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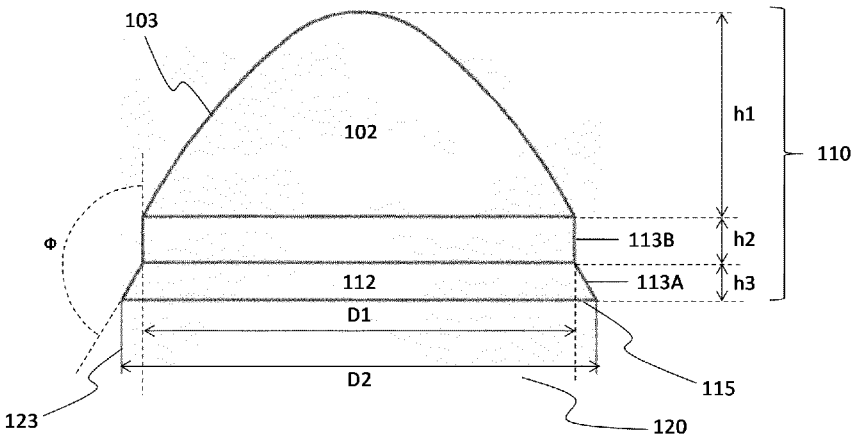


Fig. 4

(57) Abstract: A super-hard tip for a super-hard bit comprises a super-hard volume (102) and a substrate (112). The super-hard volume is sinter-joined to a distal end of the substrate at a join boundary (105), opposite a proximal end of the substrate configured for joining to a support body (120). A substrate side (113) connects the proximal and distal ends of the substrate. The distal end defines a distal circumscribing circle, and the proximal end defines a proximal circumscribing circle. The side of the substrate may include a divergent area, configured such that the diameter of the proximal circumscribing circle (D2) is greater than the diameter of the distal circumscribing circle (D1).

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SUPER-HARD BITS, SUPER-HARD TIPS FOR SAME, TOOLS COMPRISING SAME AND METHODS FOR MAKING SAME

FIELD OF THE INVENTION

This disclosure relates generally to super-hard bits for tools, super-hard tips for the bits, tools comprising same and methods for making same. Particularly but not exclusively, the super-hard bits and tips may comprise diamond or cubic boron nitride (cBN) grains, and the tools may be pick tools for boring into the earth, cutting into rock, or milling pavement.

BACKGROUND

EP 2 049 769 discloses an attack tool for degrading materials, comprising a cemented carbide first segment bonded to a base segment, and a cemented carbide second segment brazed to the first segment. Super-hard material is bonded to an end of the second segment. Excess braze material may extrude to the outside of the brazed joint and brazing may result in an affected zone, which may be weakened by cracks, depressions, scrapes or other irregularities or imperfections. The affected zone will be removed by grinding.

EP 3 071 791 discloses a method of making a strike construction for a pick tool, the strike construction comprising a cemented carbide strike tip joined to an end of a cemented carbide support body, sides of which depend divergently from the end. The method includes processing a precursor to the support body to increase the area of the end, and joining the strike tip and the support body. The method may include processing the strike construction to modify its surface roughness, its size dimension, the sharpness or roundedness of an edge, characterised by an osculating circle radius.

There is a need for tools having extended working life in applications such as cutting, drilling or milling formations or structures comprising rock, concrete or pavement, for example. In particular, there is a need for tools comprising super-hard bits, and bits comprising super-hard tips, and for methods of making same.

SUMMARY

Viewed from a first aspect, there is provided super-hard bit for a tool (for example, a pick tool), comprising a super-hard volume, a substrate and a support body; the super-hard volume sinter-joined to a distal end of the substrate, and a proximal end of the substrate joined to the support body; a substrate side connecting the proximal and distal ends of the substrate; each

of the proximal and distal ends having a respective peripheral edge; the peripheral edge of the proximal end defining a proximal circumscribing circle, and the peripheral edge of the distal end defining a distal circumscribing circle; in which the substrate side includes a divergent side area that diverges from the distal end towards the proximal end, configured such that the diameter of the proximal circumscribing circle is greater than the diameter of the distal circumscribing circle.

Viewed from a second aspect, there is provided a super-hard tip for a super-hard bit, the super-hard tip comprising a super-hard volume and a substrate; the super-hard volume sinter-joined to a distal end of the substrate, opposite a proximal end of the substrate; a substrate side connecting the proximal and distal ends of the substrate; each of the proximal and distal ends having a respective peripheral edge; the peripheral edge of the proximal end defining a proximal circumscribing circle, and the peripheral edge of the distal end defining a distal circumscribing circle; in which the substrate side includes a divergent side area that diverges from the distal end towards the proximal end, configured such that the diameter of the proximal circumscribing circle is greater than the diameter of the distal circumscribing circle.

Viewed from a third aspect, there is provided a method for making a super-hard tip, including: providing a precursor body for the substrate, the precursor body having proximal and distal end surfaces connected by a side; each of the proximal and distal ends having a respective peripheral edge; the peripheral edge of the proximal end defining a proximal circumscribing circle, and the peripheral edge of the distal end defining a distal circumscribing circle; in which the side includes a divergent side area that diverges from the distal end towards the proximal end, configured such that the diameter of the proximal circumscribing circle is greater than the diameter of the distal circumscribing circle (for example, the diameter of the circumscribing proximal circle may be at least about 0.75 mm, or at least about 1 mm greater than the circumscribing distal circle); the method including forming a precursor aggregation comprising super-hard grains against the distal end of the substrate precursor body to form a pre-sinter assembly, the precursor aggregation capable of being sintered to form the super-hard material (in some examples, the precursor aggregation may be capable of being sintered in response to molten material from the substrate precursor body infiltrating into the precursor aggregation); in which the precursor aggregation has a density of at least about 60%, or at least about 70% of the (maximum) theoretical density of the density of the material (in other words, at least about 60% or 70% of the weighted sum of the densities of the constituent material, without the presence of pores); assembling the pre-sinter assembly into a capsule

for an ultra-high pressure, high temperature (HPHT) press; and subjecting the pre-sinter assembly to an HPHT condition to sinter the super-hard grains and form the super-hard volume joined to the distal end surface of the substrate.

Viewed from a fourth aspect, there is provided a method of making a super-hard tip, including providing a precursor tip body comprising a super-hard volume and a substrate, the substrate having a proximal and a distal end, and the super-hard volume being sinter-joined (at a join boundary) to the distal end of the substrate; and processing the substrate such that a distal circumscribing circle defined by a peripheral edge of the distal end has a smaller diameter than a proximal circumscribing circle defined by a peripheral edge of the proximal end, and such that a substrate side connecting the distal and proximal ends includes a divergent area diverging from the distal end towards the proximal end.

Viewed from a fifth aspect, there is provided a method of making a super-hard bit, including providing an example disclosed super-hard tip, providing a support body for a super-hard bit for a pick tool, having an end surface; and joining the proximal substrate end of the super-hard tip to the end surface of the support body by means of braze material.

Viewed from a sixth aspect, there is provided a pick tool assembly comprising an example disclosed super-hard bit coupled to a tool drive apparatus for driving the super-hard tip against a body to be degraded (or broken).

Various arrangements of super-hard bits, tips and tool assemblies, and methods of making super-hard bits and tips are envisaged by this disclosure, of which non-limiting, non-exhaustive examples are disclosed below.

In some example arrangements, the super-hard volume comprising or consisting essentially of super-hard material may be sinter-joined to the distal end of the substrate at a join boundary area, which may be less than, or substantially equal to, the area of the distal end of the substrate.

In some examples, the tool may be a pick tool for breaking a body. The super-hard volume may define a strike surface opposite the distal end of the substrate. In use, the strike surface may be driven by a tool drive apparatus to strike the body (once or repeatedly). In some

example arrangements, the support body may be configured for coupling the super-hard bit to a tool drive apparatus.

The super-hard volume comprises or consists of sintered polycrystalline super-hard material, such as polycrystalline diamond (PCD) material, polycrystalline cubic boron nitride (PCBN) material, or silicon carbide-bonded diamond (SCD) material (as used herein, unless otherwise specified, the term “diamond” will include both natural and fabricated diamond), characteristic may not be present in PCBN or other polycrystalline super-hard materials.

In some example arrangements, the peripheral edge of the proximal end of the substrate may lie on a proximal plane; and / or the peripheral edge of the distal end of the substrate may lie on a distal plane; and / or the proximal and distal planes may be substantially opposite each other, or they may be disposed at an angle of about 2° to about 45° to each other. In some examples, the distal end may be substantially non-planar; for example, a join boundary area of the distal end may include a projecting area.

The divergent area of the substrate side may be configured that it extends away from a longitudinal axis as it extends away from the distal end of the substrate, and / or the join boundary, the longitudinal axis passing through the centres of the proximal and distal ends of the substrate. The divergent area may extend azimuthally all the way around the substrate (in other words, through 360°), or azimuthally part of the way around the substrate (for example, through an azimuthal angle of at least about 10°, at least about 60°, or at least about 120°, and / or at most about 120°, or at most about 160°). The divergent area may be conformal through its azimuthal extent, or its shape may vary with azimuthal angle along its extent. The shape of the divergent area may such that its surface will define a straight or curved line when viewed in longitudinal cross-section (in other words, when viewed in a plane that includes the longitudinal axis, being parallel to the longitudinal axis); the surface may define a concave curve on the cross-section plane; for example, a hyperbolic, or a parabolic curve.

