(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 September 2014 (04.09.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/134390 A1

(51) International Patent Classification:
E21B 10/46 (2006.01)

(21) International Application Number:
PCT/US2014/019240

(22) International Filing Date:
28 February 2014 (28.02.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/780,698 28 February 2013 (28.02.2013) US

(71) Applicant: **BAKER HUGHES INCORPORATED** [US/US]; P.O. Box 4740, Houston, TX 77210-4740 (US).

(72) Inventors: **NELMS, Derek, L.**; 8802 Headstall Drive, Tomball, TX 77375 (US). **DOSTER, Michael, L.**; 30551 Riverstone Springs Drive, Spring, TX 77386 (US). **DEGEORGE, Jarod**; 3711 Deerbend Court, Spring, TX 77386 (US). **FUSELIER, Danielle, M.**; 3506 Durango Canyon Lane, Spring, TX 77386 (US).

(74) Agents: **WELBORN, Brian S.** et al.; Baker Hughes Incorporated, P.O. Box 4740, Houston, TX 77210-4740 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

[Continued on next page]

(54) Title: CUTTING ELEMENTS INCLUDING NON-PLANAR INTERFACES, EARTH-BORING TOOLS INCLUDING SUCH CUTTING ELEMENTS, AND METHODS OF FORMING CUTTING ELEMENTS

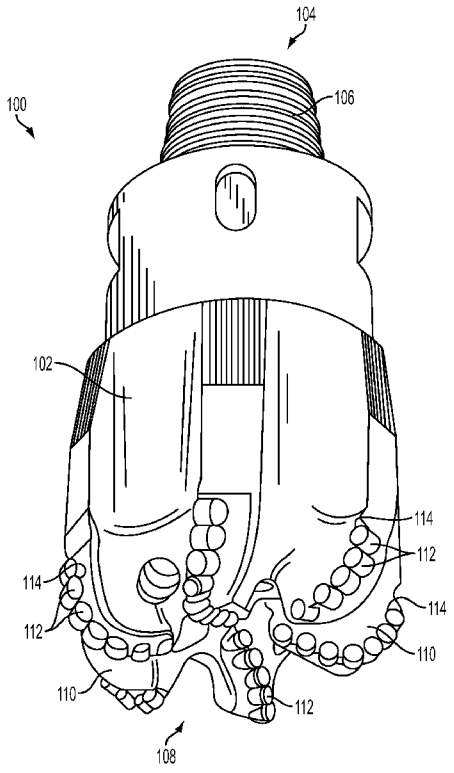


FIG. 1

(57) Abstract: Cutting elements for earth-boring tools may comprise a substrate, a polycrystalline table comprising superhard material secured to the substrate at an end of the substrate, and a non-planar interface defined between the polycrystalline table and the substrate. The non-planar interface may comprise a cross-shaped groove extending into one of the substrate and the polycrystalline table and L-shaped grooves extending into the other of the substrate and the polycrystalline table proximate corners of the cross-shaped groove. Transitions between surfaces defining the non-planar interface may be rounded. Methods of forming cutting elements for earth-boring tools may comprise forming a substrate to have a non-planar end. The non-planar end of the substrate may be provided adjacent particles of superhard material to impart an inverse shape to the particles. The particles may be sintered to form a polycrystalline table, with a non-planar interface defined between the substrate and the polycrystalline table.

WO 2014/134390 A1

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

CUTTING ELEMENTS INCLUDING NON-PLANAR INTERFACES, EARTH-BORING TOOLS INCLUDING SUCH CUTTING ELEMENTS, AND METHODS OF FORMING CUTTING ELEMENTS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. patent application Serial No. 13/780,698, filed February 28, 2013, pending, entitled "Cutting Elements Including Non-Planar Interfaces, Earth-Boring Tools Including Such Cutting Elements, and Methods of Forming Cutting Elements".

FIELD

[0002] The disclosure relates generally to cutting elements for earth-boring tools. More specifically, disclosed embodiments relate to non-planar interfaces between polycrystalline tables and substrates of cutting elements for earth-boring tools that may manage stress in regions of the polycrystalline table and interrupt crack propagation through the polycrystalline table.

BACKGROUND

[0003] Earth-boring tools for forming wellbores in subterranean earth formations may include cutting elements secured to a body. For example, fixed-cutter earth-boring rotary drill bits (also referred to as "drag bits") include cutting elements that are fixedly attached to a bit body of the drill bit. Roller cone earth-boring rotary drill bits may include cones that are mounted on bearing pins extending from legs of a bit body such that each cone is capable of rotating about the bearing pin on which it is mounted. Cutting elements may extend from each cone of the drill bit.

[0004] The cutting elements used in such earth-boring tools often include polycrystalline diamond compact (PDC) cutting elements, also termed "cutters," which are cutting elements including a polycrystalline diamond (PCD) material, which may be characterized as a superabrasive or superhard material. Such polycrystalline diamond materials are formed by sintering and bonding together relatively small synthetic, natural, or a combination of synthetic and natural diamond grains or crystals, termed "grit," under conditions of high temperature and high pressure in the presence of a catalyst, such as, for example, cobalt, iron, nickel, or alloys and mixtures thereof, to form a layer of polycrystalline diamond material,

also called a diamond table. These processes are often referred to as high temperature/high pressure (HTHP) processes. The polycrystalline diamond material may be secured to a substrate, which may comprise a cermet material, *i.e.*, a ceramic-metallic composite material, such as, for example, cobalt-cemented tungsten carbide. In some instances, the polycrystalline diamond table may be formed on the cutting element, for example, during the HTHP sintering process. In such instances, cobalt or other catalyst material in the cutting element substrate may be swept among the diamond grains or crystals during sintering and serve as a catalyst material for forming a diamond table from the diamond grains or crystals. Powdered catalyst material may also be mixed with the diamond grains or crystals prior to sintering the grains or crystals together in an HTHP process. In other methods, however, the diamond table may be formed separately from the cutting element substrate and subsequently attached thereto.

[0005] As the diamond table of the cutting element interacts with the underlying earth formation, for example by shearing or crushing, the diamond table may delaminate, spall, or otherwise fracture because of the high forces acting on the cutting element and resulting high internal stresses within the diamond table of the cutting element. Some cutting elements may include non-planar interfaces, such as, for example, grooves, depressions, indentations, and notches, formed in one of the substrate and the diamond table, with the other of the substrate and the diamond table including corresponding, mating interface features. Illustrative non-planar interface designs are disclosed in, for example, U.S. Patent 6,283,234, issued September 4, 2001, to Torbet, U.S. Patent 6,527,069, issued March 4, 2003, to Meiners et al., U.S. Patent 7,243,745, issued July 17, 2007, to Skeem et al., and U.S. Patent 8,020,642, issued September 20, 2011, to Lancaster et al., the disclosure of each of which is incorporated herein in its entirety by this reference.

BRIEF SUMMARY

[0006] In some embodiments, cutting elements for earth-boring tools may comprise a substrate, a polycrystalline table comprising superhard material secured to the substrate at an end of the substrate, and a non-planar interface defined between the polycrystalline table and the substrate. The non-planar interface may comprise a cross-shaped groove extending into one of the substrate and the polycrystalline table and L-shaped grooves extending into the other of the substrate and the polycrystalline table proximate corners of the cross-shaped groove. Transitions between surfaces defining the non-planar interface may be rounded.

[0007] In other embodiments, earth-boring tools may comprise a body and cutting elements secured to the body. At least one of the cutting elements may comprise a substrate, a polycrystalline table comprising superhard material secured to the substrate at an end of the substrate, and a non-planar interface defined between the polycrystalline table and the substrate. The non-planar interface may comprise a cross-shaped groove extending into one of the substrate and the polycrystalline table and L-shaped grooves extending into the other of the substrate and the polycrystalline table proximate corners of the cross-shaped groove. Transitions between surfaces defining the non-planar interface may be rounded.

[0008] In still other embodiments, methods of forming cutting elements for earth-boring tools may comprise forming a substrate to have a non-planar end. The non-planar end comprises a cross-shaped groove extending into the substrate and L-shaped protrusions extending from a remainder of the substrate proximate corners of the cross-shaped groove. Transitions between surfaces defining the non-planar end are shaped to be rounded. Particles of superhard material are positioned adjacent the non-planar end of the substrate in a container. The particles are sintered in a presence of a catalyst material to form a polycrystalline table secured to the substrate, with a non-planar interface being defined between the substrate and the polycrystalline table.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] While the disclosure concludes with claims particularly pointing out and distinctly claiming embodiments within the scope of the disclosure, various features and advantages of embodiments encompassed by the disclosure may be more readily ascertained from the following description when read in conjunction with the accompanying drawings, in which:

[0010] FIG. 1 is a perspective view of an earth-boring tool;

[0011] FIG. 2 is a perspective partial cross-sectional view of a cutting element of the earth-boring tool of FIG. 1;

[0012] FIG. 3 is a perspective view of a substrate of the cutting element of FIG. 2;

[0013] FIG. 4 is an end view of the substrate of the cutting element of FIG. 2;

[0014] FIG. 5 is a perspective view of another embodiment of a substrate for a cutting element;

[0015] FIG. 6 is an end view of the substrate of FIG. 5;

[0016] FIG. 7 is a perspective view of another embodiment of a substrate for a cutting element;

[0017] FIG. 8 is an end view of the substrate of FIG. 7;

[0018] FIG. 9 is a perspective view of another embodiment of a substrate for a cutting element;

[0019] FIG. 10 is an end view of the substrate of FIG. 9;

[0020] FIG. 11 is a perspective view of another embodiment of a substrate for a cutting element;

[0021] FIG. 12 is an end view of the substrate of FIG. 11;

[0022] FIG. 13 is a perspective view of another embodiment of a substrate for a cutting element;

[0023] FIG. 14 is an end view of the substrate of FIG. 13;

[0024] FIG. 15 is a cross-sectional view of a container in a first stage of a process for forming a cutting element; and

[0025] FIG. 16 is a cross-sectional view of the container of FIG. 15 in a second stage of a process for forming a cutting element.

DETAILED DESCRIPTION

[0026] The illustrations presented herein are not meant to be actual views of any particular earth-boring tool, cutting element, non-planar interface, component thereof, or act in a method of forming such structures, but are merely idealized representations employed to describe illustrative embodiments. Thus, the drawings are not necessarily to scale.

[0027] Disclosed embodiments relate generally to non-planar interfaces between polycrystalline tables and substrates of cutting elements for earth-boring tools that may manage stress in regions of the polycrystalline table and interrupt crack propagation through the polycrystalline table. More specifically, disclosed are embodiments of non-planar interfaces that may strengthen high-stress regions within the polycrystalline table, interrupt crack propagation tending to extend circumferentially around the polycrystalline table, and reduce stress concentrations associated with conventional non-planar interface designs.

