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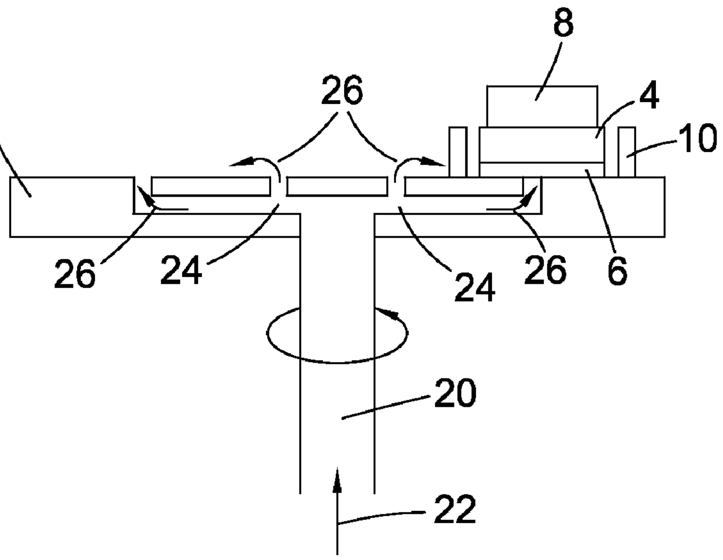

Fig. 4

(57) **Abstract**: A method of lapping a super-hard material product having a Vickers hardness of no less than 2000 kg/mm^2, the method comprising: mounting the super-hard material product with a surface of the super-hard material product in contact with a surface of a processing wheel with an interface region disposed between the surface of the super-hard product and the surface of the processing wheel; loading the super-hard material product such that the super-hard material product is pressed against the surface of the processing wheel with a loading force; rotating the processing wheel; and feeding an abrasive slurry onto the surface of the processing wheel, the abrasive slurry comprising super-hard abrasive grit particles disposed in a carrier fluid, wherein the super-hard abrasive grit particles of the abrasive slurry have a particle size of at least 1 μm and roll between the surface of the processing wheel and the surface of the super-hard material product within the interface region in order to cause surface micro-cracking of the super-hard material product and removal of material from the surface of the super-hard material product, and wherein the surface of the processing wheel has one or more feed ports disposed therein and at least a portion of the abrasive slurry is fed directly from the one or more feed ports into the interface region between the surface of the processing wheel and the super-hard material product being processed.

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POST-SYNTHESIS PROCESSING OF DIAMOND AND RELATED SUPER-HARD MATERIALS

Background of Invention

The present invention relates to post-synthesis processing of diamond and related super-hard materials. In particular, the present invention relates to optimized lapping processes for diamond and related super-hard materials.

Summary of Invention

In the context of the present invention super-hard materials are defined as those materials having a Vickers hardness of no less than 2000 kg/mm^2. These materials include a range of diamond materials, cubic boron nitride materials (cBN), sapphire, and composites comprising the aforementioned materials. For example, diamond materials include chemical vapour deposited (CVD) single crystal and polycrystalline synthetic diamond materials of a variety of grades, high pressure high temperature (HPHT) synthetic diamond materials of a variety of grades, natural diamond material, and diamond composite materials such as polycrystalline diamond which includes a metal binder phase (PCD) or silicon cemented diamond (ScD) which includes a silicon/silicon carbide binder phase.

In relation to the above, it should be noted that while super-hard materials are exceedingly hard, they are generally very brittle and have low toughness. As such, these materials are notoriously difficult to process into a product after the raw material is synthesized. Any processing method must be sufficiently aggressive to overcome the extreme hardness of the super-hard material while at the same time must not impart a large degree of stress or thermal shock to the material which would cause macroscopic fracturing of the material due to its brittle nature and low toughness. Furthermore, for certain applications it is important that surface and sub-surface damage at a microscopic scale, such as microcracking, is minimized to avoid deterioration of functional properties which may result from such surface and sub-surface damage including, for example, optical scattering, increased optical absorption, decreased wear resistance, and increased internal stress resulting in a decrease in coherence time for quantum spin defects near the processed surface.

There is narrow operating window for achieving successful processing of super-hard materials and many available processing methods fall outside this operating window. For example, most processing methods are not sufficiently aggressive to process super-hard materials to any significant extent in reasonable time-frames. Conversely, more aggressive processing techniques tend to impart too much stress and/or thermal shock to the super-hard material thus causing cracking and material damage or failure.

Certain processing methods have operational parameters which can be altered so as to move from a regime in which no significant processing of a super-hard material is achieved into a regime in which processing is achieved but with associated cracking and damage or failure of the super-hard material. In this case, there may or may not be a transitional window of parameter space in which processing can be achieved without cracking and damage or failure of the super-hard material. The ability to operate within a suitable window of parameter space in which processing can be achieved without cracking and damage or failure of the super-hard material will depend on the processing technique, the size of any transitional operating window for such a technique, and the level of operation parameter control which is possible to maintain processing within the window of parameter space in which processing can be achieved without cracking and damage or failure of the super-hard material.

In light of the above, it will be appreciated that post-synthesis processing of super-hard materials is not a simple process and, although a significant body of research has been aimed at addressing this problem, current processing methods are still relatively time consuming and expensive, with processing costs accounting for a significant proportion of the production costs of super-hard material products.

Post synthesis processing may comprise one or more of the following basic processes:

surface processing to remove material from the surface of the as-grown super-hard material in order to increase surface flatness, decrease surface roughness, remove surface defects, and/or attain a target thickness for the super-hard material;

surface processing to achieve a fine surface finish where minimal material is removed from the super-hard product, i.e. polishing; and

cutting of the super-hard material into target shapes and sizes for particular product application.

