

## HIGH POROSITY VITRIFIED SUPERABRASIVE PRODUCTS AND METHOD OF PREPARATION

### CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application Serial  
5 No. 61/132,808, filed June 23, 2008, incorporated herein by reference.

### BACKGROUND OF THE INVENTION

Since this world is moving towards thinner and smaller devices, the requirements for thinner wafers (less than 50 microns) is growing. To achieve higher strength of ground silicon wafers, use of smaller grains will be required.  
10 During grinding, a decrease in the size of the grain in the composite microstructure will decrease the force required to reduce the effective chip thickness coming out of the wafer. As a result of reduced chip thickness, the strength of the final ground silicon wafers will increase. In addition, new developments in wafer manufacturing technology are moving toward wafers of larger size, thereby causing increasing  
15 difficulty in maintaining flatness of a wafer during the grinding process.

Many conventional abrasive tools employed in roughing and finishing these materials include metal-bonded superabrasive. Metal-bonded abrasive tools generally grind fewer parts per hour than glass-bonded tools. Further, metal-bonded abrasive tools can contaminate surfaces of components to be incorporated into  
20 electronic devices, thereby severely limiting their use for grinding applications or slicing silicon wafers.

Typically, vitrified bonded tools offer a higher stiffness and low degradation, thereby resulting in better tolerances, flatness in product and an increase number of parts that can be produced per wheel. Although vitrified bonded grinding tools could  
25 be employed having a lower grit size, they typically do not have sufficient self-dressing ability due to low porosity or pore structure.

Resin bonds are often exhibit higher wear and have a self-dressing ability. Typically, the relatively low stiffness of resin bonds produces lower surface

roughness or a better finish than grinding tools that employ a vitrified bond and grains of similar grit size. However, resin bonds typically can not be used where grit size is lower than 2 microns because the grains are pushed inside of the compliant resin bond during grinding, thereby requiring higher applied pressure and,  
5 consequently, causing elevated temperature at the grinding surface. As a result, when particularly applied to larger wafers, maintaining an acceptable flatness of the wafer during grinding becomes more difficult.

A preferred structure for backgrinding will be resin bonded superabrasive  
10 wheels. Life of the resin bonded superabrasive wheels is not at all attractive with smaller grains. Therefore, there is a need for a high porosity vitrified superabrasive wheel with finer grains with a self-dressing ability.

#### SUMMARY OF THE INVENTION

15 The invention generally relates to a vitrified diamond superabrasive product, and a method of making the vitrified superabrasive product.

The vitrified superabrasive product of the invention includes a superabrasive component and a vitrified bond component in which the superabrasive component is dispersed, wherein the vitrified bond component defines pores occupying greater  
20 than about 50% of the total volume at the vitrified superabrasive product.

In another embodiment, the invention is a vitrified superabrasive that includes a vitrified bond component including silica and having a porosity of at least about 50% of the total volume of the vitrified diamond abrasive. A superabrasive component is dispersed in the vitrified bond component. The superabrasive  
25 component consists essentially of particles having a number average particle size in a range of between about 0.5 microns and about 60 microns, and wherein the volume ratio of the superabrasive component to the vitrified bond component is in a range of between about 3:2 and about 1:99.

In still another embodiment, the invention is directed to a grinding tool that  
30 includes a base and a vitrified superabrasive component at a surface of the base. The vitrified superabrasive component includes a superabrasive component and a

vitrified bond component in which the superabrasive component is dispersed. The vitrified bond component defines pores occupying greater than about 50% of the total volume of the vitrified superabrasive component.

In still another embodiment, the invention is a superabrasive mixture,  
5 comprising a glass powder, a superabrasive grit, a binder and a silicon carbide. In a specific embodiment, the glass powder includes at least one member selected from the group consisting of silicon dioxide ( $\text{SiO}_2$ ), boron oxide ( $\text{B}_2\text{O}_3$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), alkali oxides ( $\text{Li}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ) and alkaline earth oxides ( $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{BaO}$ ). The superabrasive grit includes diamond particulates having a number  
10 average particle size in a range of between about 0.5 microns and about 60 microns, and wherein the volume ratio of the superabrasive grit to glass particles in a range of between about 3:2 and about 1:99. The binder includes at least one member selected from a group consisting of polyethylene glycol, water, a mixture of polyethylene glycol and water, and colloidal silica. Silicon carbide is present in the form of  
15 particles having a number average size in a range of between about 0.1 microns and about 20 microns. The silicon carbide is present in the mixture in a range of between about 0.1 and about 5 volume percent of the total amount of glass powder, superabrasive grit, binder and silicon carbide components of the mixture.