In some examples, the substrate and / or the support body may comprise or consist of cemented carbide material, in which a plurality of carbide compound grains such as tungsten carbide (WC) or titanium carbide (TiC) are bonded together by cementing material. Example cementing material may comprise or consist of cobalt (Co), iron (Fe) or nickel (Ni), or an alloy comprising at least two of these elements.

In some examples, the support body may be a post comprising or consisting of cemented carbide, for example cobalt-cemented tungsten carbide material; the substrate and the support body may comprise or consist of cemented carbide of substantially the same grade, or of different grades. For example, the substrate and the support body may each comprise or consist of Co-WC material, in which the respective size distributions and / or contents of WC grains are substantially the same or different from each other.

In some example arrangements, the diameter of the proximal circumscribing circle may be at least 1.0 mm, or at least 1.5 mm, or at least 2 mm, or at least 3 mm greater than the diameter of the distal circumscribing circle. The diameter of the proximal circumscribing circle may be at most about 10 mm or at most about 5 mm greater than the diameter of the distal circumscribing circle. In some example arrangements, the diameter of the proximal circumscribing circle may be at least 5%, or at least 10% greater than the diameter of the distal circumscribing circle.

In some example arrangements, the area of the proximal circumscribing circle may be at least about 10%, or at least about 20% greater than the distal circumscribing circle.

In some example arrangements, the substrate side may include a proximal side area and a distal side area, in which the proximal side area is coterminous with a peripheral edge of the proximal substrate end of the substrate, and the distal side area may be coterminous with the peripheral edge of the super-hard volume, or at least remote (non-coterminous with) the peripheral edge of the proximal substrate end. In some examples, the peripheral edge of the proximal substrate end can be characterised, or may define, an osculating circle, which may have a radius of at most about 0.5 mm, or at most about 0.2 mm, or at most about 0.1 mm.

In some example arrangements, the proximal side area may define a tangent plane lying at angle of at least about 20°; and / or at most about 70° from a longitudinal axis (as used herein, the longitudinal axis will pass through the respective centres of the proximal and distal ends). The proximal side area may extend along the entire length of the peripheral edge of the proximal substrate end. In some example arrangements, the proximal side area may be substantially conical. In some example arrangements, the distal side area may be substantially cylindrical, and may extend along the entire length of the peripheral edge of the super-hard surface. In some example arrangements, the substrate side may include an

arcuate surface area extending longitudinally between the super-hard volume and the proximal substrate end.

In some example arrangements, a side area of the support body coterminous with a peripheral edge of the end surface may define a tangent plane lying at angle of at least 0° at and most 70° from the longitudinal axis, and may extend along the entire length of the peripheral edge of the end surface. The support body side area may be conical, and an end portion of the support body, comprising the end surface and the side area, may be frusto-conical.

In some example arrangements, the proximal side area of the substrate as well as the side area of the support body may be conical, characterised by respective cone angles having substantially the same value, or substantially different values; for example, the respective cone angles may differ by at least about 20°; and / or at most about 100°.

In some example arrangements, tangent planes to the proximal side area of the substrate and the side area of the support body may lie least about 130° from each other (referring to the angle external to the substrate and support body), or at least about 170°, about 180°, about 200°, or at least about 220° from each other; and / or at most about 260° from each other.

In some example arrangements, the peripheral edge of the super-hard volume may be circular or elliptical; and / or the peripheral edge of the proximal substrate end may be circular or elliptical.

In some examples, the join material may comprise or consist of braze alloy material; and / or the join layer may have a thickness of at least about 10 microns; and / or at most about 50 microns.

An example method for making a super-hard tip may include providing a cup defining an open cavity; forming precursor material for the super-hard grain aggregation against the surface of the cavity; placing a distal end of a precursor substrate body against the precursor material; and placing an opposing end cup over the substrate, such that the mutually opposing cups overlap each other to enclose the substrate and the precursor material and thus form a pre-sinter assembly. In some examples, the method may include placing a sacrificial disc adjacent a proximal end of the substrate; the sacrificial disc may comprise or consist of cemented

carbide material. The method may include removing the sacrificial disc, for example by machining or grinding, after the step of sintering the super-hard grains at the HPHT condition.

In some example methods, the precursor substrate body may comprise or consist essentially of raw material for forming the substrate by a method including sintering; for example, the precursor substrate body may comprise metal carbide grains, such as tungsten carbide grains, combined with material for cementing the grains to form a cemented carbide material, for example, material including cobalt, and / or iron, and / or nickel. The precursor substrate body may have substantially the shape of the substrate of the finished super-hard tip (the shape may differ from that of the substrate to the extent that the precursor substrate body may shrink when sintered when to form the substrate).

In an example method, precursor paste material comprising super-hard grains and organic binder material may be injection-moulded through a channel into a mould, in which the paste may be pressurised by means of a hydraulically operated plunger. The paste within the mould may be subjected to heat treatment to burn off substantially all the organic binder material, leaving a green body having sufficient strength to be removed from the mould. The green body may be placed into a cup defining a cavity having a surface substantially conforming with that of the green body, and a substrate precursor body may be placed against the exposed end of the green body, forming a pre-sinter assembly. In other words, the outer-most surface of the green body, having substantially the same shape as the finished super-hard volume, may be placed against the surface of the cavity of the cup.

Examples in which the green body for the super-hard volume is formed by means of injection-moulding may avoid process difficulties associated with using a plunger to compact raw material and binder powder to a sufficiently high density, where the side of the substrate is to be conical, and where there may be a risk of raw material extruding between the plunger and a conical surface of the mould. In some examples, the method may have the aspect of enhancing the consistency and process efficiency of providing a green body having substantially the desired shape and dimensions (apart from shrinkage resulting from subsequent sintering), which has sufficient strength and density for handling and assembling into a pre-sinter assembly, in which the green body comprising the super-hard grains may be combined with a substrate precursor body. Although injection moulding may yield certain advantages, various methods of making super-hard tips according to the first aspect may include providing the raw material in the form of powder, flakes, or granules, for example;

placing a sufficient quantity of the raw material into a compaction mould, and compacting this material by means of a plunger.

An example method may include heat treating the precursor material to remove some or substantially all of the binder material to provide the aggregation of super-hard grains, and compacting the aggregation to achieve a pre-sintered ('green') density of at least about 70%, and / or at most about 80% of the theoretical density (calculated based on the relative amounts and the respective densities of the constituent materials, without the presence of pores).

In some examples, the precursor material may comprise at least about 50% by volume feedstock material; and / or at most about 70% by volume feedstock material, in which the feedstock material may comprise or consist of super-hard grains, or super-hard grains combined with metal solvent / catalyst material. In some examples, the super-hard grains may comprise or consist of diamond or cBN grains, or crystallites; and / or the metal solvent / catalyst material may comprise or consist essentially of cobalt (Co), iron (Fe), nickel (Ni), or an alloy including at least one of Co, Fe or Ni. In some examples, the feedstock material may comprise diamond grains and at least 1 weight % Co, and / or at most about 15 wt.% Co, or at most about 10 wt.% Co.

In some examples, the precursor material may comprise organic binder and / or plasticiser material, for example polyethylene glycol (PEG), and / or Poly(methyl methacrylate (PMMA), and / or stearic acid. In some examples, the precursor material may comprise at least about 55 vol. %, or at least 59 vol. % diamond grains; and / or at most about 65 vol. %, or at most 63 vol. % diamond grains. For example, the green density of the green body including the super-hard grains may be at least about 2.5 g/cm^3, and / or at most about 3.0 g/cm^3, or at most 2.8 g/cm^3; and in some examples. In some examples, the precursor material may comprise about 58 vol. % to about 60 vol. % diamond grains, and the green density of the green body may be about 2.5 g/cm^3 to about 2.9 g/cm^3.

Precursor material having a disclosed example composition may exhibit suitable rheological properties for injection moulding into the cup, and for resulting in a green body having a suitable green density for sintering the super-hard material with sufficient dimensional tolerance. Suitable rheology of the paste may have the effect of prolonging the working life of the injection moulding apparatus, particularly since the paste contains super-hard grains, which may tend to abrade or erode the apparatus.

In some examples, the cavity defined by the cup may have the shape and dimensions of the strike surface of the super-hard volume, modified to substantially compensate for the changes in shape and dimensions that will occur during the process of sintering the super-hard volume. The shape and dimensions of the cavity may be such that the strike surface of the super-hard volume to be formed within the cup during the sintering process will be within about 2%, or within about 5%, or within about 10% of the shape and dimensions of the super-hard volume of the finished product.

In some examples, the cup may comprise or consist of refractory material, for example niobium, molybdenum, tantalum, or titanium, or ceramic material, for example.

In some examples, the precursor material for the super-hard grain aggregation (in other words, from which the aggregation of super-hard grains may be made) may comprise or consist of paste, granules or wafers, comprising or consisting of the super-hard grains with or without binder material holding the super-hard grains together. For example, the precursor material may be in the form of paste. The composition and content of binder material and / or plasticiser material comprised in the paste may be such that the paste has a shear rate of at least 1 per second (s^{-1}) and at most $25s^{-1}$. The paste may be extruded or injected into the cup under a pressure of about 6.5 to about 9 MPa.