[0028] As used herein, the term "earth-boring tool" means and includes any type of bit or tool used for removing earth material during the formation or enlargement of a wellbore in a subterranean formation. For example, earth-boring tools include fixed-cutter bits, rolling cone bits, impregnated bits, percussion bits, core bits, eccentric bits, bicenter bits, mills, reamers, drag bits, hybrid bits, and other drilling bits and tools known in the art.

[0029] As used herein, the terms "polycrystalline table" and "polycrystalline material" mean and include any structure or material comprising grains (*e.g.*, crystals) of a material (*e.g.*, a superabrasive material) that are bonded directly together by inter-granular bonds. The crystal

structures of the individual grains of the material may be randomly oriented in space within the polycrystalline table. For example, polycrystalline tables include polycrystalline diamond compacts (PDCs) characterized by diamond grains that are directly bonded to one another to form a matrix of diamond material with interstitial spaces among the diamond grains.

[0030] As used herein, the terms "inter-granular bond" and "interbonded" mean and include any direct atomic bond (*e.g.*, covalent, metallic, *etc.*) between atoms in adjacent grains of superabrasive material.

[0031] As used herein, the term "superhard" means and includes any material having a Knoop hardness value of about 3,000 Kg_f/mm^2 (29,420 MPa) or more. Superhard materials include, for example, diamond and cubic boron nitride. Superhard materials may also be characterized as "superabrasive" materials.

[0032] As used herein, the phrase "substantially completely removed" when used in connection with removal of catalyst material from a polycrystalline material means and includes removal of all catalyst material accessible by known catalyst removal processes. For example, substantially completely removing catalyst material includes leaching catalyst material from all accessible interstitial spaces of a polycrystalline material by immersing the polycrystalline material in a leaching agent (*e.g.*, *aqua regia*) and permitting the leaching agent to flow through the network of interconnected interstitial spaces until all accessible catalyst material has been removed. Residual catalyst material located in isolated interstitial spaces, which are not connected to the rest of the network of interstitial spaces and are not accessible without damaging or otherwise altering the polycrystalline material, may remain.

[0033] As used herein, the term "L-shaped" means and includes any shape defined by two rays extending from an intersection, wherein an angle defined by the rays is between 80° and 100°. For example, L-shapes include right angles, T-squares, perpendicular rays, and other known L-shapes.

[0034] Referring to FIG. 1, a perspective view of an earth-boring tool 100 is shown. The earth-boring tool 100 may include a body 102. An upper end 104 of the body 102 may include a connector 106 (*e.g.*, an American Petroleum Institute (API) threaded connection) configured to connect the earth-boring tool 100 to other components of a drill string (*e.g.*, drill pipe). A lower end 108 of the body 102, for example, may be configured to engage with an underlying earth formation. For example, the lower end 108 of the body 102 may include blades 110 extending outward from a remainder of the body 102 and extending radially over the lower end 108 of the body 102. Cutting elements 112 may be secured to the blades 110, such as, for example, by brazing the cutting elements 112 within pockets 114 formed in the

blades 110, at rotationally leading faces of the blades 110. The cutting elements 112 and blades 110 may cooperatively define a cutting structure configured to engage with and remove an underlying earth formation.

[0035] Referring to FIG. 2, a perspective partial cross-sectional view of a cutting element 112 of the earth-boring tool 100 of FIG. 1 is shown. The cutting element 112 may include a polycrystalline table 116 of a superhard material configured to directly contact and remove earth material. The polycrystalline table 116 may comprise a generally disk-shaped structure formed from individual grains of superhard material that have interbonded to form a polycrystalline matrix of grains with interstitial spaces located among the grains. The superhard material may comprise, for example, diamond or cubic boron nitride.

[0036] The polycrystalline table 116 may be positioned on an end of a substrate 118 and secured to the substrate 118. The substrate 118 may comprise a hard material suitable for use in earth-boring applications such as, for example, a ceramic-metallic composite material (*i.e.*, a cermet) (*e.g.*, cemented tungsten carbide), and may be formed in a generally cylindrical shape. The polycrystalline table 116 may be secured to the substrate 118 by, for example, a continuous metal material extending into the polycrystalline table 116 and the substrate 118, such as, for example, matrix material of the substrate 118 that has infiltrated among and extends continuously into the interstitial spaces of the polycrystalline table 116. An interface 120 between the polycrystalline table 116 and the substrate 118, defined by their abutting surfaces, may be non-planar. The non-planar interface 120 of the cutting element 112 may be configured to strengthen high-stress regions within the polycrystalline table 116, interrupt crack propagation tending to extend circumferentially around the polycrystalline table 116, and reduce stress concentrations associated with conventional non-planar interface designs.

[0037] Referring collectively to FIGS. 3 and 4, a perspective view and an end view of the substrate 118 of the cutting element 112 of FIG. 2 are shown. An end 122 of the substrate 118 on which the polycrystalline table 116 (see FIG. 2) will be formed or otherwise attached may be non-planar. The non-planar end 122 of the substrate 118 may include a cross-shaped (*e.g.*, cruciform) feature 124, which is depicted as a cross-shaped groove extending into the substrate 118 in the embodiment of FIGS. 3 and 4. In other embodiments, the non-planar end 122 of the substrate 118 may comprise a cross-shaped protrusion extending away from a remainder of the substrate 118. A mating cross-shaped feature, embodied as the other of a groove or a protrusion, may be located on the polycrystalline table 116 (see FIG. 2). A center point 126 of the cross-shaped feature 124 defined at an intersection of perpendicular centerlines 128 of individual radially extending features 130 (*e.g.*, grooves or protrusions)

may be located at a central axis 132 of the substrate 118. The individual radially extending features 130 may extend to the periphery of the substrate 118, such that the planar surface 134 at the periphery is interrupted by the cross-shaped feature 124.

[0038] A depth D of the cross-shaped feature 124, as measured from a planar surface 134 at a periphery of the end 122 of the substrate 118 extending into the substrate 118 or into the polycrystalline table 116 (see FIG. 2), may be, for example, between about 0.25 mm and about 0.50 mm. As a specific, non-limiting example, the depth D of the cross-shaped feature 124 may be about 0.40 mm. The depth D of the cross-shaped feature 124 may be uniform in some embodiments. In other embodiments, the depth D of the cross-shaped feature 124 may not be constant. For example, the depth D of the cross-shaped feature may change (*e.g.*, increase or decrease) as distance from the central axis 132 increases, which change may be constant (*e.g.*, linear) or may vary (*e.g.*, exponentially). A width W_{CSF} of each individual radially extending feature 130 of the cross-shaped feature 124 may be, for example, between about 0.75 mm and about 1.75 mm. As a specific, non-limiting example, the width W_{CSF} of each individual radially extending feature of the cross-shaped feature 124 may be about 1.25 mm. The width W_{CSF} of each individual radially extending feature 130 of the cross-shaped feature 124 may be uniform in some embodiments. In other embodiments, the width W_{CSF} of each individual radially extending feature 130 of the cross-shaped feature 124 may not be constant. For example, width W_{CSF} of each individual radially extending feature 130 of the cross-shaped feature 124 may change (*e.g.*, increase or decrease) as distance from the central axis 132 increases, which change may be constant (*e.g.*, linear) or may vary (*e.g.*, exponentially). In embodiments where the cross-shaped feature 124 comprises a cross-shaped groove extending into the substrate 118, the cross-shaped feature may strengthen the polycrystalline table 116 (see FIG. 2) in regions where the polycrystalline table 116 (see FIG. 2) is particularly susceptible to damage, such as, for example, at and around the central axis 132 of the substrate 118, which may also define a central axis of the cutting element 112 (see FIG. 2) and at the peripheral edge, by thickening the superhard material of the polycrystalline table 116 at those locations. In addition, the cross-shaped feature 124 may act as a conduit to channel stress away from the peripheral edge.

[0039] The non-planar end 122 of the substrate 118 may include L-shaped features 136 located proximate corners of the cross-shaped feature 124 in each quadrant defined by the cross-shaped feature 124, which L-shaped features 136 are depicted as L-shaped protrusions extending away from the remainder of the substrate 118 in the embodiment of FIGS. 3 and 4. In other embodiments, the non-planar end 122 of the substrate 118 may comprise L-shaped

grooves extending into the substrate 118. A mating L-shaped feature, embodied as the other of a groove or a protrusion, may be located on the polycrystalline table 116 (see FIG. 2). Arms 138 of the L-shaped features 136 may not extend to the periphery of the substrate 118 such that a portion of the planar surface 134 at the periphery is uninterrupted by the L-shaped features 136.

[0040] A height H of each L-shaped feature 136, as measured from the planar surface 134 at a periphery of the end 122 of the substrate 118 extending into the substrate 118 or into the polycrystalline table 116 (see FIG. 2), may be greater than the greatest depth D of the cross-shaped feature 124. For example, the height H of each L-shaped feature 136 may be at least about 2 times, at least about 3 times, or even at least about 4 times greater than the greatest depth D of the cross-shaped feature 124. The height H of each L-shaped feature 136 may be, for example, between about 1.50 mm and about 0.50 mm. As a specific, non-limiting example, the height H of each L-shaped feature 136 may be about 1.27 mm.

[0041] A width W_{LSF} of each arm 138 of the L-shaped features 136 may be greater than or equal to the greatest width W_{CSF} of each radially extending feature 130 of the cross-shaped feature 124. For example, the width W_{LSF} of each arm 138 of the L-shaped features 136 may be at least about 1.25 times, at least about 1.5 times, or even at least about 1.75 times greater than the greatest width W_{CSF} of each radially extending feature 130 of the cross-shaped feature 124. The width W_{LSF} of each arm 138 of the L-shaped features 136 may be, for example, between about 1.00 mm and about 3.00 mm. As a specific, non-limiting example, the width W_{LSF} of each arm 138 of the L-shaped features 136 may be about 2.00 mm.

[0042] In embodiments where each L-shaped feature 136 comprises an L-shaped protrusion extending away from the remainder of the substrate 118, the L-shaped feature 136 may strategically weaken regions where the polycrystalline table 116 (see FIG. 2) is not particularly susceptible to damage, such as, for example, in intermediate regions between the periphery and center of the cutting element 112 (see FIG. 2), by thinning the polycrystalline table 116 (see FIG. 2) at those locations. In addition, the L-shaped features 136 may interrupt crack propagation through the polycrystalline table 116 (see FIG. 2) such that the likelihood that cracks propagate to complete an entire circle within the polycrystalline table 116 (see FIG. 2) may be reduced, which may reduce the occurrence of spalling of the polycrystalline table 116 (see FIG. 2).