In a further embodiment, the invention is directed to a method of forming a  
20 vitrified superabrasive, comprising the steps of forming a green body from the mixture of a glass powder, a superabrasive grit, a binder and silicon carbide. The green body is fired under an atmosphere and pressure, and at a temperature, sufficient to cause the silicon carbide to oxidize.

This invention has several advantages. For example, use of silicon carbide  
25 as a foaming agent provides relatively high porosity for a vitrified product. The product, therefore, has the advantages of being able to bind superabrasive particles having relatively small size and yet has sufficient porosity to be self-dressing without sacrificing the strength necessary to effectively polish larger silicon wafers. As a consequence, the vitrified superabrasive products of the invention produce  
30 relatively low surface roughness and better finish than typically is obtained by vitrified bond abrasive products, while retaining the advantages of vitrified superabrasive tools.

Porosity plays an important role in grinding. Porosity controls the contact area between the work piece and the composite microstructure. Porosity also facilitates movement of coolant around the microstructure to keep the grinding surface temperature as low as possible.

5           The homogeneity of the structure defined by tight distribution of the pore sizes around mean sizes of pores directly relates to a consistent and steady grinding performance. Much bigger pores than the mean size of pores act as defects and adversely affect the consistency of grinding. Moreover, the aspect ratio provides another measure for the homogeneity of the structure. A value close to 1 indicates  
10   high degree of homogeneity. This invention provides a combination of tight distribution of pore sizes, low defect content and an aspect ratio close to 1.

#### BRIEF DESCRIPTION OF THE DRAWING

          The Figure is a cross-section of one embodiment of a tool that employs a  
15   vitrified superabrasive product of the invention.

#### DETAILED DESCRIPTION OF THE INVENTION

          The foregoing will be apparent from the following more particular description of example embodiments of the invention, as illustrated in the  
20   accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating embodiments of the present invention.

          The invention is generally related to vitrified superabrasive products, their precursors, and methods of their manufacture.

25           “Superabrasive,” as that term is employed herein, means abrasives having a hardness, as measured on the Knoop Hardness Scale of at least that of cubic boron nitride (CBN), i.e., a  $K_{100}$  of at least 4,700. In addition to cubic boron nitride, other examples of superabrasive materials include natural and synthetic diamond. Suitable diamond or cubic boron nitride materials can be crystalline or  
30   polycrystalline. Preferably, the superabrasive material is diamond.

The superabrasive material is in the form of grain, also known as “grit.” The superabrasive grain component of the invention can be obtained commercially or can be custom-produced. Generally, the superabrasive employed in the present invention has a number average particle size in a range of between about 0.5  
5 micrometers (microns,  $\mu\text{m}$ ) and about 60  $\mu\text{m}$ . Preferably, the particle size is in a range of between about 1  $\mu\text{m}$  and about 60  $\mu\text{m}$ . A particularly preferred size is 1-2  $\mu\text{m}$ . “Number average,” as that term is employed herein, means the median, or the value where one-half of the particle population is above the value and one-half is below the value.

10 In one embodiment, the superabrasive grain component is present in an amount of at least about 0.1% by volume of the superabrasive tool. In another embodiment, the superabrasive grain component is present in an amount in a range of between about 1% and about 20% by volume of the superabrasive tool, more preferably between about 2% and about 10% by volume of the superabrasive tool.

15 In one embodiment, the vitrified superabrasive product of the invention includes a superabrasive component that includes at least one member selected from the group consisting of diamond, cubic boron nitride, zirconia and aluminum oxide.

In one embodiment, the superabrasive component of the vitrified superabrasive product is diamond. In a particularly preferred embodiment, the  
20 volume ratio of diamond to vitrified bond component of the vitrified superabrasive is in a range of between about 3:2 and about 1:99.

The vitrified bond component is a suitable vitrified bond component, such as is known in the art. Examples of suitable vitrified bond components include at least one member selected from a group consisting of silicon dioxide ( $\text{SiO}_2$ ), boron oxide  
25 ( $\text{B}_2\text{O}_3$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), alkali oxides ( $\text{Li}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ) and alkaline earth oxides ( $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{BaO}$ ).

Typically, the vitrified superabrasive product of the invention as configured at least a component of a grinding tool. An example of a suitable grinding tool is a wheel.