In some examples, a pick tool assembly comprising an example disclosed super-hard tip may be configured for pavement milling, or breaking rock; for example, the pick tool assembly may be for use in mining, construction, pavement milling, or oil or gas drilling.

Some example methods may include processing the substrate by means of a die-sinking electrode, remove material and form the desired shape and dimensions of the substrate side. For example, a semi-finished super-hard tip may comprise or consist of the super-hard volume sinter-joined to a precursor substrate body having a substantially cylindrical side. The precursor substrate body may comprise or consist essentially of cemented carbide, such as cobalt-cemented tungsten carbide. The die-sinking electrode, which may comprise copper or another metal, may have a working end that will engage the substrate precursor body and remove material from it by means of electrical erosion, in which the working end includes a surface defining the shape of the desired side of the substrate. For example, if the side of the substrate will comprise a conical area, then the working end may include a working surface disposed at substantially the angle of the conical area (defining substantially the same cone

angle). The working end of the die-sinking electrode may be moved towards the substrate precursor body, to electrically engage it, until the side of the substrate is formed to the desired shape. The die-sinking electrode may include a cavity or depression for accommodating the super-hard volume, which may not be eroded, or which may be partly eroded by the electrode.

In some example methods that include processing the substrate of a precursor tip body, the super-hard volume of the precursor tip body may comprise PCD or PCBN material sinter-joined at a join boundary to the distal end of the substrate, in which the area of the join boundary is less than the area of the distal end of the substrate, and processing the substrate includes reducing the area of the distal end to substantially the same area as the join boundary.

Some example methods of making a super-hard tip may include shot-blasting the side of the substrate. In some examples, this may have the aspect of avoid the need to grind the side surface, which may be difficult to do by means of centreless grinding.

Since the side of the substrate will include a substantially non-cylindrical area, it may not be straightforward to grind the side of the substrate to its final dimension by means of a centreless grinding technique. Disclosed example methods may have the aspect of avoiding the need to grind the side of the substrate, since example super-hard tips may be formed with substantially the shape and dimensions of the finished super-hard tip product.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting example arrangements of super-hard bits, tools comprising super-hard bits, and example methods of making them will be described with reference to the accompanying drawings, of which:

Fig. 1A shows a schematic longitudinal cross-section view of an end portion an example super-hard bit, and Fig. 1B shows respective circles corresponding to each of the proximal and distal circumscribing circles, superimposed on the same view;

Fig. 2 shows a schematic longitudinal cross-section view of a side portion of an example super-hard bit, including the join layer between a substrate and a support body;

Fig. 3A and 3B show schematic longitudinal cross-section view of side portions of example super-hard bits, including portions of the joins between respective substrates and support bodies;

Fig. 4 shows a side view of an example super-hard tip and an end portion of an example support body to which the super-hard tip us joined;

Fig. 5A shows a longitudinal cross-section view (left-hand side) and a front view (right-hand side) of an example super-hard bit; Fig. 5B shows a schematic longitudinal cross-section view through an enlarged end portion of the example super-hard bit shown in Fig. 5A, indicated by E;

Fig. 6 shows a schematic longitudinal cross-section view through an enlarged end portion of an alternative example arrangement of a super-hard bit shown in Fig. 5A, indicated by E;

Fig. 7 shows a schematic longitudinal cross-section view through an enlarged end portion of an alternative example arrangement of a super-hard bit shown in Fig. 5A, indicated by E;

Fig. 8 shows a side view of an end portion of an example super-hard bit, and an enlarged view of the portion of indicated by E;

Fig. 9 shows a schematic longitudinal cross-section view through a pre-sinter assembly for making an example super-hard tip for a super-hard bit.

DESCRIPTION

With reference to Fig. 1 to Fig. 3B, an example super-hard bit comprises a super-hard tip 110 joined to a support body 120 by a join layer 115 comprising braze material. The super-hard tip 110 may comprise a super-hard volume 102 of polycrystalline diamond (PCD) material sinter-joined to a substrate 112. A distal end of the super-hard tip 110 defines a strike surface 103 of the super-hard volume 102, which will strike a body to be broken in use, and a proximal end 117 defines a proximal substrate end that is joined to an end surface 127 of the support body 120. A side 113 of the substrate 112 connects a peripheral edge 101 of the super-hard volume 102 with a peripheral edge 111 of the proximal substrate end 117.

In the illustrated examples, the substrate side 113 forms a conical side area. Consequently, the diameter D2 of a circle circumscribing the peripheral edge 111 of the proximal substrate end 127 is about 2.5 mm greater than the diameter D1 of a circle circumscribing the join boundary (which in this example arrangement corresponds to the peripheral edge 101 of the super-hard volume 102); and the area A2 of the former is therefore greater than the area A1 of the latter (although each circumscribing circle will be defined on the respective planes on which the peripheral edges 101, 111 will lie, they are shown superimposed on a longitudinal cross-section view in Fig. 1B).

In the illustrated examples, a conical side surface 123 of the support body 120 extends radially outward from a peripheral edge 121 of the end surface 127. Respective tangent planes (not shown) to each of the conical side area 113 of the substrate 112 and the conical side surface 123 of the support body 120 are disposed at an angle Θ to each other (the angle Θ being external to the substrate 112 and the support body 120). The angle Θ in the example illustrated in Figs. 1A and 1B is about 200°, the angle Θ illustrated in Fig. 2 is about 180°, the angle Θ illustrated in Fig. 3A is about 150°, and the angle Θ illustrated in Fig. 3B is about 220°.

With reference to Fig. 4, an example super-hard bit comprises a super-hard tip 110 braze-joined to a support body 120, in which the super-hard tip 110 comprises a super-hard layer 102 sinter-joined to a substrate 112. The side 113 of the substrate includes a conical proximal side area 113A that is coterminous with the peripheral edge 111 of the proximal substrate end 117, and a cylindrical distal side area 113B that is coterminous with the peripheral edge 101 of the super-hard volume 102. In the particular example illustrated in Fig. 4, the diameter D1 of the circle circumscribing the join boundary and the peripheral edge 101 of the super-hard volume 102 is about 15.5 mm, and the diameter D2 of the circle circumscribing the peripheral edge 121 of the proximal substrate end 117 of the substrate 112 is about 18.5 mm. An angle Φ of about 154° - 156° is defined between the conical and cylindrical side areas 113A, 113B. In this example, the support body side surface 123 is cylindrical in shape, and the angle Θ between respective tangent planes to the conical side area 113A of the substrate 112 and the side surface 123 of the support body 120 is about 200°. The overall height h1 + h2 + h3 of the super-hard tip 110 is about 10 mm, in which h1 is about 7 mm, h2 is about 1.6 mm and h3 is about 1.4 mm.

With reference to Fig. 5A to Fig. 8, example super-hard bits 100 may each comprise a super-hard tip 110 joined to a support body 120, which may be attached to a holder 130 that can be mounted onto an earth-boring apparatus (not shown). In the illustrated examples, the holder can be rotatably mounted onto the apparatus by inserting a holder shaft 134 into a holder receiver mechanism (not shown) provided on the apparatus, the holder shaft 134 depending from a body portion 132 of the holder 130 (holder shafts are not shown in Fig. 7A to Fig. 8). The support body 120 comprises a main body portion 124 and an insertion shaft 126, which is cooperatively configured with a receiver depression provided in the holder 130. The support body 120 can be attached to the holder 130 by the insertion shaft 126 being inserted and shrink-fitted into the receiver depression.

Figs. 5B, 6 and 7 show enlarged illustrations of various example arrangements of the region E including the super-hard tips 110 of the respective super-hard bits 100 shown in Figs. 5A. In Fig. 8, an enlarged illustration of the super-hard tip 110 is also shown. Each super-hard tip 110 comprises a layer 102 of super-hard material, such as sintered polycrystalline diamond (PCD) material, which is sinter-joined to a substrate 112 at an interface boundary 105 during the sintering process in which the PCD material is produced. A strike surface 103 is defined by the PCD layer 102, opposite the interface boundary 105. The substrate 112 may comprise cobalt-cemented tungsten carbide (Co-WC) material and is joined to the support body 130 by a layer 115 of braze material bonded to a join boundary 117 (illustrated schematically in Fig. 2, 3A and 3B) opposite the interface boundary 105 with the PCD layer 102. A substrate edge 111 (illustrated schematically in Fig. 2) is defined between the substrate side surface 113 and the substrate join boundary 117, the substrate side surface 113 and the join boundary 117 both depending away from the substrate edge 111. In the example super-hard bits 100 illustrated in Figs. 5A to 7, the substrate side 113 connects the substrate edge 111 with the exposed peripheral edge of the interface boundary 105. The substrate side 113 is substantially conical in shape. In the example, super-hard bits 100 illustrated in Fig. 7 and Fig. 8, a conical proximal side area 113A of the substrate 112 connects the substrate edge 111 with a cylindrical distal side area 113B of the substrate, which connects the proximal side area 113 with the exposed periphery of the interface boundary 105. In the examples illustrated in Fig. 5A to Fig. 8, the angles Θ between tangent planes to the conical side areas 113A of the substrates 112, and tangent planes to the side surfaces 123 of the support bodies 120 are about 180°. In other words, the conical side areas 113A of the substrates 112, and the conical side surfaces 123 of the support bodies 120 can be characterised by substantially the same cone angles (not shown).