In principle there are two basic forms of mechanical surface processing: (i) a two-body process in which abrasive particles are embedded/fixed in one body which is moved against a second body to process the second body; and (ii) a three-body process in which one body is moved relative to a second body to be processed and free abrasive particles, constituting a third body, are disposed between the first and second bodies in order to achieving surface processing of the second body.

The latter three-body approach to surface processing is known as lapping and it is this approach which is conventionally used to remove macroscopic quantities of surface material from super-hard materials. Three-body lapping, as opposed to a two-body surface processing technique, is preferred for removing macroscopic quantities of surface material from super-hard materials as it has been found that lapping is more efficient at removing surface material from a super-hard material without imparting a large degree of stress or thermal shock to the material which would cause macroscopic fracturing of the material due to its brittle nature and low toughness. In contrast, when it is desired to achieve a fine surface finish without removing macroscopic quantities of material then a two-body processing technique may be utilized. As such, conventionally lapping is used to remove material from the surface of an as-grown super-hard material in order to increase surface flatness, decrease surface roughness, remove surface defects, and/or attain a target thickness for the super-hard material. Subsequently, if a fine surface finish is required, the super-hard material is polished and this may be performed using a two-body surface processing technique in which abrasive material is fixed in a polishing wheel such as via resin bonding. Polishing may also be achieved using an iron or steel wheel which is diamond impregnated and this is known as scaife polishing. Although scaife polishing generally utilizes free diamond abrasive particles these are of a small size relative to pores within the iron or steel wheel and are thus embedded/fixed into the wheel thus effecting a two-body processing as opposed to a true three body lapping process.

The present invention is primarily concerned with lapping super-hard materials using relatively coarse diamond powders or grits (or other super-hard powders or grits) to remove material from the surface of the as-grown super-hard material in order to increase surface flatness, decrease surface roughness, remove surface defects, and/or attain a target thickness for the super-hard material. Lapping of super-hard materials is known in the art. The type of abrasive which should be utilized will be dependent on the type of material which is to be lapped. Obviously, when lapping super-hard materials a super-hard abrasive will be required. Accordingly, for lapping of diamond materials a diamond abrasive is utilized. In this regard diamond lapping pastes and slurries are widely available comprising a diamond powder or grit disposed within a carrier fluid. Diamond lapping slurries may have a variety of different concentrations of diamond powder/grit and varying particle sizes of diamond powder/grit. Furthermore, lapping machinery for performing the lapping process is also widely commercially available (e.g. from Kemet™, Logitech™, and Peter Wolters™).

A review article summarizing various surface polishing techniques for use on chemical vapour deposited (CVD) diamond films and substrates is provided in Diamond and Related Materials 8 (1999) 1198-1213. This review article includes a description of mechanical lapping of diamond films using coarse diamond powders greater than 1.0 μm in size (i.e. diamond grit) disposed in a binder fluid such as olive oil. It is described that this type of mechanical processing removes diamond material via a micro-chipping or micro-cleavage mechanism. It is further described that after lapping using coarse diamond abrasive particles finer diamond powers can be used for final polishing.

WO2009/059384 also discloses a lapping method for processing diamond material although it is not immediately clear how the described and claimed method differs from standard lapping of diamond material as summarized in the aforementioned review article. WO2009/059384 seems to suggest that previous methods have involved the diamond abrasive being mechanically immobilised in pores of a rotating processing wheel and that their method is distinguished in that the diamond abrasive particles are free to roll over the surface of the processing wheel and the diamond being processed. However, as described in the Handbook of Lapping and Polishing (edited by Ioan D. Mannescu, Eckhart Uhlmann, & Toshiro K. Doi, CRC Press, 2007) lapping incorporates three types of abrasive mechanism: rolling abrasive, sliding abrasive, and microcutting abrasive. As such, it is not clear how the rolling mechanism described in WO2009/059384 distinguishes the technique over standard lapping of diamond material. Indeed, the Wikipedia™ entry for lapping indicates that lapping produces microscopic conchoidal fractures as abrasive rolls about between two surfaces and removes material thus suggesting that a rolling abrasive mechanism is an inherent feature of standard lapping processes.

In fact, the aforementioned rolling mechanism is dominant when using larger abrasive grains in a coarse lapping technique as suggested in the Diamond and Related Materials review article. Such a coarse lapping process can be performed to remove material from the surface of an as-grown super-hard material in order to increase surface flatness, decrease surface roughness, remove surface defects, and/or attain a target thickness for the super-hard material. Subsequently, finer abrasive powders can be used for final polishing which are then more prone to be mechanically immobilized in pores of a processing wheel thus providing more of a microcutting processing mechanism.

Despite the fact that processing of super-hard materials using rolling, sliding, and microcutting abrasive mechanisms is known in the art as discussed above, the present inventors have found that there are still some difficulties in achieving lapping of super-hard materials in an optimized manner. Accordingly, it is an aim of certain embodiments of the present invention to provide lapping configurations and techniques which allow super-hard materials to be processed efficiently and which a high degree of precision and controllability. That is, while lapping is a standard processing technique, the difficulties in processing super-hard materials have led the present inventors to adapt standard lapping processes as described previous in the art so as to be able to more efficiently lap super-hard materials with a high degree of precision and controllability.

