



US 20050210755A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2005/0210755 A1**

**Cho et al.** (43) **Pub. Date: Sep. 29, 2005**

(54) **DOUBLED-SIDED AND MULTI-LAYERED  
PCBN AND PCD ABRASIVE ARTICLES**

(57) **ABSTRACT**

(76) Inventors: **Hyun Sam Cho**, Salt Lake City, UT  
(US); **Kyung Ryul Han**, ChunAhn-si  
(KR); **Ki Jeon Song**, ChunAhn-si (KR)

A doubled-sided PCBN and/or PCD compact can be produced using high pressure high temperature processes allowing for increased effective thickness of abrasive tools, decreased delamination, and increased useful service life. A polycrystalline compact can include a substrate having a first surface and a second surface which are non-contiguous. Additionally, a first polycrystalline layer can be attached to the first surface of the substrate and a second polycrystalline layer attached to the second surface of the substrate. The first and second polycrystalline layers can be attached to the substrate via an intermediate layer containing superabrasive particles. Such double-sided PCBN and PCD compacts allow for increased effective thickness of a tool without suffering from non-homogenous results typical of standard PCD and PCBN compacts, regardless of superabrasive particle size. Each polycrystalline layer can include superabrasive particles of varying particle sizes such that the final tool is tailored for specific abrading characteristics. Such doubled-sided PCBN and PCD compacts can be incorporated into a wide variety of abrasive tools for use in cutting, milling, grinding, polishing, drilling and other similar abrasive applications.

Correspondence Address:  
**THORPE NORTH & WESTERN, LLP.**  
**8180 SOUTH 700 EAST, SUITE 200**  
**P.O. BOX 1219**  
**SANDY, UT 84070 (US)**

(21) Appl. No.: **11/077,995**

(22) Filed: **Mar. 10, 2005**

**Related U.S. Application Data**

(63) Continuation-in-part of application No. 10/655,758,  
filed on Sep. 5, 2003.

**Publication Classification**

(51) **Int. Cl.<sup>7</sup> ..... B24D 3/02**

(52) **U.S. Cl. .... 51/293; 51/307; 51/297; 51/295;**  
**51/298; 51/308; 51/309; 428/141;**  
**428/408; 451/533; 451/539;**  
**451/548; 451/552**