An example method of manufacturing an example super-hard tip may involve forming the shape of the substrate by means of electro-discharge machining (EDM) die-sinking.

A method of making an example super-hard tip will be described with reference to Fig. 9, which shows a schematic cross-section view of an inner-capsule assembly 200 for an HPHT press. An example super-hard tip (110 in Fig. 1A to Fig. 8) may be produced by subjecting the inner-capsule assembly 200 to an ultra-high pressure of about 5.5 GPa to about 8 GPa and a temperature of at least about 1,200°C by means of an HPHT press. The super-hard volume 102 will become sinter-joined to the substrate 112 at the interface boundary 105 during the HPHT process in which the super-hard volume is formed by sintering.

The inner-capsule assembly 200 may comprise a refractory cap 250, which may substantially consist of magnesium oxide (MgO) and a pressure-transmitting housing 240, which may substantially consist of sodium chloride (NaCl). In various examples, the cap 250 may comprise or consist essentially of sodium chloride (NaCl), potassium bromide (KBr), or zirconia (ZrO). The pre-sinter assembly may comprise a substrate 212, a sacrificial buffer member 219 and an aggregation volume 202 containing the super-hard grains, a first refractory cup 262 and a second refractory cup 264, in which the first and second refractory cups may substantially consist of niobium (Nb).

The method may include forming a cobalt-cemented tungsten carbide (Co-WC) substrate 212 by sintering a green body substantially consisting of tungsten carbide (WC) grains dispersed within cobalt (Co) metal. The substrate 212 at this stage of the process may have substantially the shape and dimensions of the substrate 112 to be comprised in the finished super-hard tip 110, including a central dome portion coterminous with the interface boundary 205, and a peripheral side 213 connecting the interface boundary 205 at a distal end with a proximal boundary 217. The peripheral side 213 may include a conical side surface adjacent the proximal boundary 217; in the particular illustrated example, the peripheral side substantially consist of the conical side surface 213. The green body for the substrate 212 may be shaped by moulding and / or machining, prior to the step of sintering it to produce the substrate 212.

The paste for forming the aggregation volume 202 comprises the grains of synthetic diamond crystals mixed into organic binder material such as poly(methyl methacrylate) (PMMA), polyethylene glycol (PEG) or dibutyl phthalate binder (DBP), and the paste may include plasticiser material. The paste may comprise about 20 to 30 mass % binder material, estimated to be about 47 to 58 volume % of the paste, and the synthetic diamond crystals may have a mean equivalent sphere diameter of about 1 to 40 microns.

The nature, amount and composition of the binder material and plasticiser material should be selected to achieve a suitable viscosity of the paste for extrusion. If the paste is too viscous and has too low a shear rate, for example less than about 1 s^{-1} (per second) to about 3 s^{-1}, may not be capable of extruding effectively, or it may disintegrate. If the paste is not viscous enough and has too high a shear rate, for example greater than about 16 s^{-1} to about 21 s^{-1}, it may tend to flow excessively. The super-hard grains and solvent / catalyst material in powder form may be blended together by means of wet or dry multi-directional mixing, planetary ball milling and high shear mixing with a homogeniser. In some examples, the method may include

admixing solvent / catalyst material for promoting the sintering of the super-hard grains, into the paste or slurry. For example, the paste or slurry may contain up to about 3 mass % iron and / or cobalt and / or nickel.

The first cup 262 may define an open cavity having substantially the same shape and dimensions as the super-hard volume 102 to be comprised in the super-hard tip 110, modified to compensate for the changes in shape and dimensions that will likely occur during the HPHT sinter process. The required modifications to the shape and dimensions may be calculated, and / or determined by iterative trial-and-error experiments.

The aggregation volume 202 may be formed by a method including injection moulding a paste or slurry into the first Nb cup 262, which defines a cavity having substantially the same shape and dimensions as that of the super-hard volume to be sintered (the shape and dimensions modified to compensate for the change in shape and dimensions to occur during the HPHT sintering process). An extrusion device comprising may be used to extrude the paste into the first cup 262, and a load may be applied to the injected paste to increase its density, the pressure applied to the paste being about 5 megapascals (MPa).

In the illustrated example, a distal end boundary the aggregation volume 202 abuts the first refractory Nb cup 262, and a proximal end boundary abuts the substrate 212 at an interface boundary 205. The schematic drawing in Fig. 9 shows a carbide layer 218 comprising metal carbide material, for example NbC, that will likely form during the HPHT sinter process as a result of chemical reaction between the metal of the upper cup 262 and carbon from diamond grains in the aggregation volume 202 (the carbide layer 218 will not be present in the pre-sinter assembly prior to the HPHT sinter process, and is shown in Fig. 9 merely to indicate its likely formation). In some examples, the method may include removing the metal carbide layer 218 from the super-hard volume 102 after the HPHT sintering process.

After the first cup 262 has been substantially filled with the paste, the distal boundary end of the substrate 212 is placed against the paste at the mouth of the first cup 262, and the buffer member 219 placed against the proximal boundary 217 of the substrate 212. The buffer member 219 may be a cylindrical disc substantially consisting of cobalt-cemented tungsten carbide. Load may then be applied to the buffer member 219 by means of a hydraulic press, to densify the paste. The second cup 264, which may also substantially consist of Nb, may then be placed over the buffer member 219 such that a rim region defining an open end of the

second cup 264 overlaps with a rim region of the first cup 262 to provide the pre-sinter assembly.

The pre-sinter assembly may be placed into a furnace and subjected to heat treatment at 1,000°C within flowing nitrogen gas for 30 minutes, to remove substantially all of the organic binder from the paste of the aggregation volume 202, except for a small amount of carbonaceous residue. The density of the aggregation volume 202 after the binder had been removed may be about 50% of maximum theoretical density, the balance of the volume being pores. The pre-sinter assembly may then be subjected to cold isostatic pressing (CIP) to compact it and seal the rim portions of the first and second Nb cups 262, 264 against each other. In some examples, the cups 262, 264 may comprise or consist of titanium, tantalum, molybdenum or other refractory metals, and the first and second cups 262, 264 may be welded together.

The compacted and sealed pre-sinter assembly may be inserted into a depression defined within a refractory cap 250 substantially consisting of MgO, for example, such that the first Nb cup 262 abuts the cooperatively configured surface of the depression. The compacted and sealed pre-sinter assembly and the MgO cap 250 may be assembled into the NaCl housing 240, which may be assembled into a capsule for an HPHT press and then subjected to a pressure of at least about 5.5 GPa and a temperature of at least about 1,300°C; or a pressure of at least about 6.5 GPa and a temperature of at least about 1,400°C.

Disclosed example methods may have the aspect of enabling the manufacture of example super-hard tips 110 that include a substrate 112 having a non-cylindrical side surface 113. Example methods may avoid the need to process the super-hard tip 110, particularly the substrate 112, by centreless grinding, which may be advantageous if the substrate has a non-cylindrical peripheral side 113. The need for centreless grinding may be avoided because the super-hard volume 102 and the substrate 112 may have shapes and dimensions that are as close as possible to those of the super-hard tip 110. While wishing not to be bound by a particular theory, this may be enabled because the aggregation volume 202 may have a relatively high green density, resulting in reduced distortion of the shape of the aggregation volume 202 and, consequently, of the sintered super-hard volume 102. Providing the substrate 112 with a non-conical side surface 113 that extends radially outward may allow a relatively large join boundary 115 area.

Example super-hard bits may have the aspect that the strength of the join between the super-hard tip and the support body is substantially greater than it would be if the area of the join boundary were substantially equal to the axially-projected area of the super-hard volume. While wishing not to be bound by a particular theory, the strength of the join may be expected to be substantially directly proportional to the area of the join boundary, all else being equal.

In certain examples, the area of the join boundary may be relatively high without the need for increasing the axial height of the super-hard tip, the height being the distance from the point of the super-hard tip (the point or surface area included within the strike surface and axially furthest away from the from the interface boundary). In certain applications of example super-hard bits, it may be desirable for the axial height of the super-hard tip to be relatively small, or as small as possible, since a bending moment (or torque) may be applied to the super-hard tip in use. For example, in certain applications the super-hard tip may be repeatedly struck against a body of rock to be broken, in which the longitudinal axis of super-hard tip is tilted at a non-zero angle relative to the direction of incidence of the super-hard tip against the rock body (in some example arrangements, the tool apparatus and the super-hard bit may be cooperatively configured in this way to induce the super-hard tip to rotate about its longitudinal axis when it strikes the body). The tilted arrangement of the super-hard bit may likely apply a torque to it and consequently apply a tensile stress to the join between the super-hard tip and the support body, which may result in failure of the join and the need to replace the super-hard bit, thus reducing the efficiency and increasing the cost of the rock-breaking operation.

While wishing not to be bound by a particular theory, example strike tips may exhibit reduced formation of a wear scar at the join in use, and consequently reduced internal stress; and / or example strike tips may be substantially free of surface regions that meet at a relatively sharp slope transition, characterised by a relatively small osculating radius, since a sharp transition between the angles of surface regions may give rise to relatively high internal stress and consequent crack formation. The stress arising from a sharp transition in the slope of a surface may be inversely proportional to the radius of an osculating circle.

