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(54) PROCESS FOR THE MULTIPLE LAP CUTTING OF SOLID MATERIALS

(71) We, WACKER-CHEMITRONIC, GESELLSCHAFT FÜR ELEKTRONIK-GRUNDSTOFFE MBH., a body corporate organised according to the laws of the Federal Republic of Germany, of Johannes-Hess-Strasse 24, 8263 Burghausen, Federal Republic of Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a process for the multiple lap cutting of a solid material, especially an oxidic material (for example sapphire or ruby) or a semiconductor material (for example silicon or germanium), which comprises sawing the material by means of a set of straight blades with a to-and-fro movement through a suspension of a lap-cutting abrasive.

The sawing of semiconductor rods of, for example, silicon or germanium into wafers is often carried out using circular saws with centrally chucked saw blades which may, for example, be of nickel or steel, studded with small diamond chips on their cutting edges. In order for the circular saw blades to have sufficient stability and thus in order to ensure a straight cut, the saw blades have to be relatively thick. This results in the disadvantage that there is a fairly high loss of material on sawing.

This disadvantage can be overcome by using saws having circular blades that are chucked at their peripheries and that have central holes of a few centimetres diameter. The edges of the holes are studded with diamond particles and these edges serve as the cutting edges. Thinner blades may be used with this arrangement, with the result that the loss of material on cutting is reduced.

Both of these cutting methods, however, have several disadvantages, which become manifest in various defects in the cut discs. The most serious of these defects is microsplitting, especially microcracks, which, in an extreme case, can pass through the entire crystal, in which case they cannot be removed by subsequent operating steps such as etching or lapping. Irregular damage to the surface layer of the wafers also often occurs during sawing and this cannot always readily be removed by etching alone or, if it can be removed by etching, it is necessary to remove a relatively thick surface layer. Moreover, wafers that have been cut using circular saws or inner-hole saws sometimes bow, that is to say they are not completely flat or uniformly thick, and this can cause faults in the further processing of the discs to form electronic components.

These disadvantages of damage to the wafers can be overcome using conventional band saws having straight saw blades. Unlike the band saws conventionally used for cutting timber or stone, which have shaped saw blades and which have a cutting substance bonded to the blades, the band saws used for cutting oxidic materials and semiconductor materials generally have smooth steel blades and cutting is carried out by passing the blades through a suspension of a lap-cutting abrasive, for example diamond powder, in a coolant. Several such blades may be combined in a gang saw, which has the considerable advantage of increasing the cutting efficiency. A gang saw of this type is, for example, described in DE-PS 20 39 699. Although wafers cut by this method do have some surface damage, this is fairly uniform and can usually be eliminated by etching away only a thin surface layer. Moreover, wafers cut by this method are generally bow-free, that is to say they are uniformly flat and do not bow. This cutting method also has the advantage that the loss of material during cutting is considerably less than the loss obtained when using circular saws, because the cutting speed is much lower.

The severe disadvantage of this method, however, is that, even when using a gang saw having about 240 blades, the sawing time per wafer is about twice that required when using inner-hole saws. Semiconductor wafers are being required in increasing quantities and at decreasing cost – for example, there is an increasing need to develop energy sources to replace fossil energy sources which are expected to run low in the foreseeable future, and one such energy source is the solar cell, but at present solar cells cannot be produced sufficiently economically for industrial use. Thus, in addition to manufacturing silicon of the required purity at decreased cost, there is a need to reduce the processing costs and one way of doing this is to reduce the cost of sawing silicon rods and blocks.

The present invention provides a process for the multiple lap cutting of a solid material, which comprises sawing the material by means of a set of straight blades each having a free working length within the range of from 110 to 250 mm, with a to-and-fro movement through a suspension of a lap-cutting abrasive, at a mean speed within the range of from 30 to 150 m/min, while exerting a force within the range of from 100 to 1000 gf per blade.

The process according to the invention has the advantages of the above-mentioned sawing method using band saws and reduces the disadvantages of the use of such saws by enabling solid materials, for example silicon, to be sawn at an increased rate.

The process according to the invention may be carried out using gang saws or lap-cutting machines such as those described in DE-PS 20 39 699 with certain modifications. In such a saw, the several blades are separated from one another by spacer discs. The number of blades in the saw is advantageously as high as possible in order to give as great a cutting efficiency as possible, although the number of blades used is obviously limited by the length of the rod or other solid material to be cut.