[0043] Transitions between surfaces defining the non-planar end 122 of the substrate 118 may be rounded. For example, a radius of curvature of each transition between surfaces defining the non-planar end 122 may be about 0.5 times the depth D of the cross-shaped

feature 124 or greater. More specifically, the radius of curvature of each transition between surfaces defining the non-planar end 122 may be at least about 0.75 times the depth D of the cross-shaped feature 124, at least equal to the depth D of the cross-shaped feature 124, or at least 1.25 times the depth D of the cross-shaped feature 124. The radius of curvature of each transition between surfaces defining the non-planar end 122 may be, for example, at least about 0.25 mm. As a specific, non-limiting example, radiuses of curvature of each transition between surfaces defining the non-planar end 122 may be about 0.6 mm. In some embodiments, different transitions between different surfaces defining the non-planar end 122 (*e.g.*, between the planar surface 134 and the L-shaped features 136, and between the L-shaped features 136 and the cross-shaped feature 124, between surfaces of each individual L-shaped feature 136 or of each cross-shaped feature 124) may exhibit different radiuses of curvature. In other embodiments, each transition may have the same radius of curvature. Because the features 124 and 136 described herein are curved, the location at which one feature 124 or 136 ends and another 124 or 136 begins may not be readily visible. Accordingly, the height H, depth D, and widths W_{CSF} and W_{LSF} described previously herein are to be measured from a point where the feature 124 or 136 intersects with the elevation of the planar surface 134. By making all transitions rounded, the non-planar interface 120 (see FIG. 2) may exhibit reduced stress concentrations as compared to conventional non-planar interfaces.

[0044] Referring collectively to FIGS. 5 and 6, a perspective view and an end view of another embodiment of a substrate 118 for a cutting element 112 (see FIG. 2) are shown. The non-planar end 122 of the substrate 118 may include all the features 124 and 136 described previously in connection with FIGS. 3 and 4. In addition, the non-planar end 122 may include a curved feature 140 in each quadrant defined by the L-shaped features 136. For example, the curved feature 140 is depicted as a curved protrusion extending from a remainder of the substrate 118 in the embodiment of FIGS. 5 and 6. In other embodiments, the curved feature 140 may be a curved groove extending into the substrate 118. A mating curved feature, embodied as the other of a groove or a protrusion, may be located on the polycrystalline table 116 (see FIG. 2). The curved feature 140 may extend between the arms 138 of each of the L-shaped features 136, with a center of curvature of each curved feature 140 being located at the central axis 132 of the substrate 118, which may also define the central axis of the cutting element 112 (see FIG. 2). None of the curved features 140 may intersect with the arms 138 of the L-shaped features 136, such that a portion of the planar surface 134 may be interposed between each curved feature 140 and adjacent arms 138 of the L-shaped features 136.

Radially outermost portions of each curved feature 140 may be located at the same radial position of, or radially closer to the central axis 132 than, radially outermost portions of the L-shaped features 136. For example, a circle defined by connecting radially outermost points of the arms 138 of each L-shaped feature 136 may also define an outermost extent of each curved feature 140.

[0045] A width W_{CF} of each curved feature 140 may be less than or equal to the greatest width W_{CSF} of the radially extending features 130 of the cross-shaped feature 124. For example, the width W_{CF} of each curved feature 136 may be about 1.0 time or less, about 0.75 times or less, or about 0.5 times or less than the greatest width W_{CSF} of the radially extending features 130 of the cross-shaped feature 124. The width W_{CF} of each curved feature 140 may be, for example, between about 1.25 mm and about 0.50 mm. As a specific, non-limiting example, the width W_{CF} of each curved feature 136 may be about 0.75 mm. A height H_{CF} of each curved feature 140, as measured from the planar surface 134 at the periphery of the end 122 of the substrate 118 extending into the substrate 118 or into the polycrystalline table 116 (see FIG. 2), may be less than or equal to the height H of each L-shaped feature 136. For example, the height H_{CF} of each curved feature 140 may be about 1.0 time or less, about 0.75 times or less, or about 0.50 times or less than the height H of each L-shaped feature 136. The height H_{CF} of each curved feature 140 may be, for example, between about 1.25 mm and about 0.50 mm. As a specific, non-limiting example, the height H_{CF} of each curved feature 140 may be about 1.00 mm. The curved features 140 may interrupt crack propagation within the polycrystalline table 116 (see FIG. 2) and strategically weaken the polycrystalline table 116 (see FIG. 2) to channel stress away from critical regions of the polycrystalline table 116 (see FIG. 2), such as, for example, the peripheral edge.

[0046] Referring collectively to FIGS. 7 and 8, a perspective view and an end view of another embodiment of a substrate 118 for a cutting element 112 (see FIG. 2) are shown. The non-planar end 122 of the substrate 118 may include all the features 124, 136, and 140 described previously in connection with FIGS. 5 and 6. In addition, the non-planar end 122 may include a trench 142 formed in each curved feature 140. For example, the trench 142 is depicted as a extending into the substrate 118 in the embodiment of FIGS. 5 and 6. In other embodiments, the trench 142 extend away from the substrate 118. A mating trench, embodied as the other of a extending away from or into the polycrystalline table 116 (see FIG. 2), may be located on the polycrystalline table 116 (see FIG. 2). Each trench 142 may extend for an entire length of each curved feature 140, with each trench 142 following the curve of an associated curved feature 140. For example, a center of curvature of each trench 142 may be

located at the central axis 132 of the substrate 118, which may also define the central axis of the cutting element 112 (see FIG. 2). Each trench 142 may be centrally located on its associated curved feature 140, such that the curved feature 140 extends radially an equal distance from each of the radially innermost and radially outermost portion of the trench 142.

[0047] A width W_T of each trench 142 may be less than the width W_{CF} of its associated curved feature 140. For example, the width W_T of each trench 142 may be about 0.5 times or less, about 0.25 times or less, or about 0.125 times or less than the width W_{CF} of its associated curved feature 140. The width W_T of each trench 142 may be, for example, between about 0.75 mm and about 0.12 mm. As a specific, non-limiting example, the width W_T of each trench 142 may be about 0.25 mm. A depth D_T of each trench 142, as measured from an uppermost point on its associated curved feature 140 extending into or away from the curved feature 140, may be less than or equal to the height H_{CF} of the associated curved feature 140. For example, the depth D_T of each trench 142 may be about 0.75 times or less, or about 0.50 times or less, or about 0.25 times or less than the height H_{CF} of each associated curved feature 140. The depth D_T of each curved feature 140 may be, for example, between about 0.75 mm and about 0.25 mm. As a specific, non-limiting example, the depth D_T of each trench 142 may be about 0.50 mm. The trenches 142 may interrupt crack propagation within the polycrystalline table 116 (see FIG. 2) and channel stress away from critical regions of the polycrystalline table 116 (see FIG. 2), such as, for example, the peripheral edge.

[0048] Referring collectively to FIGS. 9 and 10, a perspective view and an end view of another embodiment of a substrate 118 for a cutting element 112 are shown. The non-planar end 122 of the substrate 118 may include all the features 124 and 136 described previously in connection with FIGS. 3 and 4. In addition, the non-planar end 122 may include a tapered surface 144 in an area between the arms 138 of each of the L-shaped features 136, extending from an intersect point 146 of each of the L-shaped features toward the one of the substrate 118 and the polycrystalline table 116 (see FIG. 2). For example, the tapered surface 144 is depicted as extending from an intersect point 146 positioned at the radially outermost location of intersection of the two arms 138 at maximum height H above the planar surface 134 toward the remainder of the substrate 118. In other embodiments, the tapered surface 114 may extend toward the polycrystalline table 116 and may extend from an intersect point defined by other features of the arms 138 (*e.g.*, centerlines, radially innermost portion at maximum height H, midway to maximum height H, *etc.*). The tapered surface 144 may intersect with the arms 138 of the L-shaped features 136 along their length, such that no portion of the planar surface 134 is interposed between each tapered surface 144 and adjacent

arms 138 of the L-shaped features 136 and the gradual taper of the tapered surface 144 is visible as compared to a more abrupt transition to the maximum height H of each L-shaped feature 136. Radially outermost portions of each tapered surface may be located at the same radial position of, or radially closer to the central axis 132 than, radially outermost portions of the L-shaped features 136. For example, a circle defined by connecting radially outermost points of the arms 138 of each L-shaped feature 136 may also define an outermost extent of each tapered surface 144.

[0049] A slope of each tapered surface 144 may be less than or equal to the height H of each L-shaped feature 136 divided by the length of an arm 138 of each L-shaped feature. For example, the slope of each tapered surface 144 may be less than or equal to the height H of each L-shaped feature 136 divided by the length of an arm 138 as measured from a radially outermost point of the arm 138 at an elevation of the planar surface 134 to a radially innermost point of the arm 138 at the elevation of the planar surface 134. The slope of each tapered surface 144 may be, for example, between about 0.50 and about 0.10. As a specific, non-limiting example, the slope of each tapered surface 144 may be about 0.30. The sloped surfaces 144 may strategically weaken the polycrystalline table 116 (see FIG. 2) to channel stress away from critical regions of the polycrystalline table 116 (see FIG. 2), such as, for example, the peripheral edge.

[0050] Referring collectively to FIGS. 11 and 12, a perspective view and an end view of another embodiment of a substrate 118 for a cutting element 112 are shown. The non-planar end 122 of the substrate 118 may include all the features 124, 136, and 144 described previously in connection with FIGS. 9 and 10. In addition, the non-planar end 122 may include a pear-shaped feature 148 in each quadrant defined by the L-shaped features 136. For example, the pear-shaped feature 148 is depicted as a pear-shaped protrusion extending from the tapered surface 144 in the embodiment of FIGS. 11 and 12. In other embodiments, the curved feature 140 may be a pear-shaped depression extending into the tapered surface 144. A mating pear-shaped feature, embodied as the other of a depression or a protrusion, may be located on the polycrystalline table 116 (see FIG. 2). An axis of symmetry 150 of each pear-shaped feature 148 may bisect an angle θ defined between the arms 138 of each of the L-shaped features 136. Radially outermost portions of each pear-shaped feature 148 may be located radially closer to the central axis 132 than radially outermost portions of the tapered surface 144. For example, the distance between a radially innermost portion of each pear-shaped feature 148 and the intersect point 146 described previously in connection with FIGS.

9 and 10 may be equal to the shortest distance between a radially outermost portion of each pear-shaped feature 148 and the radially outermost portion of the tapered surface 144.

