

DESCRIPTION

Process for the preparation of the front face of a polycrystalline silicon carbide slab

5 TECHNICAL FIELD

The invention relates to a process for the preparation of the front face of a polycrystalline silicon carbide slab, to a process for the manufacture of a polycrystalline silicon carbide slab using the process for the preparation of the front face of said slab, and to a process for the preparation of a multilayer structure using the process for the manufacture of a polycrystalline
10 silicon carbide slab.

STATE OF THE ART

Silicon carbide (SiC) is increasingly widely used in power electronics applications, in particular to meet the needs of growing ranges of electronics, such as, for example, electric
15 vehicles. Power devices and integrated power-supply systems based on single-crystal SiC can actually manage a much higher power density than their conventional silicon counterparts, and do so with active regions of smaller size.

Nevertheless, the substrates made of single-crystal SiC intended for the microelectronics
20 industry remain expensive and difficult to supply in large sizes. It is thus advantageous to resort to layer transfer solutions in order to produce composite structures typically comprising a thin layer made of single-crystal SiC (m-SiC) on a lower cost polycrystalline SiC (p-SiC) support substrate.

25 One well-known thin-layer transfer solution is the Smart Cut™ process. Such a process makes it possible, for example, to manufacture a composite structure comprising a thin layer made of single-crystal SiC, withdrawn from a donor substrate made of single-crystal SiC, in direct contact with a support substrate made of polycrystalline SiC.

30 Such a support substrate made of polycrystalline SiC can, for example, be formed by a vapour deposition of p-SiC on a growth substrate (for example a graphite substrate), so as to form a relatively thick p-SiC slab (for example, from 0.4 to 3 mm in thickness), followed by removal of the growth substrate and by thinning of the p-SiC slab, so as to obtain one or more p-SiC wafers having a desired shape (in particular a bevelled periphery) and a desired
35 thickness.

The thinning comprises, for example, successively a very coarse thinning (by electrical discharge machining or grinding), which will remove, for example, a thickness of the order of

150 μm or more, a coarse grinding, which will remove, for example, a thickness of the order of 20 μm , and a fine grinding, which will remove, for example, a thickness of the order of 3 μm . Preferably, such a thinning is carried out on the front and rear faces of the polycrystalline silicon carbide slab. When the polycrystalline silicon carbide slab is thinner, for example with a
 5 thickness of 400 μm , the very coarse grinding can be omitted.

The thinning makes it possible to obtain a self-supporting wafer, that is to say the thickness of which is such that it does not break or deform plastically under the effect of its own weight. Such a thickness is, for example, greater than or equal to 325 μm , preferably of
 10 the order of 350 μm .

The thinning of the slab can be followed by stages of surface finishing of the wafer targeted in particular at rendering it smoother.

15 Nevertheless, it remains difficult to produce high-quality bonding between two single-crystal SiC and polycrystalline SiC substrates, since managing the surface condition and roughness of said substrates is complex.

By way of example, atomic diffusion bonding (ADB) involving a silicon layer of 10 nm
 20 requires a roughness of less than 10 Å RMS. Such bonding comprises the deposition of silicon under vacuum and then bringing the two substrates into contact. The structure is subsequently heated to make possible the diffusion of the silicon and thus the bonding of said substrates.

While the use of a grinding wheel having very small grains (size of less than 1.5 μm , i.e.
 25 a mesh of greater than 15 000) makes it possible to obtain a very low roughness on a single-crystal material, the performance qualities achieved with this same type of grinding wheel on a polycrystalline material, such as polycrystalline silicon carbide, are neither reproducible nor sufficiently satisfactory to make possible effective bonding of a single-crystal SiC substrate to a polycrystalline SiC substrate. This is because the removal of matter by the teeth of such a
 30 type of grinding wheel is non-uniform at the grains and at the grain boundaries, for this reason generating a form of roughness.

Moreover, while chemical mechanical polishing, a smoothing technique known to a person skilled in the art under the name CMP, is an effective process for single-crystal
 35 substrates, this also results in the display of the grain boundaries on a polycrystalline SiC substrate and thus in a roughness which is too great to make possible good bonding of a single-crystal SiC substrate to a polycrystalline SiC substrate.

BRIEF DESCRIPTION OF THE INVENTION

An aim of the invention is to design a process for the preparation of the front face of a p-SiC substrate in order to make possible high-quality bonding of a thin layer of a single-crystal material to said front face.

