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Hall et al.

(54) **DISC CUTTER FOR AN EARTH BORING SYSTEM**

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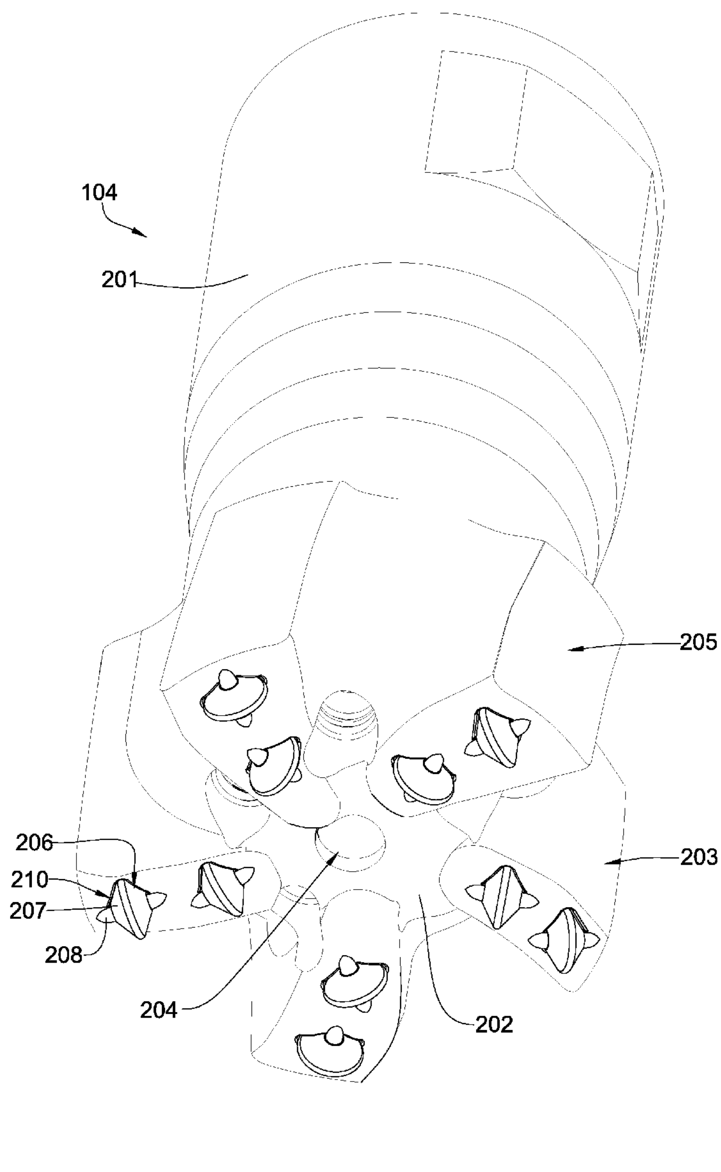
(57) **ABSTRACT**

In one aspect of the present invention a disc cutter for an earth boring system includes an axle and a sintered polycrystalline ceramic disc disposed about and forming a continuous perimeter around the axle. The disc cutter may be attached to a drill bit comprising a body, working face and plurality of blades.

Another aspect of the present invention comprises a method of forming a disc cutter including providing a can of a generally cylindrical shape with a central axis, positioning a column of disposable material, carbide, and crystalline grains in such a manner so when put under high temperature and high pressure a compact in the shape of a disc cutter may be formed and a column from the center axis may be removed. Another method for forming a disc cutter comprises forming a plurality of compacts and bonding the compacts together in a generally toroidal shape.



