting an annular grindstone including an annular base and a grind stone section. The annular grindstone 1b illustrated in

FIG. 1B is a grindstone of a what is called hub type in which a grindstone section 3b is disposed at an outer peripheral edge of an annular base 5. The annular base 5 serves as a grip section that is gripped by the user (operator) of a cutting apparatus when the annular grindstone 1b is mounted to the cutting unit of the cutting apparatus. When the annular grindstone 1b is mounted to the cutting unit of the cutting apparatus, a spindle of the cutting unit is passed through a through-hole formed in the annular base 5.

The grindstone sections 3a and 3b are produced, for example, by forming a binder containing abrasive grains such as diamond abrasive grains on a base formed of a metal such as aluminum, by a method such as electroplating. Note that the annular grindstones 1a and 1b formed by the method such as electroplating are also called electrodeposited grindstones or electroformed grindstones. The grindstone sections 3a and 3b of the annular grindstones 1a and 1b each include a binder and abrasive grains dispersed and fixed in the binder. The abrasive grains exposed from the binder to an appropriate extent is contacted with the workpiece, whereby the workpiece is cut. As cutting of the workpiece progresses, the abrasive grains are consumed by falling off the

binder or being abraded, so that the cutting performance of the annular grindstones 1a and 1b is gradually lowered. However, as the cutting of the workpiece progresses, the binder is also consumed, so that new abrasive grains are successively exposed from the binder. Therefore, the cutting performance of the annular grindstones 1a and 1b is kept at or above a predetermined level. This action is called self-sharpening.

In recent years, power devices have been drawing attention as a semiconductor device higher in voltage resistance and controlling electrical signals of larger currents as compared to devices formed from a silicon wafer. The power device is used, for example, in power source circuits for electric cars, hybrid cars and air conditioners. For manufacture of the power device, an SiC wafer is used. Conventionally, for cutting of SiC wafer which is a hard material, for example, an annular grindstone in which a binder is formed of nickel has been used. However, since the binder formed of nickel is not consumed easily, a self-sharpening action may not be achieved at a sufficient level in the case of the annular grindstone. Therefore, when an SiC wafer is cut by the annular grindstone, the cutting performance of the annular grindstone is gradually lowered, so that defects

called chipping may often be generated at side surfaces of device chips.

On the other hand, the annular grindstones 1a and 1b according to the present embodiment include the grindstone sections 3a and 3b in which a tin-nickel (Sn-Ni) alloy is used for a binder. Preferably, the binder includes a tin-nickel alloy. When the tin-nickel alloy is used as the binder, the binder is severely consumed when a hard material is cut by the annular grindstone, so that the self-sharpening action is generated suitably. Therefore, the annular grindstone can cut the hard material without lowering in processing quality.

Note that in the annular grindstones 1a and 1b, the content of tin in the tin-nickel alloy (for example, the weight of tin based on the total weight of tin and nickel) used as the binder is preferably equal to or more than 57 wt% and less than 75 wt%. More preferably, the content of tin in the tin-nickel alloy is equal to or more than 64 wt% and equal to or less than 70 wt%. The tin-nickel alloy is particularly stable when the atomic ratio of tin and nickel is 1:1. In this instance, the content of tin in the tin-nickel alloy is approximately 67 wt%. Therefore, when a binder containing as a main constituent a tin-nickel alloy having a tin content on

the order of 67 wt% is used for the grindstone sections 3a and 3b of the annular grindstones 1a and 1b, the performance of the annular grindstones 1a and 1b is stabilized. In this case, a workpiece can be cut with extremely stable quality, and variability in processing quality is extremely reduced.

In general, when cutting conditions for a workpiece are determined, cutting conditions with a certain degree of allowance are selected in consideration of variability in cutting quality. In other words, in order that allowable results of processing can be obtained even if a certain degree of variability is generated in cutting quality, cutting conditions severer than the cutting conditions considered to be sufficient for obtaining predetermined results of processing should be selected. Therefore, in the case where variability in processing supposed is large, the width of the processing conditions that can be selected may be narrowed.

On the other hand, since variability in the performance of the annular grindstone according to the present embodiment is small, variability in cutting quality is also small when a workpiece is cut by use of the annular grindstone. Therefore, at the time of determining the cutting conditions for cutting a

workpiece by use of the annular grindstone, limitations on the cutting conditions are comparatively small, and the width of selection of the cutting conditions is broadened. Further, when the binder containing a tin-nickel alloy as a main constituent is formed by an electroplating method as described later, the atomic ratio of tin and nickel is liable to be 1:1, so that the binder with a tin content of approximately 67 wt% is easy to produce stably, and productivity is good. For example, in producing the annular grindstone, even when a variation is generated in the composition of the plating solution placed in a plating tank in which electroplating is conducted, the composition of the binder formed is not largely varied. Therefore, the annular grindstone according to the present embodiment is easy to manage the production process thereof.