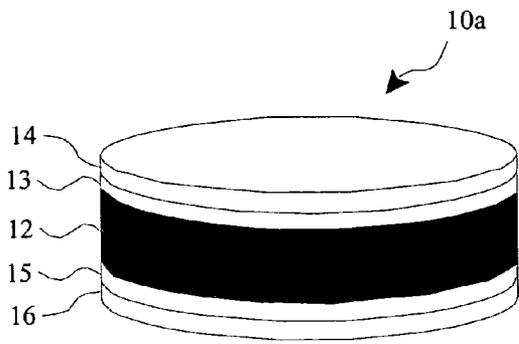


FIG. 1A

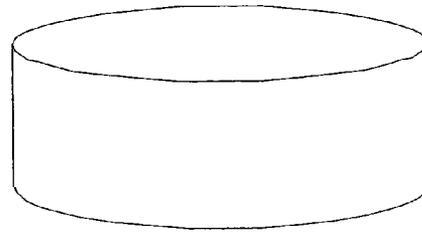


FIG. 1B

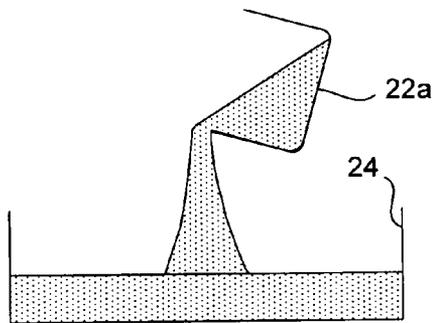


FIG. 2

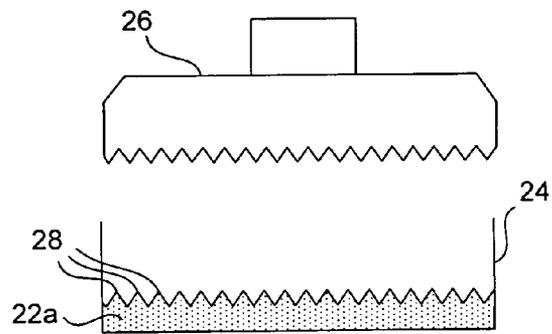


FIG. 3

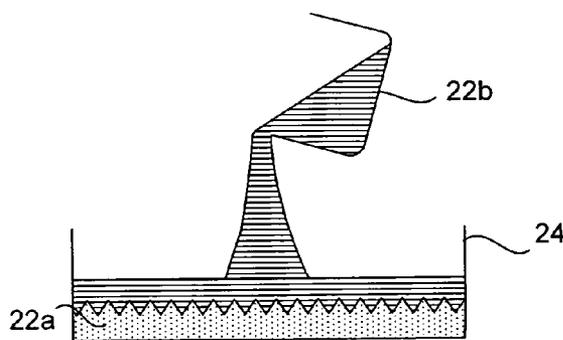


FIG. 4

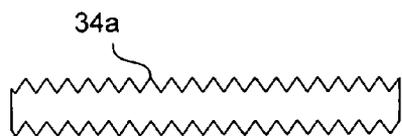


FIG. 5A



FIG. 5B



FIG. 6A



FIG. 6B

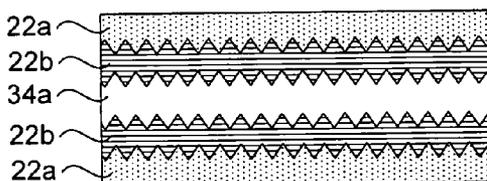


FIG. 7A

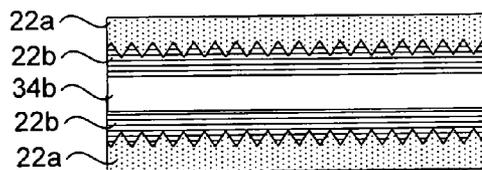


FIG. 7B

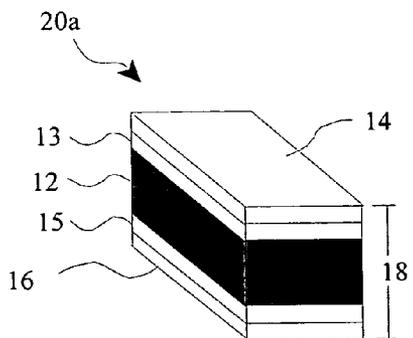


FIG. 8A

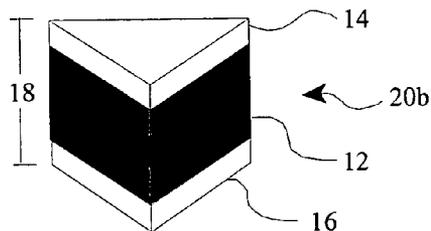