To this end, the invention provides a process for polishing the front face of a polycrystalline silicon carbide slab comprising a surface region at least partially work-damaged under the effect of grinding, comprising:

- the relative movement of a rotationally driven grinding wheel and of the polycrystalline silicon carbide slab up to the removal from the polycrystalline silicon carbide slab, with the rotating grinding wheel in contact with the front face of the slab, of a layer comprising the at least partially work-damaged surface region and exhibiting a thickness of less than or equal to 3 μm ,

- the halting of the relative movement and the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time of greater than 15 seconds.

The holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time makes it possible to use the grinding wheel in "rubbing" mode in order to polish the front face of the p-SiC slab, without removing matter. The displaying of the grain boundaries of the p-SiC substrate observed in more conventional polishing processes, such as chemical mechanical polishing, is then avoided, which thus makes it possible to obtain a level of roughness of the front face compatible with the bonding of a layer of a single-crystal material.

Some preferred but non-limiting aspects of this process are as follows:

- the grinding wheel exhibits a greater hardness than the maximum hardness making possible the removal of a non-work-damaged layer of the same thickness as the at least partially work-damaged surface region made of polycrystalline silicon carbide;
- the grinding wheel comprises diamond grains coated in a binder, the size of the diamond grains being greater than 2 μm (mesh 12 000);
- during the relative movement of the grinding wheel and of the polycrystalline silicon carbide slab, the relative speed of the grinding wheel and of the front face of the polycrystalline silicon carbide slab is of between 0.05 $\mu\text{m/s}$ and 0.5 $\mu\text{m/s}$, preferentially of between 0.1 $\mu\text{m/s}$ and 0.45 $\mu\text{m/s}$, more preferentially of between 0.15 $\mu\text{m/s}$ and 0.45 $\mu\text{m/s}$, up to the removal of the thickness of less than or equal to 3 μm from the polycrystalline silicon carbide slab;
- the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab is carried out for a period of time of greater than or equal to 30 seconds, preferentially a period of time of greater than or equal to 40 seconds;

- the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time of greater than or equal to 30 seconds, preferentially a period of time of greater than or equal to 40 seconds, is divided up into several sequences;
- it additionally comprises, subsequent to the halting of the relative movement and to the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab, an additional stage of relative movement of the grinding wheel and of the front face of the polycrystalline silicon carbide slab up to the removal, with the rotating grinding wheel in contact with the front face of the slab, of an additional thickness from the polycrystalline silicon carbide slab of less than or equal to 1 μm ;
- the rotational speed of the grinding wheel during the polishing is of between 10 m/s and 45 m/s, preferentially between 10 m/s and 25 m/s;
- during the polishing, the front face of the polycrystalline silicon carbide slab is driven in rotation at a speed of between 200 rev/min and 600 rev/min.

The invention applies to a process for the manufacture of a polycrystalline silicon carbide slab comprising the thinning by grinding of a thick polycrystalline silicon carbide slab on at least its front face, so as to obtain a thinned polycrystalline silicon carbide slab, and the polishing of the front face of the thinned polycrystalline silicon carbide slab in accordance with the invention. The thinning of the thick polycrystalline silicon carbide slab on at least its front face can be carried out by means of a grinding wheel, the size of the grains of which is of between 10 μm (mesh 2000) and 30 μm (mesh 600).

The invention also applies to a process for the preparation of a multilayer structure comprising the manufacture of a polycrystalline silicon carbide slab in accordance with the invention, the provision of a substrate which is a donor of a layer to be transferred and the transfer of the layer to be transferred from the donor substrate onto the front face of the polycrystalline silicon carbide slab. The donor substrate can be a single-crystal silicon carbide substrate. The transfer stage can comprise the formation of a weakened zone by implantation of atomic entities in the donor substrate so as to delimit the layer to be transferred, the bonding of the implanted face of the donor substrate to the front face of the polycrystalline silicon carbide slab and the detachment from the donor substrate along the weakened zone. The bonding can be direct bonding, for example atomic diffusion bonding.

BRIEF DESCRIPTION OF THE FIGURES

Other characteristics and advantages of the invention will become apparent from the detailed description which will follow, with reference to the appended drawings, in which:

- Figure 1 represents an abrasive grain in the binder of a grinding wheel, before (left-hand representation) and after (right-hand representation) blunting,

- Figure 2 represents different states of wear of an abrasive grain at the periphery of a grinding wheel,

- Figure 3 compares the bonding efficiency and haze value of polycrystalline silicon carbide slabs (arbitrary unit indicative of roughness), the front face of which has been prepared according to a process of the state of the art, with the bonding efficiencies and the haze values of slabs, the front face of which has been prepared according to two different embodiments of the process of the invention.

For reasons of readability, the drawings are not necessarily produced to scale.