[0051] A greatest width W_{PSF} of each pear-shaped feature 148 taken in a direction perpendicular to the axis of symmetry 150 of a respective pear-shaped feature 148 may be less than or equal to the greatest width W_{CSF} of the radially extending features 130 of the cross-shaped feature 124. For example, the greatest width W_{PSF} of each pear-shaped feature 148 may be about 1.0 time or less, about 0.75 times or less, or about 0.5 times or less than the greatest width W_{CSF} of the radially extending features 130 of the cross-shaped feature 124. The greatest width W_{PSF} of each pear-shaped feature 148 may be, for example, between about 1.25 mm and about 0.50 mm. As a specific, non-limiting example, the greatest width W_{PSF} of each pear-shaped feature 148 may be about 0.75 mm. A length L_{CF} of each pear-shaped feature 148 taken in a direction parallel to the axis of symmetry 150 of a respective pear-shaped feature 148 may be greater than or equal to the greatest width W_{PSF} of the pear-shaped feature 148. For example, the length L_{PSF} of each pear-shaped feature 148 may be about 1.0 time or greater, about 1.1 times or greater, or about 1.25 times or greater than the greatest width W_{PSF} of the pear-shaped feature 148. The length L_{PSF} of each pear-shaped feature 148 may be, for example, between about 1.50 mm and about 0.50 mm. As a specific, non-limiting example, the length L_{PSF} of each pear-shaped feature 148 may be about 1.00 mm. A height H_{PSF} of each pear-shaped feature 148, as measured from the planar surface 134 at the periphery of the end 122 of the substrate 118 extending into the substrate 118 or into the polycrystalline table 116 (see FIG. 2), may be less than or equal to the height H of each L-shaped feature 136. For example, the height H_{PSF} of each pear-shaped feature 148 may be about 1.0 time or less, about 0.75 times or less, or about 0.50 times or less than the height H of each L-shaped feature 136. The height H_{PSF} of each curved feature 148 may be, for example, between about 1.25 mm and about 0.50 mm. As a specific, non-limiting example, the height H_{PSF} of each curved feature 148 may be about 1.00 mm. The pear-shaped features 148 may interrupt crack propagation within the polycrystalline table 116 (see FIG. 2) and strategically weaken the polycrystalline table 116 (see FIG. 2) to channel stress away from critical regions of the polycrystalline table 116 (see FIG. 2), such as, for example, the peripheral edge.

[0052] Referring collectively to FIGS. 13 and 14, a perspective view and an end view of another embodiment of a substrate 118 for a cutting element 112 are shown. The non-planar end 122 of the substrate 118 may include all the features 124, 136, and 144 described previously in connection with FIGS. 9 and 10. In addition, the non-planar end 122 may

include concentric arcs 152 in each quadrant defined by the L-shaped features 136. For example, the concentric arcs 152 are depicted as concentric arc-shaped protrusions extending from the tapered surface 144 in the embodiment of FIGS. 13 and 14. In other embodiments, the concentric arcs 152 may be a concentric arc-shaped grooves extending into the tapered surface 144. Mating concentric arcs, embodied as the other of a groove or a protrusion, may be located on the polycrystalline table 116 (see FIG. 2). The concentric arcs 152 may extend between the arms 138 of each of the L-shaped features 136, with a center of curvature of each concentric arc 152 being located at the central axis 132 of the substrate 118, which may also define the central axis of the cutting element 112 (see FIG. 2). None of the concentric arcs 152 may intersect with the arms 138 of the L-shaped features 136, such that a portion of the tapered surface 144 may be interposed between each concentric arc 152 and adjacent arms 138 of the L-shaped features 136. Radially outermost portions of radially outermost concentric arcs 152 may be located radially closer to the central axis 132 than radially outermost portions of the L-shaped features 136. For example, a circle defined by connecting radially outermost points of the arms 138 of each L-shaped feature 136 may be located radially outward from the radially outermost portions of radially outermost concentric arcs 152.

[0053] A width W_{CA} of each concentric arc 152 may be less than the greatest width W_{CSF} of the radially extending features 130 of the cross-shaped feature 124. For example, the width W_{CA} of each concentric arc 152 may be about 0.50 times or less, about 0.25 times or less, or about 0.125 times or less than the greatest width W_{CSF} of the radially extending features 130 of the cross-shaped feature 124. The width W_{CA} of each concentric arc may be, for example, between about 0.75 mm and about 0.10 mm. As a specific, non-limiting example, the width W_{CA} of each concentric arc 152 may be about 0.25 mm. A height H_{CA} of each concentric arc 152, as measured from the tapered surface 144 extending into the substrate 118 or into the polycrystalline table 116 (see FIG. 2) may be sufficiently small that the concentric arcs 152 do not extend above any L-shaped feature 136. For example, the height H_{CA} of each concentric arc 152 may be between about 0.50 mm and about 0.10 mm. As a specific, non-limiting example, the height H_{CA} of each concentric arc 152 may be about 0.25 mm. A distance D between adjacent concentric arcs 152 may be greater than or equal to the height H_{CA} of each concentric arc 152. For example, the distance D between adjacent concentric arcs 152 may be 1.0 times or greater, 1.25 times or greater, or 1.5 times or greater than the height HCA of each concentric arc 152. The distance D between adjacent concentric arcs 152 may be, for example, between about 0.75 mm and about 0.25 mm. as a specific, non-limiting

example, the distance D between adjacent concentric arcs 152 may be about 0.50 mm. A number of arcs may be between about three and about six. For example, the number of arcs may be about four. The concentric arcs 152 may interrupt crack propagation within the polycrystalline table 116 (see FIG. 2) and strategically weaken the polycrystalline table 116 (see FIG. 2) to channel stress away from critical regions of the polycrystalline table 116 (see FIG. 2), such as, for example, the peripheral edge.

[0054] In some embodiments, the polycrystalline table 116 (see FIG. 2) may be formed by subjecting particles of superhard material to a high temperature/high pressure (HTHP) process, sintering the particles to one another to form the polycrystalline material of the polycrystalline table 116 (see FIG. 2). Such a process may be performed by placing a container in which the particles are located into a press and subjecting the particles to the HTHP process. The HTHP process may also be used to attach the polycrystalline table 116 to a substrate 112 to form a cutting element 112 (see FIG. 2). For example, a cross-sectional view of such a container 154 for forming a cutting element 112 (see FIG. 2) is shown in FIG. 15 in a first stage of a process for forming the cutting element 112 (see FIG. 2). The container 154 may include one or more generally cup-shaped members, such as cup-shaped member 156c, which may act as a receptacle. Particles 158 may be placed in the cup-shaped member 156c, which may have a circular end wall and a generally cylindrical lateral side wall extending perpendicularly from the circular end wall, such that the cup-shaped member 134c is generally cylindrical and includes a first closed end and a second, opposite open end. The particles 158 may include a superhard material in the form of, for example, powdered diamond (*e.g.*, natural, synthetic, or natural and synthetic diamond) or powdered cubic boron nitride, which may optionally be mixed with a liquid (*e.g.*, alcohol) to form a slurry (*e.g.*, a paste). The particles 158 may include a catalyst material (*e.g.*, iron, nickel, or cobalt) selected to catalyze formation of inter-granular bonds between individual particles of the superhard material in some embodiments. The particles 158 may exhibit a monomodal or multimodal (*e.g.*, bimodal, trimodal, *etc.*) particle size distribution.

[0055] Referring to FIG. 16, a cross-sectional view of the container 154′ of FIG. 15 is shown in a second stage of a process for forming a cutting element 112 (see FIG. 2). The container 154′ may include the cup-shaped member 156c and two additional cup-shaped members 156a and 156b, which may be assembled and swaged and/or welded together to form the container 154′. A substrate 118 having a non-planar end 122, such as, for example, any of those shown in FIGS. 3 through 14, may be placed in the container 154′ with the non-planar end 122 facing the particles 158. In some embodiments, the substrate 118 may be in a green state (*i.e.*,

an unsintered state with less than a final density) with hard particles (*e.g.*, tungsten carbide) held in place by a binder material (*e.g.*, wax). In other embodiments, the substrate may be in a brown state (*i.e.*, a sintered state still with less than a final density) with hard particles bound in a matrix material (*e.g.*, a solvent metal catalyst). In still other embodiments, the substrate 118 may be a fully sintered part (*e.g.*, cemented tungsten carbide at a final density). The non-planar end 122 may be pressed against the particles 158 to impart a shape inverse to the shape of the non-planar end 122 to the particles 158. In other embodiments, the substrate 118 may be placed in the container 154' before the particles 158, and the particles 158 may simply conform to the shape of the non-planar end 122 when they are placed adjacent the non-planar end 122 within the container 154'. Assembly of the container 154' may be completed, and the substrate 118 and particles 158 may be subjected to a high temperature/high pressure (HTHP) process to cause the particles 158 to interbond with one another in the presence of catalyst material (*e.g.*, melted to flow among the rest of the particles 158 or swept among the particles 158 from within the substrate 118) to form the polycrystalline table 116 and to secure the polycrystalline table 116 to the substrate 118 at the non-planar interface 120. In embodiments where the substrate 118 has less than a final density, the HTHP process may also sinter the substrate 118 to a final density. Conventional HTHP processing may be used to form the cutting element 112 (see FIG. 2).

[0056] Additional, non-limiting embodiments within the scope of the present disclosure include, but are not limited to, the following:

[0057] Embodiment 1: A cutting element for an earth-boring tool comprises a substrate, a polycrystalline table comprising superhard material secured to the substrate at an end of the substrate, and a non-planar interface defined between the polycrystalline table and the substrate. The non-planar interface comprises a cross-shaped groove extending into one of the substrate and the polycrystalline table and L-shaped grooves extending into the other of the substrate and the polycrystalline table proximate corners of the cross-shaped groove. Transitions between surfaces defining the non-planar interface are rounded.

[0058] Embodiment 2: The cutting element of Embodiment 1, further comprising a tapered surface in an area between arms of each of the L-shaped grooves, the tapered surface extending from an intersect point of each of the L-shaped grooves toward the one of the substrate and the polycrystalline table.

[0059] Embodiment 3: The cutting element of Embodiment 2, further comprising concentric grooves extending from each tapered surface into the other of the substrate and the polycrystalline table, wherein the concentric grooves do not intersect with the arms of the L-

shaped grooves and a center of curvature of each of the concentric grooves is located at a central axis of the cutting element.

[0060] Embodiment 4: The cutting element of Embodiment 2, further comprising a pear-shaped depression extending from each tapered surface into the other of the substrate and the polycrystalline table, wherein an axis of symmetry of the pear-shaped depression bisects an angle defined between the arms of each of the L-shaped grooves.

[0061] Embodiment 5: The cutting element of Embodiment 4, wherein a depth of each pear-shaped depression is less than a depth of each of the L-shaped grooves.

[0062] Embodiment 6: The cutting element of Embodiment 1, further comprising a curved groove extending between arms of each of the L-shaped grooves into the other of the substrate and the polycrystalline table, wherein a center of curvature of each curved groove is located at a central axis of the cutting element and wherein the curved grooves do not intersect with the arms of the L-shaped grooves.