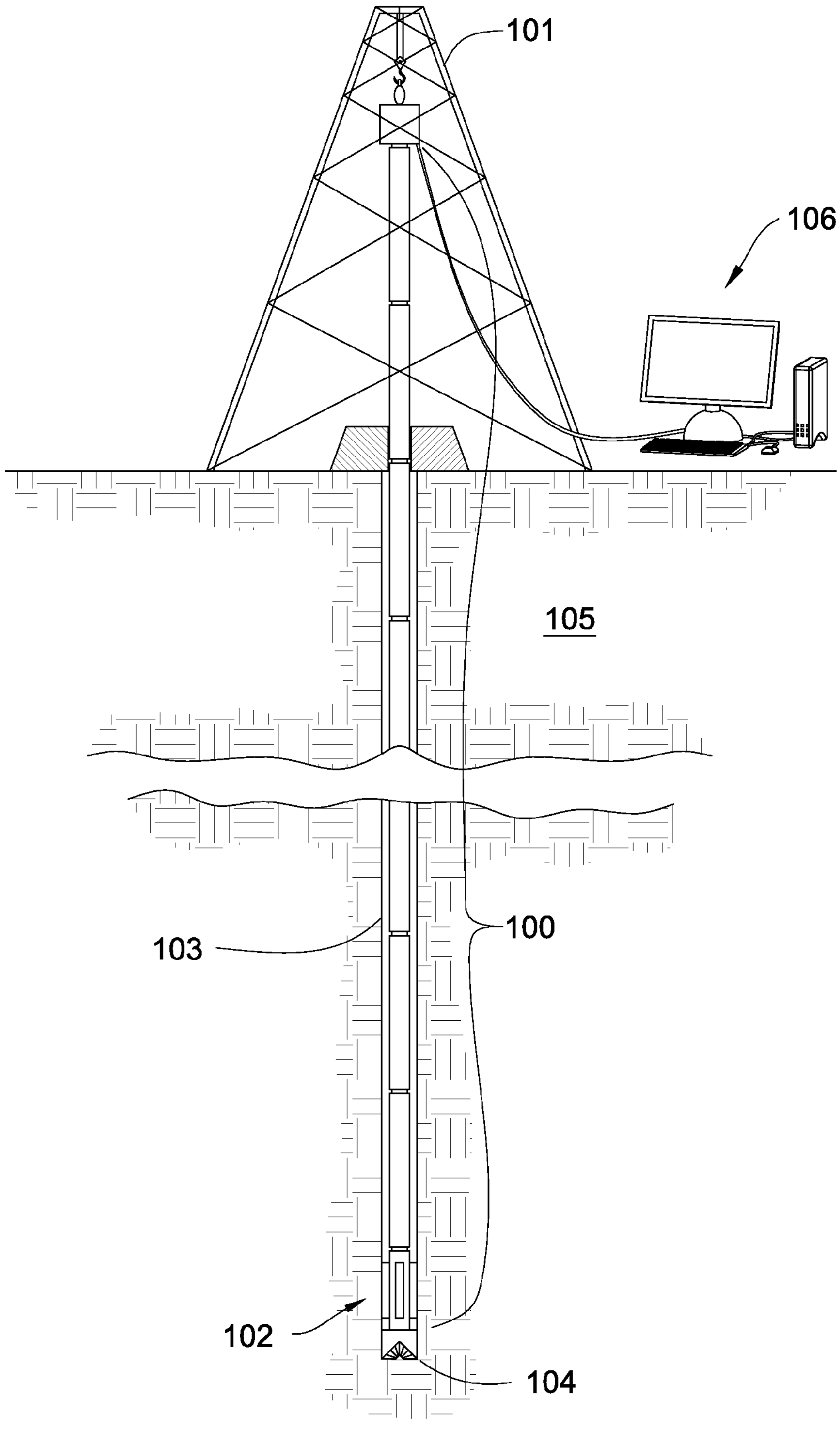


Fig. 1

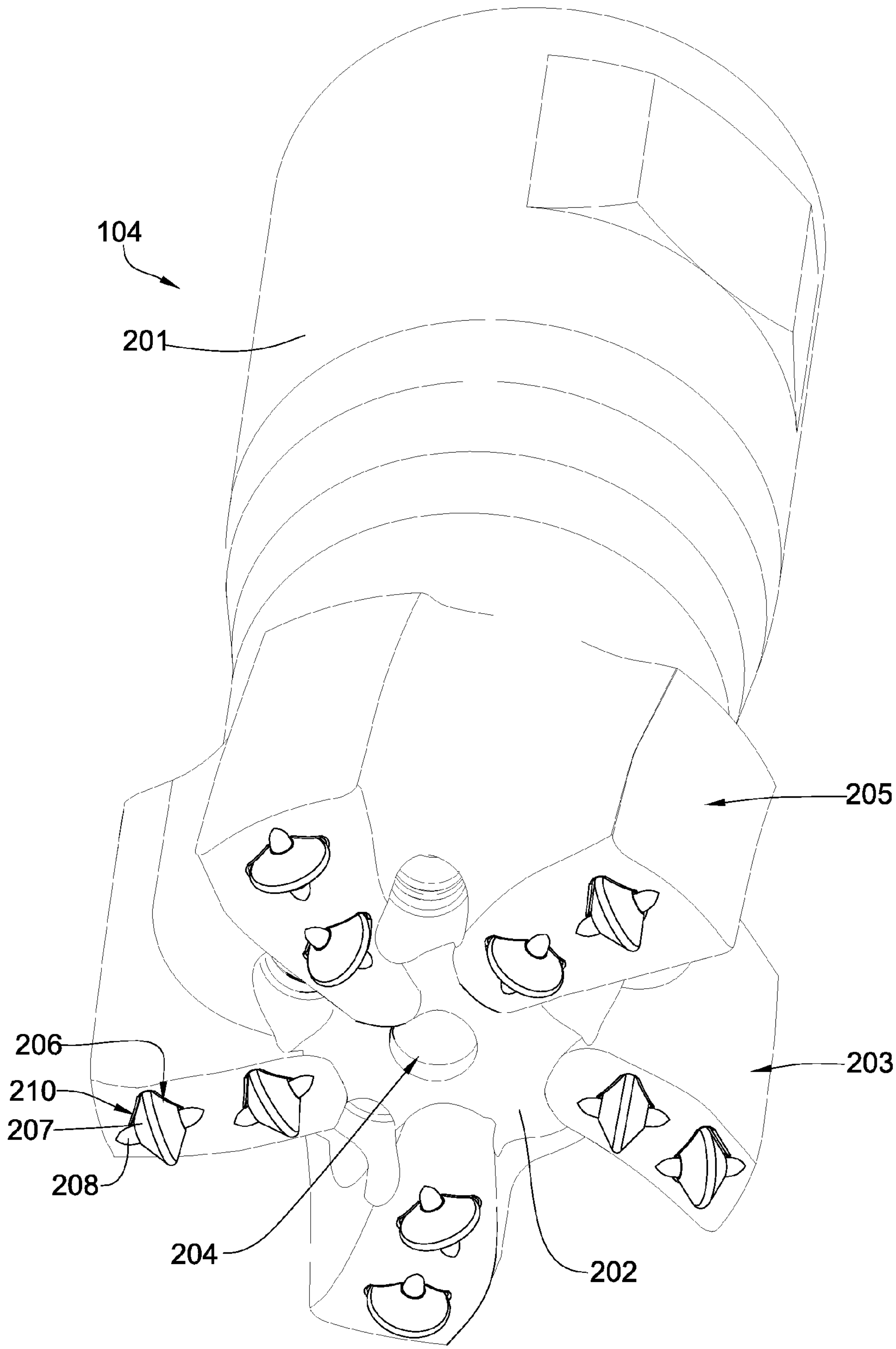


Fig. 2

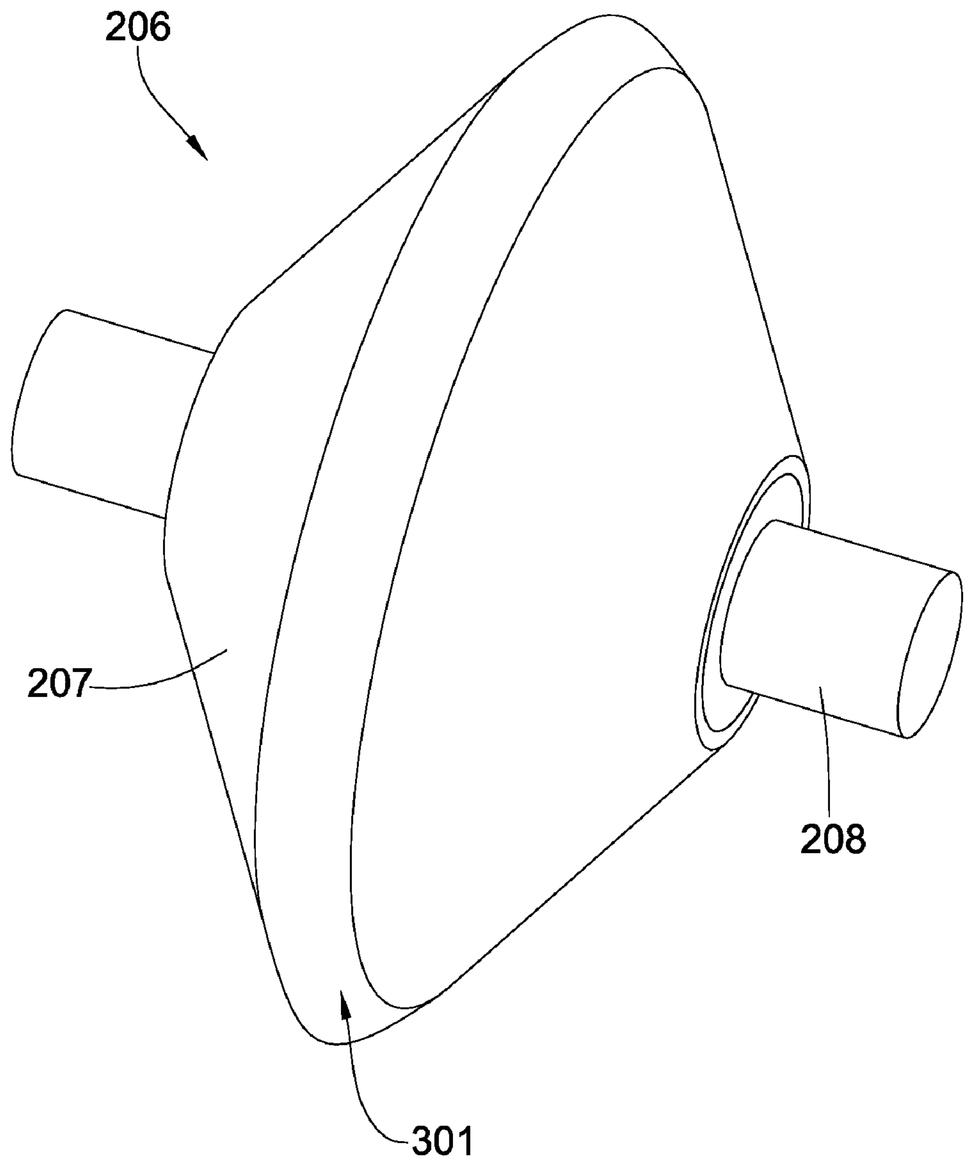


Fig. 3

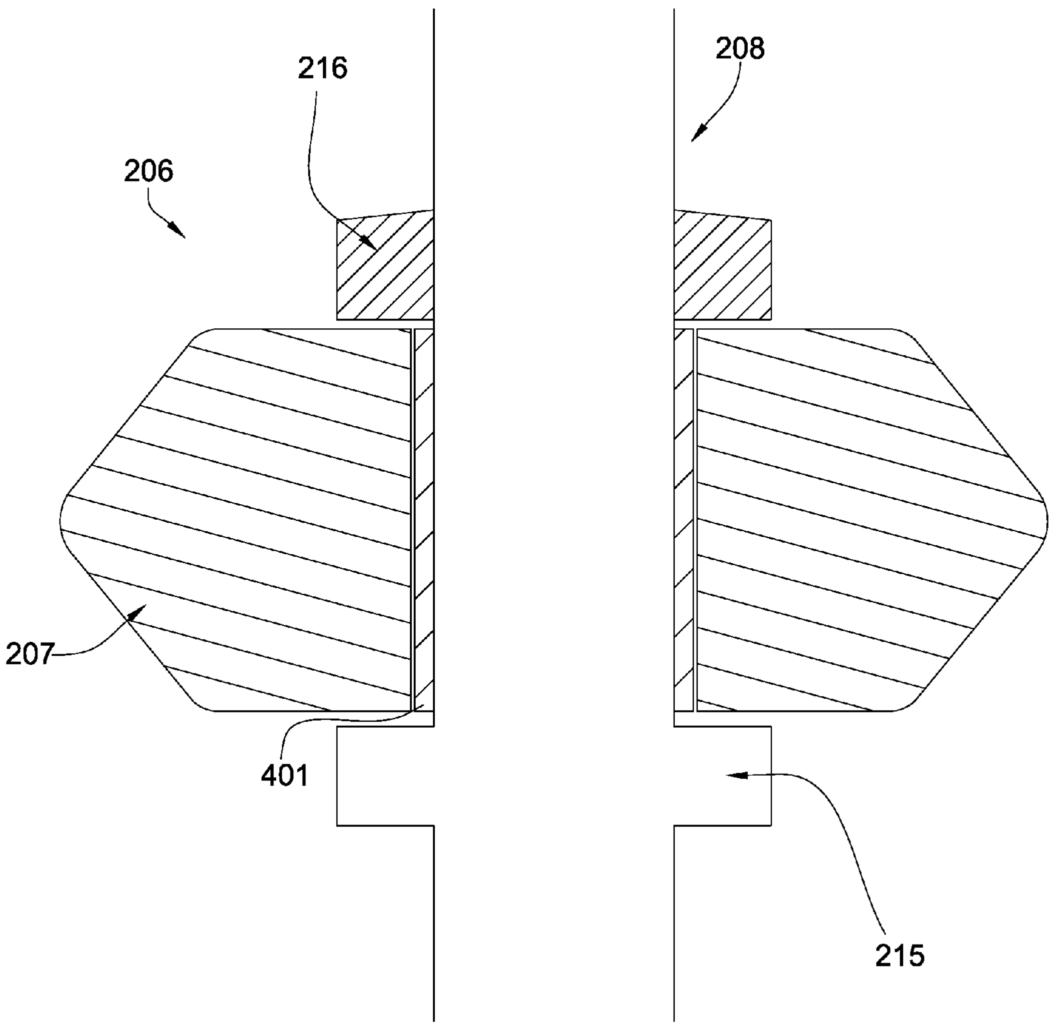


Fig. 4a

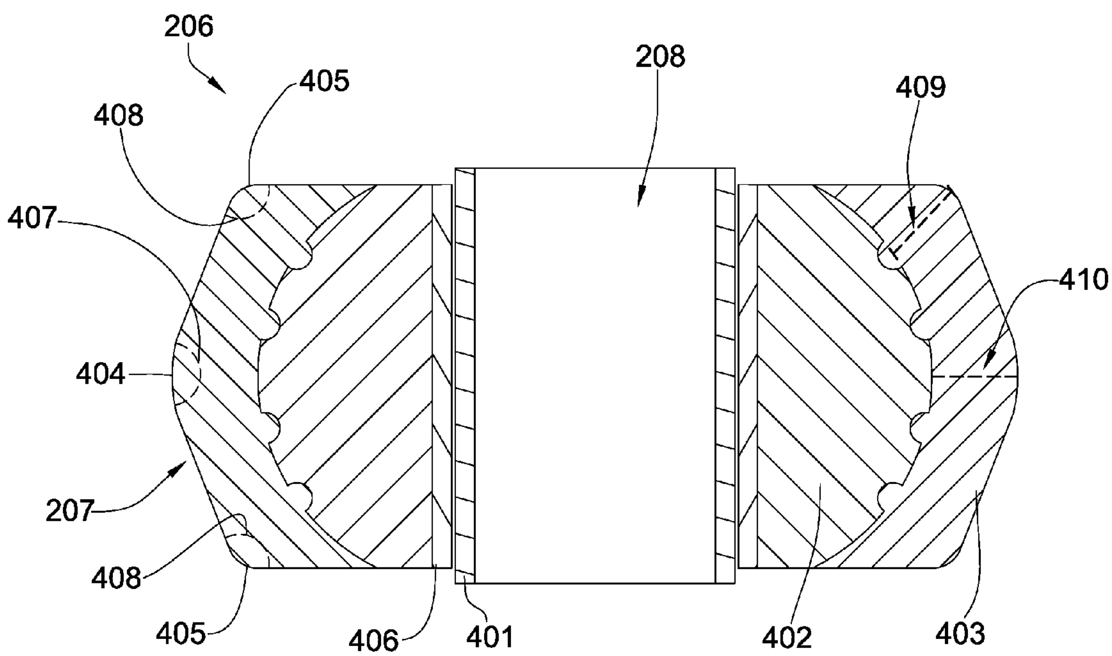


Fig. 4b

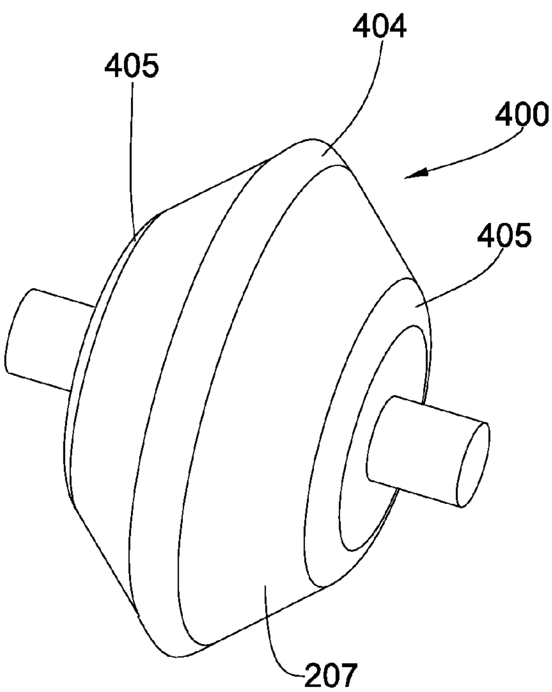


Fig. 5a

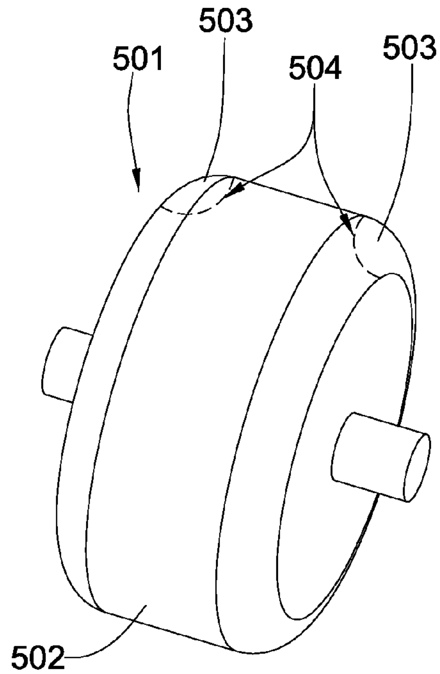


Fig. 5b

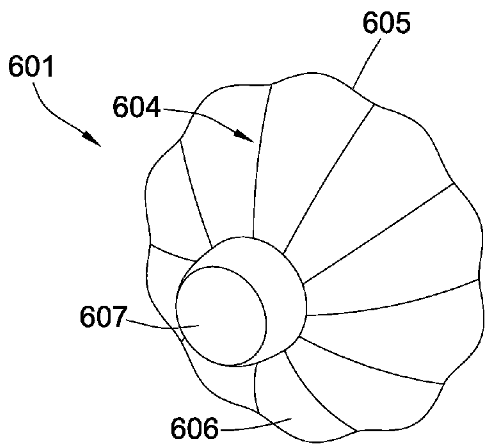


Fig. 6a

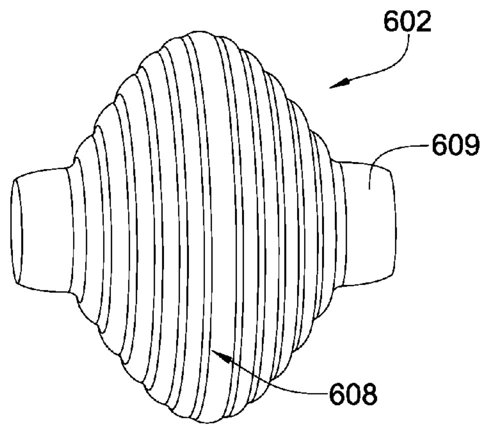


Fig. 6b

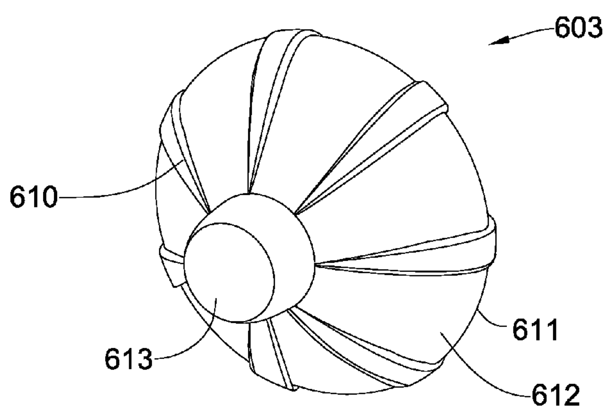


Fig. 6c

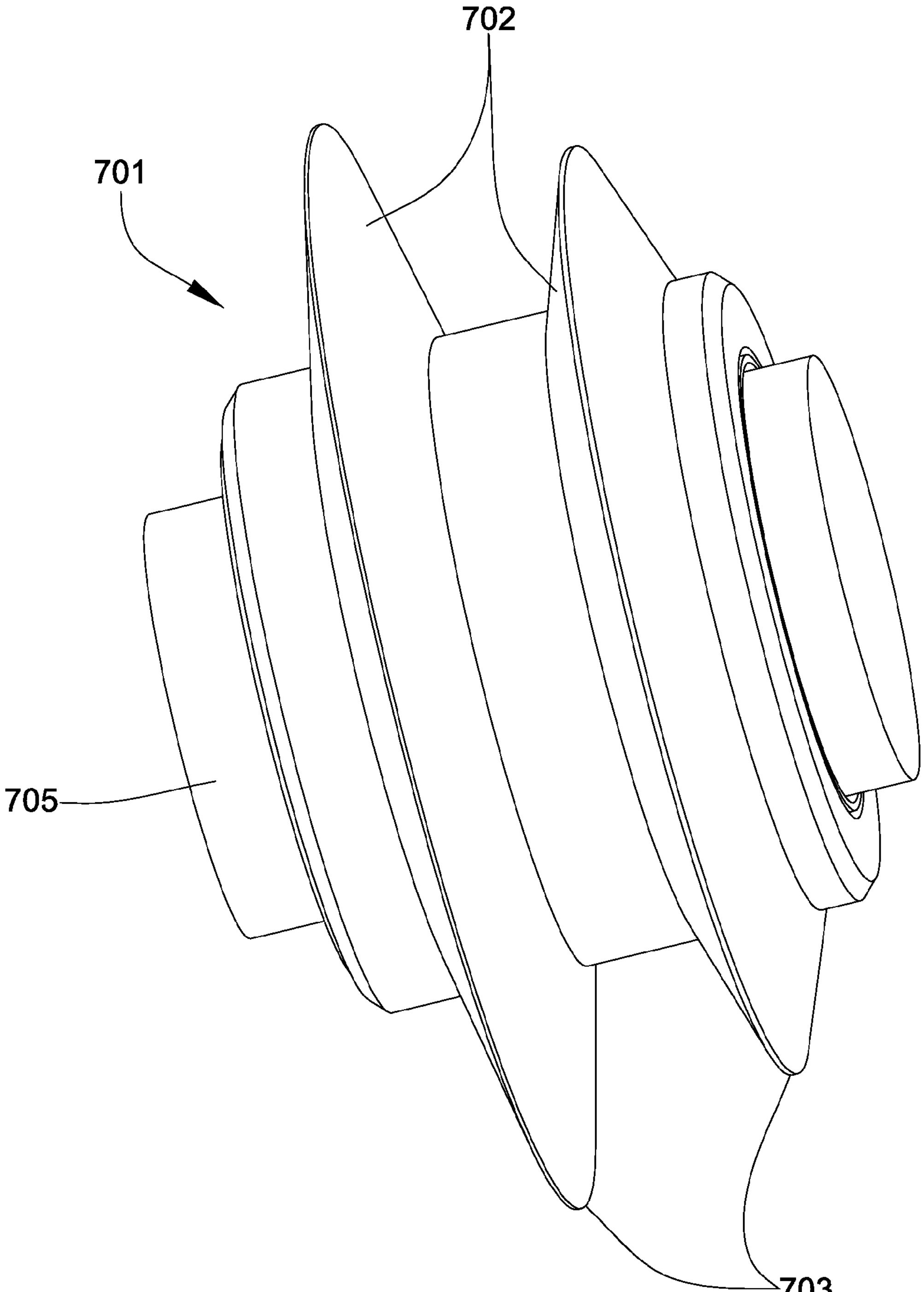


Fig. 7

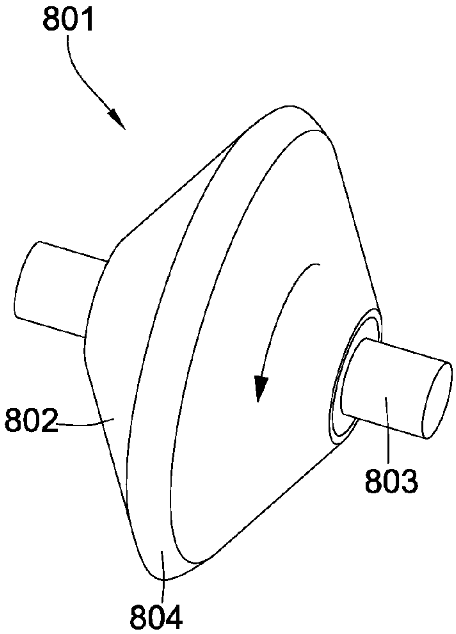


Fig. 8a

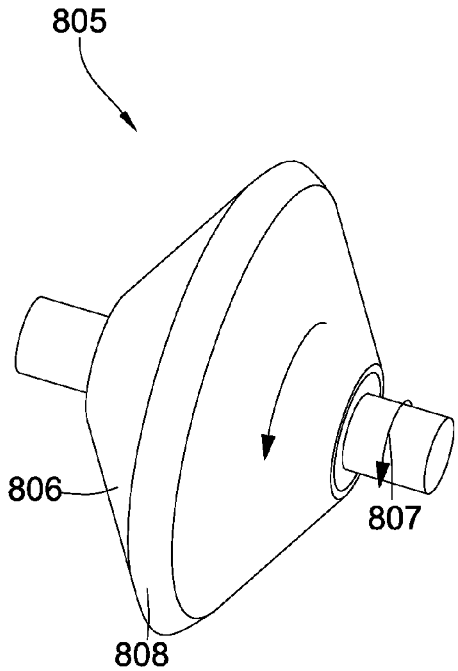


Fig. 8b

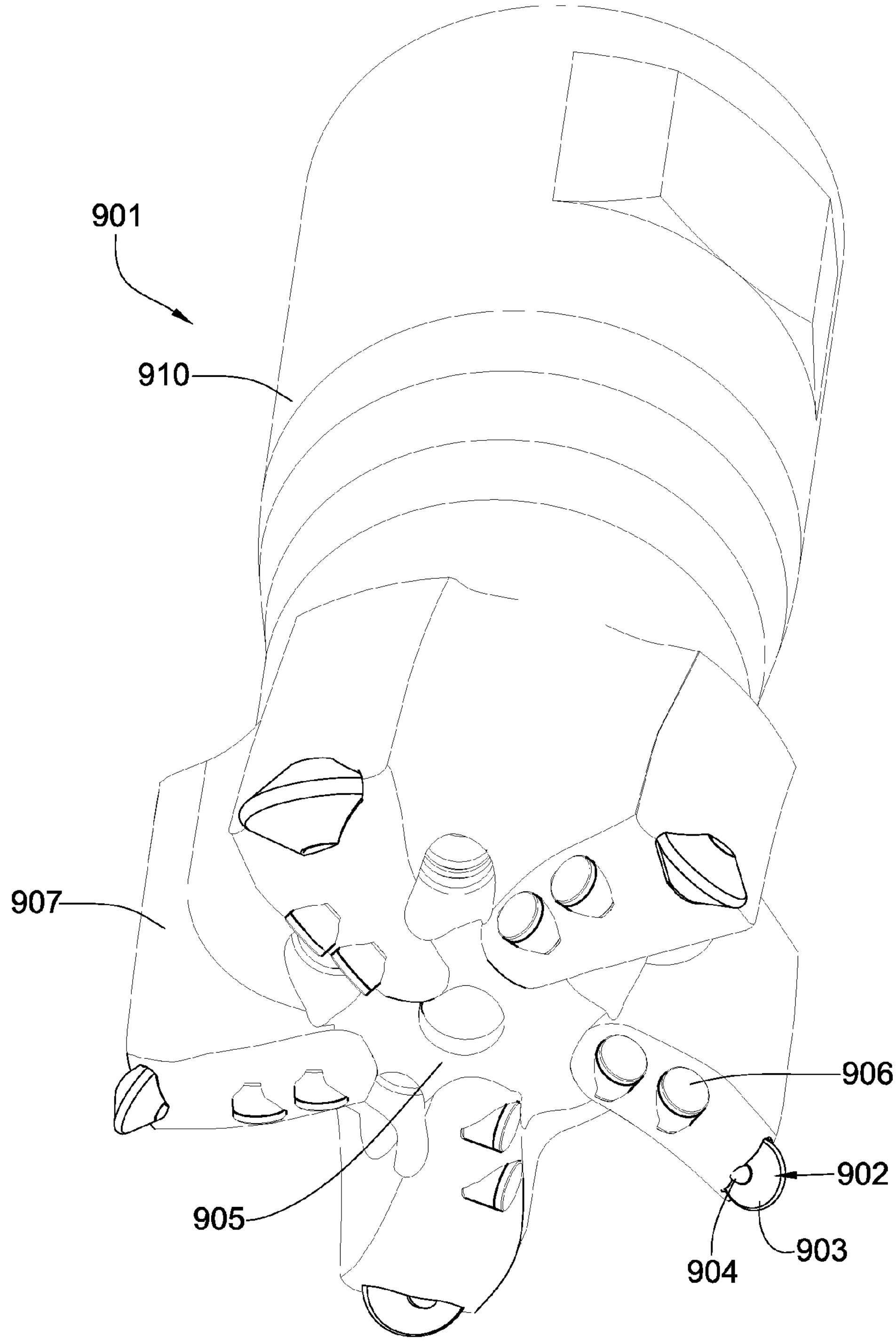


Fig. 9

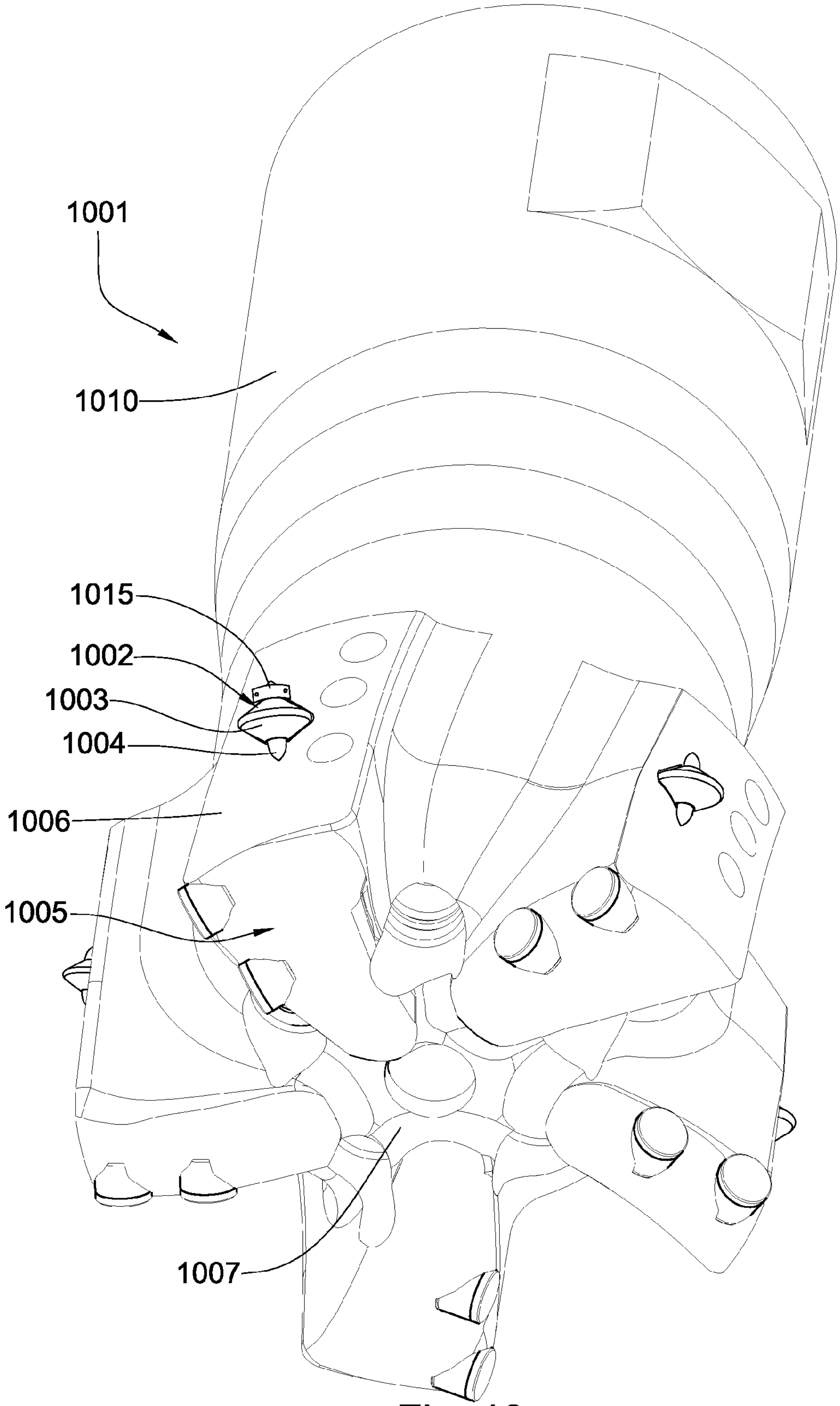


Fig. 10

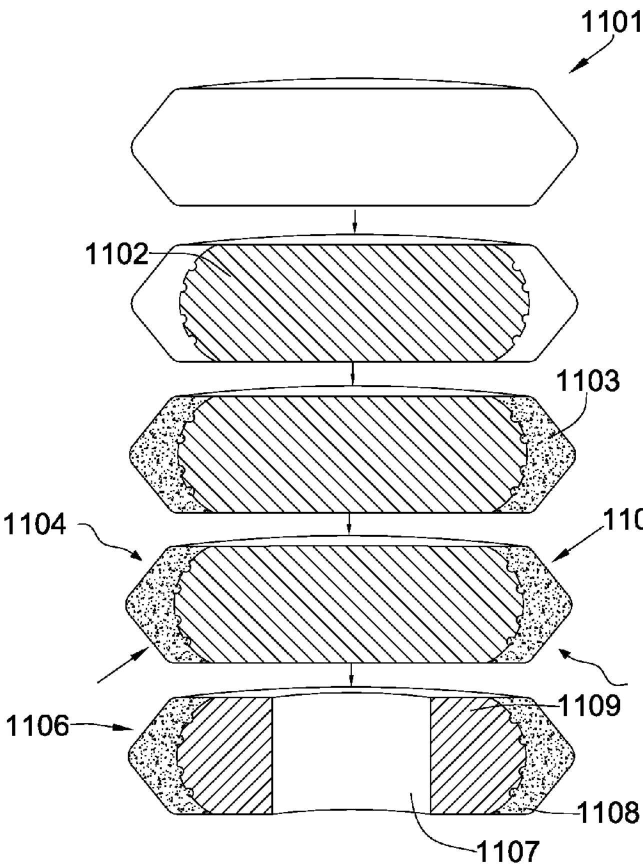


Fig. 11a

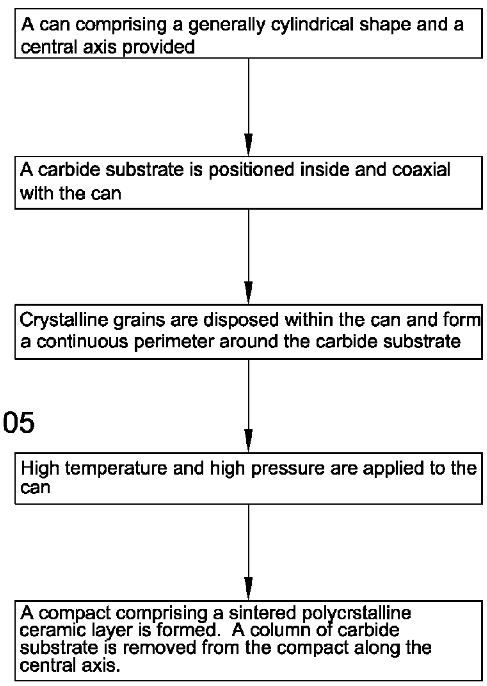


Fig. 11b

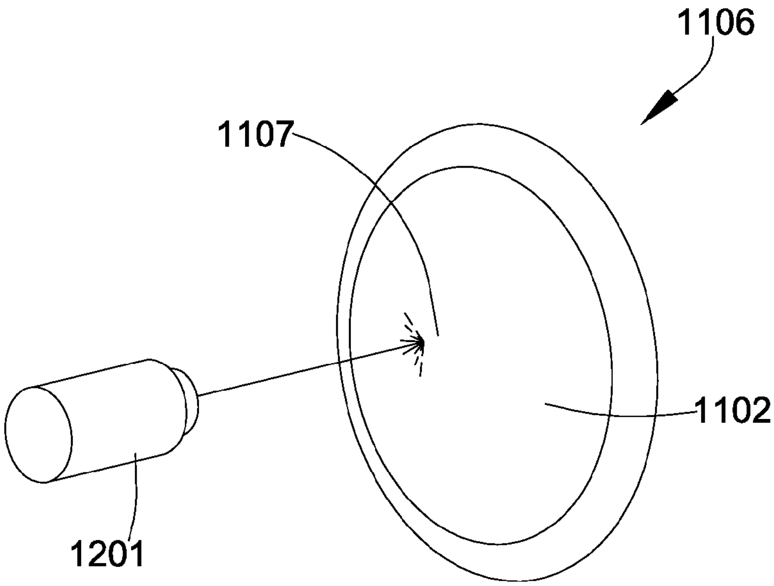


Fig. 12a

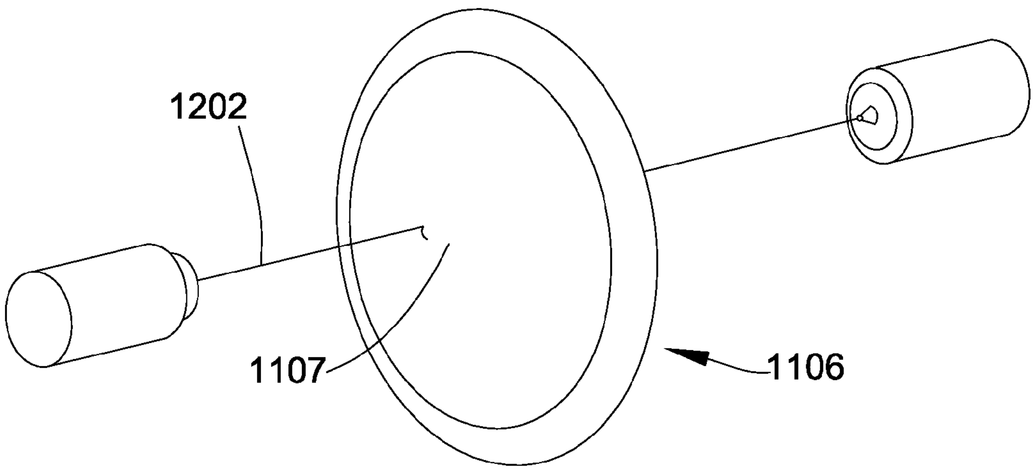


Fig. 12b

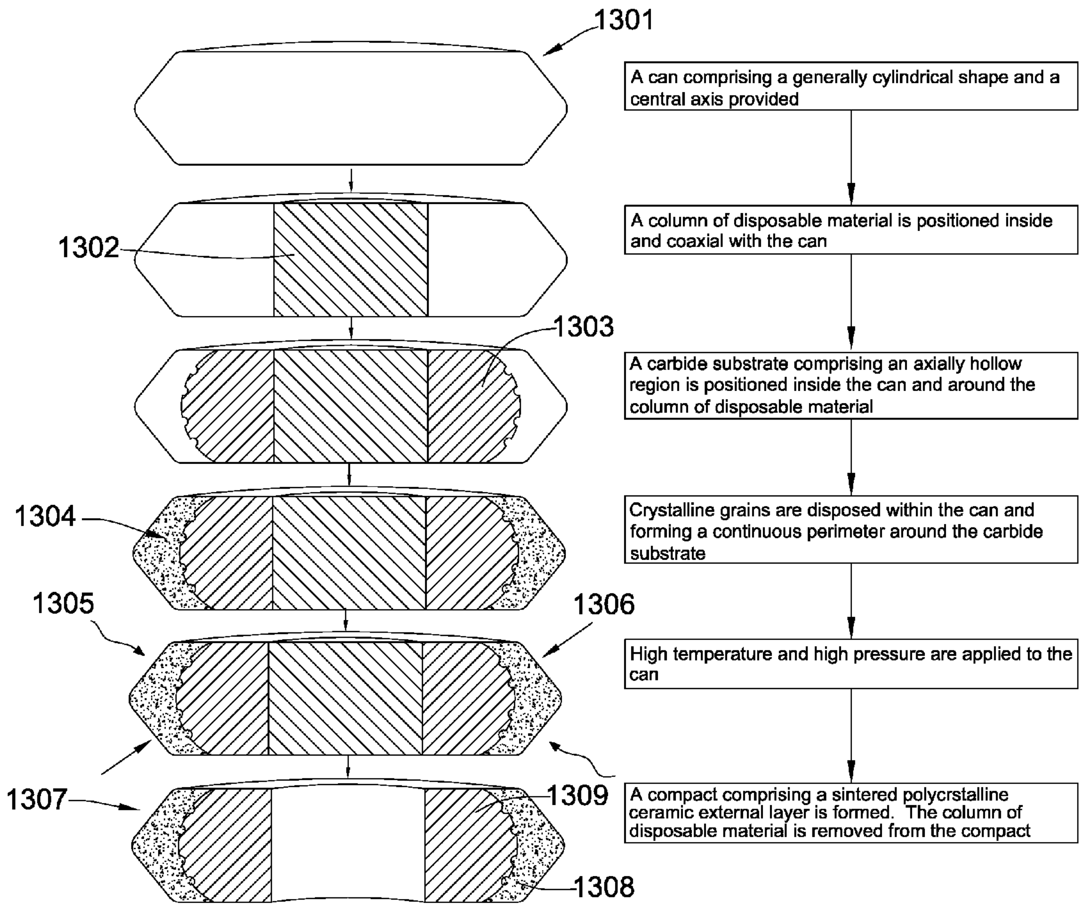


Fig. 13a Fig. 13b

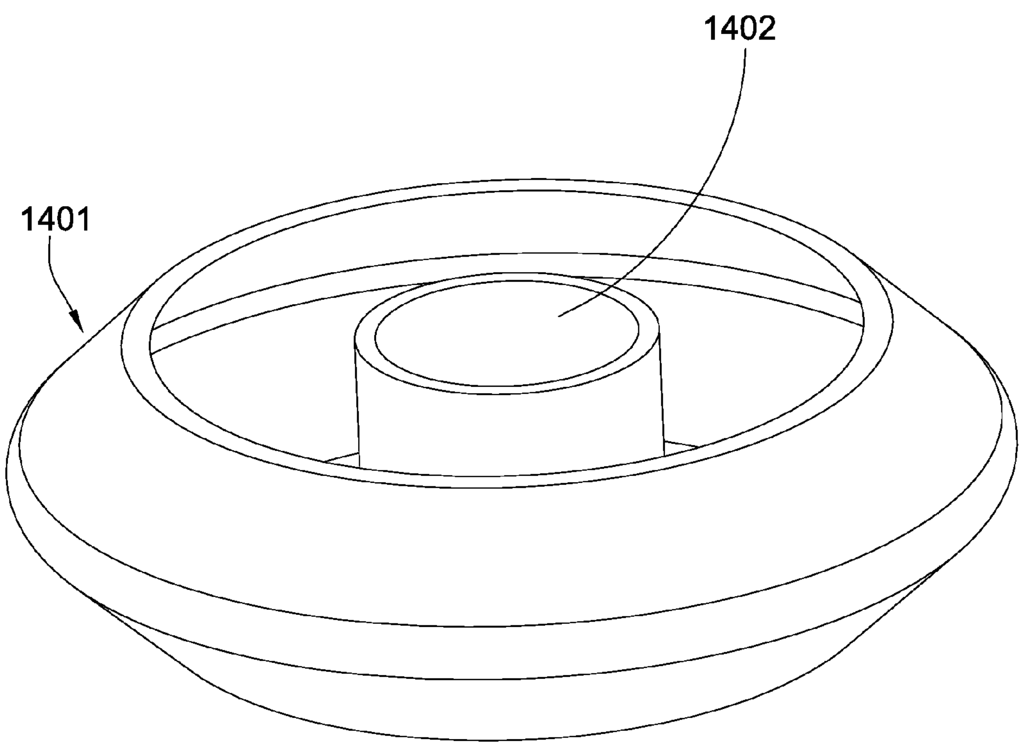


Fig. 14

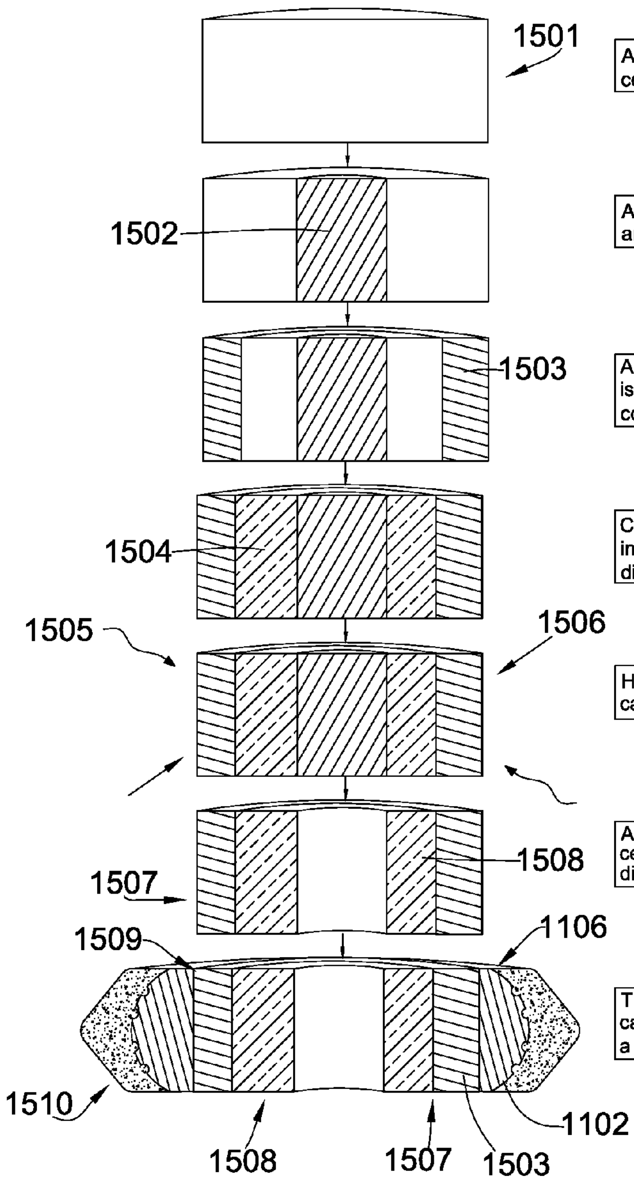


Fig. 15a

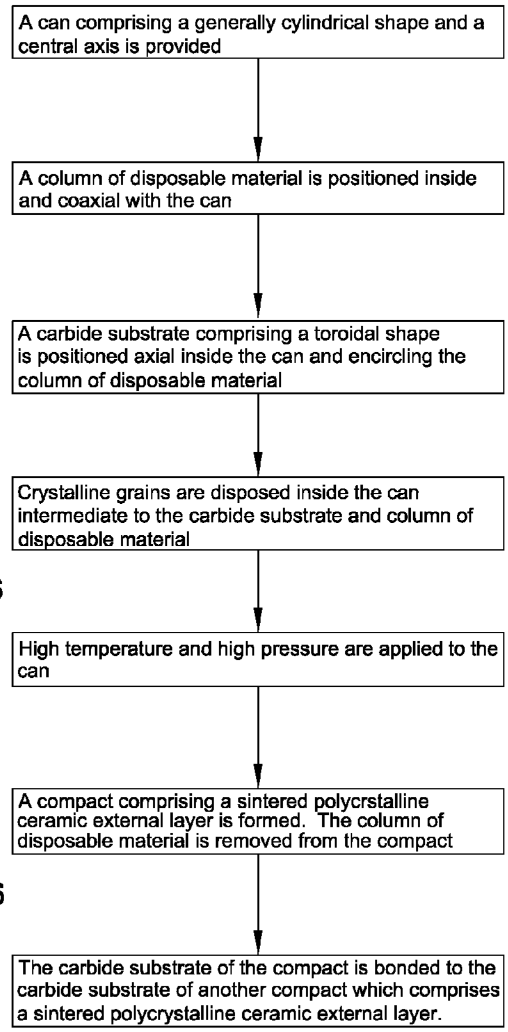


Fig. 15b

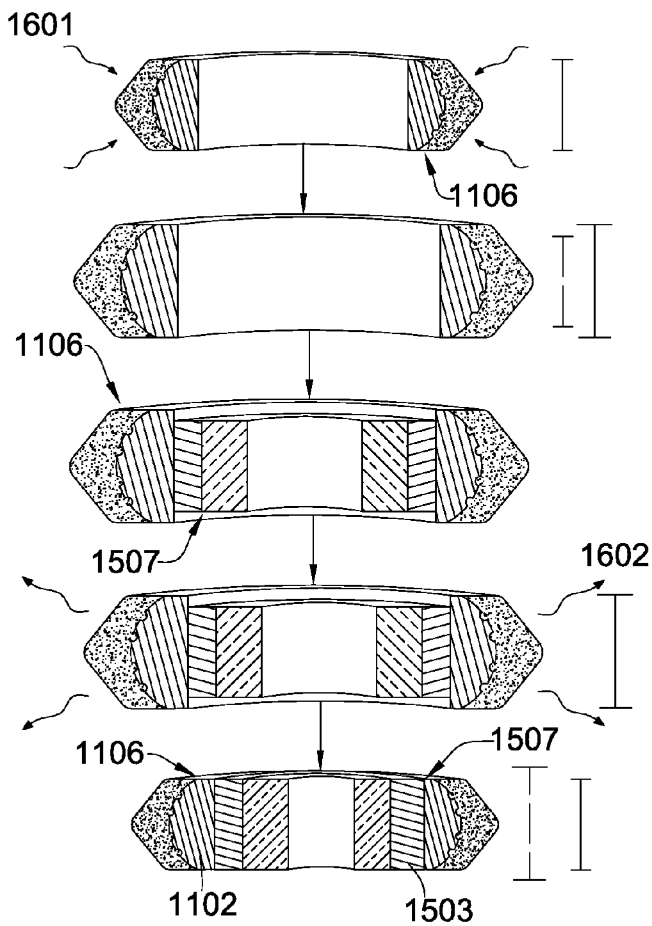


Fig. 16a

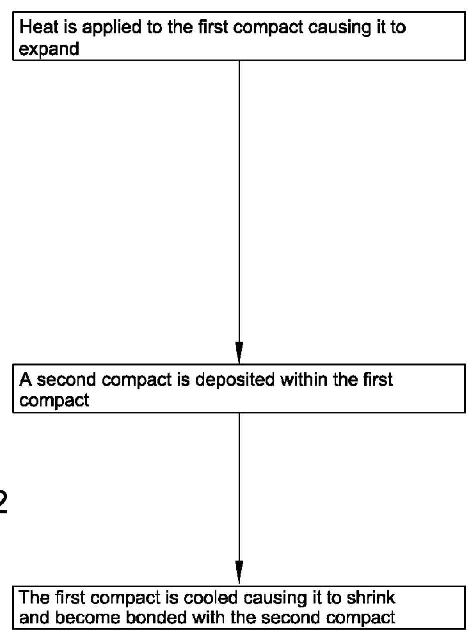


Fig. 16b

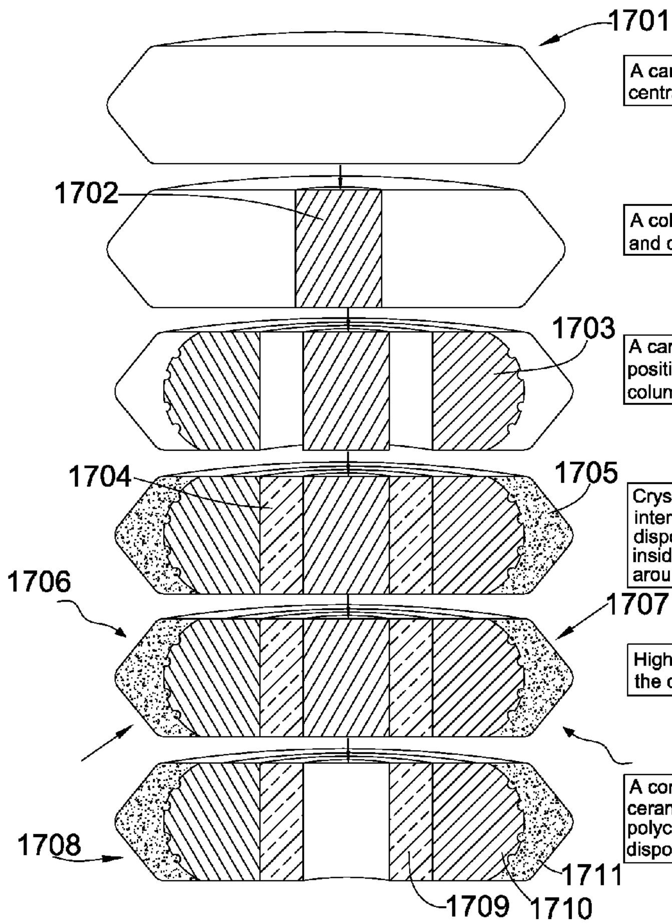


Fig. 17a

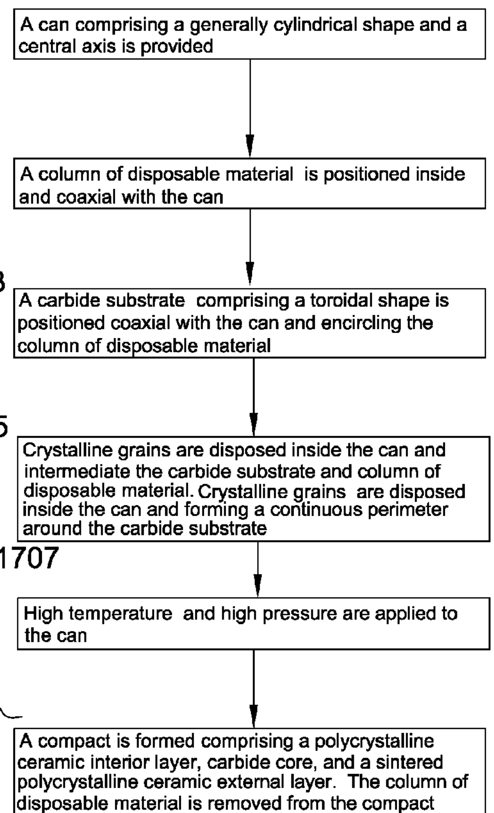


Fig. 17b

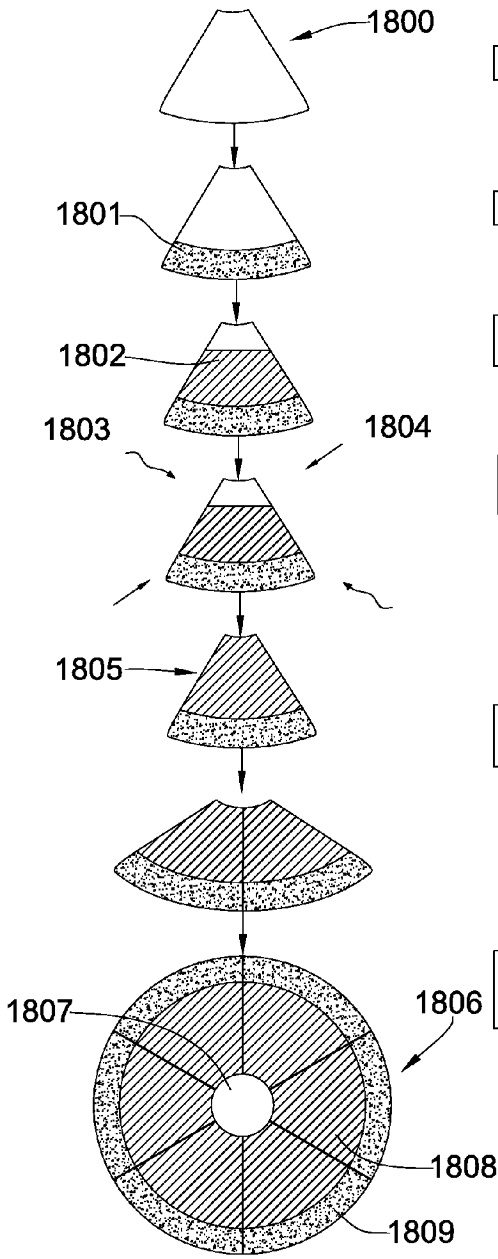


Fig. 18a

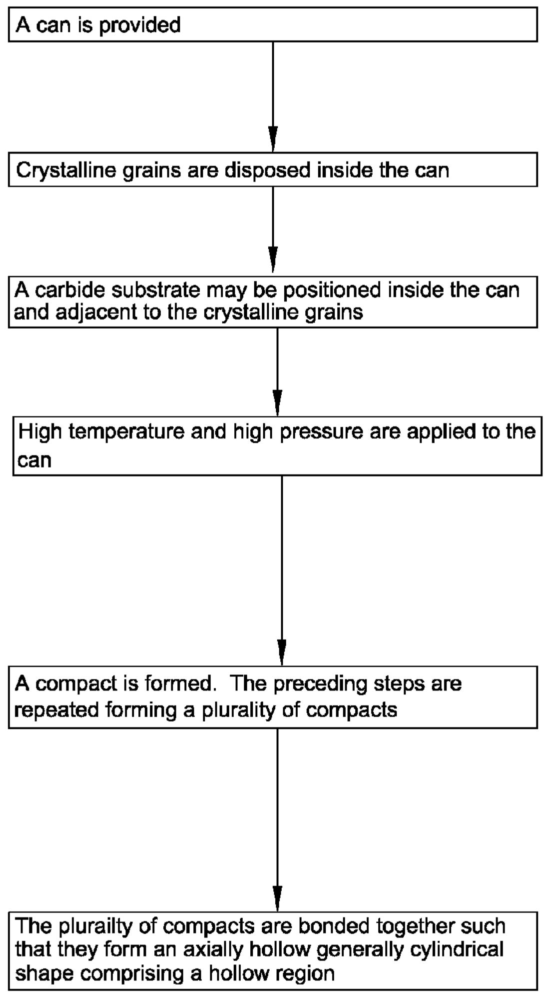


Fig. 18b

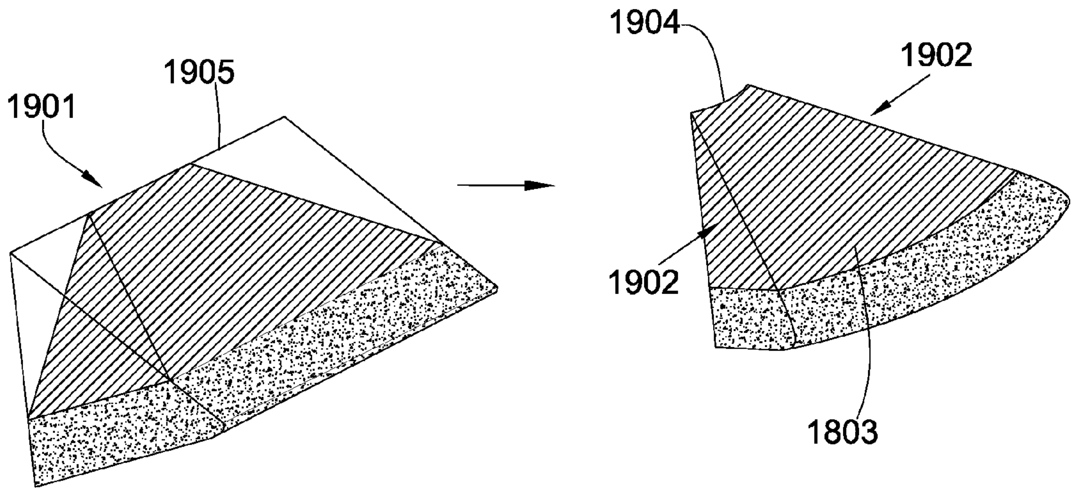


Fig. 19

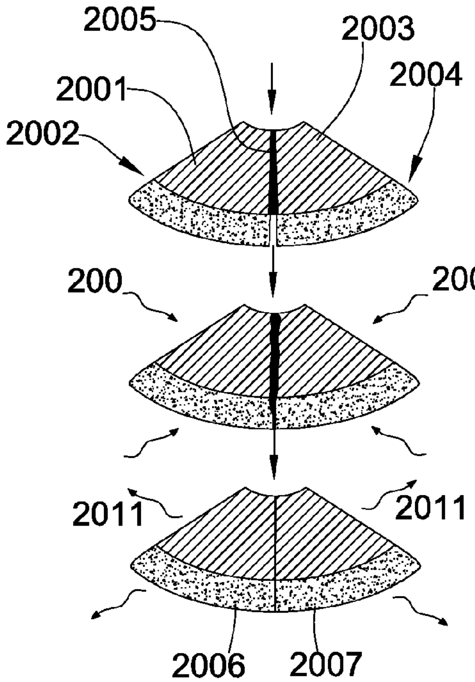


Fig. 20a

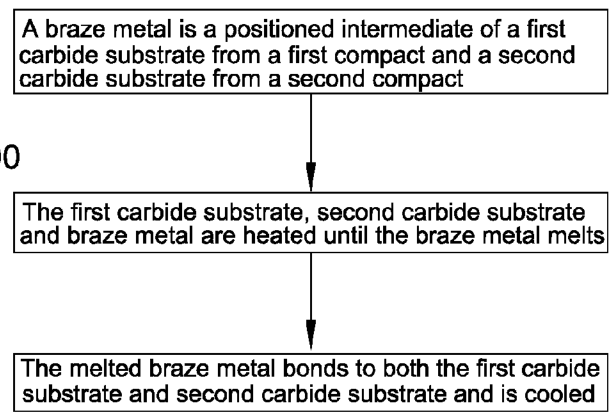


Fig. 20b

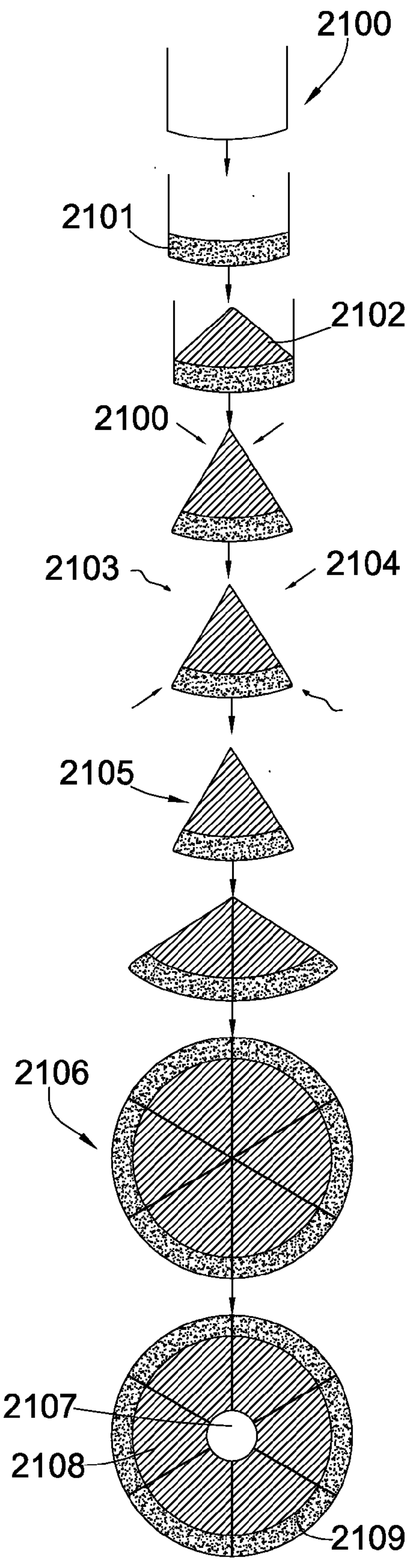


Fig. 21a

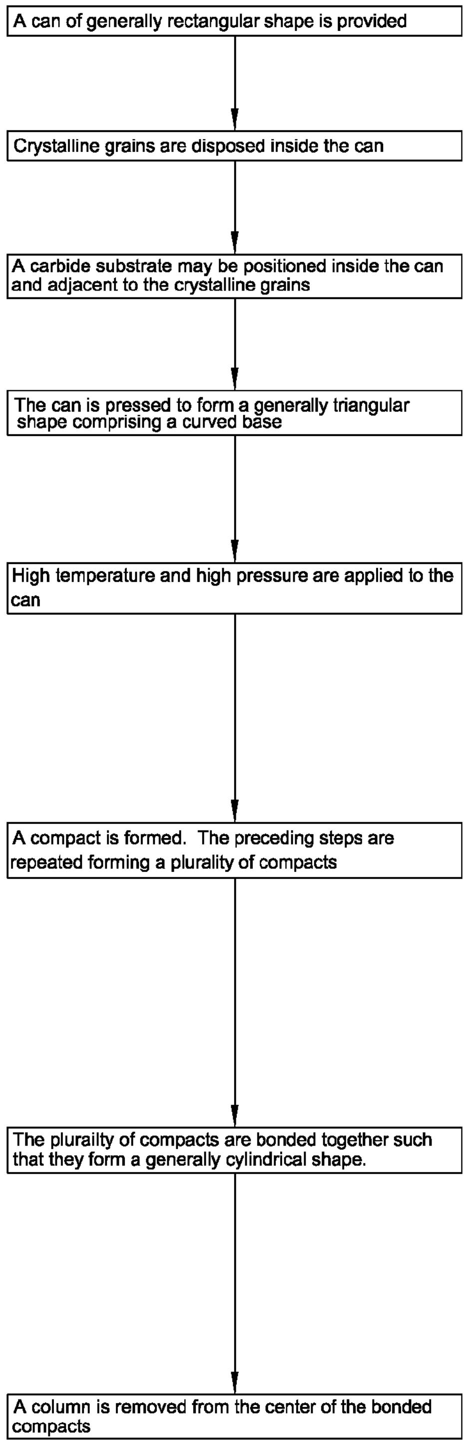


Fig. 21b

DISC CUTTER FOR AN EARTH BORING SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This patent application is a continuation of U.S. patent application Ser. No. 12/766,522 which is herein incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] There exists a variety of rock boring machines used to cut through rock formations. Some machines such as the tunnel boring machine (TBM) may contain disc cutters. Disc cutters are generally rotatable around an axis and contain a continuous cutting surface. The prior art discloses rock boring machines containing said disc cutters.