DETAILED DESCRIPTION OF EMBODIMENTS

The invention relates to the polishing of the front face of a p-SiC substrate in order to make possible high-quality bonding of a thin layer of a single-crystal material to said front face. This surface preparation is carried out by means of a grinding tool, such as a grinding wheel, instead of the tools conventionally used for polishing, such as chemical mechanical polishing tools. This is because chemical mechanical polishing or CMP makes it possible to achieve very low roughnesses on single-crystal substrates. However, this process reveals the grain boundaries of a polycrystalline silicon carbide substrate, thus creating a new form of roughness.

The invention relates more particularly to the polishing of the front face of a polycrystalline silicon carbide slab which comprises, at least on the side of its front face, an at least partially work-damaged surface region generated by grinding. Such grinding could be carried out to thin the polycrystalline silicon carbide slab beforehand on at least its front face, preferentially on its front face and on its rear face, for example using a grinding wheel having coarse grains (typically abrasive grains with a size of between 10 μm and 18 μm , i.e. a mesh of between 1000 and 2000).

Any grinding leaves an at least partially work-damaged surface region also known to a person skilled in the art under the name "damaged layer". In other words, following the grinding, the slab exhibits, on its front face, a surface region in which the crystal is disorganized with scratches and fractured zones. The thickness of the work-damaged surface region depends on the grinding carried out: the coarser the grinding, the thicker the work-damaged surface region. The thickness of the work-damaged surface region is typically of between 500 nm and 1 μm .

With reference to Figures 1 and 2, the term “grinding wheel” refers to a tool having symmetry of revolution comprising mainly grains made of an abrasive material – called abrasive grains 1 – embedded in a binder 2 exhibiting pores 3, everything being deposited on a support perpendicular to the axis of revolution of the grinding wheel. By way of example, the binder 2 can comprise resins, ceramics or metals. The abrasive grains 1 are, for example, diamond grains. The binder 2 defines overall a surface opposite the support on which abrasive grains 1 protrude, rendering said surface abrasive.

Such grinding wheels are conventionally used to remove matter in order to thin substrates in “grinding” stages.

Typically, the substrate 4 to be thinned is brought into contact on its front face with the abrasive surface of a rotating grinding wheel (see Figure 1). A relative axial movement of the grinding wheel and of the substrate to be thinned along the axis of revolution of the grinding wheel makes it possible to apply pressure to the front face of said substrate 4. Under the effect of the pressure, each grain of abrasive matter on the periphery of the grinding wheel then acts as a separate cutting tool which causes a tiny chip of the substrate to be thinned to fly off from its front face. As the abrasive grains become blunt (see Figure 1, moving from left to right), the pressure and the heat generated by the machining cause the blunted abrasive grains to break and then split (see Figure 2) so as to cause new abrasive grains with brand new sharp edges to appear at the periphery and to thus regenerate the abrasiveness of the surface of the grinding wheel. The removal of matter from the substrate to be thinned continues with new abrasive grains as long as the grinding wheel and the substrate are in relative translational movement.

The invention consists in using such a grinding wheel not simply for removing matter from a polycrystalline silicon carbide slab but also for polishing the front face of said slab, by contact between the front face of the slab and the abrasive surface of the rotating grinding wheel.

To this end, the process according to the invention for polishing the front face of a polycrystalline silicon carbide slab, comprising an at least partially work-damaged surface region as described above, comprises:

- the relative movement of the rotationally driven grinding wheel and of the polycrystalline silicon carbide slab up to the removal from the polycrystalline silicon carbide slab, with the rotating grinding wheel in contact with the front face of the slab, of a layer comprising the at least partially work-damaged surface region and exhibiting a thickness of less than or equal to 3 μm ,

- the halting of the relative movement and the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time of greater than 15 seconds.

5 The relative movement of the grinding wheel and of the polycrystalline silicon carbide slab up to removing at least the at least partially work-damaged surface region makes it possible to blunt the grains of the grinding wheel without, however, promoting the splitting thereof. Thus, when the rotating grinding wheel is held in contact with the front face of the slab following the halting of the relative movement of the slab and of the grinding wheel, it is the
10 blunted grains which rub against the front face of the slab and not new, very sharp, grains. This rubbing action ensures gentle polishing of said front face without revealing the boundaries between the silicon carbide grains.

 The holding of the rotating grinding wheel in contact with the front face of the
15 polycrystalline silicon carbide slab without relative axial movement of the slab and of the grinding wheel for a period of time of less than 5 s can be carried out conventionally in order to protect the grinding tool, for example in order to avoid large variations in the supply current of the motor. The holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time of more than 15 seconds according to
20 the invention makes it possible to observe a decrease in the surface roughness and a significant polishing effect.