FIG. 8B

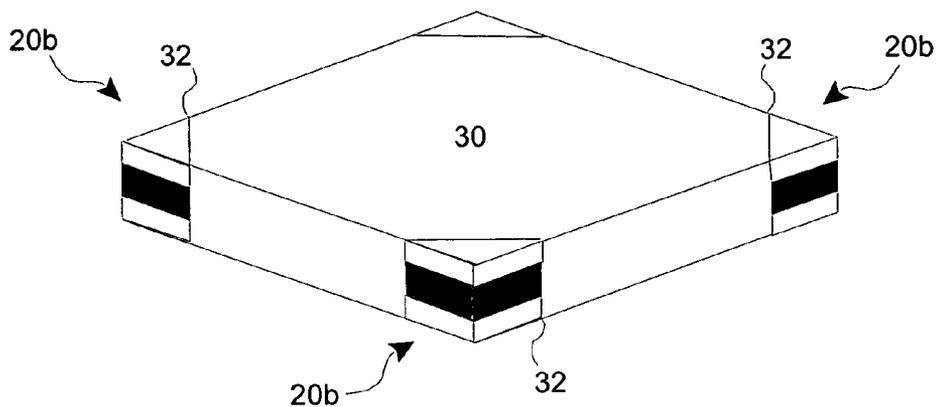


FIG. 9

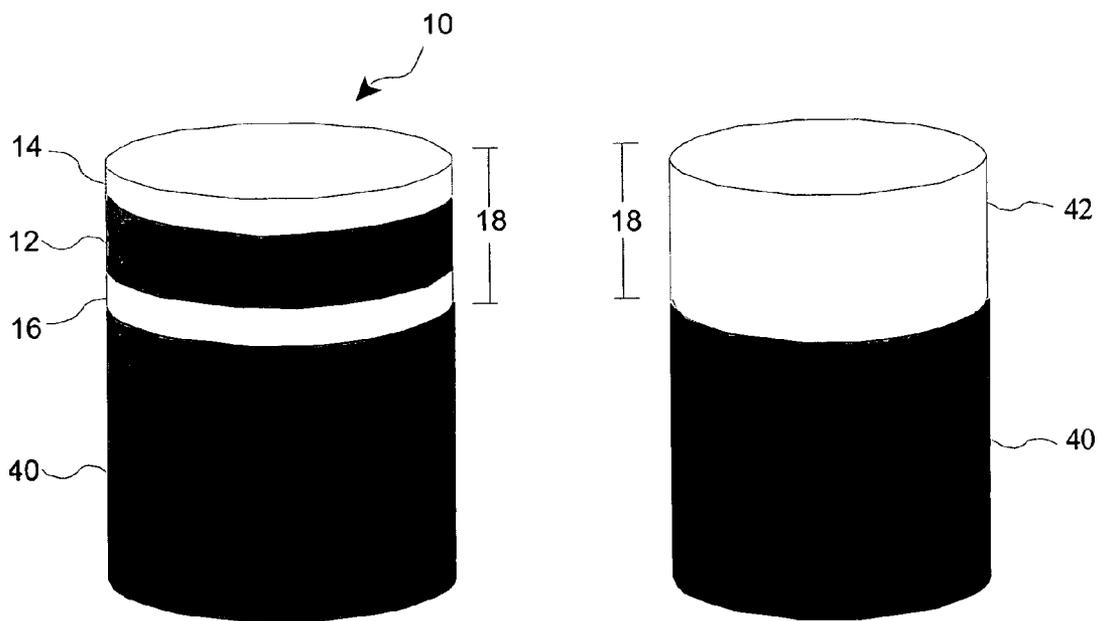


FIG. 10A

FIG. 10B  
(Prior Art)

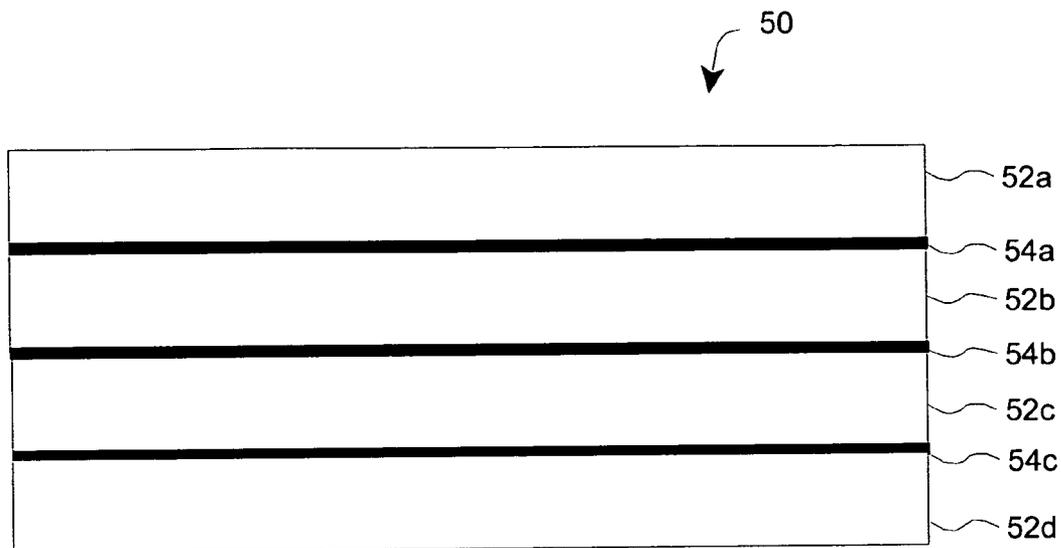


FIG. 11

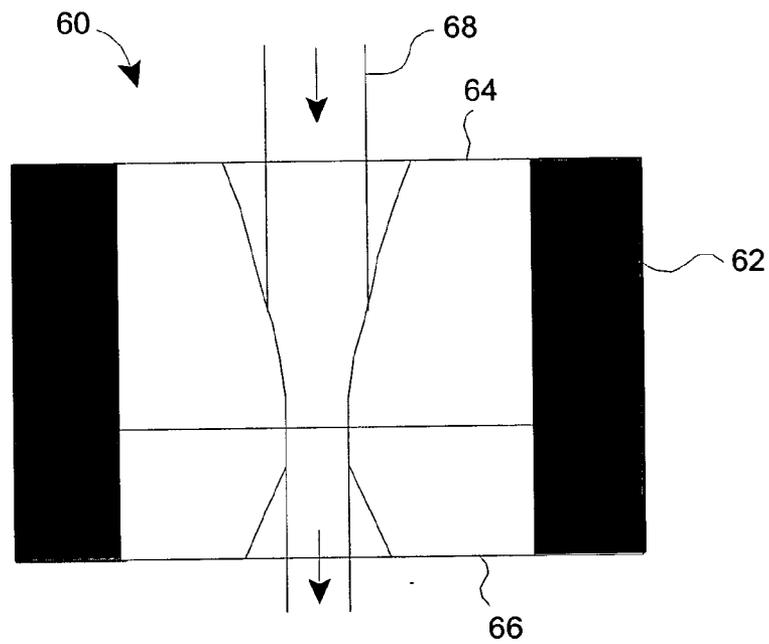


FIG. 12

## DOUBLED-SIDED AND MULTI-LAYERED PCBN AND PCD ABRASIVE ARTICLES

### RELATED APPLICATIONS

[0001] This application is a continuation-in-part of U.S. patent application Ser. No. 10/655,758, filed Sep. 5, 2003, which is hereby incorporated by reference in its entirety.