30 In one preferred embodiment, the vitrified superabrasive product is a fixed abrasive vertical spindle (FAVS). An example of a FAVS, is shown in the Figure. As shown in the Figure, tool 10 is configured as a wheel having a base 12 about an

axis 14. Raised perimeter 16 of wheel supports abrasive segment 18 about the perimeter of base 12. Abrasive segment is one embodiment of a vitrified superabrasive product of the invention. Typically, base will have a diameter in a range of between about six inches and about twelve inches, the height of the  
5 abrasive segment will be in a range of between about 2 millimeters (mm) and about 20 millimeters and have a width of between about 2 millimeters and about 10 millimeters. Wheels, as described with reference to the Figure, are suitable for wafer grinding by rotation about their axis. In a direction counterclockwise to a rotation of the axis of a wafer being ground by the tool. Methods for grinding wafers by use of  
10 grinding wheels as generally described with respect to the Figure are known in the art.

In another embodiment, the invention is a superabrasive mixture that includes a glass powder, a superabrasive grit, a binder and silicon carbide. In a particularly preferred embodiment the superabrasive grit includes diamond  
15 particulate. Generally, the volume ratio of superabrasive grit to glass powder is in a range of between about 3:2 and about 1:99. Examples of suitable glass powder include silicon dioxide ( $\text{SiO}_2$ ), boron oxide ( $\text{B}_2\text{O}_3$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ) and potassium oxide ( $\text{K}_2\text{O}$ ). Preferred glass powder, or "frits," are those that have relatively low glass transition such as in a range of between about 450°C and about  
20 800°C.

Examples of suitable binder include polyethylene glycol, water, a mixture of polyethylene glycol and water and colloidal silica.

In one embodiment, the SiC is 1200 grit "37C" SiC from Saint-Gobain Ceramics & Plastics, Inc., Worcester, MA. Preferably, the silicon carbide is present  
25 in the mixture in a range of between about 0.1 and about 5 volume percent of the total amount of glass powder, abrasive grit, binder and silicon carbide components of the mixture.

In one particular preferred embodiment, the superabrasive mixture includes a glass powder that includes at least one member selected from a group consisting of  
30 silicon dioxide ( $\text{SiO}_2$ ), boron oxide ( $\text{B}_2\text{O}_3$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), alkali oxides ( $\text{Li}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ) and alkaline earth oxides ( $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{BaO}$ ). The abrasive grit of the superabrasive mixture includes a diamond particulate having a number

average particle size in a range of between about 0.5 microns and about 60 microns, and wherein the mass ratio of the superabrasive to glass particles is in a range of between about 3:2 and about 1:99. The binder includes at least one member selected from a group consisting of polyethylene glycol, water, a mixture of polyethylene glycol and water and colloidal silica. The silicon carbide of superabrasive mixtures in the form of particles having a number average particle size in a range of between about 0.1 microns and about 20 microns, wherein the silicon carbide is present in the mixture in an amount in a range of between about 0.1 and about 5 volume percent of the total amount of glass powder, abrasive grit, binder and silicon carbide components of the mixture. In one embodiment, the superabrasive mixture is a green body precursor to a vitrified superabrasive product.

A method of forming a vitrified superabrasive product of the invention includes forming a green body that includes a glass powder, a superabrasive grit, a binder and silicon carbide. The green body is fired under an atmosphere and pressure, and at a temperature sufficient to form a porous vitrified superabrasive structure.

The green body, or superabrasive mixture, employed in forming the vitrified superabrasive product, has the features described above with respect to the superabrasive mixture or green body embodiments of the invention. A superabrasive mixture of the invention is formed by combining the components of the mixture in a suitable manner, such as is known in the art. A green body of the invention can be formed from the mixture, also by a suitable method, such as is known in the art. The green body typically is fired under an atmosphere at a temperature in a range of between about 600°C and 820°C for a period of time in a range of between about one-half hour and about ten hours. The fired product is then allowed to cool by a suitable method, such as by naturally-cooling of the furnace, to thereby form the superabrasive product of the invention.

The invention is further described by the following examples which are not intended to be limiting.