 Subsequently, the choice of the grinding wheel for the implementation of the process according to the invention is considered.

25 Different types of grinding wheel are distinguished, depending, for example, on the size of the abrasive grains of said grinding wheels or on their hardness.

 It should be noted that the hardness of the grinding wheel is defined as being a measure
30 of the force for holding the grains in the grinding wheel. The harder a grinding wheel, the less easily the blunted grains detach from the grinding wheel, so as to regenerate the abrasive surface of said grinding wheel. Conversely, the less hard the grinding wheel, the more easily the rows of abrasive grains split and succeed one another. The hardness of the grinding wheel depends on the nature of the binder, on the porosity and on the size of the abrasive grains.

35 In order to remove matter, a person skilled in the art conventionally chooses a grinding wheel which is not too hard, so as to continually regenerate cutting grains. In addition, a grinding wheel which is too hard is less effective in removing matter and creates a risk of

heating – and thus of breakage of the grinding wheel or of the slab – and of jamming – and thus of scratches on the slab.

5 In order to carry out the polishing process according to the invention, the inventors recommend the use of a harder grinding wheel than the grinding wheels conventionally used to remove matter. This is because the partially work-damaged nature of the surface region to be removed advantageously makes possible the blunting of the abrasive grains of the harder grinding wheel without causing breakage or jamming of said grinding wheel. In addition, because the grinding wheel is harder, blunting of the grains without causing them to split is
10 facilitated.

Thus, a grinding wheel with a hardness greater than the maximum hardness making possible the removal of a non-work-damaged layer of the same thickness as the at least partially work-damaged surface region to be removed and made of the same material as said
15 surface region is preferentially chosen. In other words, the grinding wheel preferentially used is too hard to remove a non-work-damaged layer made of the same material and of the same thickness as the partially work-damaged surface region to be removed, in particular without causing breakage or jamming.

20 By way of example, the grinding wheel used is a grinding wheel from Accretech referenced with the letter I or higher in alphabetical order, for example the Accretech HW8000VB-I144 grinding wheel.

As regards the choice of the size of the grains of the grinding wheel, for a single-crystal
25 substrate, it is known to use grinding wheels exhibiting abrasive grains which are all the smaller since it is desired to obtain, following the grinding, a surface exhibiting a low roughness. Thus, a grinding wheel comprising very small grains (typically a size of less than 1.5 μm , i.e. a mesh of greater than 15 000) makes it possible, for example, to obtain free surfaces of single-crystal silicon carbide substrates of very low roughness, of less than 1 nm RMS.

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However, the result obtained with this type of grinding wheel having very small grains on a polycrystalline silicon carbide slab remains insufficient to make possible quality bonding of a single-crystal substrate to said slab, for example bonding carried out in the context of the Smart Cut TM process.

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The inventors have noticed that grinding wheels having very small grains tend to reveal the grain boundaries of the polycrystalline material, which results in the high roughness observed. The inventors attribute this effect to the fact that, at these grain sizes, the grinding

wheel used is not necessarily hard enough, and thus that, during the rotation of the grinding wheel, the blunted grains break more easily and new grains with brand new sharp edges, which tend to “scrape” the grain boundaries, are placed more easily at the surface.

5 In the process according to the invention, use is thus preferentially made of a grinding wheel with a smaller mesh (thus coarser abrasive grains) than the grinding wheels having very small grains conventionally used to obtain a very low surface roughness but which exhibits a hardness which is not achievable for these grinding wheels having very small grains. Thus, use is preferentially made of a grinding wheel, the size of the grains of which is of between
10 2 μm and 3 μm (mesh of between 8000 and 12 000). In addition, the hardness of said grinding wheel is preferentially greater than the hardness achievable by a grinding wheel, the size of the grains of which is less than or equal to 1.5 μm (mesh is greater than or equal to 15 000).

This type of grinding wheel advantageously promotes the blunting of the abrasive grains
15 during the removal of the at least partially work-damaged surface region without causing them to break and to be replaced by new grains.

Preferentially, the relative movement of the grinding wheel and of the silicon carbide slab is carried out so that the total thickness of the removal of matter does not exceed by more than
20 2.5 μm the thickness of the at least partially work-damaged surface region. Thus, if the at least partially work-damaged surface region exhibits a thickness of 500 nm, the total thickness of the removal of matter is preferably less than or equal to 3 μm . Not removing a total thickness of matter which exceeds by more than 2.5 μm the thickness of the work-damaged surface region advantageously makes it possible not to bring about the exposure, at the surface, of a
25 new row of new grains with sharp edges.