### FIELD OF THE INVENTION

[0002] The present invention relates generally to abrasive tools and methods for producing such abrasive tools. Specifically, the present invention relates to high pressure high temperature polycrystalline diamond and polycrystalline cubic boron nitride articles and methods for producing these polycrystalline articles. Accordingly, the present application involves the fields of physics, chemistry, and material science.

### BACKGROUND OF THE INVENTION

[0003] Polycrystalline diamond (PCD) and polycrystalline cubic boron nitride (PCBN) compacts are used extensively in the superabrasive industry for the production of cutting tools, drill bits, wire drawing dies, dressers, and a wide variety of other tools. The basic process of forming PCD/PCBN compacts was developed in the 1960's and has become a fundamental process in the superabrasive industry. A typical PCD compact is formed by loading a reaction cup assembly with small diamond grains, e.g., often from 1  $\mu\text{m}$  to 50  $\mu\text{m}$  in size. A metal substrate, typically cobalt cemented tungsten carbide, is placed adjacent to the diamond grains and the entire assembly is subjected to high pressure. Heat is then applied sufficient to melt the cobalt and allow the cobalt to flow into the interstitial pores of the diamond grains. At these high pressures and temperatures, the cobalt, or other carbide forming infiltrating alloy, acts as a sintering aid to sinter adjacent diamond particles together. Additionally, the diamond becomes more soluble in the infiltrant at higher pressures. The final product can contain diamond-to-diamond bridges with the infiltrating alloy occupying a small volume, typically a few volume percent. The diamond content of such infiltrated PCD is typically in excess of 80% by volume, whereas a similar non-infiltrated pressed diamond compact results in a diamond content of around 65% by volume.

[0004] However, the thickness of a typical PCD/PCBN layer is often limited to less than about 1 mm, although some methods can increase this thickness somewhat. For example, larger grain sizes can allow for some increase in thickness. Polycrystalline layers of up to about 0.7 to 0.9 mm can be formed using superabrasive particles having a particle size a from about 2  $\mu\text{m}$  to 4  $\mu\text{m}$ . At thicknesses greater than about 1 mm, typical sintering of PCD and PCBN compacts results in non-homogenous sintering of superabrasive particles. In order to form thicker solid or layered polycrystalline articles such as 3 mm to 5 mm, particle sizes of from 10  $\mu\text{m}$  to 40  $\mu\text{m}$  can be used. Thus, typical thick solid and layered polycrystalline materials have certain limits to the available grain sizes for particular thicknesses. Further, the non-homogenous sintering of the compacts leaves interior volumes of the compact which are weaker due at least in part to poorly bonded microstructures than exterior portions. This is thought to be the result of the finer particles having

a low porosity for infiltration of the metal binder and a dramatically increased surface area. As a result, the compact is prone to premature chipping and/or cracking during use, or even during high pressure high temperature (HPHT) sintering stages, thus reducing the useful life of any tool formed therewith. A variety of methods have attempted to overcome this difficulty with moderate success. For example, one method utilizes a mixture of diamond and pre-cemented carbide which lessens the non-homogeneities and lessens the tendency of the PCD portion to separate from various metal substrates. However, these methods also tend to increase production costs and manufacturing complexity and still have limitations on the achievable thickness of the PCD.

[0005] In addition to the aforementioned PCD and PCBN compacts that include a cobalt cemented tungsten carbide substrate, the PCD and PCBN materials can also be produced as a solid PCD or a solid PCBN. These solid PCD or PCBN are widely used in the industry and are sintered in the presence of sintering aids under a typical HPHT process as a free-standing PCD or PCBN with no support layer. For example, a typical solid PCBN available as AMBORITE (manufactured by Element Six Co.) contains about 90% by volume CBN grains having a particle size of about 10  $\mu\text{m}$  and 10% by volume sintering aids such as AlN and AlB<sub>2</sub> in a ceramic phase. The typical thickness of AMBORITE is between 3.0 mm and 5.0 mm. It is also noted that to maintain a homogeneous PCBN quality of this thickness, i.e. up to 5.0 mm thick, the solid PCBN is specifically made of a coarser CBN powder, i.e. 10  $\mu\text{m}$ ~20  $\mu\text{m}$ . Such a solid PCBN is not easily processed with finer powders and results in a limited grade of products and is further limited in utility since most non-solid products are produced for use in a wide range of applications having various grades of PCBN products. There are recognized general guidelines for successful design and use of PCD and PCBN tools over a range of materials and machining conditions in the industry. For example, there are a wide variety of grades of PCBN compact that are classified by CBN content, e.g., 50%-95%, and CBN grain size, e.g., 0.5  $\mu\text{m}$ -30  $\mu\text{m}$ . Such grades of PCBN are specifically designed for machining various workpiece materials such as hardened steels, superalloys, cast irons, and high temperature alloy components.