[0003] One such disc cutter is disclosed in U.S. Pat. No. 6,131,676 to Friant et al., which is herein incorporated by reference for all that it contains. Friant et al. discloses small diameter rotary drill bits using rolling disc cutters. Novel small diameter rotary drill bits with detachable pedestal mounted rolling disc cutters are provided. The bit body has a plurality of longitudinal edge mounting slots located at preselected angularly spaced apart locations. Preferable, the slots each have an upper protective ledge and downwardly extending sidewalls. A set of peripheral pedestal mounts each having a mounting portion sized and shaped to fit into a preselected mounting slot are provided and each is detachably mounted in its preselected mounting slot. In one embodiment, the longitudinally extending slots further comprise a wedge shaped edge portion, and the pedestal mounts have a complimentary angularly shaped portion, so that when the pedestal mount is brought into a close fitting relationship with the longitudinal slot, the pedestal mount and the longitudinal slot are tightly and securely interfitting. The pedestal mounts each include, at the lower reaches thereof, at least one small diameter single cutting edge rolling disc cutter. The rolling disc cutters are affixed at individually preselected radially spaced apart locations with respect to a central longitudinal axis forming the center of rotation of the rotary drill bit. Also, each of the rolling disc cutters is mounted at a preselected angle delta with respect to the central longitudinal axis forming the center of rotation of the rotary drill bit. Also, the rolling disc cutters are preferable detachably affixed to the pedestal mounts.