[0063] Embodiment 7: The cutting element of Embodiment 6, wherein a circle defined by connecting outermost points of the arms of the L-shaped grooves also defines an outermost extent of the curved grooves.

[0064] Embodiment 8: The cutting element of Embodiment 6 or Embodiment 7, further comprising a trench formed in each curved groove extending into the one of the substrate and the polycrystalline table, wherein the trench follows the curve of each curved groove.

[0065] Embodiment 9: The cutting element of any one of Embodiments 1 through 8, wherein a depth of the cross-shaped groove is less than a depth of each of the L-shaped grooves.

[0066] Embodiment 10: The cutting element of any one of Embodiments 1 through 9, wherein the transitions between the surfaces defining the non-planar interface have a radius of curvature of at least 0.25 mm.

[0067] Embodiment 11: An earth-boring tool comprises a body and cutting elements secured to the body. At least one of the cutting elements comprises a substrate, a polycrystalline table comprising superhard material secured to the substrate at an end of the substrate, and a non-planar interface defined between the polycrystalline table and the substrate. The non-planar interface comprises a cross-shaped groove extending into one of the substrate and the polycrystalline table and L-shaped grooves extending into the other of the substrate and the polycrystalline table proximate corners of the cross-shaped groove. Transitions between surfaces defining the non-planar interface are rounded.

[0068] Embodiment 12: A method of forming a cutting element for an earth-boring tool comprises forming a substrate to have a non-planar end. The non-planar end comprises a

cross-shaped groove extending into the substrate and L-shaped protrusions extending from a remainder of the substrate proximate corners of the cross-shaped groove. Transitions between surfaces defining the non-planar end are shaped to be rounded. Particles of superhard material are positioned adjacent the non-planar end of the substrate in a container. The particles are sintered in a presence of a catalyst material to form a polycrystalline table secured to the substrate, with a non-planar interface being defined between the substrate and the polycrystalline table.

[0069] Embodiment 13: The method of Embodiment 12, further comprising forming the non-planar end to comprise a tapered surface in an area between arms of each of the L-shaped grooves, the tapered surface extending from an intersect point of each of the L-shaped grooves toward the remainder of the substrate.

[0070] Embodiment 14: The method of Embodiment 13, further comprising forming the non-planar end to comprise concentric protrusions extending from each tapered surface away from the remainder of the substrate, wherein the concentric protrusions do not intersect with the arms of the L-shaped protrusions and a center of curvature of each of the concentric protrusions is located at a central axis of the substrate.

[0071] Embodiment 15: The method of Embodiment 13, further comprising forming the non-planar end to comprise a pear-shaped protrusion extending from each tapered surface away from the remainder of the substrate, wherein an axis of symmetry of the pear-shaped protrusion bisects an angle defined between the arms of each of the L-shaped protrusions.

[0072] Embodiment 16: The method of Embodiment 12, further comprising forming the non-planar end to comprise a curved protrusion extending between arms of each of the L-shaped protrusions into the substrate, wherein a center of curvature of each curved protrusion is located at a central axis of the substrate and wherein the curved protrusions do not intersect with the arms of the L-shaped protrusions.

[0073] Embodiment 17: The method of Embodiment 16, wherein forming the non-planar end to comprise the curved protrusion extending between the arms of each of the L-shaped protrusions comprises forming an outermost extent of each curved protrusion to coincide with a circle defined by connecting outermost points of the arms of the L-shaped protrusions.

[0074] Embodiment 18: The method of Embodiment 16 or Embodiment 17, further comprising forming the non-planar end to comprise a trench extending toward the substrate formed in each curved protrusion, wherein the trench follows the curve of each curved protrusion.

[0075] Embodiment 19: The method of any one of Embodiments 12 through 18, further comprising forming a depth of the cross-shaped groove to be less than a height of each of the L-shaped protrusions.

[0076] Embodiment 20: The cutting element of any one of Embodiments 12 through 18, further comprising pressing the non-planar end of the substrate against the particles to impart an inverse shape of the non-planar end to the particles.

[0077] While certain illustrative embodiments have been described in connection with the figures, those of ordinary skill in the art will recognize and appreciate that the scope of the disclosure is not limited to those embodiments explicitly shown and described herein. Rather, many additions, deletions, and modifications to the embodiments described herein may be made to produce embodiments within the scope of the disclosure, such as those hereinafter claimed, including legal equivalents. In addition, features from one disclosed embodiment may be combined with features of another disclosed embodiment while still being within the scope of the disclosure, as contemplated by the inventors.

CLAIMS

What is claimed is:

1. A cutting element for an earth-boring tool, comprising:

a substrate;

a polycrystalline table comprising superhard material secured to the substrate at an end of the substrate; and

a non-planar interface defined between the polycrystalline table and the substrate, the non-planar interface comprising a cross-shaped groove extending into one of the substrate and the polycrystalline table and L-shaped grooves extending into the other of the substrate and the polycrystalline table proximate corners of the cross-shaped groove, wherein transitions between surfaces defining the non-planar interface are rounded.

2. The cutting element of claim 1, further comprising a tapered surface in an area between arms of each of the L-shaped grooves, the tapered surface extending from an intersect point of each of the L-shaped grooves toward the one of the substrate and the polycrystalline table.

3. The cutting element of claim 2, further comprising concentric grooves extending from each tapered surface into the other of the substrate and the polycrystalline table, wherein the concentric grooves do not intersect with the arms of the L-shaped grooves and a center of curvature of each of the concentric grooves is located at a central axis of the cutting element.

4. The cutting element of claim 2, further comprising a pear-shaped depression extending from each tapered surface into the other of the substrate and the polycrystalline table, wherein an axis of symmetry of the pear-shaped depression bisects an angle defined between the arms of each of the L-shaped grooves.

5. The cutting element of claim 4, wherein a depth of each pear-shaped depression is less than a depth of each of the L-shaped grooves.

6. The cutting element of claim 1, further comprising a curved groove extending between arms of each of the L-shaped grooves into the other of the substrate and the polycrystalline table, wherein a center of curvature of each curved groove is located at a central axis of the cutting element and wherein the curved grooves do not intersect with the arms of the L-shaped grooves.

7. The cutting element of claim 6, wherein a circle defined by connecting outermost points of the arms of the L-shaped grooves also defines an outermost extent of the curved grooves.

8. The cutting element of claim 6, further comprising a trench formed in each curved groove extending into the one of the substrate and the polycrystalline table, wherein the trench follows the curve of each curved groove.

9. The cutting element of claim 1, wherein a greatest depth of the cross-shaped groove is less than a depth of each of the L-shaped grooves.

10. The cutting element of claim 1, wherein the transitions between the surfaces defining the non-planar interface have a radius of curvature of at least 0.25 mm.

11. An earth-boring tool, comprising:

a body; and

cutting elements secured to the body, at least one of the cutting elements comprising:

a substrate;

a polycrystalline table comprising superhard material secured to the substrate at an end of the substrate; and

a non-planar interface defined between the polycrystalline table and the substrate, the non-planar interface comprising a cross-shaped groove extending into one of the substrate and the polycrystalline table and L-shaped grooves extending into the other of the substrate and the polycrystalline table proximate corners of the cross-shaped groove, wherein transitions between surfaces defining the non-planar interface are rounded.

12. A method of forming a cutting element for an earth-boring tool, comprising:

forming a substrate to have a non-planar end, the non-planar end comprising a cross-shaped groove extending into the substrate and L-shaped protrusions extending from a remainder of the substrate proximate corners of the cross-shaped groove;

shaping transitions between surfaces defining the non-planar end to be rounded;

positioning particles of superhard material adjacent the non-planar end of the substrate in a container; and

sintering the particles in a presence of a catalyst material to form a polycrystalline table secured to the substrate, with a non-planar interface being defined between the substrate and the polycrystalline table.

13. The method of claim 12, further comprising forming the non-planar end to comprise a tapered surface in an area between arms of each of the L-shaped grooves, the tapered surface extending from an intersect point of each of the L-shaped grooves toward the remainder of the substrate.

14. The method of claim 13, further comprising forming the non-planar end to comprise concentric protrusions extending from each tapered surface away from the remainder of the substrate, wherein the concentric protrusions do not intersect with the arms of the L-shaped protrusions and a center of curvature of each of the concentric protrusions is located at a central axis of the substrate.

15. The method of claim 13, further comprising forming the non-planar end to comprise a pear-shaped protrusion extending from each tapered surface away from the remainder of the substrate, wherein an axis of symmetry of the pear-shaped protrusion bisects an angle defined between the arms of each of the L-shaped protrusions.

16. The method of claim 12, further comprising forming the non-planar end to comprise a curved protrusion extending between arms of each of the L-shaped protrusions into the substrate, wherein a center of curvature of each curved protrusion is located at a central axis of the substrate and wherein the curved protrusions do not intersect with the arms of the L-shaped protrusions.

17. The method of claim 16, wherein forming the non-planar end to comprise the curved protrusion extending between the arms of each of the L-shaped protrusions comprises forming an outermost extent of each curved protrusion to coincide with a circle defined by connecting outermost points of the arms of the L-shaped protrusions.

18. The method of claim 16, further comprising forming the non-planar end to comprise a trench extending toward the substrate formed in each curved protrusion, wherein the trench follows the curve of each curved protrusion.

19. The method of claim 12, further comprising forming a greatest depth of the cross-shaped groove to be less than a height of each of the L-shaped protrusions.

20. The cutting element of claim 12, further comprising pressing the non-planar end of the substrate against the particles to impart an inverse shape of the non-planar end to the particles.