While wishing not to be bound by a particular theory, the torque applied to the super-hard tip may be expected to be proportional to the axial height of the super-hard tip, all else being equal. The bending stress applied to the join between the substrate and the support body when the super-hard tip strikes a body with a force may be directly proportional to the axial height of the super-hard tip, being the axial distance from the join boundary to the point on the

strike surface of the super-hard volume to which the strike force is applied, and inversely proportional to the fourth power of the diameter of the join boundary (assuming that the join boundary is substantially circular). Consequently, certain example arrangements of super-hard bits, in which the area of the join boundary is substantially greater than the axially projected equivalent circle area of the super-hard volume, may have substantially increased resistance to failure of the join in use.

Example super-hard bits may have the aspect that formation of a notch defect at the join between the strike tip and the support base in use may be retarded or practically eliminated. This may extend the working life of a tool comprising the strike tip, which may fail by some other mechanism. While wishing not to be bound by a particular theory, this may be due to the join boundary area being increased, or maximised; and / or of internal stress within the substrate and / or support base being reduced or minimised. The likelihood of a crack passing through the braze material and extending between the joined surfaces of the substrate and the support base may be reduced or eliminated.

Certain concepts and terms as used herein will be briefly explained.

As used herein, a pick tool is for the mechanised degradation (or breaking) of a body, for example a geological formation, rocks, pavement, building constructions, or other bodies comprising or consisting of rock, coal, potash or other geological material, or concrete, or asphalt, as non-limiting examples. As used herein, degrading or breaking a body may include fragmenting, cutting, milling, planing or removing pieces of material from the body. A pick tool can be coupled to a drive apparatus for driving the pick against the body to be degraded, in which a strike tip comprised in the pick tool is driven to strike the body. In some examples, the drive apparatus may include a rotatable drum, to which a plurality of pick tools is coupled. Some pick tools may be used in mining operations or for boring into the earth; for example, pick tools may be used to mine coal or potash, or to drill into the earth in oil and gas extraction operations. Some picks may be used for milling road surfaces, for example road surfaces comprising asphalt or concrete.

Synthetic and natural diamond, polycrystalline diamond (PCD) material, cubic boron nitride (cBN) and polycrystalline cBN (PCBN) material are examples of super-hard materials. As used herein, PCBN material comprises grains of cubic boron nitride (cBN) dispersed within a matrix comprising or consisting essentially of metal or ceramic material. As used herein,

polycrystalline diamond (PCD) material comprises an aggregation of a plurality of diamond grains, a substantial portion of which are directly inter-bonded with each other and in which the content of diamond is at least about 80 volume % of the PCD material. Interstices between the diamond grains may be at least partly filled with a filler material that may comprise catalyst material for synthetic diamond, or they may be substantially empty. As used herein, a catalyst material for synthetic diamond is capable of promoting the growth of synthetic diamond grains and or the direct inter-growth of synthetic or natural diamond grains at a temperature and pressure at which synthetic or natural diamond is thermodynamically stable. Examples of catalyst materials for diamond are Fe, Ni, Co and Mn, and certain alloys including these. Other examples of super-hard materials may include certain composite materials comprising diamond or cBN grains held together by a matrix comprising ceramic material, such as silicon carbide (SiC), or cemented carbide material, such as Co-bonded WC material. For example, certain SiC-bonded diamond materials may comprise at least about 30 volume % diamond grains dispersed in a SiC matrix (which may contain a minor amount of Si in a form other than SiC).

As used herein, sintered polycrystalline super-hard material is 'sinter-joined' when it becomes joined to a substrate in the same process in which the polycrystalline material is formed by sintering. Polycrystalline super-hard material, such as PCD or PCBN, may be formed by sintering raw materials including diamond or cBN grains, respectively, at an ultra-high pressure of at least about 2 GPa, at least about 4 GPa or at least about 5.5 GPa, and a high temperature of at least about 1,000°C, or at least about 1,200°C. The raw material, which may also include a non-super-hard phase or material, may be sintered in contact with a surface of a substrate, so that the sintered polycrystalline material becomes sinter-joined to the substrate during the sinter process. The sinter process may include molten cementing material from the substrate infiltrating among the plurality of super-hard grains within a precursor aggregation of super-hard grains. Bonding or cementing material from the substrate may be evident within the sintered super-hard volume, and / or phases or compounds including material from the substrate may be present within the super-hard volume adjacent the join boundary, and / or phases or compounds including material from the super-hard volume may be present in a volume of the substrate adjacent the join boundary. For example, the substrate may comprise cobalt-cemented tungsten carbide, and phases or compounds including tungsten (W) and / or cobalt (Co) may be present in the super-hard volume; and / or the super-hard material may comprise diamond and phases or compounds indicative of a high carbon (C) content may be present in the substrate; and / or the super-hard material may

comprise cBN and phases or compounds including boron (B) and / or nitrogen (N) may be present in the substrate. In some examples, intrusions of Co (so-called 'plumes') from the substrate into the super-hard volume may be present at the join boundary.

Other indiciae of sinter-joining may be evident. For example, the substrate may comprise cemented polycrystalline material such as cobalt-cemented tungsten carbide, and a stratum (or layer) comprising the cementing material, for example cobalt, may be present at, or adjacent the join boundary, in which the stratum may comprises a substantially higher content of the cementing material than the mean content in the substrate. In some examples, the content of cobalt within the stratum may be substantially higher than the mean content of cobalt in the substrate; the content of cobalt within a region of the substrate adjacent the stratum may comprise a lower content of cobalt than the mean content in the substrate.

CLAIMS

1. A super-hard bit for a tool, comprising:
a super-hard volume,
a substrate and
a support body; the super-hard volume sinter-joined to
a distal end of the substrate;
a proximal end of the substrate joined to the support body; and
a substrate side connecting the proximal and distal ends of the substrate; the proximal and distal ends of the substrate each having
a respective proximal and distal peripheral edge, each of the proximal and distal peripheral edges defining
a respective proximal and distal circumscribing circle; in which
the substrate side includes a divergent area that diverges from the distal end towards the proximal end, the substrate configured such that the diameter of the proximal circumscribing circle is greater than the diameter of the distal circumscribing circle.

2. A super-hard bit as claimed in claim 1, in which the tool is a pick tool for breaking a body.

3. A super-hard bit as claimed in claim 1 or claim 2, in which the diameter of the proximal circumscribing circle is at least 0.75 mm greater than the diameter of the distal circumscribing circle.

4. A super-hard bit as claimed in any of the preceding claims, in which the area of the proximal circumscribing circle is at least 10% greater than the distal circumscribing circle.

5. A super-hard bit as claimed in any of the preceding claims, in which the divergent area defines a tangent plane lying at angle of 20° - 70° from a longitudinal axis passing through the proximal and distal ends of the substrate.

6. A super-hard bit as claimed in any of the preceding claims, in which the divergent area includes a conical area that is coterminous with the proximal end of the substrate.

7. A super-hard bit as claimed in any of the preceding claims, in which the substrate side includes a cylindrical area that is coterminous with the distal end of the substrate.

8. A super-hard bit as claimed in any of the preceding claims, in which the proximal end of the substrate is joined to a join surface of the support body, from which a support body side area depends, the support body side area defining a tangent plane lying at angle of 0° - 70° from a longitudinal axis passing through the proximal and distal ends.

9. A super-hard bit as claimed in any of the preceding claims, in which the proximal end of the substrate is joined to a join surface of the support body, from which a support body side area depends; and a tangent plane to the divergent area of the substrate side will be disposed at least 130° in relation to a tangent plane to the support body side area.

10. A super-hard bit as claimed in any of the preceding claims, in which the proximal end of the substrate is joined to a join surface of the support body, from which a support body side area depends; the support body side area comprising a conical surface area.

11. A super-hard bit as claimed in claim 10, in which
the divergent area of the substrate side is coterminous with the proximal end of the substrate and comprises a conical surface area,
respective cone angles defined by each of the conical areas of the substrate and the support body differ by 20° to 100°.

12. A super-hard bit as claimed in any of the preceding claims, in which the super-hard volume defines a circular or elliptical peripheral edge adjacent the join boundary.

13. A super-hard bit as claimed in any of the preceding claims, in which the peripheral edge of the proximal substrate end is circular or elliptical.

14. A super-hard bit as claimed in any of the preceding claims, in which the substrate is joined to the support body by a join layer comprising braze alloy material.

15. A super-hard bit as claimed in claim 14, in which the join layer has a thickness of 10 microns to 50 microns.

16. A super-hard bit as claimed in any of the preceding claims, in which the super-hard volume comprises synthetic or natural diamond grains, or cBN grains.

17. A super-hard bit as claimed in claim 16, in which the super-hard volume comprises polycrystalline diamond (PCD) material or polycrystalline cBN (PCBN) material.