[0006] In addition, typical PCBN and PCD compacts and tools can tend to have problems with delamination of the superabrasive layer from an underlying substrate. This delamination is generally due to thermal expansion mismatch between the substrate and polycrystalline superabrasive layers. Through repeated cycling of heating and cooling, the interface between the layers becomes weakened and fatigued due to thermal mismatch such that delamination occurs.

[0007] As such, methods capable of producing superabrasive compacts having increased thickness and improved abrasive properties continue to be sought through ongoing research and development efforts.

### SUMMARY OF THE INVENTION

[0008] Accordingly, the present invention provides new PCD and PCBN materials especially designed for much wider applications than existing PCD/PCBN having limited product properties. Further, the present invention can pro-

vide polycrystalline bodies which have significantly reduced delamination problems and have an increased useful service life. The present invention also provides HPHT methods for producing tools and devices having increased effective thicknesses and tailored abrasive properties. Therefore, the PCD and PCBN materials of the present invention can be a viable alternative for existing products such as solid PCBN and drill-bit PCD cutters and have improved cutting and abrasive properties.

[0009] In accordance with the present invention, a polycrystalline compact includes a substrate having a first surface and a second surface. In one aspect of the present invention, the first and second surfaces are non-contiguous. In yet another aspect, the first and second surfaces can be opposing and parallel. Additionally, a first polycrystalline layer can be attached to the first surface of the substrate using an intermediate layer. Similarly, a second polycrystalline layer can be attached to the second surface of the substrate using a second intermediate layer. The intermediate layers can include superabrasive particles and a metal binder. In accordance with the present invention, the first and second polycrystalline layers can include superabrasive particles bonded together. In one detailed aspect, the superabrasive particles can be bonded together by sintering or chemical bonding with an additional metal binder.

[0010] In one aspect of the present invention, the intermediate layers can include a mixture of cBN and diamond particles. The intermediate layers can be tailored specifically for a desired polycrystalline superabrasive working layer.

[0011] In another detailed aspect, the substrate can be formed of a material such as cemented tungsten carbide, cemented titanium carbide, cemented tantalum carbide, tungsten, titanium, and mixtures or composites thereof, although other materials can also be used as described in more detail below. One currently preferred substrate material includes cobalt cemented tungsten carbide.

[0012] In yet another detailed aspect of the present invention, the superabrasive can be either diamond or cubic boron nitride.

[0013] In accordance with the present invention, the polycrystalline compact can be formed in a wide variety of configurations suitable for different abrasive applications.

[0014] In one aspect, the first and second surfaces can be substantially parallel, although this is not always required. In another aspect, the first and second polycrystalline layers can have a thickness of from about 5  $\mu\text{m}$  to about 2 mm. In a related aspect, for some applications the first and second polycrystalline layers can have a thickness of from about 10  $\mu\text{m}$  to about 1.6 mm. In yet another aspect of the present invention, the entire polycrystalline compact can have an effective thickness of from about 1 mm to about 19 mm.

[0015] In still another aspect, the polycrystalline compacts of the present invention can be incorporated into a tool for a wide variety of abrading, cutting, or other applications. For example, polycrystalline tools which can advantageously utilize the compacts and methods of the present invention include drill bits, cutting inserts, wire drawing dies, saw blades, wire saws, indexable inserts, and other known abrasive tools.

[0016] Additionally, one aspect of the present invention includes a method of forming a polycrystalline compact.

This method can include providing a substrate having a first surface and a second surface such that the first and second surfaces are non-contiguous. A first superabrasive layer can be formed on the first surface and a second superabrasive layer can be formed on the second surface to form a precursor assembly. Formation of the superabrasive layers and providing of the substrate can occur in any order. For example, a superabrasive layer can be placed in a mold such as a reaction cup-assembly, followed by placement of the substrate over the superabrasive layer. Subsequently, a second superabrasive layer can then be formed on the substrate such that the substrate is located between two superabrasive layers. Regardless of the order of assembling the precursor, the precursor can then be heated, e.g., in an HPHT apparatus. The step of heating can be sufficient to bond together the superabrasive particles of each layer to form a multi-layer polycrystalline compact.

[0017] In a detailed aspect of the present invention, the multi-layer polycrystalline compact can be cut such that a plurality of polycrystalline tool inserts are formed having at least two polycrystalline surfaces. The polycrystalline tool inserts can be any desired shape such as but not limited to cylindrical, rectangular, or triangular, depending on the intended application. Further, such inserts can be contoured or otherwise shaped to provide predetermined abrading effects to a work piece.