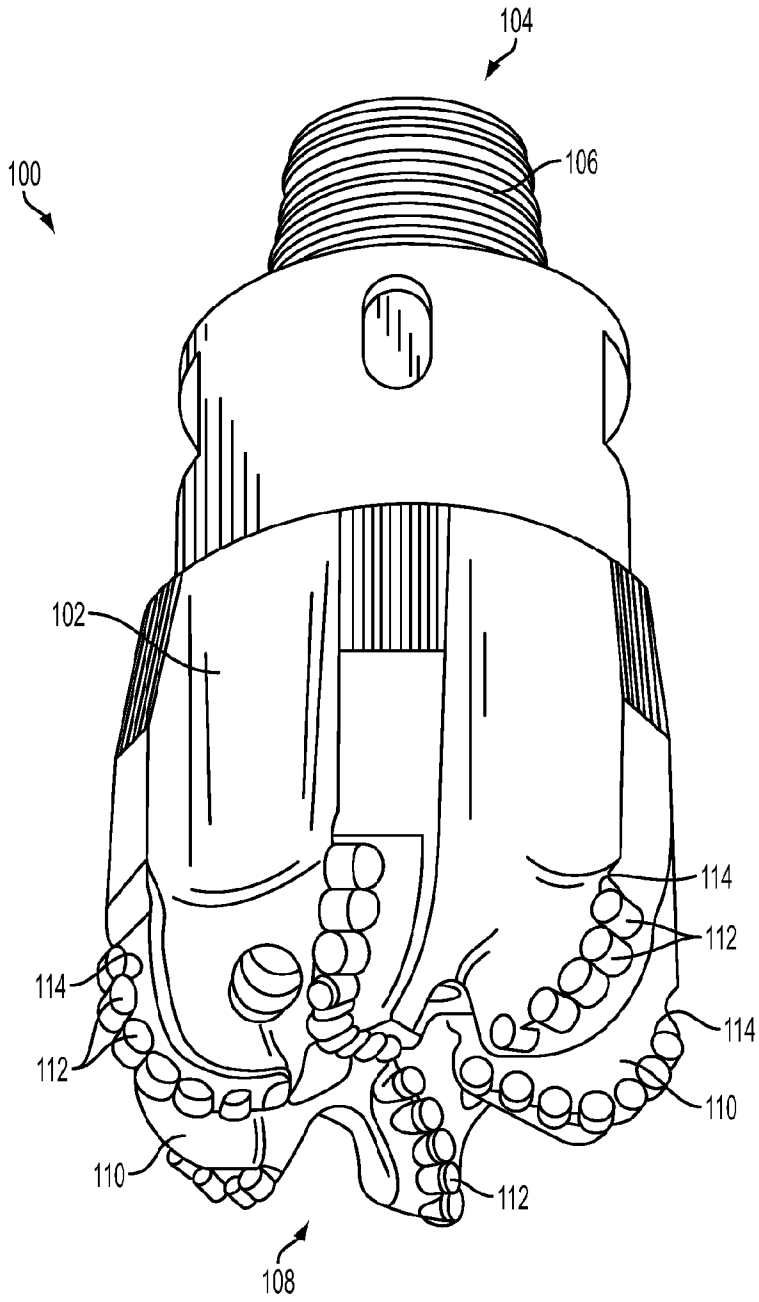


FIG. 1

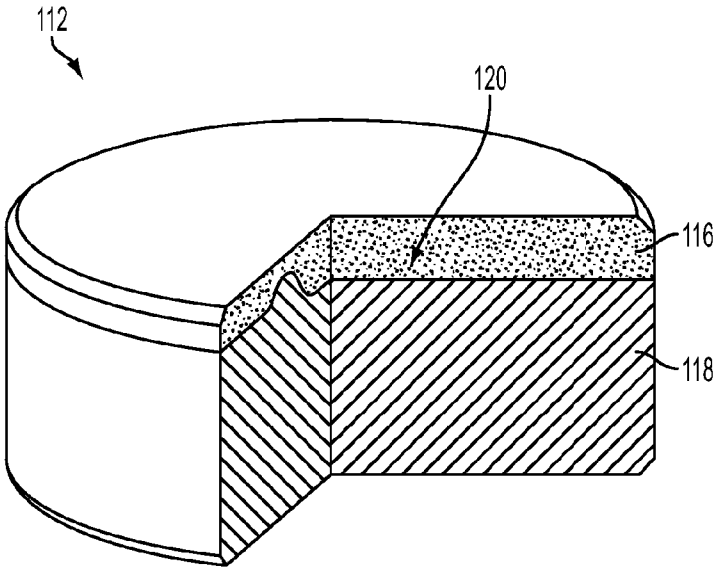


FIG. 2

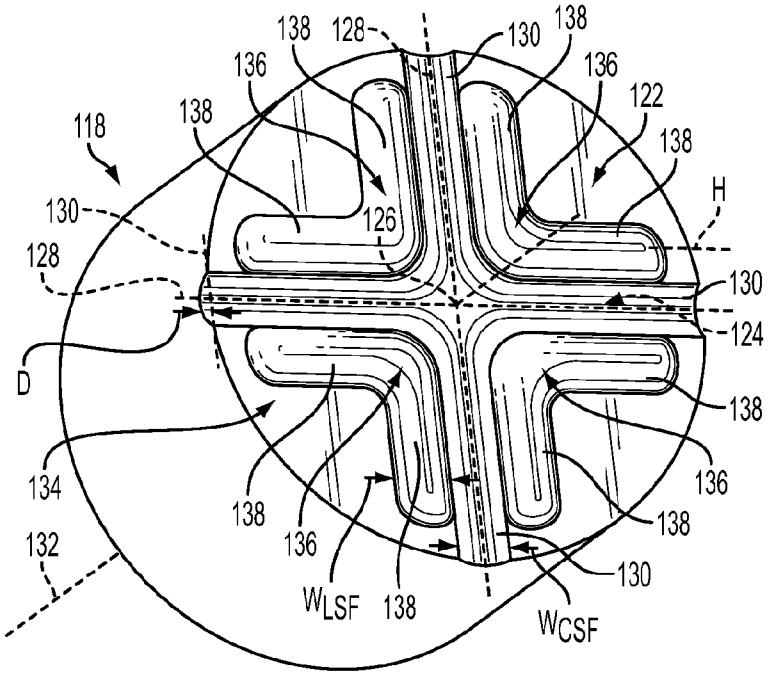

138
128
130
138
136
136
122
118
138
138
H
130
126
128
130
124
D
138
134
136
138
136
138
132
136
130
W_{LSF}
138
W_{CSF}

FIG. 3

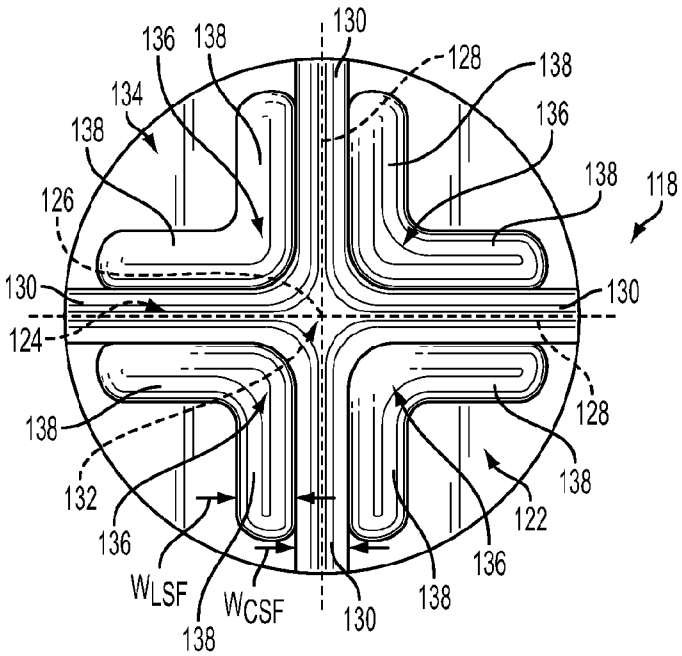

130
136
138
128
138
134
136
138
138
118
126
130
130
124
128
138
132
138
122
136
136
W_{LSF}
W_{CSF}
130
138
138

FIG. 4

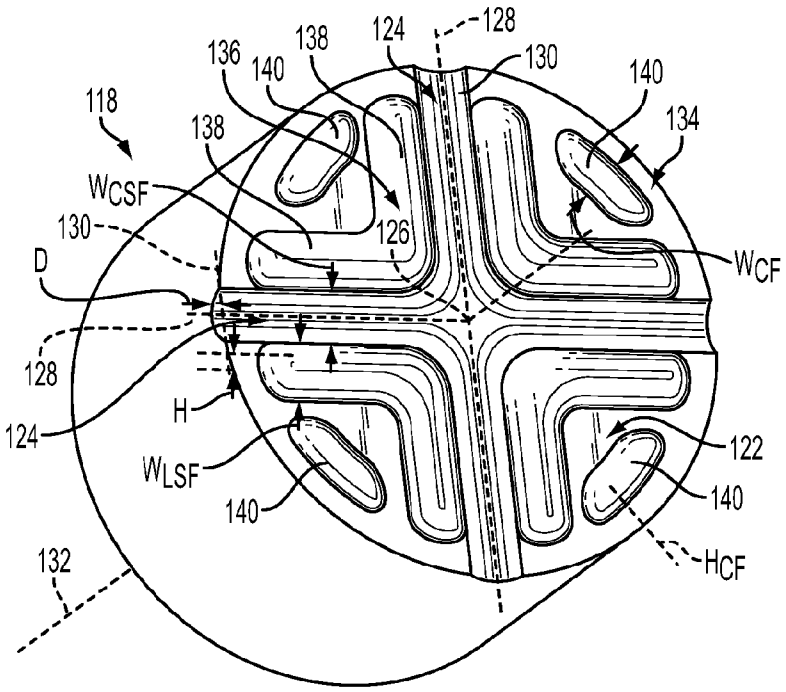

128
124
138
136
140
130
140
118
138
134
W_{CSF}
126
130
W_{CF}
D
128
H
124
122
W_{LSF}
140
140
132
H_{CF}

FIG. 5

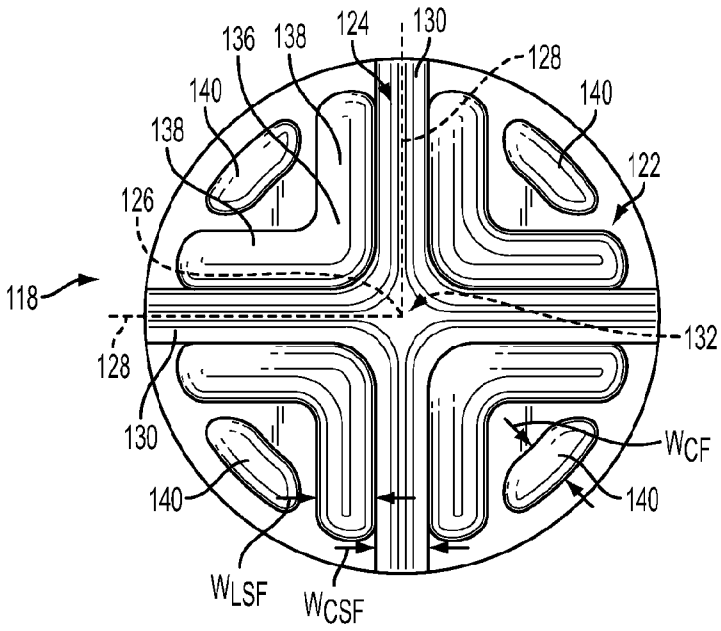

136
138
124
130
128
140
140
138
122
126
118
132
128
130
W_{CF}
140
140
W_{LSF}
W_{CSF}

FIG. 6