During the relative axial movement of the grinding wheel and of the polycrystalline silicon carbide slab, the relative axial speed of the grinding wheel and of the front face of the polycrystalline silicon carbide slab is of between 0.05 $\mu\text{m/s}$ and 0.5 $\mu\text{m/s}$, preferentially of
30 between 0.1 $\mu\text{m/s}$ and 0.45 $\mu\text{m/s}$, more preferentially of between 0.15 $\mu\text{m/s}$ and 0.45 $\mu\text{m/s}$, up to the removal of the thickness of less than or equal to 3 μm from the polycrystalline silicon carbide slab.

A speed of greater than 0.5 $\mu\text{m/s}$ risks causing the splitting of the line of previously
35 blunted abrasive grains, and thus the updating of a new line of abrasive grains which it is desired to avoid, or the breakage of the grinding wheel. A speed of less than 0.005 $\mu\text{m/s}$ is too slow to be economically profitable.

The rotational speed of the grinding wheel during the polishing is, for example, of between 10 m/s and 45 m/s, preferentially between 10 m/s and 25 m/s. Thus, for a grinding wheel with a diameter of 300 mm, the rotational speed of the grinding wheel is of between 500 rev/min and 1500 rev/min. A rotational speed of the grinding wheel of less than 10 m/s unnecessarily increases the duration of the stage and is not economically advantageous. A speed of greater than 45 m/s would risk bringing about the splitting of the previously blunted abrasive grains of the grinding wheel and/or the breakage of the grinding wheel and/or of the polycrystalline silicon carbide slab.

Figure 3 gives a comparison of the results obtained by the implementation of such a process for the preparation of the front face of a polycrystalline silicon carbide slab (histograms (c) and (d)) with the results obtained by the implementation of a preparation process according to the state of the art (histograms (a) and (b)).

The histograms (a) and (b) correspond to fine grinding to remove a thickness of the order of 10 μm using a grinding wheel which is less hard than that preferentially used by the invention. The histograms (c) and (d) correspond to polishing carried out according to the invention by removing a thickness of 10 μm using a hard grinding wheel and by subsequently holding the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time taken here of less than 5 seconds.

The histograms (a) and (c) correspond to the percentage of polycrystalline silicon carbide slabs, the surface condition of the front face of which makes possible high-quality bonding of said front face to a single-crystal substrate. In other words, the histograms (a) and (c) correspond to the percentage of single-crystal substrates flawlessly bonded to a polycrystalline silicon carbide slab. The term "flaw" is understood to mean, for example, partial bonding of the single-crystal substrate, the single-crystal substrate layer not being transferred onto certain parts of the polycrystalline silicon carbide slab. The histograms (b) and (d) correspond for their part to the haze value measured on a polycrystalline silicon carbide slab by light scattering, for example using the Surfscan SP1 inspection system from KLA-Tencor or by the SICA88 inspection system from Lasertec. More precisely, it is a mean value measured at several points on a polycrystalline silicon carbide slab. The haze value is an indirect tool for measuring the roughness of the front face of the polycrystalline silicon carbide slab. This haze value results from a method using the optical reflectivity properties of the surface to be characterized and corresponds to an optical signal scattered by the surface, due to its microroughness: the greater the roughness of the surface, the greater the scattering on said surface and the greater the haze value measured.

Thus, it can be observed that the implementation of the process according to the invention makes it possible to obtain a bonding efficiency of the order of 30%, which is greater than the efficiency of the process according to which a thickness of the order of 10 μm is removed, which is itself of the order of 10%. Furthermore, the haze value of a front face of a silicon carbide slab prepared by the process according to the invention is less than the haze value of a front face prepared by the process according to the state of the art.

The holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab can advantageously be carried out for a period of time of greater than 30 seconds and more preferably still of greater than 40 seconds, in order to maintain the frictional contact between the grinding wheel and the slab for as long as possible (while keeping the same row of previously blunted abrasive grains).

The holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time of greater than 30 seconds, preferentially a period of time of greater than 40 seconds, is preferentially divided up into several sequences, so that the contact between the grinding wheel and the front face of the polycrystalline silicon carbide slab is broken between each sequence by relative movement of the grinding wheel and of the polycrystalline silicon carbide slab. In this case, the sum of the durations of each sequence during which the rotating grinding wheel is held in contact with the front face of the polycrystalline silicon carbide slab remains equal to the chosen period of time of greater than 40 seconds. By way of example, the holding of the grinding wheel can comprise two sequences: a first sequence, the duration of which is of between 5 seconds and 10 seconds, and then a second sequence, so that the sum of the durations of the first sequence and of the second sequence is greater than or equal to 30 seconds, preferentially of greater than 40 seconds. Dividing up the period of rubbing between the rotating grinding wheel and the front face of the polycrystalline silicon carbide slab makes it possible to avoid overheating episodes and thus the splitting of the line of previously blunted abrasive grains.