Summary of Invention

According to a first aspect of the present invention there is provided a method of lapping a super-hard material product having a Vickers hardness of no less than 2000 kg/mm^2, the method comprising:

mounting the super-hard material product with a surface of the super-hard material product in contact with a surface of a processing wheel with an interface region disposed between the surface of the super-hard product and the surface of the processing wheel;

loading the super-hard material product such that the super-hard material product is pressed against the surface of the processing wheel with a loading force;

rotating the processing wheel; and

feeding an abrasive slurry onto the surface of the processing wheel, the abrasive slurry comprising super-hard abrasive grit particles disposed in a carrier fluid,

wherein the super-hard abrasive grit particles of the abrasive slurry have a particle size of at least 1 μm and roll between the surface of the processing wheel and the surface of the super-hard material product within the interface region in order to cause surface micro-cracking of the super-hard material product and removal of material from the surface of the super-hard material product, and

wherein the surface of the processing wheel has one or more feed ports disposed therein and at least a portion of the abrasive slurry is fed directly from the one or more feed ports into the interface region between the surface of the processing wheel and the super-hard material product being processed.

According to a second aspect of the present invention there is provided a lapping machine configured for processing a super-hard material product having a Vickers hardness of no less than 2000 kg/mm^2, the lapping machine comprising:

a rotatable processing wheel; and

a mounting part configured to mount the super-hard material product with a surface thereof in contact with a surface of the processing wheel with an interface region disposed between the surface of the super-hard product and the surface of the processing wheel, the mounting part being further configured to press the super-hard material product against the surface of the processing wheel with a loading force,

wherein the surface of the processing wheel has one or more feed ports disposed therein configured such that in use an abrasive slurry is fed through the feed ports onto the surface of the processing wheel, at least a portion of the abrasive slurry being fed directly from the one or more feed ports into the interface region between the surface of the processing wheel and the super-hard material product being processed.

<u>Brief Description of the Drawings</u>

For a better understanding of the present invention and to show how the same may be carried into effect, embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings, in which:

Figure 1 shows a cross-sectional view of a lapping configuration not according to the present invention;

Figure 2 shows a plan view of a lapping configuration not according to the present invention;

Figure 3 shows a side view of a constraining ring used to mount a super-hard material product on a processing wheel as illustrated in Figures 1 and 2;

Figure 4 shows a cross-sectional view of a lapping configuration according to the present invention;

Figure 5 shows a plan view of a lapping configuration according to the present invention; and

Figure 6 shows a cross-sectional view of a carrier substrate with a super-hard material product mounted thereto for processing.

Detailed Description

Figures 1 to 3 illustrate a lapping apparatus which is not according to the present invention. The apparatus comprises a rotatable processing wheel 2 on which a super-hard material product to be processed is mounted. The mounting configuration comprises a carrier substrate 4 to which the super-hard material 6 is adhered. The carrier substrate 4 on which the super-hard material 6 is adhered is arranged such that a surface of the super-hard material is in contact with a surface of the processing wheel 2 with an interface region disposed between the surface of the super-hard material 6 and the surface of the processing wheel 2. A weight 8 is provided on the carrier substrate 4 such that the super-hard material 6 is pressed against the surface of the processing wheel 2 with a suitable loading force.

The carrier substrate 4 and super-hard material product 6 is mounted on the processing wheel within a constraining ring 10 which constrains a location of the super-hard material product 6 over the processing wheel 2. The constraining ring 10 comprises a number of slots 11 for allowing the passage of abrasive fluid therethrough as illustrated in Figure 3. The constraining ring 10 has an internal diameter which is larger than the diameter of the super-hard material product 6 and carrier substrate 4. Furthermore, both the constraining ring 10 and the super-hard material product 6 are mounted so as to rotate on the surface of the processing wheel 2 driven by rotation of the processing wheel. In the illustrated configuration the constraining ring 10 is rotatable mounted on the processing wheel 2 via constraining arm 12.

In use, an abrasive slurry comprising super-hard abrasive particles within a carrier fluid is dripped onto the surface of the processing wheel 2 from above. In the illustrated configuration the abrasive slurry 14 is housed in a slurry container 16 and a tube 18 runs from the slurry container 16 to a position above the processing wheel 2 for dripping abrasive slurry 14 onto the processing wheel 2. A pump, such as a peristaltic pump, may be provided to control the drip rate of abrasive slurry onto the processing wheel 2. Generally, the abrasive slurry is dripped onto the processing wheel 2 near a central region thereof and the abrasive slurry moves radial outwards across the processing wheel 2 during rotation of the processing wheel in use.

For a rough lapping process where a significant amount of material is to be removed from a surface of the super-hard material product, the super-hard abrasive particles may be relatively large in size, e.g. having a particle size of greater than 1 μm. These abrasive particle are larger than pores within the surface of the processing wheel 2 and thus roll between the surface of the processing wheel 2 and the surface of the super-hard material product 6 within the interface region in order to cause surface micro-cracking of the super-hard material product 6 and removal of material from the surface of the super-hard material product 6.

One problem the present inventors have found with the aforementioned lapping configuration is that the lapping process can be difficult to control in order to achieve high rates of material processing without causing undue damage to the surface of the super-hard material being processed. Furthermore, another problem the present inventors have found with the aforementioned lapping configuration is that the lapping process can be difficult to obtain uniform processing across large areas of super-hard material.

Figures 4 to 6 illustrate a lapping apparatus re-configured according to the present invention. The apparatus shares many common features with that illustrated in Figures 1 to 3 and like reference numerals have been used for like parts to highlight common features.