The blades used in the process of the invention are advantageously made of steel that may be obtained at a reasonable price, because the blades are normally discarded after being used once. This is because the blades essentially serve merely for guiding the cutting particles through the material to be sawn and this results in abrasion, not only of the material to be sawn, but also of the steel blades. A suitable material for the blades is spring band steel having a tensile strength within the range of from 120 to 250 kgf/mm^2, preferably from 200 to 240 kgf/mm^2.

Because of the increased pressure used in the process according to the invention as compared with conventional processes using band saws, blades having a shorter free working length have to be used. The blades used according to the process of the invention each have a free working length within the range of from 110 to 250 mm, preferably from 180 to 220 mm. The shorter are the blades, the greater is the force that can be exerted during sawing without distortion of the blade. By "the free working length" of the blades is meant that length of blade that is situated between the mountings at either end and that is available for cutting. The blades advantageously each have a depth within the range of from 5 to 10 mm, preferably from 5 to 7 mm, and a width within the range of from 100 to 300 μm, preferably from 150 to 250 μm. It is, of course, preferable to use blades that are as thin as possible in order to reduce the loss of material during cutting, and this may generally be achieved by using relatively short blades: only when using relatively long blades and a relatively high force is it necessary to use blades having a thickness toward the upper end of the mentioned ranges.

According to the process of the invention, a force within the range of from 100 to 1000 gf per blade, preferably from 100 to 400 gf per blade, is exerted during sawing. This force is, however, generally fully brought to bear only when all blades in the set of blades being used are biting into the rod. If the material to be cut had surface irregularities, only some of the blades may initially be in contact with the material to be cut and, if the full force were brought to bear on the set of blades at this stage, it would be effective only on those blades in contact with the material to be cut, with the result that the force on these blades would be undesirably high and could cause distortion or even breakage of these blades.

In previously used processes for cutting semiconductor materials using band saws, cutting has generally been effected at a mean speed of about 27 m/min at the maximum, whereas according to the process of the invention cutting is effected at a mean speed within the range of from 30 to 150 m/min, preferably from 90 to 120 m/min. This increased speed is achieved by increasing the frequency by which the blades are moved backward and forward through the material to be cut. The actual speed used depends on the length of the blades and on the dimension in the direction of cutting of the material to be cut and, in simple terms, may be given by the formula

$$V = (\frac{l-\epsilon}{2}).\nu.c$$

in which l denotes the free working length of the blade, ϵ denotes the dimension of cutting of the material to be cut, ν denotes the frequency, V denotes the speed of cutting, and c denotes a constant (0.24). The cutting speed should not be greater than 150 m/min, because it has been found that, at a speed slightly greater than this, the degree of abrasion drops abruptly to almost zero, this effect being similar to that familiar to motorists as aquaplaning.

When using frequencies up to about 20

Hz, the set of blades may be driven by means of a conventional crank drive having a connecting rod moved by means of a crank disc. When using frequencies higher than this, however, with mean speeds of more than about 90 m/min, drive mechanisms of this type are not suitable because of the enormous acceleration forces involved. In this case, it is necessary to use drive mechanisms operated by means of linear motors, electromagnetic drive mechanisms or, preferably, drive mechanisms operated by means of servohydraulic drives, such as those available under the Trade Mark "Hydropuls" from Messrs. Schenck, Darmstadt, Federal Republic of Germany, in which the acceleration and breaking forces occurring are controlled by an oil pressure cylinder.

In order to effect cutting, the blades are passed through a suspension of a lap-cutting abrasive. Lap-cutting abrasives such as are used for the multiple lap cutting of solid materials with band saws or wire saws may be used in the process according to the invention. The cutting particles used in the lap-cutting abrasives may be, for example, corundum powder, silicon carbide, boron carbide, cubic boron nitride, and diamond powder; the hardness of these materials, and thus their life, increases in the order given. The cutting particles preferably have a particle size within the range of from 10 to 50 μm. They are generally suspended in an oil, for example, a mineral oil fraction having an average viscosity within the range of from 30 to 60 cP. The weight of cutting particles to oil is preferably within the range of from 1:10 to 1:3.