In one possible embodiment, the polishing additionally comprises, subsequent to the halting of the relative movement and to the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab, an additional stage of relative movement of the grinding wheel and of the front face of the polycrystalline silicon carbide slab. The additional stage of relative movement of the grinding wheel and of the front face can comprise, in a first step, the breaking of the contact between the grinding wheel and the front face and then, in a second step, the re-establishing of said contact. The additional stage of relative movement of the grinding wheel and of the front face of the polycrystalline silicon carbide slab is in this case halted, for example by the operator, as soon as contact of the

grinding wheel and of the front face of the polycrystalline silicon carbide slab is re-established, so as not to cause the previously blunted abrasive grains of the grinding wheel to split.

The additional stage of relative movement is carried out so as to result in the removal of a very small additional thickness from the polycrystalline silicon carbide slab, preferentially an additional thickness from the polycrystalline silicon carbide slab of less than or equal to 1 μm , more preferably a thickness of less than 200 nm.

This additional stage of relative movement of the grinding wheel and of the front face of the polycrystalline silicon carbide slab makes it possible to further reduce the roughness of the front face of the polycrystalline silicon carbide slab and thus to improve the surface quality thereof.

In Figure 3, the histograms (e) and (f) respectively represent the efficiency and the haze value obtained following the implementation of the protocol followed for the histograms (c) and (d), supplemented by this additional stage removing a thickness of 1 μm . Thus, Figure 3 shows the effectiveness of the stage, since the efficiency increases further to reach a value of the order of 80% and the haze value decreases further compared with the histogram (d).

In a particular embodiment of the invention, the polycrystalline silicon carbide slab is rotated about an axis X perpendicular to the front face of the polycrystalline silicon carbide slab. The grinding wheel is itself in rotation about an axis Y perpendicular to the abrasive surface of said grinding wheel, the axis Y being parallel to the axis X.

The polycrystalline silicon carbide slab is, for example, a slab with a diameter of 150 mm and the grinding wheel is, for example, a grinding wheel with a diameter of 300 mm.

By way of example, the front face of the polycrystalline silicon carbide slab can be driven in rotation at a speed of between 200 rev/min and 600 rev/min.

In this embodiment, the relative movement of the grinding wheel and of the polycrystalline silicon carbide slab comprises, for example, the axial movement of the rotating grinding wheel along the Y axis, so as to bring the abrasive surface of the grinding wheel into contact with the front face of the polycrystalline silicon carbide slab, and then to remove the thickness of less than or equal to 3 μm from said slab under the effect of the pressure exerted by the grinding wheel in axial movement.

The movement of the grinding wheel along the Y axis is then blocked, the grinding wheel and the slab remaining in rotation about the X and Y axes respectively, so as to maintain the contact between the grinding wheel and the front face of the polycrystalline silicon carbide slab for a period of greater than 15 seconds, preferentially a period of greater than 30 seconds and more preferentially a period of greater than 40 seconds.

According to this embodiment, if the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period with a duration of greater than 30 seconds, preferentially for a period of time of greater than 40 seconds, is divided up into several sequences as described above, the breaking of the contact between the grinding wheel and the front face can be carried out by translation along the Y axis of the grinding wheel held in rotation, so as to move said grinding wheel away from the front face of the slab. By way of example, the holding of the grinding wheel can comprise a first sequence with a duration of 10 seconds, a separation period of one minute, during which contact between the grinding wheel and the front face of the slab is broken, and a second sequence of 30 seconds.

The invention applies to a process for the preparation of a polycrystalline silicon carbide slab. Said process for the preparation of a polycrystalline silicon carbide slab comprises the thinning, by means of a grinding wheel of a first type, of a thick polycrystalline silicon carbide slab on its front face and optionally on its rear face, so as to obtain a thinned polycrystalline silicon carbide slab. Preferentially, the polycrystalline silicon carbide slab thinned by means of the grinding wheel of the first type exhibits a thickness of greater than or equal to 325 μm , more preferably a thickness of 350 μm .

The thick polycrystalline silicon carbide slab (for example from 0.4 mm to 3 mm in thickness) can, for example, be produced by a deposition of p-SiC on a growth substrate (for example a graphite substrate), typically a chemical vapour deposition at a temperature of between 1200°C and 1400°C.