The annular grindstones 1a and 1b according to the present embodiment are particularly suitable for use of cutting a workpiece formed of a hard material represented by SiC. It is to be noted, however, that the workpiece that can be cut by the annular grindstones 1a and 1b is not limited to this, and, for example, workpieces formed of a material such as a semiconductor such as silicon or a material such as sapphire, glass and quartz may also be

cut. For example, a surface of the workpiece is partitioned by a plurality of streets arranged in a grid pattern, and a device such as an IC or a light emitting diode (LED) is formed in each of the regions partitioned. Finally, the workpiece is divided along the streets, whereby individual device chips are formed.

Next, a manufacturing method for the annular grindstone 1a of the washer type depicted in FIG. 1A will be described. FIG. 2 is a sectional view schematically depicting a manufacturing process for the annular grindstone 1a consisting of a grindstone section. The annular grindstone 1a is formed by such a method as electroplating. In the manufacturing method, first, a plating bath tank 2 filled with a plating solution 16 with abrasive grains mixed therein is prepared. The plating solution 16 is an electrolytic solution in which a salt containing nickel and a salt containing tin are dissolved. Each of the salts is any one of, for example, sulfate, sulfamate, chloride, bromide, acetate, citrate, and pyrophosphate. The salts are put into the plating solution 16 in such a manner that the atomic ratio of nickel and tin will be approximately 1:1. It is to be noted, however, that even in the case where the atomic ratio of the ions contained in the plating solution 16 is

not 1:1, the composition of the plating layer to be formed is hardly influenced. In other words, management of the plating liquid 16 is easy.

Further, it may be recommendable to add a fluoride such as ammonium bifluoride or sodium fluoride to the plating solution 16. Alternatively, it may be recommendable to add an alpha amino acid such as glycine to the plating solution 16. When such an additive is introduced into the plating solution 16, the precipitation potentials of Sn^{2+} and Ni^{2+} are brought closer to each other. In addition, the plating solution 16 further has abrasive grains such as diamond abrasive grains mixed therein. After a plating bath tank 2 is prepared, a base 20a on which a grindstone section 3a is to be formed by electroforming and a nickel electrode 6 are immersed in the plating solution 16 in the plating bath tank 2. The base 20a is formed, for example, in a circular disk shape from a metallic material such as stainless steel or aluminum, and a mask 22a having an opening in a shape corresponding to the shape of the desired grindstone section 3a is formed on a surface of the base 20a. Note that in the present embodiment, the mask 22a is formed such that a circular annular grindstone 1a can be formed.

The base 20a is connected to a minus terminal (negative electrode) of a DC power source 10 through a switch 8. On the other hand, the nickel electrode 6 is connected to a plus terminal (positive electrode) of the DC power source 10. It is to be noted, however, that the switch 8 may be disposed between the nickel electrode 6 and the DC power source 10. Thereafter, with the base 20a as a cathode and with the nickel electrode as an anode, a DC current is passed through the plating solution 16, whereby a plating layer is deposited on the surface of the base 20a that is not covered with the mask 22a. As illustrated in FIG. 2, while rotating a fan 14 by a rotational drive source 12 such as a motor to stir the plating solution 16, the switch 8 disposed between the base 20a and the DC power source 10 is turned on.

FIG. 3A is a sectional view schematically depicting the plating layer 24a thus formed. When the plating layer 24a has reached a predetermined thickness, the switch 8 is cut off, to stop the deposition of the plating layer 24a. The plating layer 24a is a tin-nickel alloy in which the diamond abrasive grains are dispersed uniformly. Thereafter, the whole of the base 20a is removed, and the plating layer 24a is peeled off from the base 20a. FIG. 3B is a sectional view schematically depicting the

removal of the base 20a. As a result, the grindstone section 3a that includes the binder including the tin-nickel alloy and the abrasive grains dispersed and fixed in the binder can be formed, and the annular grindstone 1a of the washer type is completed.