[0018] In a further aspect, the polycrystalline compacts and inserts of the present invention can be attached to a tool body. Typically, at least a portion of the substrate is attached to the tool body via brazing, gluing, welding, clamping, or other known techniques. In a detailed aspect, the choice of braze can include typical braze materials or additionally may include carbide, nitride, or boride forming metals. Alternatively, one of the first or second polycrystalline layers can be attached to the tool body to produce a tool such as that shown in FIG. 10A.

[0019] In a further alternative aspect of the present invention, a method of fabricating a multi-layered polycrystalline article can include HPHT sintering of a polycrystalline layer next to substrate, with an optional sintering aid. Subsequently, a second polycrystalline layer and second substrate can be formed as described in connection FIG. 10A. More specifically, this multi-layered polycrystalline tool can be used in the oil/gas drilling market as an alternative to existing PCD drill-bit cutters having a thicker PCD layer (about 3.0 mm). The polycrystalline tools of the present invention provide a stronger polycrystalline layer and a more uniform microstructure and homogeneity. Currently, drill bit PCD cutters of about 3.0 mm PCD thickness, e.g., SYNDRILL 1313 or 1913 (available from Element Six Co.), is widely used in the oil/gas drilling industry. In one aspect, the present invention provides a viable alternative material for use in the drilling industry. Furthermore, in one detailed aspect of the present invention the abrasive properties of each polycrystalline layer can be tailored depending on the application. For example, in drilling earth, a first contact area of a first polycrystalline layer can be coarser superabrasive while a second polycrystalline layer of finer diamond grained microstructure can provide finer cutting properties. Further, as can be seen, the order of formation of the polycrystalline layers and joining thereof can be varied.

[0020] In one alternative aspect of the present invention, a method of forming a polycrystalline compact includes

extending an effective thickness of a polycrystalline layer using a non-superabrasive intermediate material. Similarly, a multi-layered polycrystalline compact having at least two external polycrystalline layers separated by a substrate can be formed by such methods.

[0021] There has thus been outlined, rather broadly, the more important features of the invention so that the detailed description thereof that follows may be better understood, and so that the present contribution to the art may be better appreciated. Other features of the present invention will become clearer from the following detailed description of the invention, taken with the accompanying drawings and claims, or may be learned by the practice of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. 1A shows a perspective view of a polycrystalline compact in accordance with one embodiment of the present invention.

[0023] FIG. 1B shows a perspective view of a typical solid polycrystalline article in accordance with the prior art.

[0024] FIG. 2 shows a step of forming a superabrasive layer in a reaction cup in accordance with one embodiment of the present invention.

[0025] FIG. 3 shows a step of stamping a surface to form a plurality of features in accordance with one embodiment of the present invention.

[0026] FIG. 4 shows a step of forming an intermediate layer in a reaction cup in accordance with one embodiment of the present invention.

[0027] FIG. 5A shows a contoured substrate having a plurality of features in accordance with one embodiment of the present invention.

[0028] FIG. 5B shows a substantially planar substrate in accordance with another embodiment of the present invention.

[0029] FIG. 6A shows a step of forming a portion of the precursor assembly using the substrate of FIG. 5A in accordance with one embodiment of the present invention.

[0030] FIG. 6B shows a step of forming a portion of the precursor assembly using the substrate of FIG. 5B in accordance with one embodiment of the present invention.

[0031] FIG. 7A shows a precursor assembly where all interfaces are contoured having a plurality of features in accordance with one embodiment of the present invention.

[0032] FIG. 7B shows a precursor assembly where only some interfaces are contoured having a plurality of features in accordance with another embodiment of the present invention.

[0033] FIG. 8A shows a perspective view of a rectangular polycrystalline tool insert formed from the compact of FIG. 1A in accordance with the present invention.

[0034] FIG. 8B shows a perspective view of a triangular polycrystalline tool insert formed from the compact of FIG. 1A in accordance with the present invention.

[0035] FIG. 9 shows a perspective view of a tool formed using double-sided polycrystalline tool inserts formed in accordance with the present invention.

[0036] FIG. 10A shows a perspective view of a polycrystalline compact having multiple polycrystalline layers formed in accordance with the present invention.

[0037] FIG. 10B shows a perspective view of a polycrystalline compact in accordance with the prior art.

[0038] FIG. 11 shows a side view of a multi-layered precursor assembly in accordance with one embodiment of the present invention.

[0039] FIG. 12 shows a side cross-sectional view of a wire drawing die formed in accordance with one aspect of the present invention.

[0040] The above figures are provided merely for purposes of illustrating the principles of the present invention and no limitation is intended thereby. For example, the specific dimensions and relative sizes of features are illustrated for convenience in illustration and may vary from that illustrated.