Prior to the thinning by means of the grinding wheel of the first type, one or more very coarse grinding operations can optionally be carried out on the front face, preferentially on the front face and on the rear face, of the thick silicon carbide slab.

The grinding wheel of the first type is a grinding wheel comprising abrasive grains coated in a binder, the size of the grains of the grinding wheel of the first type being of between 10 μm and 30 μm (mesh of between 600 and 2000). Given the size of the relatively large abrasive grains of the grinding wheel of the first type, the thinning of the polycrystalline silicon carbide

slab thus corresponds to a grinding operation described as coarse by a person skilled in the art.

5 The thinning of the thick polycrystalline silicon carbide slab on its front face by means of the grinding wheel of the first type generates an at least partially work-damaged surface region on said front face, that is to say a region in which the crystal is disorganized exhibiting scratches and/or fractured zones. The smaller the mesh of the grinding wheel of the first type (thus the greater the size of the abrasive grains of said grinding wheel), the thicker the at least partially work-damaged surface region. Given the mesh range of the grinding wheel of the first
10 type, the thickness of the work-damaged surface region is of between 500 nm and 1 μm .

The process for the preparation of a polycrystalline silicon carbide slab according to the invention additionally comprises the polishing of the front face of the polycrystalline silicon carbide slab thinned by means of the grinding wheel of the first type, said polishing being
15 carried out according to any one embodiment of the polishing process described above by means of a grinding wheel of a second type.

The grinding wheel of the second type preferentially exhibits the characteristics of sizes of grains and of hardness as stated above.
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Thus, the grinding wheel of the second type preferentially exhibits a hardness greater than the maximum hardness making possible the removal of a non-work-damaged layer of the same thickness as the at least partially work-damaged surface region generated by the grinding wheel of the first type and made of the same material as said surface region.
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The grinding wheel of the second type preferentially exhibits a size of grains of between 2 μm and 3 μm (mesh of between 8000 and 12 000). In addition, the hardness of said grinding wheel of the second type is preferentially greater than the hardness achievable by a grinding wheel, the size of the grains of which is less than or equal to 1.5 μm (mesh greater than or
30 equal to 15 000).

In this process for the manufacture of a polycrystalline silicon carbide slab, the polishing of the front face of said slab, thinned beforehand by grinding by means of the grinding wheel of the first type, comprises the relative movement of the grinding wheel of the second type and of the polycrystalline silicon carbide slab up to the removal of a thickness of less than or equal
35 to 3 μm prior to the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time of greater than 15 seconds, preferentially a period of time of greater than 30 seconds, more preferentially a period of time of greater than 40 seconds. The removal of the thickness of less than or equal to 3 μm comprises the removal

of the at least partially work-damaged surface region previously generated by the thinning carried out by means of the grinding wheel of the first type.

Thus, the process according to the invention makes it possible to polish the front face of the polycrystalline silicon carbide slab directly after the thinning by coarse grinding on at least the front face of said slab, being freed from additional stages of finer grinding.

The invention furthermore applies to a process for the manufacture of a multilayer structure, comprising the polishing of a p-SiC slab as set out above and the transfer of a thin layer of a single-crystal material from a substrate of said single-crystal material to the polycrystalline silicon carbide slab.

The single-crystal substrate is, for example, a single-crystal silicon carbide (m-SiC) substrate. Alternatively, the single-crystal substrate is a gallium nitride (GaN), indium phosphide (InP), diamond or silicon substrate. Optionally, an intermediate silicon dioxide (SiO₂) layer is arranged between the polycrystalline silicon carbide slab and the single-crystal substrate.

The transfer of the thin layer of the single-crystal material can be carried out according to the Smart Cut™ technology and can thus comprise an implantation of ionic entities in the single-crystal material substrate so as to form therein a weakened plane delimiting the thin layer to be transferred, the bonding of the single-crystal material substrate to the polycrystalline silicon carbide slab (if appropriate via one or more bonding layers), then the detachment (brought about by a heat treatment, a mechanical action or a combination of these means) of the single-crystal material substrate along the weakened plane, so as to transfer the thin active layer to the polycrystalline silicon carbide slab. The single-crystal material substrate can be subjected to mechanical or chemical mechanical polishing before bonding. The process for the manufacture of the composite structure can additionally comprise the formation of electronic components, in particular of power or radiofrequency components, in the transferred thin layer.