Next, a manufacturing method for an annular grindstone 1b of the hub type depicted in FIG. 1B will be described. FIG. 4 is a sectional view schematically depicting the manufacturing method for the annular grindstone 1b including a grindstone section and an annular base. Like the annular grindstone 1a, the annular grindstone 1b is formed, for example, by such a method as electroplating in a plating bath tank 2. In the manufacturing method, a plating bath tank similar to that in the manufacturing method for the annular grindstone 1a is prepared. The configurations of the plating bath tank 2 and the plating solution 16 are similar to those in the manufacturing method for the annular grindstone 1a described above, and therefore, description thereof is omitted. It is to be noted, however, that a part of the base 20b connected to the negative electrode of the DC power source 10 is an annular base 5 supporting the grindstone section 3b of the annular grindstone 1b, and therefore, the shape of the base 20b is a shape

corresponding to the annular base 5. In addition, a mask 22b having an opening corresponding to the shape of the grindstone section 3b is formed on the surface of the base 20b. Then, similarly to the manufacturing method for the annular grindstone 1a described above, a plating layer is deposited on an exposed part of the base 20b.

FIG. 5A is a sectional view schematically depicting the plating layer 24b formed on the surface of the base 20b. After the plating layer 24 is formed in a predetermined thickness, as depicted in FIG. 5A, a part of the base 20b is removed to expose a part of that region of the plating layer 24b which has been covered with the base 20b. In addition, prior to carrying out the base removing step, the mask 22b is preliminarily removed from the base 20b. Then, as depicted in FIG. 5B, an outer peripheral region on the side of the base 20b on which the plating layer 24b is not formed is partially etched, to expose a part of that region of the plating layer 24b which has been covered with the base 20b. As a result, the annular grindstone 1b of the hub type in which the grindstone section 3b is fixed to the outer peripheral region of the annular base 5 is completed.

[Example]

In the present embodiment, an annular grindstone 1a

having a grindstone section 3a that includes a binder including a tin-nickel alloy and abrasive grains dispersed and fixed in the binder is produced. The annular grindstone thus produced is referred to as an example blade. Using the example blade, an SiC single crystal substrate as a workpiece is cut, the workpiece after the cutting is observed, and the size of damages such as chipping generated in the workpiece is measured. In addition, the diameter of the example blade after the cutting is measured, and the measured value is compared with the diameter of the example blade before the cutting, to calculate a consumption amount. Besides, in the present embodiment, for comparison, an annular grindstone having a grindstone section that includes a binder including nickel and abrasive grains dispersed and fixed in the binder is produced. The annular grindstone thus produced is referred to as a comparative example blade. Using the comparative example blade, an SiC single crystal substrate is cut similarly to the above, the size of damages such as chipping generated in the workpiece is measured, and the consumption amount is calculated.

First, the respective annular grindstones 1a produced will be described. The thickness of the example blade is set in such a manner that the width of a cut

groove formed in a workpiece when the workpiece is cut would be 25 to 30 μm . In the grindstone section, a tin-nickel alloy is used as the binder, and diamond abrasive grains are used as the abrasive grains. Here, the content of tin in the tin-nickel alloy is set to 67 wt%. In addition, as the diamond abrasive grains, abrasive grains of a grain size of #2000 are used. For the grain size, refer to JIS R 6001-2:2017 (Bonded abrasives-Determination and designation of grain size distribution-Part 2: Microgrits) enacted by Japanese Industrial Standards Committee (JISC). In addition, the degree of concentration of the abrasives is set to 50. Note that the comparative example blade is produced similarly to the example blade, except that nickel (100 wt%) is used in place of the tin-nickel alloy as the binder.

As a workpiece to be cut by the example blade and the comparative example blade, a disk-shaped SiC single crystal substrate having a thickness of 130 μm and a diameter of 4 inches is prepared. In the present embodiment, a pressure sensitive adhesive tape is adhered to the back side of the SiC single crystal substrate, the SiC single crystal substrate is placed on a holding table of a cutting apparatus through the pressure sensitive adhesive tape, and the SiC single crystal substrate is

held on the holding table. Besides, the example blade or the comparative example blade is mounted to a cutting unit of the cutting apparatus.

The example blade or the comparative example blade mounted to the cutting unit is rotated at a speed of 50,000 rpm, the cutting unit is positioned at a predetermined height position, and the holding table and the cutting unit are put into relative movement in a direction parallel to a holding surface of the holding table. As a result, the rotating example blade or comparative example blade cuts the SiC single crystal substrate, whereby the SiC single crystal substrate is divided. In this instance, a lower end of the example blade or the comparative example blade is set at such a height as to be positioned at a height position approximately 30 μm below the upper surface of the pressure sensitive adhesive tape adhered to the back side of the SiC single crystal substrate. In other words, the SiC single crystal substrate is cut together with part of the pressure sensitive adhesive tape by the cutting unit, to divide the SiC single crystal substrate. In addition, the relative velocity of the holding table and the cutting unit is set to 5 mm/sec.