#### DETAILED DESCRIPTION

[0041] Before the present invention is disclosed and described, it is to be understood that this invention is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

[0042] It must be noted that, as used in this specification and the appended claims, the singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a substrate” includes one or more of such substrates, reference to “the layer” includes reference to one or more of such layers, and reference to “infiltrating” includes reference to one or more of such techniques.

[0043] Definitions

[0044] In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set forth below.

[0045] As used herein, “diamond” refers to a crystalline structure of carbon atoms bonded to other carbon atoms in a lattice of tetrahedral coordination known as  $sp^3$  bonding and includes amorphous diamond. Specifically, each carbon atom is surrounded by and bonded to four other carbon atoms, each located on the tip of a regular tetrahedron. The structure and nature of diamond, including its physical properties are well known in the art.

[0046] As used herein, “non-contiguous,” when referring to surfaces, indicates the surfaces can be in almost any position relative to one another, as long as the surfaces do not share a common boundary. For example, non-contiguous first and second surfaces can be opposite ends of a cylindrical substrate.

[0047] As used herein, “bonded”, “bonding”, and the like refer to carbide bonding, nitride bonding, boride bonding, mechanical bonding, and/or sintering of superabrasive particles. For example, diamond superabrasive particles can be bonded using a sintering aid such as cobalt to form a

polycrystalline structure. Further, the addition of carbide and/or nitride formers such as titanium can provide for formation of chemical bonds between the diamond, CBN, and/or other components of the superabrasive layer to form a bonded mass of superabrasive particles.

[0048] As used herein, “feature,” when used in connection with an interface, refers to a three-dimensional structure or protrusion which varies substantially from planar. For example, common features can include pyramids, cones, mounds, divots, and the like. One purpose of the features is to provide a significantly increased surface area of contact in order to reduce delamination of the layers. Another benefit of the features is to extend the diffusion path of materials across the polycrystalline layer during formation and/or use of the compact. Detrimental materials such as cobalt and the like can cause back-conversion of diamond and cBN to carbon or other weaker materials. These materials tend to diffuse along a path which is nearly normal to the interface surface. Thus, by providing non-planar surfaces the diffusion path is extended sufficiently to reduce the occurrence of thermal breakdown and fatigue at a working surface of the tool which contacts a workpiece.

[0049] As used herein, “forming,” when used in conjunction with superabrasive layers, refers to attaching a superabrasive layer to a surface. As such, the superabrasive layer can be provided as a powdered mass which is then shaped or otherwise formed into a coherent mass. Alternatively, the superabrasive layer can be formed on a surface by providing a coherent, partially sintered, or sintered superabrasive layer which is independently produced and then “formed” on the surface by adhesion, brazing or other like methods.

[0050] As used herein, “substantial” when used in reference to a quantity or amount of a material, or a specific characteristic thereof, refers to an amount that is sufficient to provide an effect that the material or characteristic was intended to provide. Therefore, “substantially free” when used in reference to a quantity or amount of a material, or a specific characteristic thereof, refers to the absence of the material or characteristic, or to the presence of the material or characteristic in an amount that is insufficient to impart a measurable effect, normally imparted by such material or characteristic. The exact degree of deviation allowable may in some cases depend on the specific context. Thus, for example, a substrate which is substantially planar may deviate from planar within a range which is imperceptible or nearly imperceptible upon visual inspection.

[0051] As used herein, “non-superabrasive” is any material which is not CBN, diamond, or diamond-like material. Suitable non-superabrasive materials can include metals, metal-carbides, ceramics, cermets, polymeric resins, and composites or alloys thereof. It is noted that a number of non-superabrasive materials can exhibit abrasive properties and may impart a degree of abrasive and/or cutting capacity to the final tool in addition to the superabrasive layers.

[0052] As used herein, “high pressure” and “high temperature” refer to pressures and temperatures within the stability field of diamond or CBN. These pressures and temperatures can vary widely and are well known to those skilled in the art. For example, as pressures increase, lower temperatures can be used to successfully sinter diamond and CBN. Typical pressures can range from about 1 GPa to about 7 GPa and temperatures often range from about 1,200° C. to

about 1,500° C. Those skilled in the art will recognize that conditions outside these ranges can be used depending on the apparatus and specific superabrasive properties, e.g., particle size, added components, etc., and such are considered within the scope of the present invention.

[0053] Concentrations, amounts, and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. As an illustration, a numerical range of “about 1  $\mu\text{m}$  to about 5  $\mu\text{m}$ ” should be interpreted to include not only the explicitly recited values of about 1  $\mu\text{m}$  and about 5  $\mu\text{m}$ , but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3, and 4 and sub-ranges such as from 1-3, from 2-4, and from 3-5, etc. This same principle applies to ranges reciting only one numerical value. Furthermore, such an interpretation should apply regardless of the breadth of the range or the characteristics being described.