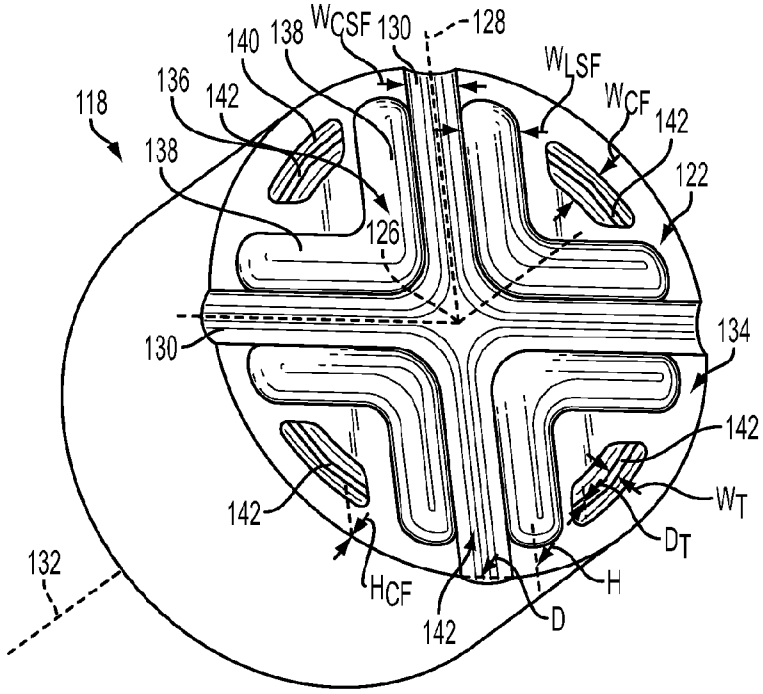

140
138
W_{CSF}
130
128
W_{LSF}
W_{CF}
142
136
142
118
138
126
122
130
134
142
142
W_T
D_T
132
H_{CF}
H
142
D

FIG. 7

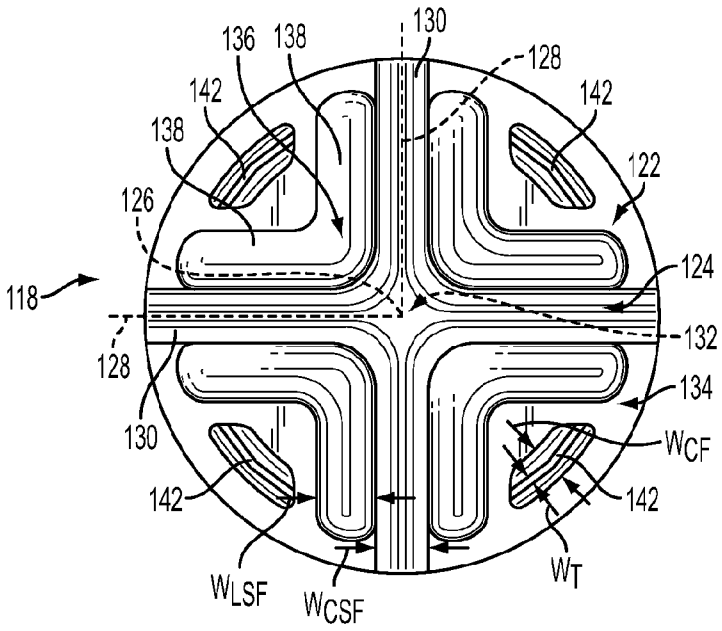

136
138
130
128
142
142
138
122
126
124
118
132
128
134
130
W_{CF}
142
142
W_T
W_{LSF}
W_{CSF}

FIG. 8

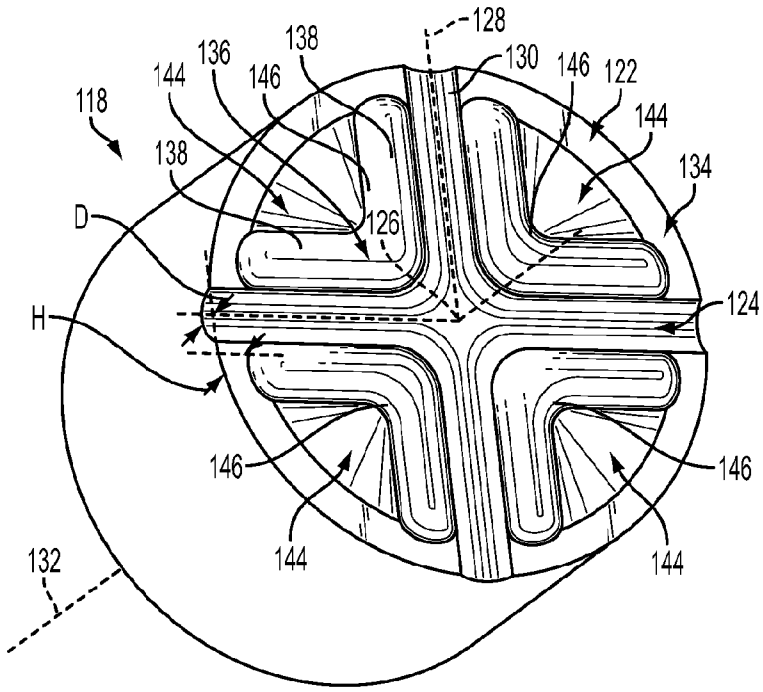

128
130
146
122
144
134
124
146
144
132
118
138
136
144
146
138
D
H
126
146
144

FIG. 9

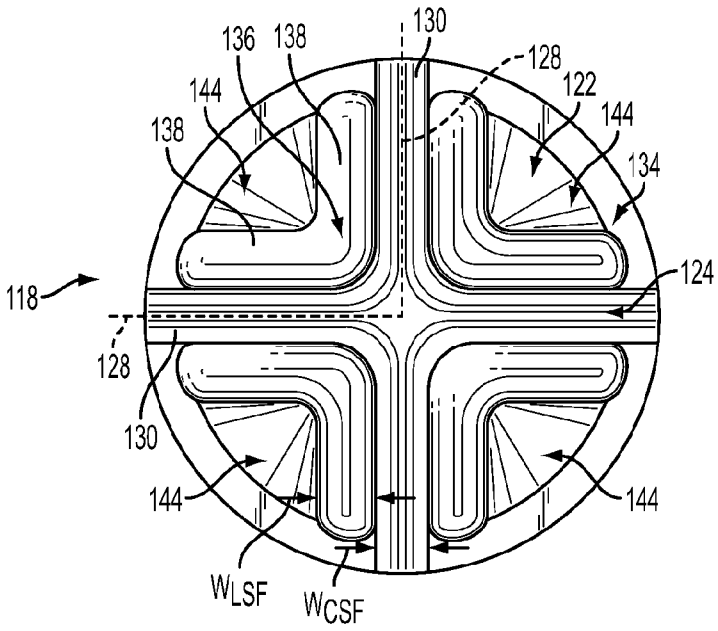

130
136
138
128
122
144
144
138
134
124
118
128
130
144
144
W_{LSF}
W_{CSF}

FIG. 10

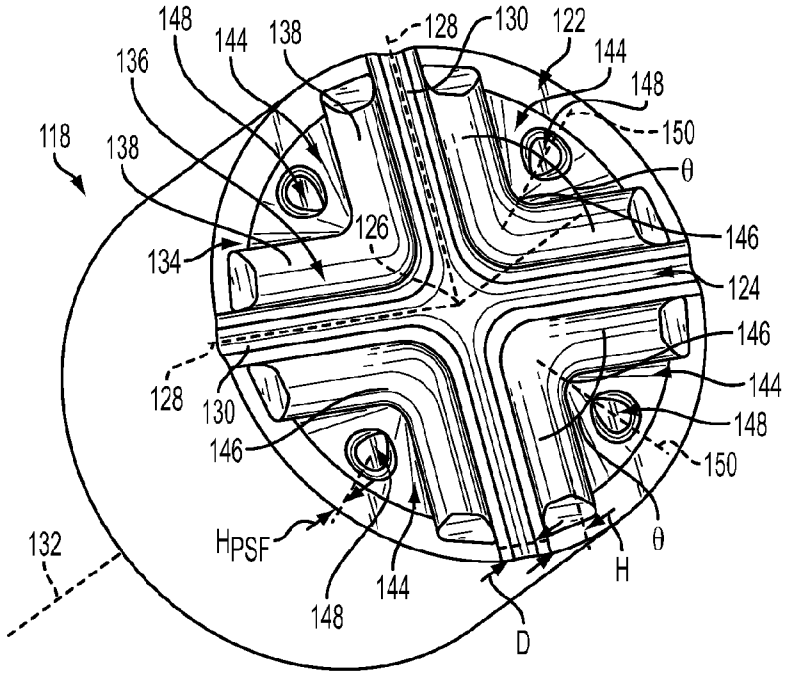

148
144
138
128
130
122
136
144
148
118
138
150
θ
126
146
134
124
146
128
130
144
148
146
150
θ
132
HPSF
144
H
148
D