After the SiC single crystal substrate is cut, the

back side of the SiC single crystal substrate is observed under an optical microscope, to detect damages such as chipping. Specifically, the SiC single crystal substrate is cut from one end to the other end in 15 lines, and the SiC single crystal substrate is observed along each of the lines. The size of a maximum one of the chippings generated in each line is measured. Table 1 below sets forth the size of the maximum one of the chippings confirmed in each line of the SiC single crystal substrate cut, in the case where the example blade is used and in the case where the comparative example blade is used. In addition, FIG. 6 depicts distribution status of the size of the maximum chipping confirmed in each line.

[Table 1]

Line number	Comparative example blade (μm)	Example blade (μm)
1	8.0	5.5
2	25.6	11.0
3	14.5	5.7
4	21.9	6.0
5	34.1	10.8
6	34.1	9.0

7	29.2	8.0
8	13.6	9.3
9	37.7	6.1
10	20.1	8.2
11	31.9	7.2
12	29.5	13.3
13	29.6	8.4
14	31.0	10.9
15	37.7	6.6

Note that the size of the maximum one of the chippings confirmed in the SiC single crystal substrate when the example blade is used is 13.3 μm , and the average of the sizes of maximum chippings in the lines is 8.4 μm . Further, in regard of the distribution of the sizes of the maximum chippings in the 15 lines, a value obtained by adding 3σ to the average is 15.4 μm . In other words, it is understood that when the SiC single crystal substrate is cut by use of the example blade, chippings in excess of 15.4 μm are hardly generated. On the other hand, the size of the maximum one of the chippings confirmed in the SiC single crystal substrate when the comparative example blade is used is 37.7 μm , and the average of the sizes of maximum chippings in the lines is 26.6 μm . Further, in regard of the distribution of the

sizes of the maximum chippings in the 15 lines, a value obtained by adding 3σ to the average is $53.8\text{ }\mu\text{m}$. In other words, it is understood that when the SiC single crystal substrate is cut by use of the comparative example blade, chippings of equal to or less than $53.8\text{ }\mu\text{m}$ may be generated. Therefore, it has been confirmed from the present embodiment that the annular grindstone in which the binder including the tin-nickel alloy is provided at the grindstone section can perform cutting with extremely high quality, even in the case where the workpiece is a hard material.

Further, as a consumption amount of the blade when the SiC single crystal substrate is cut until a cutting length of 5 m is reached, using the example blade or the comparative example blade, variation in the diameter of each of the blades is measured. As a result, while the consumption amount of the example blade is $14.7\text{ }\mu\text{m}$, the consumption amount of the comparative example blade is $2.5\text{ }\mu\text{m}$. From this result, it is understood that the example blade is liable to be consumed more by cutting of a workpiece as compared to the comparative example blade, and permits the self-sharpening action to be positively generated. In other words, the annular grindstone in which the binder including the tin-nickel alloy is

provided at the grindstone section ensures that its cutting performance is maintained by the self-sharpening action, even when used to cut the workpiece. Therefore, it has been suggested that the workpiece can be cut with high quality by the annular grindstone since the self-sharpening action is sufficiently generated.

As has been described above, according to the present embodiment, there is provided an annular grindstone which is able to cut a hard material such as an SiC wafer with high quality. The annular grindstone according to the present embodiment is similar in shape to the existing annular grindstones, and therefore, can be easily mounted to an existing cutting apparatus. For this reason, it becomes possible to perform high-quality cutting of hard materials by the existing cutting apparatus, so that processing cost for the workpiece is suppressed. Further, since a new use is imparted to the existing cutting apparatus, the value of the existing cutting apparatus is enhanced.

Note that while a case of dividing a workpiece by cutting the workpiece with the annular grindstone has been described in the above embodiment, the annular grindstone according to a mode of the present invention may be used for other purposes. For example, the annular

grindstone may be made to cut into a workpiece with such a cutting depth as not to reach the back side of the workpiece, to form a cut groove whose bottom surface does not reach the back surface of the workpiece. In this case, also, the annular grindstone according to one mode of the present invention can cut the workpiece with high quality.

The present invention is not limited to the details of the above described preferred embodiment. The scope of the invention is defined by the appended claims and all changes and modifications as fall within the equivalence of the scope of the claims are therefore to be embraced by the invention.

WHAT IS CLAIMED IS:

1. An annular grindstone comprising:
a grindstone section that includes a binder and abrasive grains dispersed and fixed in the binder, wherein
the binder includes a tin-nickel alloy.
2. The annular grindstone according to claim 1, wherein
a content of tin in the tin-nickel alloy is equal to or more than 57 wt% and less than 75 wt%.
3. The annular grindstone according to claim 1, consisting of the grindstone section.
4. The annular grindstone according to claim 1, further comprising:
an annular base having a grip section, wherein
the grindstone section is exposed to an outer peripheral edge of the annular base.