Alternatively, a lap-cutting abrasive as described and claimed in GB-PS 19263/78 Serial No. 1597928 may be used in the process according to the invention. The lap-cutting abrasive comprises cutting particles having an average particle size within the range of from 10 to 50 μm suspended in a low-viscosity carrier liquid, the weight ratio of cutting particles to carrier liquid being within the range of from 1:1 to 3:1.

The process according to the invention is especially suitable for cutting semiconductor materials, for example silicon, germanium, or III-V compounds (for example gallium arsenide and gallium phosphide), and oxidic substances, for example, sapphire, spinel and ruby, but it may also be used for cutting relatively soft substances, for example hexagonal boron nitride. The lap-cutting abrasive used obviously depends on the material to be cut; for example, sapphire or spinel may be cut economically only by using cubic boron nitride or diamond powder.

The following Example 1 illustrates a process for the multiple lap cutting of a silicon rod by means of a conventional process and Example 2 illustrates the process according to the invention.

In each example, a monocrystalline silicon rod of square cross-section and measuring 220 mm − 50 mm − 50 mm was sawn, transversely to the longitudinal axis, into a plurality of wafers.

Example 1

Sawing was carried out using a gang saw manufactured by Meyer & Burger AG., Steffisburg, Switzerland (type GS 1). The saw had 240 blades, each having a thickness of 200 μm, a depth of 6 mm, and a free working length of 355 mm. The blades were placed on the rod and moved over the crystal in the usual manner at a low initial speed of only a few m/min, with very little pressure. When all the blades had started to bite into the rod, the speed was increased to 27 m/min and the force was increased to 60 gf per blade.

A lap-cutting abrasive consisting of silicon carbide having a particle size distribution of 27 to 30 μm suspended in a mineral oil fraction having a viscosity of 45 cP, the weight ratio of mineral oil to silicon carbide being 3:1, was used.

239 silicon wafers each having a thickness of 470 μm were obtained after a total sawing time of 24.5 hours, which corresponds to a sawing efficiency of 0.017 cm^2/min/blade.

Example 2

The gang saw used was similar to that used in Example 1 except that it was modified for use with shorter blades at a higher speed and an increased pressure. The free working length of each blade was 200 mm, the other dimensions being the same as in Example 1. Again sawing was commenced at a low speed and with little pressure, but after all the blades had started to bite into the rod, the speed was increased to 45 m/min and the force was increased to 180 gf per blade. The lap-cutting abrasive used was the same as in Example 1.

239 wafers each having a thickness of 470 μm were obtained after a total sawing time of 2.6 hours, corresponding to a sawing efficiency of 0.16 cm^2/min/blade.

WHAT WE CLAIM IS:

1. A process for the multiple lap cutting of a solid material, which comprises sawing the material by means of a set of straight blades each having a free working length within the range of from 110 to 250 mm, with a to-and-fro movement through a suspension of a lap-cutting abrasive, at a mean speed within the range of from 30 to 150 m/min, while exerting a force within the range of from 100 to 1000 gf per blade.

2. A process as claimed in claim 1, wherein each blade has a free working length within the range of from 180 to 220 mm.

3. A process as claimed in claim 1 or

claim 2, wherein the mean speed is within the range of from 90 to 120 m/min.

4. A process as claimed in any one of claims 1 to 3, wherein the force is within the range of from 100 to 400 gf per blade.

5. A process as claimed in any one of claims 1 to 4, wherein each blade has a depth within the range of from 5 to 10 mm.

6. A process as claimed in claim 5, wherein each blade has a depth within the range of from 5 to 7 mm.

7. A process as claimed in any one of claims 1 to 6, wherein each blade has a width within the range of from 100 to 300 μm.

8. A process as claimed in claim 7, wherein each blade has a width within the range of from 150 to 250 μm.

9. A process as claimed in any one of claims 1 to 8, wherein the blades are of spring band steel having a tensile strength within the range of from 120 to 250 kgf/mm^2.

10. A process as claimed in claim 9, wherein the blades are of spring band steel having a tensile strength within the range of from 200 to 240 kgf/mm^2.

11. A process as claimed in any one of claims 1 to 10, wherein the lap-cutting abrasive is a lap-cutting abrasive as claimed in British Patent Specification No. 19263/78 Serial No. 1597928.

12. A process as claimed in claim 1, carried out substantially as described in Example 2 herein.

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