[0004] Another such disc cutter is disclosed in U.S. Pat. No. 3,981,370 to Bingham et al., which is herein incorporated by reference for all that it contains. Bingham et al. discloses a rock-boring machine of the type comprising a rotatable headplate having a plurality of disc cutting units mounted on the front face of the headplate. Each disc cutting unit includes an annular rotatable body having a continuous recess extending around its periphery and a plurality of cutting segments located in the recess. The segments are secured in the recess by means of removable clamping means.

BRIEF SUMMARY OF THE INVENTION

[0005] In one aspect of the present invention a disc cutter for an earth boring system comprises an axle and a sintered polycrystalline ceramic disc disposed about and forming a continuous perimeter around the axle.

[0006] The sintered polycrystalline ceramic disc may be comprised of a uniform polycrystalline ceramic material. The disc may contain a carbide core proximate the axle wherein a sintered polycrystalline ceramic external layer may be bonded to the carbide core. The carbide core may contain a polycrystalline ceramic interior layer proximate to the axle.

[0007] The sintered polycrystalline ceramic disc may contain grooves. The grooves may originate from a rim of the disc and terminate at the axle or may be continuous around the axle. The disc may also contain protrusions which extend from and add texture to the ceramic disc.

[0008] The sintered polycrystalline ceramic disc may contain two parallel cutting edges comprising supplemental internal angles or two parallel cutting edges each comprising an internal angle greater than 90 degrees with a rim comprising an internal angle measuring 80 to 140 degrees. The distance from at least one cutting edge to the core may be equal to the distance from the rim to the core.

[0009] The disc cutter may contain a plurality of sintered polycrystalline ceramic discs.

[0010] The axle may include a polycrystalline ceramic layer on its exterior surface.

[0011] In another aspect of the present invention a drill bit for penetrating earthen formations may include a body comprising of a working face. The working face may comprise a plurality of blades converging towards its center and diverging toward a gauge of the working face. An axle may be bonded to one of the plurality of blades. A sintered polycrystalline ceramic disc may be disposed about and forming a continuous perimeter around the axle.