18. A super-hard tip for a super-hard bit as claimed in any of the preceding claims, comprising:
a super-hard volume, and
a substrate; the super-hard volume sinter-joined to
a distal end of the substrate, opposite a proximal end of the substrate,
a substrate side connecting the proximal and distal ends of the substrate; the proximal and distal ends of the substrate each having
a respective proximal and distal peripheral edge, each of the proximal and distal peripheral edges defining
a respective proximal and distal circumscribing circle; in which
the substrate side includes a divergent area that diverges from the distal end towards the proximal end, the substrate configured such that the diameter of the proximal circumscribing circle is greater than the diameter of the distal circumscribing circle.

19. A super-hard tip as claimed in claim 18, in which the diameter of the proximal circumscribing circle is at least 0.75 mm greater than the diameter of the distal circumscribing circle.

20. A super-hard tip as claimed in claim 18 or claim 19, in which the area of the proximal circumscribing circle is at least 10% greater than the distal circumscribing circle.

21. A super-hard tip as claimed in any of the preceding claims, in which the divergent area defines a tangent plane lying at angle of 20° - 70° from a longitudinal axis passing through the proximal and distal ends of the substrate.

22. A super-hard tip as claimed in any of the preceding claims, in which the divergent area includes a conical area that is coterminous with the proximal substrate end.

23. A super-hard tip as claimed in any of the preceding claims, in which the substrate side includes a cylindrical area that is coterminous with the distal end.

24. A super-hard tip as claimed in any of the preceding claims, in which the super-hard volume defines a circular or elliptical peripheral edge adjacent the join boundary.

25. A super-hard tip as claimed in any of the preceding claims, in which the peripheral edge of the proximal substrate end is circular or elliptical.

26. A super-hard tip as claimed in any of the preceding claims, in which the super-hard volume comprises synthetic or natural diamond grains, or cBN grains.

27. A super-hard tip as claimed in claim 26, in which the super-hard volume comprises polycrystalline diamond (PCD) material or polycrystalline cBN (PCBN) material.

28. A method for making a super-hard tip as claimed in any of claims 18 to 27, including:
providing a precursor substrate body having
a proximal end and
a distal end, the proximal and distal ends connected by
a side; each of the proximal and distal ends having
a respective peripheral edge, the peripheral edge of the proximal end defining
a proximal circumscribing circle, and the peripheral edge of the distal end defining
a distal circumscribing circle; the side including
a divergent area diverging from the distal end towards the proximal end, and configured such that the diameter of the proximal circumscribing circle is greater than the diameter of the distal circumscribing circle;
forming a precursor aggregation against the distal end to form

a pre-sinter assembly, the precursor aggregation comprising super-hard material grains and capable of being sintered to form super-hard material, and having a density of at least 60% the density of the super-hard material;

assembling the pre-sinter assembly into a capsule for an ultra-high pressure, high temperature (HPHT) press; and

subjecting the pre-sinter assembly to an HPHT condition to sinter the super-hard grains and form the super-hard volume, sinter-joined to the distal end surface of the substrate.

29. A method as claimed in claim 28, in which the diameter of the proximal circumscribing circle is at least 0.75 mm greater than the distal circumscribing circle.

30. A method as claimed in claim 28 or claim 29 in which the method includes:

combining the super-hard grains with organic binder material to provide paste;

injecting the paste into a mould including a surface defining substantially the shape of the strike surface; and

heat treating the paste to remove binder material and form the precursor aggregation.

31. A method as claimed in claim 30, including injecting the paste into a mould cavity under a pressure of 6.5 to 9 MPa.

32. A method as claimed in claim 30 or claim 31, in which the composition and content of the paste are such that the paste has a shear rate of at least 1 per second (s^{-1}) and at most $25s^{-1}$.

33. A method as claimed in any of claims 28 to 32, in which the precursor aggregation comprises at least 60 volume % super-hard grains.

34. A method of making a super-hard tip as claimed in any of claims 18 to 27, including providing a precursor tip body comprising

a super-hard volume and

a substrate, the substrate having

a proximal and

a distal end, and

the super-hard volume being sinter-joined to the distal end; and

processing the substrate such that
a distal circumscribing circle defined by
a peripheral edge of the distal end has a smaller diameter than
a proximal circumscribing circle defined by
a peripheral edge of the proximal end, and such that
a side connecting the distal and proximal ends includes
a divergent area diverging from the distal end towards the proximal end.

35. A method as claimed in claim 34, in which processing the substrate includes removing material from the substrate by means of die sinking.

36. A method as claimed in claim 34 or 35, in which the diameter of the proximal circumscribing circle is at least 0.75 mm greater than the distal circumscribing circle.

37. A method of making a super-hard bit as claimed in any of claims 1 to 16, including:
providing a super-hard tip as claimed in claim 17 to 26;
providing a support body for a super-hard bit for a pick tool, having an end surface; and
joining the proximal substrate end of the super-hard tip to the end surface of the support body by means of braze material.

38. A pick tool assembly comprising a super-hard bit as claimed in any of claims 1 to 16, coupled a tool drive apparatus for driving the super-hard tip against a body to be degraded.

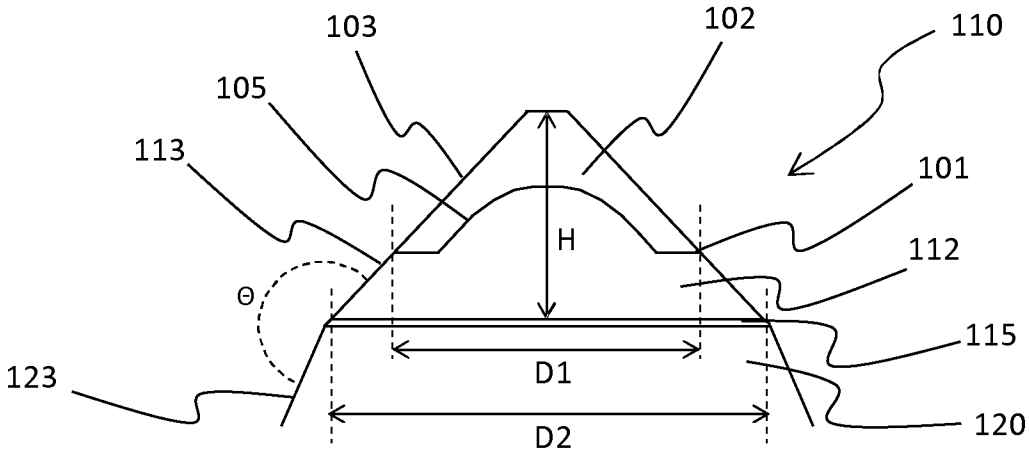

103
102
110
105
113
101
H
112
Θ
115
123
D1
120
D2

Fig. 1A

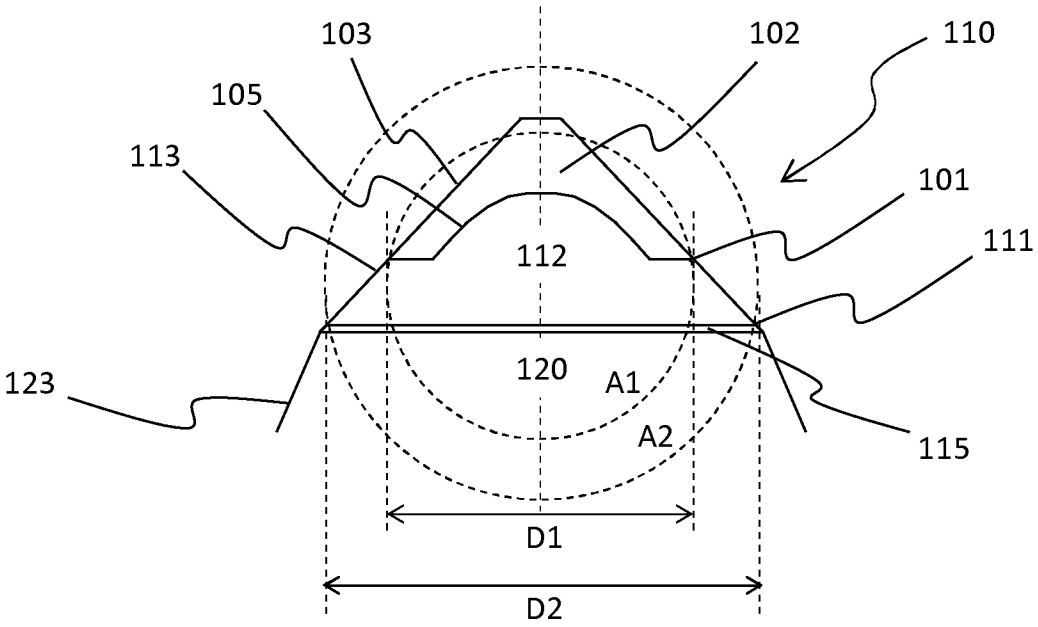

103
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105
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101
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111
120
A1
123
A2
115
D1
D2