As in the previously described arrangement, the apparatus comprises a rotatable processing wheel 2 on which a super-hard material product to be processed is mounted. The mounting configuration may comprise a carrier substrate 4 mounted to the super-hard material 6 such that a loading force is applied to the super-hard material 6 via the carrier substrate 4. For example, the super-hard material 6 may be bonded to the carrier substrate 4. Alternatively, the super-hard material may be retained in a free-standing configuration which is not bonded to a carrier substrate.

In the illustrated embodiment, the super-hard material 6 is adhered to a carrier substrate 4 and arranged such that a surface of the super-hard material is in contact with a surface of the processing wheel 2 with an interface region disposed between the surface of the super-hard material 6 and the surface of the processing wheel 2. A weight 8 is provided on the carrier substrate 4 such that the super-hard material 6 is pressed against the surface of the processing wheel 2 with a suitable loading force. In an alternative configuration a pneumatic arrangement can be utilized to apply the loading force in place of the weight 8.

As in the previously described arrangement, the carrier substrate 4 (if present) and the super-hard material product 6 can be mounted on the processing wheel within a constraining ring 10 which constrains a location of the super-hard material product 6 over the processing wheel 2. The constraining ring 10 may comprise a number of slots for allowing the passage of abrasive fluid therethrough as previously illustrated in Figure 3 although it is possible to utilize a constraining ring which does not comprise slots. The constraining ring 10 has an internal diameter which is larger than the diameter of the super-hard material product 6 and carrier substrate 4. Furthermore, both the constraining ring 10 and the super-hard material product 6 are mounted so as to rotate on the surface of the processing wheel 2 driven by rotation of the processing wheel. In the illustrated configuration the constraining ring 10 is rotatable mounted on the processing wheel 2 via constraining arm 12. In certain configurations the constraining ring 10 and/or the super-hard material product 6 are rotatably driven independently of the processing wheel 2 and this can be desirable to provide a controlled rotation of the constraining ring 10 and/or the super-hard material product 6 relative to the processing wheel 2. In this case, the constraining arm 12 may comprise driven wheels for rotating the constraining ring 10 and/or the super-hard material product 6. Alternatively, a rotating force may be applied from directly above the super-hard material product 6, e.g. via an upper surface of the super-hard material product 6, the carrier substrate 4, the weight 8, and/or via a pneumatic loading configuration if present.

One of the major differences between the apparatus of Figures 4 to 6 and that illustrated in Figures 1 to 3 is that the apparatus of Figures 4 to 6 is configured to provide an under-feed arrangement for the abrasive slurry. As illustrated in Figure 4, abrasive slurry is fed upwards through a rotational post 20 as illustrated by arrow 22. The processing plate 2 is adapted to provide a plurality of feed ports 24 disposed in the surface thereof such that in use an abrasive slurry is fed through the feed ports 24 onto the surface of the processing wheel from underneath the processing wheel as illustrated by arrows 26. The abrasive particles then move radial outwards from the feed ports 24 across the surface of the processing wheel 2 and roll through the interface region between the super-hard material product 6 and the processing wheel 2 in order to cause surface micro-cracking of the super-hard material product and removal of material from the surface of the super-hard material product.

The plurality of feed ports 24 can be radially distributed across the surface of the processing wheel such that at least a portion of the abrasive slurry is fed directly from the feed ports into the interface region between the surface of the processing wheel and the surface of the super-hard material product being processed.

Surprisingly, the present inventors have found that higher rates of material processing can be achieved in a much more controllable manner using a lapping configuration in which the surface of the processing wheel has one or more feed ports disposed therein and the abrasive slurry is fed through the feed ports during processing of the super-hard material product onto the surface of the processing wheel from underneath the processing wheel rather than dripped onto the surface of the processing wheel from above as is done in a more standard lapping configuration. A better surface finish is also achieved, especially for large polycrystalline CVD diamond wafers when compared with a top feed approach. While not being bound by theory, it is believed that the under-feed configuration is advantage over the top-feed configuration for the following reasons.

Using a top feed approach all abrasive particles entering an interface region between the surface of the processing wheel and the surface of the super-hard material must do so from an edge of the super-hard material. It has been found that this can lead to edge chipping, edge rounding, and/or groove formation across the surface of the super-hard material being processed. In contrast, if the abrasive slurry is under-fed then at least a portion of the slurry can be introduced directly under the super-hard material being processed in the interface region. As such, this abrasive material moves from a central region of the super-hard material to an edge region rather than from an edge region to a central region. It has been found that such a modified lapping technique reduces edge chipping, edge rounding, and grooving in the super-hard material being processed and thus can lead to a better surface finish. In addition, regardless of the direct under-feed to interface region configuration, it is also believed that generally an under-feed configuration allows the abrasive slurry to be introduced onto the surface of the processing wheel at a more controllable rate and optionally in a continuous stream.

In addition to the above, it is also possible using the modified lapping process to achieve more uniform processing across a large surface of a super-hard material such as a polycrystalline CVD diamond wafer. As previously indicated, standard lapping techniques involve dripping a suspension of diamond grit onto the lapping wheel from above. However, using such a technique requires grit to move into a peripheral region of the interface between the lapping wheel and a polycrystalline CVD diamond wafer and then propagate across the interface region in order to process the surface of the polycrystalline CVD diamond wafer. The grit particles are broken down as they hit the peripheral region of the wafer and during propagation under the wafer. This can result in differential processing of peripheral and central regions of the wafer with central regions being processed by smaller particles of grit than peripheral regions. This problem is particular to processing of super-hard materials, such as diamond wafers, as other materials do not cause the diamond grit to be broken down into smaller particles. As previously described, in order to solve this problem the lapping apparatus has been modified to feed the suspension of diamond grit from an underside of the lapping wheel through holes in the lapping wheel at locations which result in the grit being fed directly into the interface region between the wafer and the lapping wheel. As such, using this arrangement it is possible to avoid differential processing of peripheral and central regions of the wafer.