[0012] The drill bit may also comprise at least one shear cutter disposed on one of the plurality of blades. The axle may be bonded to one of the plurality of blades at the gauge of the working face.

[0013] The sintered polycrystalline ceramic disc may be aligned tangent to a periphery of the working face or may be aligned perpendicular to the working face.

[0014] In another aspect of the present invention a method of forming a disc cutter comprises providing a first can which may be of a generally cylindrical shape and contain a central axis, positioning a first carbide substrate inside and coaxial with the first can, disposing crystalline grains inside the first can and forming a continuous perimeter around the first carbide substrate, applying high temperature and high pressure to the first can to form a first compact, and removing a column from the first compact along the central axis.

[0015] The first carbide substrate or the first can may comprise an axially hollow region wherein a disposable material may be disposed. The disposable material may be comprised of salt, silicon oxide, aluminum oxide, or tungsten carbide.

[0016] The column removed from the first compact may be removed by blasting, abrasive lapping, abrasive grinding, or electric discharge machining.

[0017] A second can of a generally cylindrical shape and central axis may be provided and a column of disposable material may be positioned inside and coaxial with the second can. A second carbide substrate comprising a toroidal shape may be positioned inside the second can and encircling the second column. Crystalline grains may be disposed inside the second can and intermediate to the second carbide substrate and the column of disposable material. High temperature and high pressure may be applied to the second can to form a second compact. The first carbide substrate and the second carbide substrate may then be bonded together.