The single-crystal material substrate on the polycrystalline silicon carbide slab is bonded, for example, by bonding, such as ADB bonding. ADB bonding comprises, for example, the deposition of a silicon layer with a thickness preferably of between 4 nm and 20 nm, more preferably a thickness of 10 nm, on each of the surfaces to be bonded. This is because a silicon layer with a thickness of less than 4 nm brings about risks of bubbling. Alternatively, the single-crystal material substrate on the polycrystalline silicon carbide slab is bonded by means of surface activation bonding (SAB). The polishing process according to the invention

advantageously makes it possible to achieve the very low roughness demanded by these bonding methods.

CLAIMS

1. Process for polishing the front face of a polycrystalline silicon carbide slab comprising a surface region at least partially work-damaged under the effect of grinding, said process comprising:

- the relative movement of a rotationally driven grinding wheel and of the polycrystalline silicon carbide slab up to the removal from the polycrystalline silicon carbide slab, with the rotating grinding wheel in contact with the front face of the slab, of a layer comprising the at least partially work-damaged surface region and exhibiting a thickness of less than or equal to 3 μm ,

- the halting of the relative movement and the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time of greater than 15 seconds.

2. Process according to Claim 1, in which the grinding wheel exhibits a greater hardness than the maximum hardness making possible the removal of a non-work-damaged layer of the same thickness as the at least partially work-damaged surface region made of polycrystalline silicon carbide.

3. Process according to either of Claims 1 and 2, in which the grinding wheel comprises diamond grains coated in a binder, the size of the diamond grains being greater than 2 μm (mesh 12 000).

4. Process according to one of Claims 1 to 3, in which, during the relative movement of the grinding wheel and of the polycrystalline silicon carbide slab, the relative speed of the grinding wheel and of the front face of the polycrystalline silicon carbide slab is of between 0.05 $\mu\text{m/s}$ and 0.5 $\mu\text{m/s}$, preferentially of between 0.1 $\mu\text{m/s}$ and 0.45 $\mu\text{m/s}$, more preferentially of between 0.15 $\mu\text{m/s}$ and 0.45 $\mu\text{m/s}$, up to the removal of the thickness of less than or equal to 3 μm from the polycrystalline silicon carbide slab.

5. Process according to one of Claims 1 to 4, in which the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab is carried out for a period of time of greater than or equal to 30 seconds, preferentially a period of time of greater than or equal to 40 seconds.

6. Process according to Claim 5, in which the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab for a period of time of

greater than or equal to 30 seconds, preferentially a period of time of greater than or equal to 40 seconds, is divided up into several sequences.

7. Process according to one of Claims 1 to 6, additionally comprising, subsequent to the halting of the relative movement and to the holding of the rotating grinding wheel in contact with the front face of the polycrystalline silicon carbide slab, an additional stage of relative movement of the grinding wheel and of the front face of the polycrystalline silicon carbide slab up to the removal, with the rotating grinding wheel in contact with the front face of the slab, of an additional thickness from the polycrystalline silicon carbide slab of less than or equal to 1 μm .

8. Process according to one of Claims 1 to 7, in which the rotational speed of the grinding wheel during the polishing is of between 10 m/s and 45 m/s, preferentially between 10 m/s and 25 m/s.

9. Process according to one of Claims 1 to 8, in which, during the polishing, the front face of the polycrystalline silicon carbide slab is driven in rotation at a speed of between 200 rev/min and 600 rev/min.

10. Process for the manufacture of a polycrystalline silicon carbide slab comprising:
- the thinning by grinding of a thick polycrystalline silicon carbide slab on at least its front face, so as to obtain a thinned polycrystalline silicon carbide slab,
- the polishing of the front face of the thinned polycrystalline silicon carbide slab, said polishing being carried out by a process according to one of Claims 1 to 9.

11. Process according to Claim 10, in which the thinning of the thick polycrystalline silicon carbide slab on at least its front face is carried out by means of a grinding wheel, the size of the grains of which is of between 10 μm (mesh 2000) and 30 μm (mesh 600).

12. Process for the preparation of a multilayer structure comprising:
- the manufacture of a polycrystalline silicon carbide slab by a process according to either of Claims 10 and 11,
- the provision of a substrate which is a donor of a layer to be transferred,
- the transfer of the layer to be transferred from the donor substrate onto the front face of the polycrystalline silicon carbide slab.

13. Process according to Claim 12, in which the donor substrate is a single-crystal silicon carbide substrate.

14. Process according to either of Claims 12 and 13, in which the transfer stage
5 comprises:

- the formation of a weakened zone by implantation of atomic entities in the donor substrate so as to delimit the layer to be transferred,

- the bonding of the implanted face of the donor substrate to the front face of the polycrystalline silicon carbide slab,

- the detachment from the donor substrate along the weakened zone.

15. Process according to Claim 14, in which the bonding is direct bonding, preferentially atomic diffusion bonding.