In the above described arrangement, abrasive slurry is fed onto the surface of the processing wheel though one or more feed ports from underneath the processing wheel. Furthermore, the abrasive slurry is preferably fed onto the surface of the processing wheel though the one or more feed ports in a continuous stream. In this regard, the lapping apparatus may further comprise a pump configured to feed abrasive slurry though the one or more feed ports in a continuous stream and the pump may be configured to vary a rate of flow of the abrasive slurry though the one or more feed ports in the processing wheel. The processing wheel may also comprise one or more grooves or slots disposed in the working surface thereof, e.g. radially disposed slots, concentrically disposed grooves, or spiral grooves. Such slots and grooves can aid in controlling the movement of abrasive slurry across the processing wheel and/or removal of abrasive slurry from the surface of the processing wheel. The one or more feed ports disposed in the processing wheel may be configured to inject abrasive slurry into one or more slots or grooves on the surface of the processing wheel. Alternatively, the processing wheel may be planar without any such grooves. While slots or grooves are known to increase lapping rates in certain applications, the presence of such slots and grooves can make the re-conditioning of such processing wheels more problematic.

As an alternative to the illustrated configuration, it is also envisaged that the entire apparatus could, in principle, be inverted relative to the Earth. In that case, the super-hard material product would be mounted against a lower surface of the processing wheel and abrasive slurry would be fed through feed ports in the processing wheel from above the processing wheel to the lower surface with at least a portion of the abrasive slurry being fed directly from the one or more feed ports into the interface region between the surface of the processing wheel and the super-hard material product being processed.

In addition to the above, the present inventors have also found that the lapping process as described herein is sensitive to the rotation speed of the processing wheel and that the rotation speed of the processing wheel may be selected to optimize processing rates while retaining a good surface finish. It has been found that the rotation speed of the processing wheel may advantageously be selected to be in a range 0.2 ms^{-1} to 7.5 ms^{-1} with certain embodiments optionally using a rotation speed in a range 1.5 ms^{-1} to 5.5 ms^{-1}. For example, for a 350 mm diameter processing wheel this would equate to a rotational speed of about 10 rpm (revolutions per minute) to about 400 rpm with certain embodiments optionally using a rotation speed of about 80 rpm to 300 rpm. That said, for certain applications it has been found that higher rotational speeds can be utilized (e.g. up to 1000 rpm).

The present inventors have also found that the lapping process as described herein is sensitive to the loading force which presses the super-hard material product against the surface of the processing wheel and that the loading force may be selected to optimize processing rates while retaining a good surface finish. It has been found that the loading per unit area of the super-hard material product which presses the super-hard material product against the surface of the processing wheel may advantageously be selected to be in a range 0.05 g/mm^2 to 1.5 g/mm^2 with certain embodiments optionally using a loading in a range 0.1 g/mm^2 to 0.6 g/mm^2.

In relation to the above, it may be noted that in principle control of the super-hard material product relative to the surface of the processing wheel may be achieved in two different ways: (i) controlling a distance between the super-hard material product and the surface of the processing wheel; or (ii) controlling the applied force as described above. Either of these methods of control could be utilized in combination with the underfeed configuration as described herein.

The present inventors have also found that the lapping process as described herein is sensitive to the particle size of the super-hard abrasive grit and that the particle size of the abrasive may be selected to optimize processing rates while retaining a good surface finish. It has been found that the particle size of the super-hard abrasive grit may advantageously be selected to be in a range 5 μm to 100 μm with certain embodiments optionally using an abrasive particle size in a range 10 μm to 65 μm. It has been found that surprisingly good surface finishes with relatively low surface roughness can be achieved when lapping with relatively coarse grit.

Different grades of abrasives grit may be used either individually or sequentially to achieved particular surfaces finishes. For example, a coarse grit having an average particle size of approximately 50 μm to 60 μm, an intermediate grit having an average particle size of approximately 35 μm to 45 μm, and a fine grit having an average particle size of approximately 20 μm to 30 μm. Finer grits are more expensive and should only generally be used when a very high degree of flatness and smoothness are required. As previously indicated, it has been found that a low roughness finish can be achieved for diamond material using relatively coarse grits. For example, using a grit size of 20 to 25 μm it is possible to achieve a surface roughness of better than 150 nm R_a. To achieve a comparable surface roughness on a metal wafer would require grit particles of approximately 2 μm in size. One reason for this is that when processing a diamond surface the diamond grit particles roll across the surface, form microcracks in the surface, and then these microcracks intersect such that a portion of the diamond surface falls away from the wafer. In contrast, when processing a metal wafer the diamond grit particles gouge metal material out of the surface as they are dragged across the surface resulting in a less smooth finish.

As described above, in a lapping method for processing a super-hard material, super-hard abrasive grit particles roll between the lapping wheel and the surface of the super-hard material being processed, form microcracks in the surface of the super-hard material, and then these microcracks intersect such that a portion of the super-hard material surface falls away. It will be appreciated that in order to achieve this rolling and microcracking mechanism, the processing wheel should be relatively non-porous such that the super-hard abrasive grit particles do not become embedded or impregnated into the surface of the lapping wheel as, for example, in a 2-body polishing technique. As such, the processing wheel should comprise a relatively non-porous surface, e.g. having pores of size less than 100 μm, 80 μm, 60 μm, 40 μm, 20 μm, 10 μm, 5 μm, or 1 μm. Furthermore, in a lapping method for processing a super-hard material using a super-hard abrasive slurry, the processing wheel should be made of a relatively hard, relatively tough material to allow the rolling mechanism and also achieve relatively long lifetimes in such a process. In this regard, lapping wheels are usually formed of a metallic material such as a steel or iron material.