[0018] The first carbide substrate and the second carbide substrate may be bonded together by heating the first compact causing it to expand, depositing the second compact within the first compact, and cooling the first compact causing it to shrink onto the second compact.

[0019] In another aspect of the present invention a method of forming a disc cutter comprises providing a can which may be of a generally cylindrical shape and contain a central axis, positioning a column of disposable material along the axis of the can, positioning a carbide substrate which may be of a toroidal shape coaxial with the can and encircling the column, disposing crystalline grains inside the can and intermediate to the carbide substrate and column of disposable material, disposing crystalline grains inside the can and forming a continuous perimeter around the carbide substrate, applying high temperature and high pressure to the can to form a compact and removing the column from the compact.

[0020] In another aspect of the present invention a method of forming a disc cutter includes providing a can, disposing crystalline grains inside the can, positioning a carbide substrate adjacent to the crystalline grains, and applying high temperature and high pressure to the can to form a compact. The preceding steps may be repeated to form a plurality of compacts and wherein the compacts may be bonded together.

[0021] The compacts may be bonded together by brazing the carbide substrates of each compact. The sintered polycrystalline ceramic external layers of the compacts may be flush with each other after brazing. The compacts may be bonded so that they form a generally cylindrical shape. The generally cylindrical shape may be axially hollow, or a column from the center may be removed from the bonded compacts. The column may be removed by blasting, abrasive lapping, abrasive grinding, or electric discharge machining.

[0022] The can may be of a generally annular sector shape which may be formed by pressing the can around the carbide substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. **1** is a cutaway view of an embodiment of a drilling operation.