#### EXEMPLIFICATION

A high porosity vitrified diamond superabrasive structure of the invention was made by firing a mixture of a superabrasive grain, a glass frit, a binder and a silicon carbide powder. A mixture of the abrasive grain, glass frit and silicon carbide was prepared first and then, binder was added to it. The composition of the mixture in volume percentage, before firing, was: 19% diamond, 80% glass frit, 1% of SiC. Polyethylene glycol in water (PEG) solution was used as binder and it was used in 15 mass percentage of the above mix. The polyethylene glycol was purchased from Union Carbide Corporation, USA. Diamond of grit size 1-2 micron was obtained from Diamond Innovation, Inc, OH, USA. Glass frit used composed of following oxides:  $\text{Al}_2\text{O}_3$ ,  $\text{B}_2\text{O}_3$ ,  $\text{BaO}$ ,  $\text{CaO}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ ,  $\text{Li}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{SiO}_2$ ,  $\text{ZnO}$  and  $\text{ZrO}_2$ .

SiC of 1200 grit was used and it was obtained from Saint-Gobain Ceramics & Plastics, Inc., Worcester, MA USA.

All the components of the mixture except PEG were weighed in a steel bowl to obtain the above-described superabrasive mixture. A steel spoon was used to blend all powder components of the mixture until a visually homogeneous mix was obtained. The blend was then screened three times through a 165 mesh stainless steel mesh. (Generally, the mesh size can range from about 40 to about 400 mesh.) Binder was added to the mixture in the amount specified above. The mixture was again spoon blended until all the binder was integrated into it. The mixture was screened once using a 20 mesh stainless screen mesh to obtain granules. (Generally, the mesh size can range from about 4 to about 60 mesh (stainless).) These granules were spread on wax paper and left to dry for one day. (Generally, the range can be from about 1 hour to about 3 days.) After the drying, granules were screened using a 16 mesh screen. (Generally, the mesh range can be from about 4 to about 60 mesh.)

The theoretical density of the final mixture was calculated using information on their proportion in the mixture. This information was used to obtain the weight of the granules needed to make a disc 5" in diameter (Generally, the range can be from about 1" to about 10") and 0.200" height (Generally, the range can be from about 0.100" to about 5"). To make the green body for firing, dried granules were weighed and transferred into a stainless steel mould 5.00" in diameter and leveled

using a small steel plate. The whole mould setup was now transferred onto a cold isostatic press. A pressure of 1 Ton/in<sup>2</sup> was applied to yield a green body.

(Generally, the range can be from about 0.1 to about 10 Ton/in<sup>2</sup>.)

This green body was transferred into a furnace and following firing schedule  
5 was applied: 5°C/min ramp to 550°C from room temperature, soak for 60 min at 550°C, 5°C/min ramp to 700°C, soak for 240 min at 700°C and the naturally cool down in the furnace. The furnace atmosphere was air. Example of other suitable alternatives include nitrogen, vacuum and argon. (Also, generally, the range of temperature can be from 600°C to about 820°C, and the time for firing can be from  
10 about 0.1 hours to about 10 hours.

The resulting superabrasive product had essentially no pores having a diameter greater than 250 µm. About 80% of the pores had a diameter in a range of between about 100 µm and 200 µm, and the average aspect ratio of the pores was less than about 1.2. Porosity of the superabrasive product was estimated to be in a  
15 range of between about 62% and about 68%.

In other embodiments, essentially no bubbles will be larger than about 800 µm, or no larger than about 500 µm. Further, in preferred embodiments, about 80% of the bubbles will have diameters in a range of between about 60 µm and about 500 µm, or between about 80 µm and about 300 µm. In still other embodiments, about  
20 80% will have a diameter between about 150 µm and about 250 µm, or between about 200 µm and about 300 µm. Further, in preferred embodiments the average aspect ratio (largest:smallest diameter) of the pores is no greater than about 1.5, or no greater than about 1.3. Still further, in another embodiment, the porosity is between about 50% and about 90%, or between about 60% and about 74%.

25 The fired body was dome-shaped. It was lapped into a disc shape to easily cut out segments for making a superabrasive wheel. A speedfame double sided lap unit was employed for lapping. The lap unit used 280/400 grit SiC for lapping. The lapped plate was cut into segments using a waterjet cutting machine. These segments were mounted on a 5" wheel using glue to make a superabrasive wheel of  
30 the invention. A second wheel was then made to the same specification.

The wheels were tested on a backgrinding machine (Disco 840 machine). The wheel was dressed using an extra-fine pad. The wheels were used to grind 8

inch silicon wafers. The silicon wafers were rough ground with a rough wheel followed by fine wheel – the same specification mentioned above. Three different incremental feed rates were used to evaluate the grinding performances. All the feed rates are listed in the table.