The present inventors have also found that the lapping process as described herein is sensitive to the concentration of super-hard abrasive grit particles within the abrasive slurry and that the concentration of super-hard abrasive grit particles within the abrasive slurry may be selected to optimize processing rates while retaining a good surface finish. It has been found that the concentration of super-hard abrasive grit particles within the abrasive slurry may advantageously be selected to be in a range 50 to 150 carats per litre (10 grams/litre to 30 grams/litre) for cost effective processing. Higher concentrations can work well and have a faster material removal rate but are not as attractive on a cost basis due to the cost of the super-hard abrasive grit. As such, higher concentrations (e.g. up to 500 carats per litre or 100 grams/litre) are generally only used for higher margin products where cost is less of an issue. Very high concentrations can result in aggregation of grit particles which is not desirable. On the other hand, very low concentrations can cause processing damage.

The present inventors have also found that the lapping process as described herein is sensitive to the rate at which the abrasive slurry is fed onto the surface of the processing wheel and that the feed rate may be selected to optimize processing rates while retaining a good surface finish. It has been found that the feed rate may advantageously be selected to be in a range 0.1 litres/hour to 2 litres/hour with certain embodiments optionally using a feed rate in a range 0.2 litres/hour to 0.7 litres/hour. Furthermore, typically if the rate of grit supplied to the lapping wheel is doubled then the weight on the wafer being processed should also be doubled such that the load per grit particle remains reasonably constant.

A number of possible carrier fluids may be utilized for the abrasive grit particles. The carrier fluid should have a viscosity which is sufficient to suspend the abrasive grit particles during transport through the one or more feed ports to the surface of the processing wheel. The precise requirements for the carrier fluid will also depend on flow rate, grit size, suspension time, and grit concentration. Glycerine based carrier fluids may be utilized but even water based carrier fluids with various additives have been found to be suitable.

The processing parameters of rotation speed, loading force, grit size, grit concentration, and slurry feed rate are inter-related and preferably a combination of the aforementioned parameters is utilized to achieve the best lapping of super-hard products.

In addition to the use of an under-feed lapping configuration and optimized processing parameters as described above, the present inventors have also developed a simple and effective mounting configuration for ensuring that highly flat surface finishes can be achieved. In particular, it has been found to be advantageous to use an ultra-flat carrier substrate (e.g. one which has a surface flatness of better than 20 μm, better than 10 μm, better than 5 μm, or better than 1 μm). Furthermore, it has been found to be advantageous to use a very low viscosity adhesive to mount the super-hard material product to the carrier substrate. Use of a low viscosity adhesive avoids the adhesive drying with a non-uniform flatness which introduces non-uniformities in the reference surface to which the super-hard material product is adhered. Such non-uniformities can result in non-uniformities in the flatness of the super-hard material being processed. That said, while low viscosity adhesives have been found to be useful for mounting super-hard material products for processing, another alternative is to leave the super-hard material product in an un-bonded state.

A suitable mounting configuration for the super-hard material to be processed is illustrated in Figure 6. The mounting configuration comprises a carrier plate 30 having an ultra-flat surface. The carrier plate 30 may be formed from a number of different materials including invar, silicon carbide, silicon cemented diamond, quartz, or borosilicate glass. Ideally, the carrier plate 30 should be made of a material which has a low thermal expansion coefficient and which is capable of being processed to a high degree of flatness. The carrier substrate may be cylindrical in shape and may comprise an o-ring 32 disposed around a peripheral surface thereof. The o-ring 32 is advantageous to protect the carrier in use where it abuts against a constraining ring as previously described. A super-hard material product plate 34 is mounted to the ultra-flat surface of the carrier plate 30, e.g. via a low viscosity adhesive 36. While in Figure 6 the super-hard material product plate 34 has a diameter substantially equal to that of the carrier plate 30, in practice the diameter of the super-hard material product plate 34 may often be smaller than that of the carrier plate 30.

One mounting technique involves pressing a wafer of super-hard material onto a carrier substrate (nucleation face down as this provides the smoothest, flattest reference face when compared with the growth face which is rough and comprises larger particles) and beading glue around the edge of the wafer. The glue is drawn into the interface between the wafer and the carrier substrate around a peripheral region by capillary action and sets to adhere the wafer to the carrier substrate. If the wafer or the substrate is not sufficiently flat then glue may be drawn into a more central region of the interface which is not desirable as flatness is compromised. What is desired is a very small volume of glue within the interface region only around a peripheral region. The glue must be a low viscosity adhesive in order to be drawn into the interface and set in the required manner. The glue must also be capable of withstanding the temperatures generated during lapping and polishing in order to retain adhesion during processing. After processing one surface, the substrate-wafer composite is heated to soften the glue and release the wafer which is then turned over and re-adhered to the carrier substrate for processing the nucleation face of the wafer.

While the above described mounting configuration is suitable for processing flat super-hard material products, the lapping process as described herein may also be utilized for non-planar super-hard material products. In this case the working surface of the processing wheel may be curved and the carrier plate may also be curved to provide a suitable mounting configuration and processing surface for a non-planar super-hard material product such a dome or lens.