[0024] FIG. **2** is a perspective view of an embodiment of a downhole drill bit.

[0025] FIG. **3** is a perspective view of an embodiment of a disc cutter.

[0026] FIG. **4***a* is a cross-sectional view an embodiment of a disc cutter.

[0027] FIG. **4***b* is a cross-sectional view of another embodiment of a disc cutter.

[0028] FIG. **5***a* is a perspective view of an embodiment of a disc cutter.

[0029] FIG. **5***b* is a perspective view of another embodiment of a disc cutter.

[0030] FIG. **6***a* is a perspective view of an embodiment of a disc cutter.

[0031] FIG. **6***b* is a perspective view of another embodiment of a disc cutter.

[0032] FIG. **6***c* is a perspective view of another embodiment of a disc cutter.

[0033] FIG. **7** is a perspective view of an embodiment of a disc cutter.

[0034] FIG. **8***a* is a perspective view of an embodiment of a disc cutter.

[0035] FIG. **8***b* is a perspective view of another embodiment of a disc cutter.

[0036] FIG. **9** is a perspective view of an embodiment of a downhole drill bit.

[0037] FIG. **10** is a perspective view of an embodiment of a downhole drill bit.

[0038] FIG. **11***a* is a plurality of longitudinal sections representing a method of forming a disc cutter.

[0039] FIG. **11***b* is a flow chart of the steps in a method of forming a disc cutter.

[0040] FIG. **12***a* is a perspective diagram of an embodiment depicting a method of subjecting a center column to the electrode of an electric discharge machine (EDM).

[0041] FIG. **12***b* is a perspective diagram of an embodiment depicting a method of cutting a center column using an EDM wire.

[0042] FIG. **13***a* is a plurality of longitudinal sections representing a method of forming a disc cutter.

[0043] FIG. **13***b* is a flow chart of the steps in a method of forming a disc cutter.

[0044] FIG. **14** is a perspective view of an embodiment of a can.

[0045] FIG. **15***a* is a plurality of longitudinal sections representing a method of forming a disc cutter.

[0046] FIG. **15***b* is a flow chart of the steps in a method of forming a disc cutter.

[0047] FIG. **16***a* is a plurality of longitudinal sections representing a method of bonding two substrates together.

[0048] FIG. **16***b* is a flow chart of the steps in a method of bonding two substrates together.

[0049] FIG. **17***a* is a plurality of longitudinal sections representing a method of forming a disc cutter.

[0050] FIG. **17***b* is a flow chart of the steps in a method of forming a disc cutter.

[0051] FIG. **18***a* is a plurality of longitudinal sections representing a method of forming a disc cutter.

[0052] FIG. **18***b* is a flow chart of the steps in a method of forming a disc cutter.

[0053] FIG. **19** is a perspective view of an embodiment of a can.

[0054] FIG. **20***a* is a plurality of longitudinal sections representing a method of bonding two substrates together.

[0055] FIG. **20***b* is a flow chart of the steps in a method of bonding two substrates together.

[0056] FIG. **21***a* is a plurality of longitudinal sections representing a method of forming a disc cutter.

[0057] FIG. **21***b* is a flow chart of the steps in a method of forming a disc cutter.

DETAILED DESCRIPTION OF THE INVENTION AND THE PREFERRED EMBODIMENT

[0058] Referring now to the figures, FIG. **1** discloses an embodiment of a drilling operation comprising a drilling derrick **101** supporting a drill string **100** inside a borehole **103**. The drill string **100** comprises a drilling assembly **102** with a drill bit **104**. The drilling assembly **102** may comprise electronic equipment able to send signals through a data communication system in the drill string **100** to a computer or data logging system **106** located at the surface.

[0059] FIG. **2** discloses an embodiment of a drill bit **104** comprising a body **201** and a working face **202**. The working face **202** may comprise a plurality of blades **203** which may converge towards a center **204** of the working face **202** and diverge towards a gauge **205** of the working face **202**. The drill bit **104** may comprise a disc cutter **206** comprising a sintered polycrystalline ceramic disc **207** disposed about and forming a continuous perimeter around an axle **208**. The disc cutter **206** may be disposed in a hole **210** on the drill bit **104**

such that the hole **210** may comprise bearing surfaces to slide against the disc cutter **206** and maintain the position of the disc cutter **206** on the axle **208**. In this embodiment, the sintered polycrystalline ceramic disc **207** of the disc cutter **206** is aligned perpendicular to the working face **202**.

[0060] FIG. **3** discloses an embodiment of a disc cutter **206** containing an axle **208** and a sintered polycrystalline ceramic disc **207** which may be disposed about and the axle **208**. The sintered polycrystalline ceramic disc **207** contains a continuous perimeter **301** around the axle **208** such that cutting radius of the disc **207** may be the same as the radius of the disc cutter **206**. In this figure, the sintered polycrystalline ceramic disc **207** may be composed of a uniform polycrystalline ceramic material. It is believed that the uniformity of the material eliminates weak areas from forming in the disc **207**. The life of the disc cutter **206** may thus be extended during normal drilling operations.

[0061] FIG. **4***a* discloses a cross sectional view of an embodiment of a disc cutter **206**. The axle **208** acts as a central axis on which the sintered polycrystalline ceramic disc **207** can rotate. The axle **208** may comprise a polycrystalline ceramic layer **401** disposed on its exterior surface. The sintered polycrystalline ceramic disc **207** and the polycrystalline ceramic layer **401** may create a plain bearing. The sintered polycrystalline ceramic disc **207** and polycrystalline ceramic layer **401** may rub against each other without a sealing or lubricant. It is believed that this bearing extends the life of the disc cutter **206**. In prior art disc cutters a bearing with a sealing has been necessary due to the materials used. However, abrasive substances may penetrate the sealing causing the sealing to deteriorate causing the need for the disc cutter to be replaced.

[0062] Also in FIG. **4***a*, the axle **208** may comprise a first stopper **215** and a second stopper **216**. The first stopper **215** may create an increased diameter on a portion of the axle **208**. The second stopper **216** may comprise a ring such as a snap ring disposed around the axle **208**. The first stopper **215** and the second stopper **216** may comprise bearing surfaces to slide against the disc cutter **206** and maintain the position of the disc cutter **206** on the axle **208**.

[0063] FIG. **4***b* discloses a cross sectional view of another embodiment of a disc cutter **206**. In this figure, the sintered polycrystalline ceramic disc **207** may comprise a carbide core **402** proximate the axle **208**. The carbide core **402** may comprise a polycrystalline ceramic interior layer **406** proximate the axle **208**. The axle **208** may comprise a polycrystalline ceramic layer **401** disposed on its exterior surface. The polycrystalline ceramic interior layer **406** of the carbide bore **402** and the polycrystalline ceramic layer **401** on exterior surface of the axle **208** may create a bearing like that described previously.

[0064] A sintered polycrystalline ceramic external layer **403** may be bonded to the carbide core **402**. The sintered polycrystalline ceramic external layer **403** may comprise polycrystalline diamond, synthetic diamond, vapor deposited diamond, silicon bonded diamond, cobalt bonded diamond, thermally stable diamond, polycrystalline diamond with a binder concentration of 1 to 40 weight percent, infiltrated diamond, layered diamond, monolithic diamond, polished diamond, course diamond, fine diamond, cubic boron nitride, diamond impregnated matrix, diamond impregnated carbide, silicon carbide, metal catalyzed diamond, or combinations thereof. It is believed that cubic boron nitride's metallic properties and heat tolerance make it a particularly effective external layer in certain formations.

[0065] Also in FIG. **4***b*, the sintered polycrystalline ceramic disc **207** comprises a rim **404** comprising an internal angle **407** measuring 80 to 140 degrees located between two parallel cutting edges **405** each comprising an internal angle **408** greater than 90 degrees. The two parallel cutting edges **405** may allow for side loading. The two parallel cutting edges **405** may be significant because they may increase the cutting area of the disc cutter **206**.

[0066] The rim **404** and the two parallel cutting edges **405** can be susceptible to breaking off during drilling operations. To minimize the likelihood of breaking off, the distance **409** from at least one parallel cutting edge **405** to the carbide core **402** may be equal to the distance **410** from the rim **404** to the carbide core **402**.

[0067] FIG. **5***a* discloses a perspective view of a disc cutter **400**. The disc cutter **400** may contain a sintered polycrystalline ceramic disc **207** comprised of a rim **404** located between two parallel cutting edges **405**.

[0068] FIG. **5***b* discloses an embodiment of a disc cutter **501** containing a sintered polycrystalline ceramic disc **502** comprising two parallel cutting edges **503** comprising supplemental internal angles **504**. This figure presents a disc cutter **501** which may be valuable in cases where only side loading is present.

[0069] FIG. **6***a* discloses an embodiment of a disc cutter **601** containing grooves **604**. Grooves **604** may be beneficial in downhole drilling by increasing the productivity and life of a disc cutter **601**. During downhole operations, occasionally a disc cutter begins to slide along the earthen formation instead of cutting into it. This may put great wear on and could even break the disc cutter. The grooves **604** in the present embodiment may act like tread and grip into an earthen formation disallowing sliding. Grooves **604** can appear in a disc cutter **601** in a variety of patterns. In the embodiment shown, the grooves **604** originate at a rim **605** of the sintered polycrystalline ceramic disc **606** and terminate at an axle **607**.

[0070] FIG. **6***b* discloses another embodiment of a disc cutter **602** containing grooves **608**. In this embodiment the grooves **608** are continuous around an axle **609**.

[0071] FIG. **6***c* discloses an embodiment of a disc cutter **603** containing protrusions **610** which may extend from and add texture to a sintered polycrystalline ceramic disc **612**. The protrusions **610** may increase productivity and life of a disc cutter by preventing the disc cutter from sliding. Protrusions **610** can appear on a disc cutter in a variety of patterns. In this figure, the protrusions **610** originate at a rim **611** of the sintered polycrystalline ceramic disc **612** and terminate at an axle **613**.

[0072] FIG. **7** discloses an embodiment of a disc cutter **701** comprising a plurality of sintered polycrystalline ceramic discs **702** disposed about an axle **705**. The plurality of discs **702** may increase the cutting area of the disc cuter **701**. Each disc **702** may be composed of a uniform polycrystalline ceramic material and comprise a continuous perimeter **703**.

[0073] FIG. **8***a* discloses an embodiment of a disc cutter **801**. The disc cutter **801** comprises a sintered polycrystalline ceramic disc **802** which may be disposed about and form a continuous perimeter **804** around an axle **803**. In this embodiment, the ceramic disc **802** is freely rotatable about the axle **803**.

[0074] FIG. **8***b* discloses an embodiment of a disc cutter **805**. The disc cutter **805** comprises a sintered polycrystalline ceramic disc **806** which may be disposed about and form a continuous perimeter **808** around an axle **807**. In this embodiment, the ceramic disc **805** is fixed to the axle **807** such that the ceramic disc **805** and the axle **807** rotate together.

[0075] FIG. **9** discloses another embodiment of a drill bit **901** comprising a body **910** and a working face **905**. In the embodiment shown, the drill bit **901** contains a disc cutter **902** comprising a sintered polycrystalline ceramic disc **903** disposed about and forming a continuous perimeter around an axle **904**. The sintered polycrystalline ceramic disk **903** may be aligned tangent to the periphery of the working face **905**. The drill bit **901** may also contain at least on shear cutter **906** disposed on one of the plurality of blades **907**. During the drilling process, the at least one shear cutter **906** and disc cutter **902** may serve different functions. The combination of using both types of cutters may be superior over using only one type in certain conditions.

[0076] FIG. **10** discloses another embodiment of a drill bit **1001** comprising a body **1010** and a working face **1007**. In this figure, the drill bit **1001** contains a disc cutter **1002** comprising a sintered polycrystalline ceramic disc **1003** disposed about and forming a continuous perimeter around an axle **1004**. The sintered polycrystalline ceramic disc **1003** may be bonded to one of the plurality of blades **1005** at a gauge **1006** of the working face **1007**. A disc cutter **1002** located in this position may enlarge the area in which the drill bit **1001** is drilling. This embodiment may also include a covering **1015** which may be placed over the axle **1004**. The covering **1015** may prevent the axle **1004** from coming loose during normal drilling operations. The covering **1015** may comprise bearing surfaces to slide against the disc cutter **1002** and maintain the position of the disc cutter **1002** on the axle **1004**.

[0077] FIG. **11***a* discloses steps in a method of forming a disc cutter comprising a sintered polycrystalline ceramic external layer **1108** and a carbide core **1109**. A can **1101** comprising a generally cylindrical shape and a central axis may be provided. A carbide substrate **1102** may be positioned inside and coaxial with the can **1101**. Crystalline grains **1103** may be disposed inside the can **1101** and form a continuous perimeter around the carbide substrate **1102**. High temperature **1104** and high pressure **1105** may be applied to the can **1101** to form a compact **1106** comprising a sintered polycrystalline ceramic external layer **1108**. A column **1107** of carbide substrate **1102** may be removed from the compact **1106** along the central axis thus forming a compact **1106** of a generally toroidal shape. The compact **1106** may be used as a disc cutter comprising a sintered polycrystalline ceramic external layer **1108** and a carbide core **1109** with the insertion of an axle.