5

| Numbers | Feed rates in microns/second | Current in Amps |
|---------|------------------------------|-----------------|
| 1       | 0.2, 0.1, 0.1                | 5.5 - 6.1       |
| 2       | 0.3, 0.2, 0.2                | 7.1 – 7.3       |
| 3       | 0.5, 0.3, 0.2                | 8.4 – 8.6       |

Both the wheels drew current in the comparable range at all the feed rates. During the first and second tests, 25 wafers and 75 wafers were ground, respectively.

10

#### EQUIVALENTS

While this invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the pending claims.

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## CLAIMS

What is claimed is:

1. A vitrified superabrasive product, comprising:
  - a) a superabrasive component; and
  - 5 b) a vitrified bond component in which the superabrasive component is dispersed, wherein the vitrified bond component defines pores that are essentially all less than 800  $\mu\text{m}$  in diameter, eighty percent of which are in a range of between about 60  $\mu\text{m}$  and about 500  $\mu\text{m}$ , have an average aspect ratio less than about 1.5, and have a porosity in a  
10 range of between about 50% and about 90% of the total volume of the superabrasive product.
2. The vitrified superabrasive product of claim 1, wherein the superabrasive  
15 component includes at least one member selected from the group consisting of diamond, cubic boron nitride, zirconia and aluminum oxide.
3. The vitrified superabrasive product of claim 2, wherein the superabrasive  
20 component is present in an amount in a range of between about 0.1 and about 20 volume percent of the vitrified diamond superabrasive.
4. The vitrified superabrasive product of claim 3, wherein the number average  
particle size of the superabrasive component is in a range of between about  
0.5 microns and about 60 microns.
- 25 5. The vitrified superabrasive product of claim 3, wherein the volume ratio of diamond abrasive component to vitrified bond component is in a range of between about 3:2 and about 1:99.
6. The vitrified superabrasive product of claim 1, wherein the vitrified bond  
30 component includes at least one member selected from the group consisting

of silicon dioxide ( $\text{SiO}_2$ ), boron oxide ( $\text{B}_2\text{O}_3$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), alkali oxides ( $\text{Li}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ) and alkaline earth oxides ( $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{BaO}$ ).

- 5     7.     The vitrified superabrasive product of claim 1, wherein the vitrified diamond superabrasive is configured as at least a component of a grinding tool.
8.     The vitrified superabrasive product of claim 7, wherein the grinding tool is a wheel.
- 10     9.     A vitrified superabrasive product, comprising:
- a)     a vitrified bond component including silica and having a porosity of at least about fifty percent of the total volume of the vitrified diamond abrasive; and
- 15     b)     a superabrasive component dispersed in the vitrified bond component, the superabrasive component consisting essentially of particles having a number average particle size in a range of between about 0.5 microns and about 60 microns, and wherein the volume ratio of superabrasive component to the vitrified bond component is
- 20     in a range of between about 3:2 and about 1:99.
10.     A superabrasive mixture, comprising:
- a)     a glass powder;
- b)     a superabrasive grit;
- 25     c)     a binder; and
- d)     silicon carbide.
11.     The superabrasive mixture of claim 10, wherein the superabrasive grit includes a diamond particulate.
- 30     12.     The superabrasive mixture of claim 11, wherein the superabrasive grit has an average particle size in a range of between about 0.5  $\mu\text{m}$  and about 60  $\mu\text{m}$ .

13. The superabrasive mixture of claim 12, wherein volume ratio of superabrasive grit to glass powder is in a range of between about 3:2 and about 1:99.
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14. The superabrasive mixture of claim 10, wherein the silicon carbide is present in the form of particles having a number average particle size in a range of between about 0.1 microns and about 20 microns.
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15. The superabrasive mixture of claim 10, wherein the silicon carbide is present in the mixture in an amount in a range of between about 0.1 and about 5 volume percent of the total amount glass powder, abrasive grit, binder and silicon carbide components of the mixture.
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16. The superabrasive mixture of claim 10, wherein the glass powder includes at least one member selected from the group consisting of silicon dioxide ( $\text{SiO}_2$ ), boron oxide ( $\text{B}_2\text{O}_3$ ), aluminum oxide ( $\text{Al}_2\text{O}_3$ ), alkali oxides ( $\text{Li}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ) and alkaline earth oxides ( $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{BaO}$ ).
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17. The superabrasive mixture of claim 10, wherein the binder includes at least one member selected from the group consisting of polyethylene glycol, water, a mixture of polyethylene glycol and water and colloidal silica.
- 25
18. The superabrasive mixture of claim 10, wherein the mixture is in the form of a green body.