Embodiments of the present invention may be applied to a range of super-hard materials including a range of diamond materials, cubic boron nitride materials (cBN), sapphire, and composites comprising the aforementioned materials. For example, diamond materials include chemical vapour deposited (CVD) single crystal and polycrystalline synthetic diamond materials of a variety of grades, high pressure high temperature (HPHT) synthetic diamond materials of a variety of grades, natural diamond material, and diamond composite materials such as polycrystalline diamond which includes a metal binder phase (PCD) or silicon cemented diamond (ScD) which includes a silicon/silicon carbide binder phase.

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

Claims

1. A method of lapping a super-hard material product having a Vickers hardness of no less than 2000 kg/mm^2, the method comprising:

mounting the super-hard material product with a surface of the super-hard material product in contact with a surface of a processing wheel with an interface region disposed between the surface of the super-hard product and the surface of the processing wheel;

loading the super-hard material product such that the super-hard material product is pressed against the surface of the processing wheel with a loading force;

rotating the processing wheel; and

feeding an abrasive slurry onto the surface of the processing wheel, the abrasive slurry comprising super-hard abrasive grit particles disposed in a carrier fluid,

wherein the super-hard abrasive grit particles of the abrasive slurry have a particle size of at least 1 μm and roll between the surface of the processing wheel and the surface of the super-hard material product within the interface region in order to cause surface micro-cracking of the super-hard material product and removal of material from the surface of the super-hard material product, and

wherein the surface of the processing wheel has one or more feed ports disposed therein and at least a portion of the abrasive slurry is fed directly from the one or more feed ports into the interface region between the surface of the processing wheel and the super-hard material product being processed.

2. A method according to claim 1, wherein the abrasive slurry is fed onto the surface of the processing wheel though the one or more feed ports from underneath the processing wheel.

3. A method according to claim 1 or 2, wherein the abrasive slurry is fed onto the surface of the processing wheel though the one or more feed ports in a continuous stream.

4. A method according to any preceding claim, wherein the processing wheel it rotated at a speed in a range 0.2 ms^{-1} to 7.5 ms^{-1} or 1.5 ms^{-1} to 5.5 ms^{-1}.

5. A method according to any preceding claim, wherein the loading force which presses the super-hard material product against the surface of the processing wheel is in a range 0.05 g/mm^2 to 1.5 g/mm^2 or 0.1 g/mm^2 to 0.6 g/mm^2.

6. A method according to any preceding claim, wherein the super-hard abrasive grit particles have a particle size in a range 5 μm to 100 μm or 10 μm to 55 μm.

7. A method according to any preceding claim, wherein the abrasive slurry comprises a concentration of super-hard abrasive grit particles in a range 50 to 150 carats per litre (10 grams/litre to 30 grams/litre).

8. A method according to any preceding claim, wherein the abrasive slurry is fed onto the surface of the processing wheel though the one or more feed ports at a feed rate in a range 0.1 litres/hour to 2 litres/hour or 0.2 litres/hour to 0.7 litres/hour.

9. A method according to any preceding claim, wherein a carrier substrate is mounted to the super-hard material product and the loading force is applied via the carrier substrate.

10. A method according to claim 9, wherein the carrier substrate has a surface flatness better than 20 μm, 10 μm, 5 μm, or 1 μm.

11. A lapping machine configured for processing a super-hard material product having a Vickers hardness of no less than 2000 kg/mm^2, the lapping machine comprising:

a rotatable processing wheel; and

a mounting part configured to mount the super-hard material product with a surface thereof in contact with a surface of the processing wheel with an interface region disposed between the surface of the super-hard product and the surface of the processing wheel, the mounting part being further configured to press the super-hard material product against the surface of the processing wheel with a loading force,

wherein the surface of the processing wheel has one or more feed ports disposed therein configured such that in use an abrasive slurry is fed through the feed ports onto the surface of the processing wheel, at least a portion of the abrasive slurry being fed directly from the one or more feed ports into the interface region between the surface of the processing wheel and the super-hard material product being processed.

12. A lapping machine according to claim 11, wherein the one or more feed ports in the processing wheel are configured to feed the abrasive slurry onto an upper surface of the processing wheel from underneath the processing wheel.

13. A lapping machine according to claim 11 or 12, further comprising a pump configured to feed abrasive slurry though the one or more feed ports in a continuous stream.

14. A lapping machine according claim 13, wherein the pump is configured to vary a rate of flow of the abrasive slurry though the one or more feed ports in the processing wheel.