[0078] FIG. **11***b* discloses a flow chart of the steps in a method of forming a disc cutter which correspond to the longitudinal sections in FIG. **11***a*.

[0079] FIG. **12***a* discloses a first step of removing the column **1107** from the compact **1106** along the central axis as described previously. An electrode **1201** of an electric discharge machine (EDM) may be plunged into the carbide substrate **1102** of the compact **1106** forming an initial cavity.

[0080] FIG. **12***b* discloses a second step of removing the column **1107** from the compact **1106**. After the penetration by the EDM, an EDM wire **1202** may be threaded through the initial cavity. The EDM wire **1202** may clean the initial cavity of excess material forming a hollow column in the compact **1106**.

[0081] FIG. **13***a* discloses steps in a method of forming a disc cutter comprising a sintered polycrystalline ceramic external layer **1308** and a carbide core **1309**. A can **1301** comprising a generally cylindrical shape and a central axis may be provided. A column of disposable material **1302** may be positioned inside and coaxial with the can **1301**. The column of disposable material **1302** may comprise salt, silicon oxide, aluminum oxide or tungsten carbide. A carbide substrate **1303** comprising an axially hollow region may be positioned inside the can **1301** and around the column of disposable material **1302**. Crystalline grains **1304** may be disposed inside the can **1301** and form a continuous perimeter around the carbide substrate **1303**. High temperature **1305** and high pressure **1306** may then be applied to the can **1301** to form a compact **1307** comprising a sintered polycrystalline ceramic external layer **1308**. The column of disposable material **1302** may then be removed from the compact **1307**. The compact **1307** may be used as a disc cutter comprising a sintered polycrystalline ceramic external layer **1308** and a carbide core **1309** with the insertion of an axle.

[0082] FIG. **13***b* discloses a flow chart of the steps in a method of forming a disc cutter which correspond to the longitudinal sections in FIG. **13***a*.

[0083] FIG. **14** discloses a can **1401** used in a method of forming a disc cutter. The can **1401** comprises a generally cylindrical shape comprising an axially hollow region **1402**. The can **1401** could be used in a method similar to that shown in FIGS. **13***a* and **13***b*. When high temperature and high pressure is applied to the can **1401**, a disposable material may be disposed within the axially hollow region **1402**. The disposable material would prevent the can **1401** from collapsing inward under the extreme conditions.

[0084] FIG. **15***a* discloses steps in a method of forming a disc cutter comprising a polycrystalline ceramic interior layer **1508**, carbide core **1509**, and a sintered polycrystalline ceramic external layer **1510**. A can **1501** comprising a generally cylindrical shape and a central axis may be provided. A column of disposable material **1502** may be positioned inside and coaxial with the can **1501**. A carbide substrate **1503** comprising a toroidal shape may be positioned coaxial with the can **1501** and encircling the column **1502**. Crystalline grains **1504** may be disposed inside the can **1501** intermediate to the carbide substrate **1503** and the column of disposable material **1502**. High temperature **1505** and high pressure **1506** may be applied to the can **1501** to form a compact **1507** comprising a polycrystalline ceramic interior layer **1508**. The column of disposable material **1502** may be removed from the compact **1507**. The carbide substrate **1503** of compact **1507** may be bonded to the carbide substrate **1102** of compact **1106**. The carbide substrate **1503** and carbide substrate **1102** may become the carbide core **1509** when bonded together. The compact **1507** may be used as a disc cutter comprising a sintered polycrystalline ceramic external layer **1510** and carbide core **1509** with the insertion of an axle. A plain bearing may be formed when the polycrystalline ceramic interior layer **1508** is combined with an axle comprised of a polycrystalline ceramic exterior surface.

[0085] FIG. **15***b* discloses a flow chart of the steps in a method of forming a disc cutter which correspond to the longitudinal sections in FIG. **15***a*.

[0086] FIG. **16***a* discloses steps in a method of bonding the carbide substrate **1503** of compact **1507** to the carbide substrate **1102** of compact **1106**. Heat **1601** may be applied to the compact **1106** causing it to expand. The compact **1507** may be deposited within the compact **1106**. The compact **1106** may then be cooled **1602** causing it to shrink. The compact **1106**

and the compact **1507** may be bonded together as the compact **1106** shrinks with the compact **1507** deposited within it.

[0087] FIG. **16***b* discloses a flow chart of the steps in a method of bonding two substrates together which correspond to the longitudinal sections in FIG. **16***a*.

[0088] FIG. **17***a* discloses steps in a method of forming a disc cutter comprising a polycrystalline ceramic interior layer **1709**, carbide core **1710**, and a sintered polycrystalline ceramic external layer **1711**. A can **1701** comprising a generally cylindrical shape and a central axis may be provided. A column of disposable material **1702** may be positioned inside and coaxial with the can **1701**. A carbide substrate **1703** comprising a toroidal shape may be positioned inside and coaxial with the can **1701** and encircling the column of disposable material **1702**. Crystalline grains **1704** may be disposed inside the can **1701** and intermediate the carbide substrate **1703** and column of disposable material **1702**. Crystalline grains **1705** may be disposed inside the can and forming a continuous perimeter around the carbide substrate **1703**. High temperature **1706** and high pressure **1707** may be applied to the can **1701** forming a compact **1708** comprising a carbide core **1710**, and a sintered polycrystalline ceramic external layer **1711**. The column of disposable material **1702** may be removed from the compact **1708**. The compact **1708** may be used as a disc cutter comprising a sintered polycrystalline ceramic external layer **1711**, carbide core **1710** and polycrystalline ceramic interior layer **1709** with the insertion of an axle. A plain bearing may be formed when the polycrystalline ceramic interior layer **1709** is combined with an axle comprised of a polycrystalline ceramic exterior surface.

[0089] FIG. **17***b* discloses a flow chart of the steps in a method of forming a disc cutter which correspond to the longitudinal sections in FIG. **17***a*.

[0090] FIG. **18***a* discloses a method of forming a disc cutter comprising a carbide core **1808** and a sintered polycrystalline ceramic external layer **1809**. A can **1800** may be provided. Crystalline grains **1801** may be disposed inside the can **1800**. A carbide substrate **1802** may be positioned inside the can **1800** and adjacent to the crystalline grains **1801**. High temperature **1803** and high pressure **1804** may be applied to the can **1800** forming a compact **1805**. The preceding steps may then be repeated forming a plurality of compacts **1805**. The plurality of compacts **1805** may be bonded together such that they form an axially hollow generally cylindrical shape **1806** comprising a hollow region **1807**. An axle may be inserted into the hollow region **1807** such that a disc cutter comprising a carbide core **1808** and a sintered polycrystalline ceramic external layer **1809** carbide core **1808** and a sintered polycrystalline ceramic external layer **1809** is formed.

[0091] FIG. **18***b* discloses a flow chart of the steps in a method of forming a disc cutter which correspond to the longitudinal sections in FIG. **18***a*.

[0092] FIG. **19** discloses the can **1901** comprising a generally annular sector shape. The can **1901** may originally be a can **1901** of generally rectangular shape but may be formed by pressing **1902** the can **1901** around the carbide substrate **1803**. The can **1901** comprises a narrow opening **1904** such that the carbide substrate **1803** cannot fit through the narrow opening **1904** and fill the volume of the can **1901**. The carbide substrate **1803** may fit through the opening **1905** of the can **1901** wherein the can **1901** may be pressed **1902** together around the carbide substrate **1803**. The shape of the can **1901** allows a plurality of compacts to be bonded together in an axially hollow generally cylindrical shape.

[0093] FIG. **20***a* discloses steps in a method of bonding the carbide substrate **2001** of the compact **2002** to the carbide substrate **2003** of the compact **2004**. A braze metal **2005** may be positioned intermediate the carbide substrate **2001** and the carbide substrate **2003**. The carbide substrate **2001**, carbide substrate **2003** and braze metal **2005** may be heated **2010** until the braze metal **2005** melts. The melted braze metal **2005** may adhere to both the carbide substrate **2001** and carbide substrate **2003** and may be cooled **2011** to become a solid. As the metal braze **2005** is cooled, it acts as a glue between the carbide substrate **2001** and carbide substrate **2003** thus bonding them together. The compact **2002** may comprise a sintered polycrystalline ceramic external layer **2006** and the compact **2004** may comprise a sintered polycrystalline ceramic external layer **2007** wherein the ceramic external layer **2006** and ceramic external layer **2007** may be flush with each other after brazing.

[0094] FIG. **20***b* discloses a flow chart of the steps in a method of bonding carbide substrates together which correspond to the longitudinal sections in FIG. **20***a*.

[0095] FIG. **21***a* discloses a method of forming a disc cutter comprising a carbide core **2108** and a sintered polycrystalline ceramic external layer **2109**. In this figure, a can **2100** of a generally rectangular shape may be provided. Crystalline grains **2101** may be disposed inside the can **2100**. A carbide substrate **2102** may be positioned inside the can **2100** and adjacent to the crystalline grains **2101**. The can **2100** may be pressed **2110** to form a generally triangular shape comprising a curved base. High temperature **2103** and high pressure **2104** may be applied to the can **2100** forming a compact **2105**. The preceding steps may be repeated forming a plurality of compacts **2105**. The plurality of compacts **2105** may be bonded together such that they form a generally cylindrical shape **2106**. A column may be removed from the center of the bonded compacts to form a hollow region **2107**. The column may be removed by blasting, abrasive lapping, abrasive grinding, or electric discharge machining. An axle may be inserted into the hollow region **2107** such that a disc cutter comprising a carbide core **2108** and a sintered polycrystalline ceramic external layer **2109** may be formed.

[0096] FIG. **21***b* discloses a flow chart of the steps in a method of forming a disc cutter which correspond to the longitudinal sections in FIG. **21***a*.

[0097] Whereas the present invention has been described in particular relation to the drawings attached hereto, it should be understood that other and further modifications apart from those shown or suggested herein, may be made within the scope and spirit of the present invention.

1. A method of forming a disc cutter, comprising:

providing a first can comprising a generally cylindrical shape and a central axis;

positioning a first carbide substrate inside and coaxial with the first can;

disposing crystalline grains inside the first can and forming a continuous perimeter around the first carbide substrate;

applying high temperature and high pressure to the first can to form a first compact; and

removing a column from the first compact along the central axis.

2. The method of claim **1**, wherein the first carbide substrate comprises an axially hollow region.

3. The method of claim **2**, wherein a disposable material is disposed within the axially hollow region of the first carbide substrate.

4. The method of claim **3**, wherein the disposable material comprises salt, silicon oxide, aluminum oxide, or tungsten carbide.

5. The method of claim **1**, wherein the first can comprises an axially hollow region.

6. The method of claim **5**, wherein a disposable material is disposed within the axially hollow region of the first can.

7. The method of claim **1**, wherein removing a column comprises blasting, abrasive lapping, abrasive grinding, or electric discharge machining.

8. The method of claim **1**, further comprising:

providing a second can comprising a generally cylindrical shape and a central axis;

positioning a column of disposable material inside and coaxial with the second can;

positioning a second carbide substrate comprising a toroidal shape coaxial with the second can and encircling the second column;

disposing crystalline grains inside the second can and intermediate the second carbide substrate and the column of disposable material;

applying high temperature and high pressure to the second can to form a second compact; and

bonding the first carbide substrate to the second carbide substrate.

9. The method of claim **8**, wherein the bonding the first carbide substrate to the second carbide substrate comprises:

heating the first compact causing it to expand;

depositing the second compact within the first compact; and

cooling the first compact causing it to shrink around the second compact.

10. A method of forming a disc cutter, comprising:

providing a can comprising a generally cylindrical shape and a central axis;

positioning a column of disposable material along the axis of the can;

positioning a carbide substrate comprising a toroidal shape coaxial with the can and encircling the column;

disposing crystalline grains inside the can and intermediate the carbide substrate and the column of disposable material;

disposing crystalline grains inside the can and forming a continuous perimeter around the carbide substrate;

applying high temperature and high pressure to the can to form a compact; and

removing the column from the compact.

11. A method of forming a disc cutter, comprising:

providing a can;

disposing crystalline grains inside the can;

positioning a carbide substrate adjacent the crystalline grains;

applying high temperature and high pressure to the can to form a compact;

repeating the preceding steps to form a plurality of compacts; and

bonding the compacts together.

12. The method of claim **11**, further comprising removing a column from a center of the bonded compacts.

13. The method of claim **12**, wherein removing the column comprises blasting, abrasive lapping, abrasive grinding, or electric discharge machining.

14. The method of claim **11**, wherein the bonding the compacts together comprises bonding the carbide substrates of each compact.

15. The method of claim **14**, wherein the bonding the compacts together further comprises brazing the carbide substrates of each compact.

16. The method of claim **11**, wherein the bonding the compacts together comprises bonded the compacts such that they form a generally cylindrical shape.

17. The method of claim **16**, wherein the cylindrical shape is axially hollow.

18. The method of claim **17**, wherein the compacts each comprise a sintered polycrystalline ceramic external layer which are flush with each other after brazing.

19. The method of claim **11**, wherein the can comprises a generally annular sector shape.

20. The method of claim **19**, wherein the generally annular sector shape is formed by pressing the can around the carbide substrate.

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