Fig. 1B

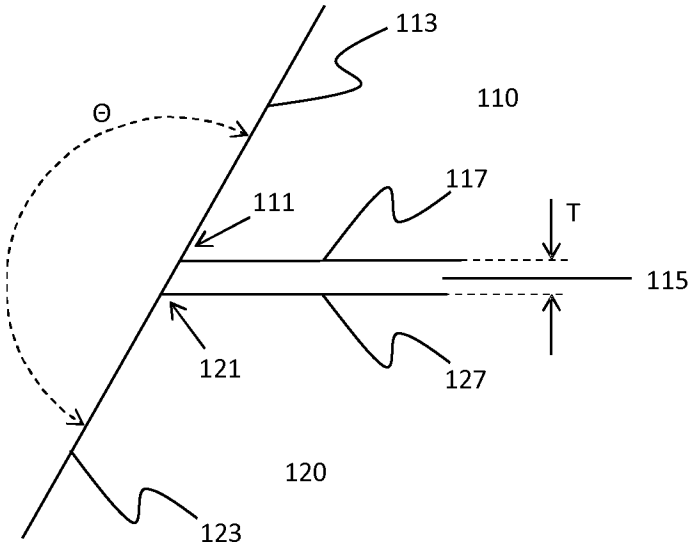


Fig. 2

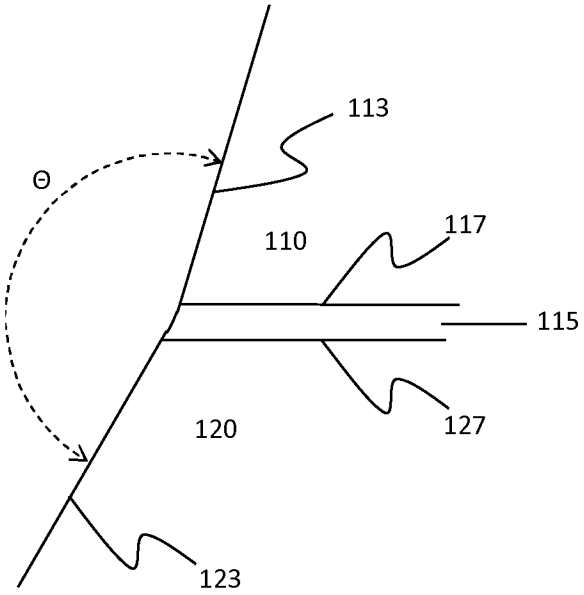


Fig. 3A

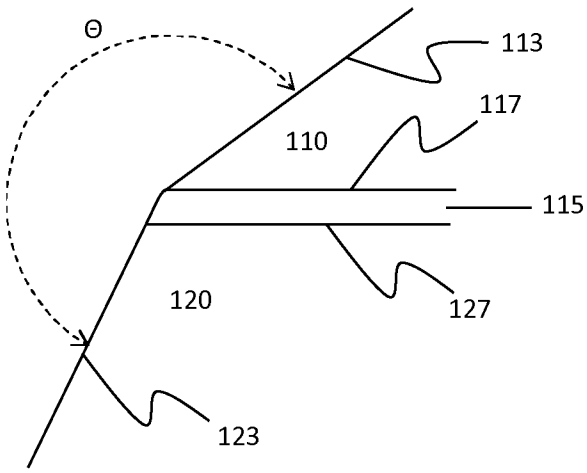


Fig. 3B

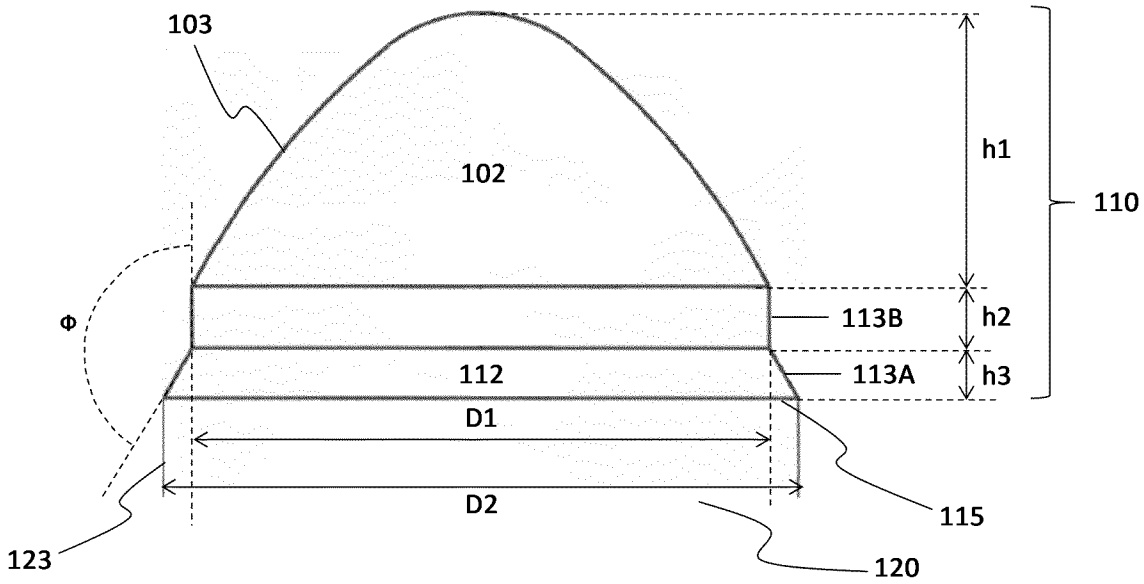


Fig. 4

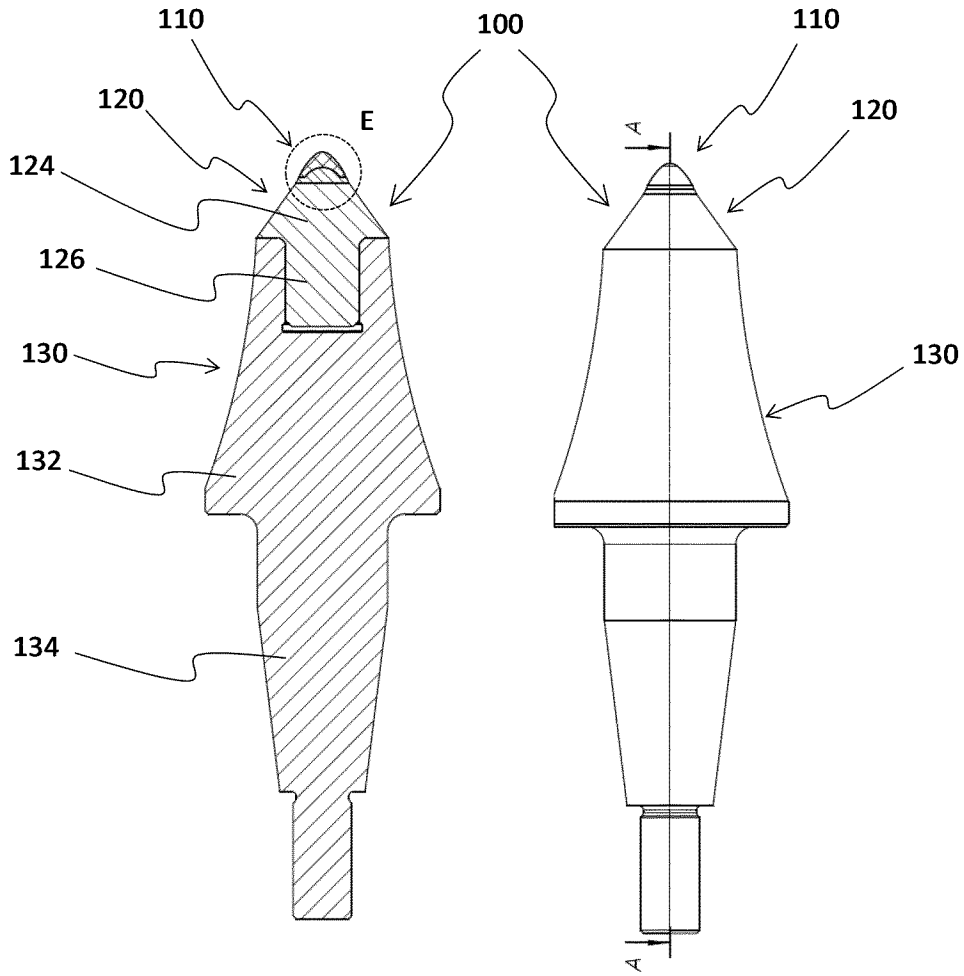

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Fig. 5A

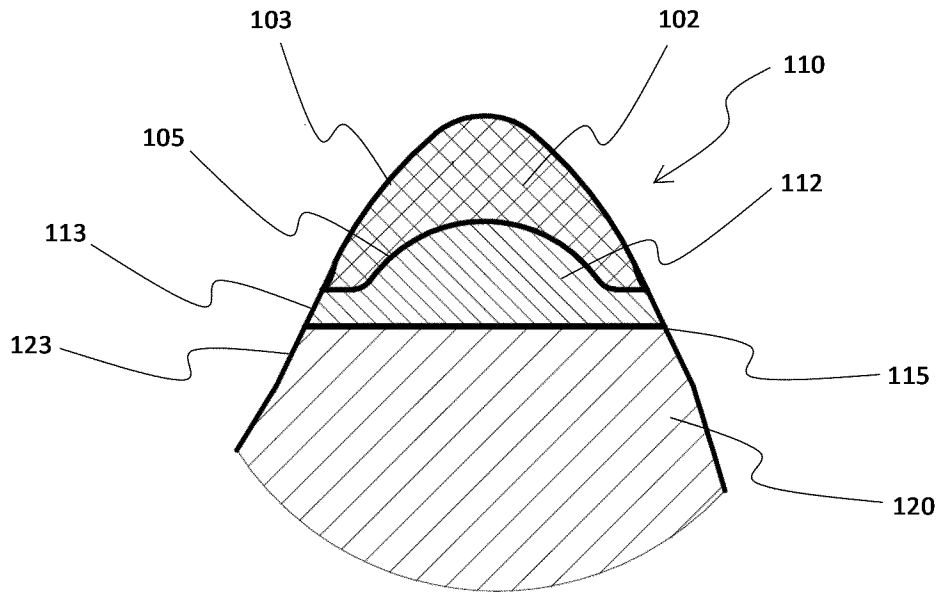

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Fig. 5B

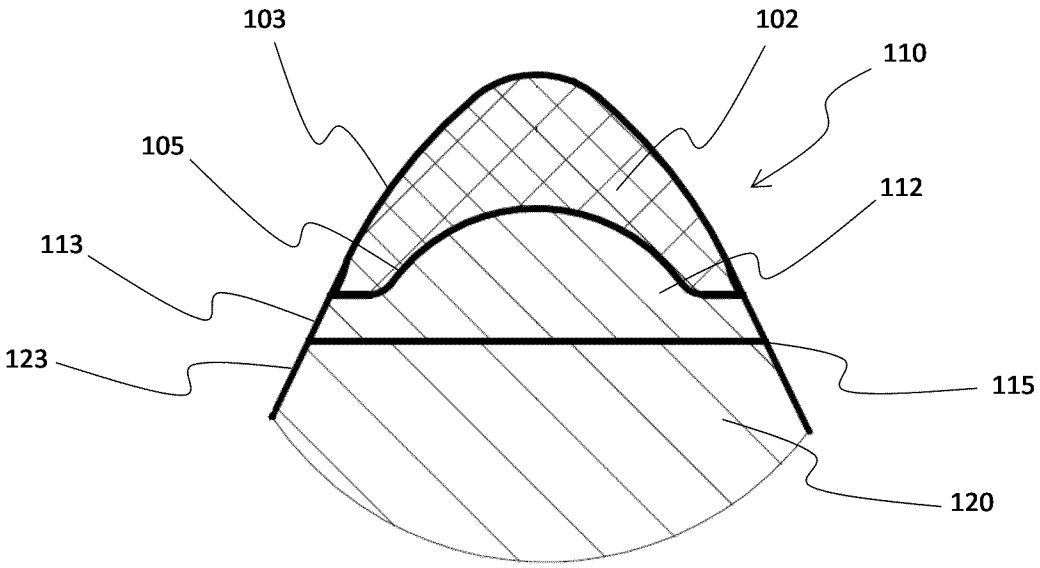

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Fig. 6

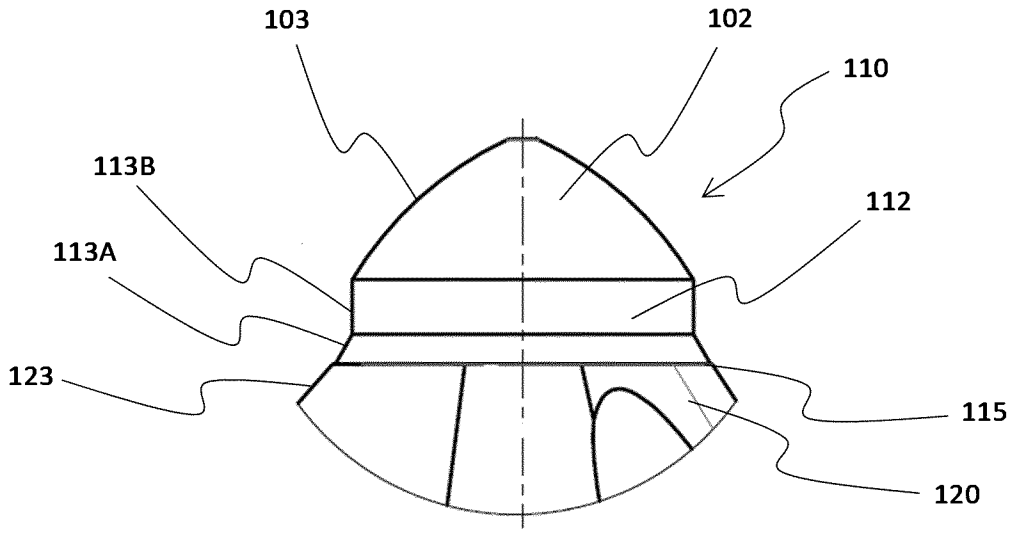

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Fig. 7

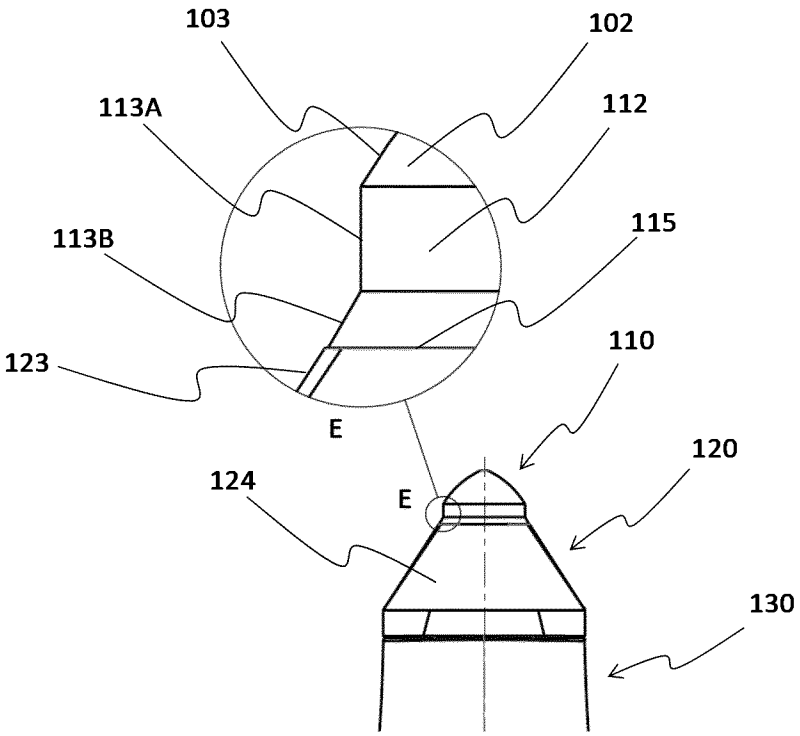


Fig. 8

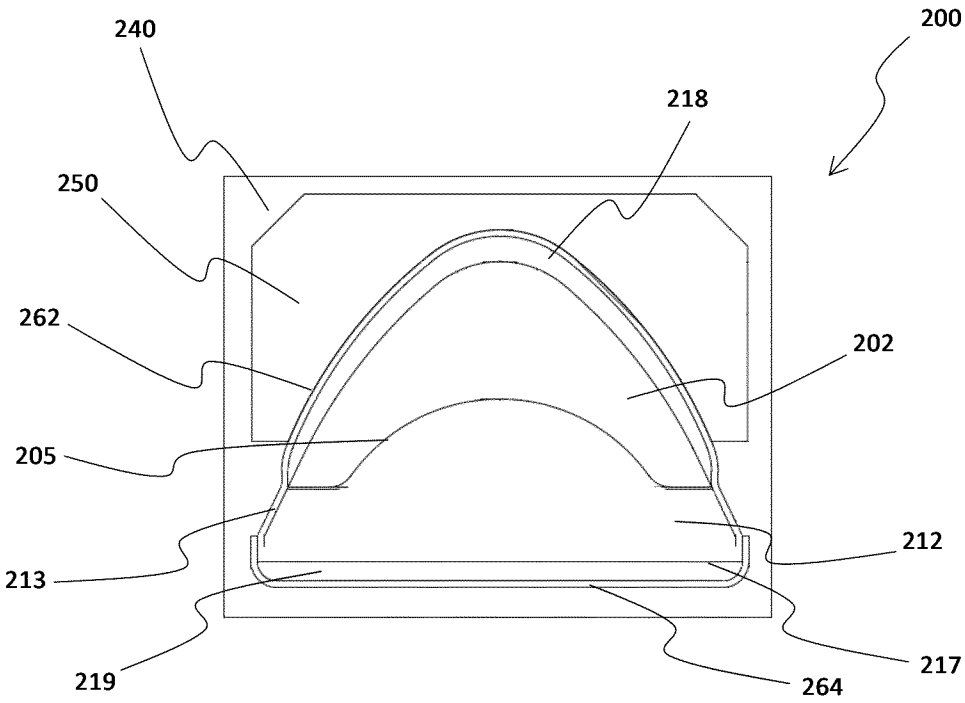


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/069875

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21C35/18 E21B10/567
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)
E21C E21B

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012/152848 A2 (ELEMENT SIX ABRASIVES SA [LU]; JONKER CORNELIS ROELOF [ZA]; BOWES DAVI) 15 November 2012 (2012-11-15) the whole document -----	1-20, 22-38
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 August 2018	29/08/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Dekker, Derk

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/069875

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 5 460 233 A (MEANY NIGEL C [US] ET AL) 24 October 1995 (1995-10-24) column 5, line 2 - line 27 claims 14-16; figure 2	1-38
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