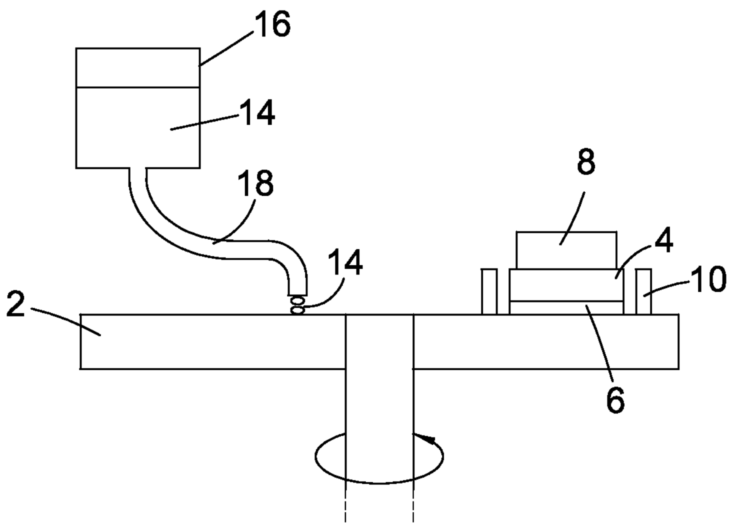

Fig. 1

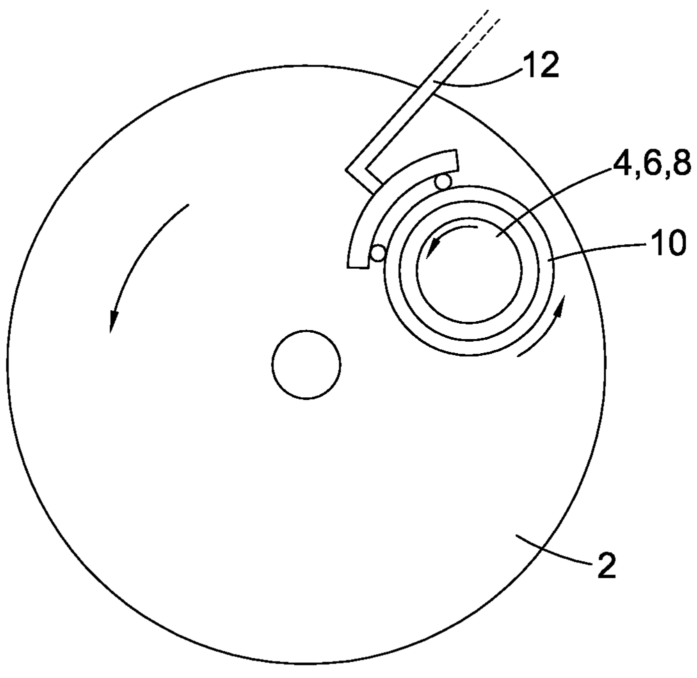

Fig. 2

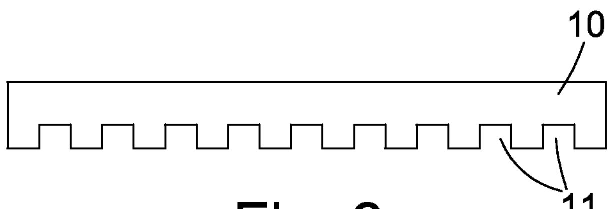

Fig. 3

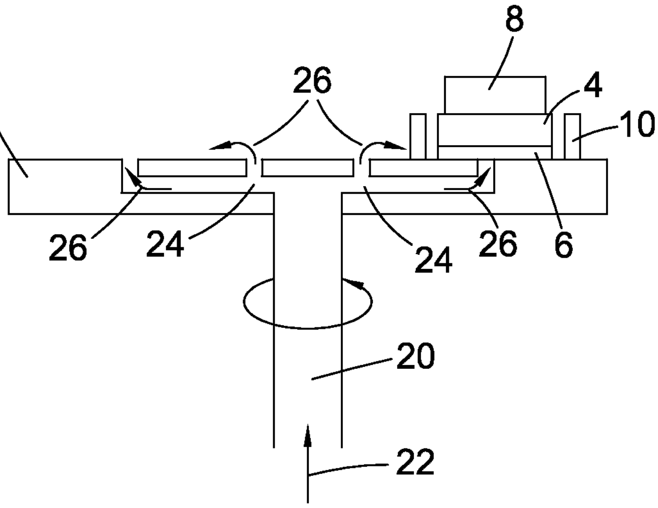

Fig. 4

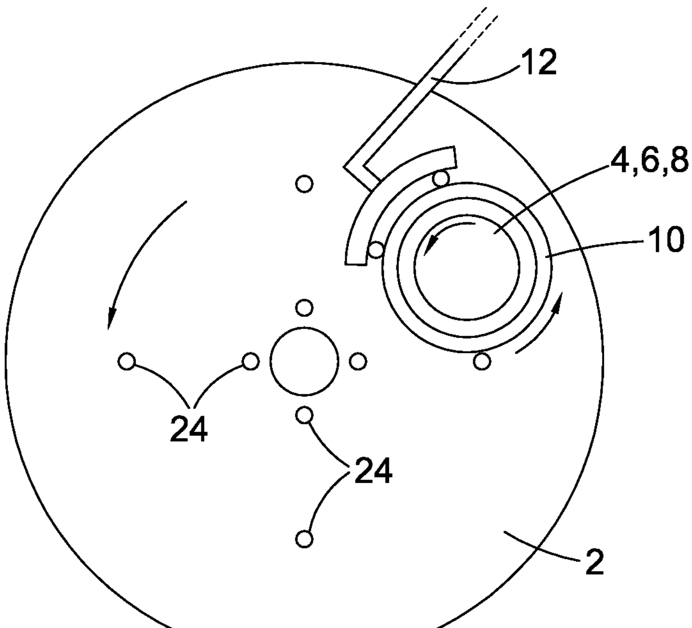

Fig. 5

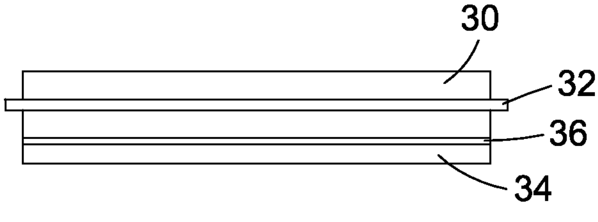

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/058205

A. CLASSIFICATION OF SUBJECT MATTER
INV. B24B37/26 B24B57/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B24B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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Y	figures 1,2	1-10

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 July 2014	06/08/2014

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/058205

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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