FIG. 11

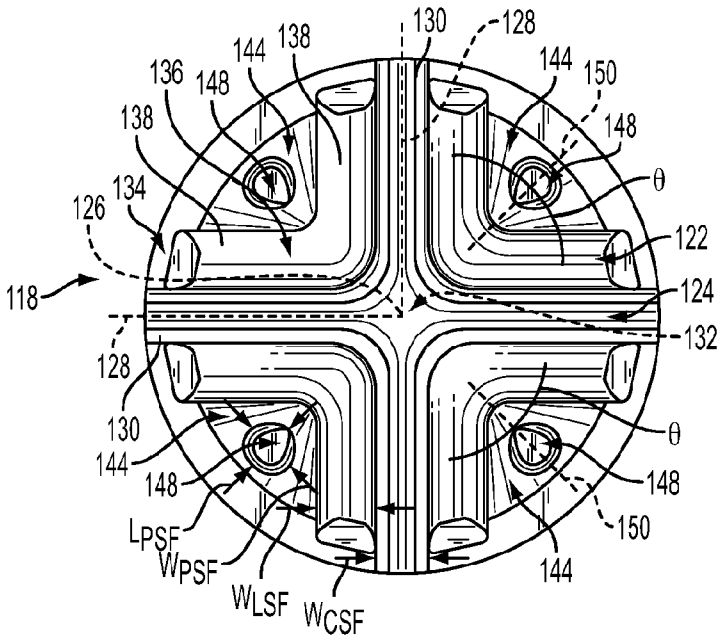

130
128
144
138
144
150
136
148
148
138
θ
134
126
122
118
124
132
128
130
θ
144
148
148
150
LPSF
WPSF
144
WLSF
WCSF

FIG. 12

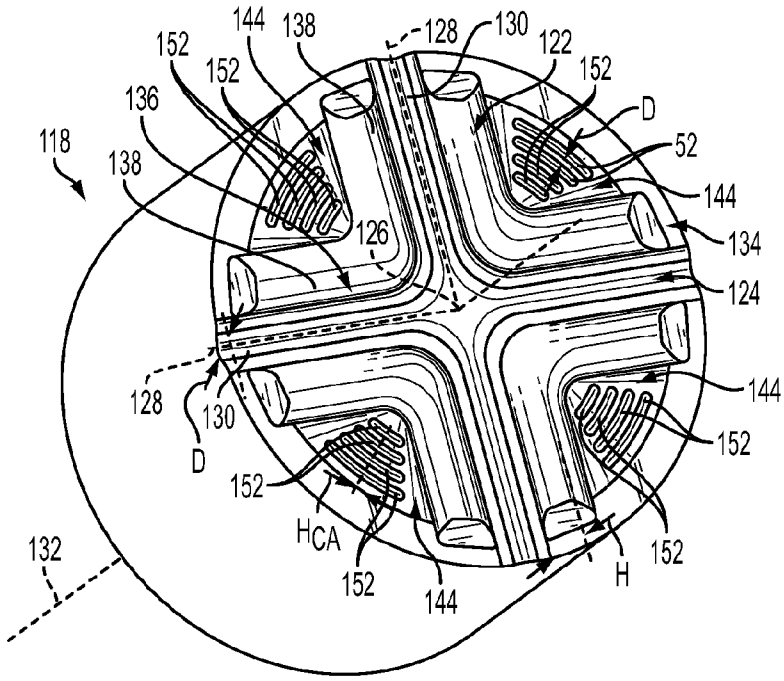

144
138
128
130
122
152
152
152
136
D
118
138
52
144
126
134
124
144
128
130
D
152
152
H_{CA}
152
132
152
144
H

FIG. 13

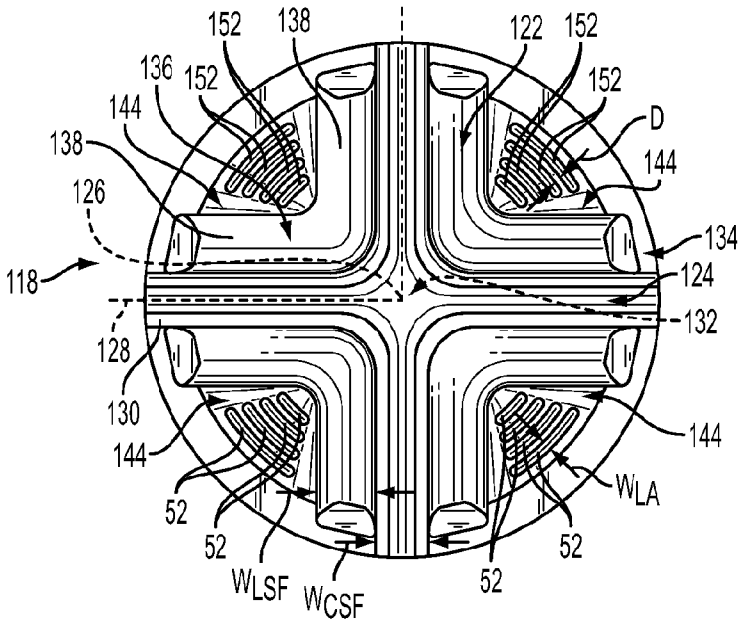

152
138
122
152
136
152
152
144
D
138
144
126
134
118
124
132
128
130
144
144
52
52
52
52
W_{LA}
W_{LSF}
W_{CSF}

FIG. 14

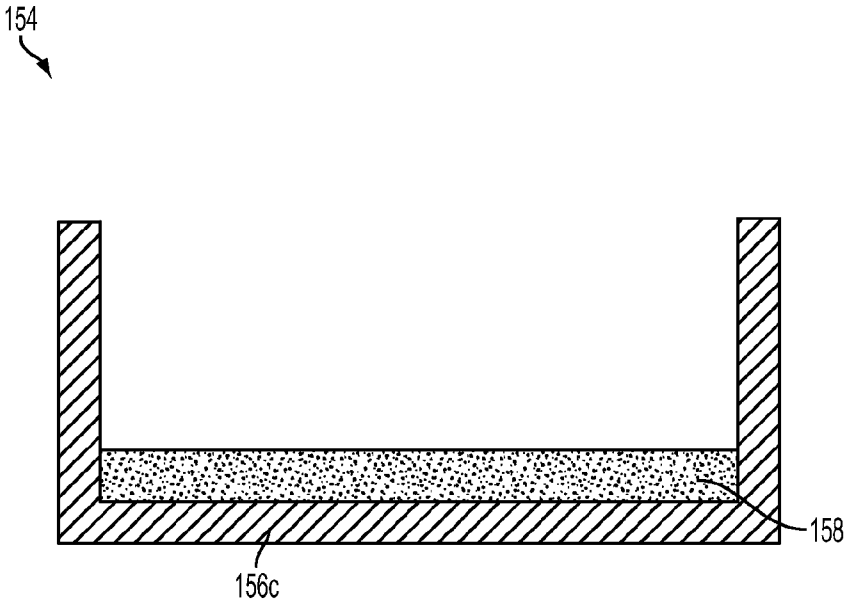


FIG. 15

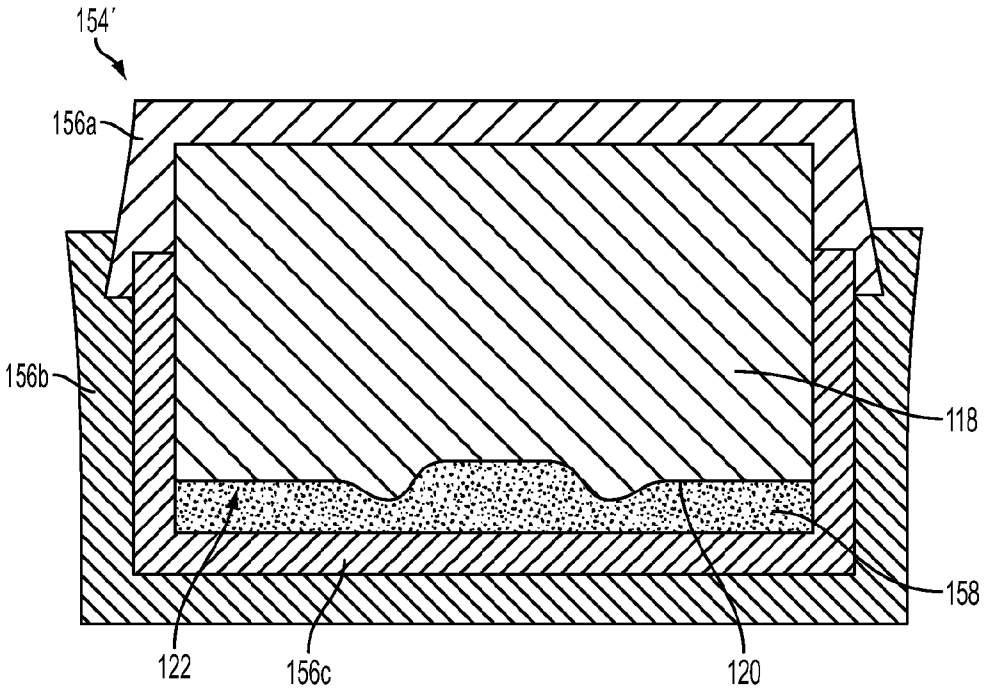


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/019240

A. CLASSIFICATION OF SUBJECT MATTER

E21B 10/46(2006.01)i

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)
E21B 10/46; B32B 9/00; B24D 3/10; E21B 10/62; B32B 18/00; E21B 10/42; B24D 3/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: cutting element, non-planar surface, polycrystalline table, substrate, groove and depression

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 8016054 B2 (LANCASTER et al.) 13 September 2011 See column 2,lines 39-43, column 3,lines 13-27, column 4,lines 31-62 and figures 1-6.	1-20
A	US 6202771 B1 (SCOTT et al.) 20 March 2001 See column 4,line 60 - column 5,line 19 and figures 3A,3B.	1-20
A	US 2004-0009376 A1 (WAN et al.) 15 January 2004 See paragraphs [0057]-[0060] and figures 4-12.	1-20
A	US 5351772 A (SMITH, REDD H.) 04 October 1994 See abstract, claim 1 and figures 11A-11C.	1-20
A	US 2011-0171414 A1 (SRESHTA et al.) 14 July 2011 See paragraph [0048] and figures 8A,8B.	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 June 2014 (23.06.2014)	**23 June 2014 (23.06.2014)**

Name and mailing address of the ISA/KR
International Application Division
Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea
Facsimile No. +82-42-472-7140

Authorized officer
JEONG, A Ram
Telephone No. +82-42-481-3388

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/US2014/019240

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 8016054 B2	13/09/2011	AT 353271 T	15/02/2007
		AT 367891 T	15/08/2007
		DE 602004004653 D1	22/03/2007
		DE 602004004653 T2	08/11/2007
		DE 602004007797 D1	06/09/2007
		DE 602004007797 T2	30/04/2008
		EP 1628805 A1	01/03/2006
		EP 1628805 B1	07/02/2007
		EP 1628806 A1	01/03/2006
		EP 1628806 B1	25/07/2007
		ES 2291880 T3	01/03/2008
		JP 05-208419 B2	12/06/2013
		JP 2006-528084 A	14/12/2006
		JP 2007-501133 A	25/01/2007
		US 2007-0181348 A1	09/08/2007
		US 2008-0222966 A1	18/09/2008
		US 2011-0286810 A1	24/11/2011
		US 2011-0303467 A1	15/12/2011
		US 8020642 B2	20/09/2011
		US 8240405 B2	14/08/2012
		US 8469121 B2	25/06/2013
		WO 2004-106003 A1	09/12/2004
		WO 2004-106004 A1	09/12/2004
US 6202771 B1	20/03/2001	BE 1013071 A5	04/09/2001
		GB 2329405 A	24/03/1999
		GB 2329405 B	26/06/2002
		GB 9819098 D0	28/10/1998
		IT 1304650 B1	28/03/2001
		IT TO980801 A1	22/03/2000
US 2004-0009376 A1	15/01/2004	US 6933049 B2	23/08/2005
US 5351772 A	04/10/1994	GB 2275068 A	17/08/1994
		US 05351772 A	04/10/1994
US 2011-0171414 A1	14/07/2011	CA 2817972 A1	31/05/2012
		US 2011-0167734 A1	14/07/2011
		WO 2012-071246 A2	31/05/2012
		WO 2012-071246 A3	03/01/2013