[0054] The Invention

[0055] In accordance with one embodiment of the present invention, a precursor assembly can be produced by providing a substrate having a first surface and a second surface. A superabrasive layer can be formed on at least a portion of each surface having an intermediate layer between each of the superabrasive layers and the corresponding substrate surface. Typically, the first and second surfaces can be non-contiguous.

[0056] Referring now to FIG. 1, a precursor assembly shown generally at 10a is shown. The substrate 12 can be any suitable material such as a solid metal, sinterable powder, partially sintered mass, green body, or the like. Typical materials can include, without limitation, cemented tungsten carbide, cemented titanium carbide, cemented tantalum carbide, tungsten, titanium, and mixtures or composites thereof. Other materials which can be used include steel, iron, ceramics, and the like, assuming appropriate adjustments to the superabrasive layers is made to avoid delamination, infiltration, and other problems. Such adjustments are known and several such methods are further described in U.S. Pat. Nos. 4,525,178 and 4,604,106, each of which are hereby incorporated by reference. In one embodiment of the present invention, the substrate includes cemented tungsten carbide. The substrate can include a wide variety of materials and can be almost any material suitable for a particular application. For example, high impact and intensive cutting applications can require a substrate such as metal carbides, while abrading of softer materials such as wood, plastics, or soft rock such as limestone, marble and the like, can allow for use of softer substrate materials such as certain ceramics, polymeric resins, and the like. In one aspect, the substrate can be formed of a non-superabrasive material. The substrate 12 is shown as a cylindrical disk, however it will be understood that the substrate can be almost any shape depending on the intended application and the available high-temperature high-pressure (HPHT) apparatus.

[0057] The precursor assembly 10a can include a first intermediate layer 13 adjacent the first surface of the sub-

strate **12** and a second intermediate layer **15** adjacent the second surface of the substrate. Each of the intermediate layers can include a mixture of intermediate superabrasive particles, a binder metal, and an optional bonding medium.

[0058] The intermediate superabrasive particles can include superabrasive particles such as those suitable for use in the superabrasive layers as discussed in more detail below. However, the intermediate superabrasive particles can typically be cBN, diamond, or a mixture of cBN and diamond particles.

[0059] In one detailed aspect of the present invention, the first and second intermediate superabrasive particles can have a ratio of largest to smallest particles which is from about 1 to about 500, and in some case can range from about 10 to about 500. This range of particle sizes is much larger than the size distribution allowable for the working or outer polycrystalline layers. Further, the broad size distribution can help to improve the adherence of the intermediate layer to each of the substrate and polycrystalline layers. The specific content of superabrasive particles in the intermediate layer can vary depending on the particular tool. However, the first and second intermediate layers can each comprise from about 50 to about 99 vol % superabrasive particles, and most often comprise from about 55 vol % to about 90 vol %.

[0060] Currently, a preferred intermediate superabrasive particle composition includes a mixture of diamond and cubic boron nitride particles. The incorporation of superabrasive particles into the intermediate layer allows the properties of the intermediate layer to be more similar to both the superabrasive layer and the substrate, thus reducing the occurrence of delamination. In addition, it has been determined that a mixture of cBN and diamond particles in the intermediate layers offers unexpectedly increased performance. More specifically, the presence of both types of superabrasive particles improves the strength and the thermal properties of the intermediate layer over an intermediate layer containing only one type of superabrasive particle.

[0061] In addition to superabrasive particles, the intermediate layers can further include a metal binder which acts as either a source of chemical bonding and/or mechanical reinforcement. Most often, the metal binder is chosen as a sintering aid which acts to form superabrasive-to-superabrasive bonding. Non-limiting examples of suitable binder metals can include Co, WC, Al, Ti, Ni, and alloys thereof. Additional binder metals can include those from Group VIII. Most often the first and second intermediate layers can comprise from about 5 vol % to about 25 vol % binder metal. In an additional detailed embodiment, the first and second binder metals can have an average particle size which is smaller than an average particle size of the first and second intermediate superabrasive particles, respectively.

[0062] In embodiments where the superabrasive layers are PCBN, the intermediate layers of the present invention can also include a bonding medium. The bonding medium can serve as a source of chemical and mechanical bonding between the superabrasive cBN and the bonding medium. Suitable bonding medium materials provide the can include, but are not limited to, TiC, TiN, TiCN, AlN, TiB<sub>2</sub>, SiO<sub>2</sub>, Si<sub>3</sub>N<sub>4</sub>, and combinations thereof. Additional bonding mediums can generally include nitrides, carbides, and carbonitrides of Group IVb, Vb, or VIb metals. Further, each of the

first and second intermediate layers can comprise from about 5 vol % to about 25 vol % bonding medium.

[0063] Although not required, each of the intermediate layers can have substantially the same composition. As mentioned below, the two opposing polycrystalline layers can be of differing compositions, i.e. PCBN versus PCD. Therefore, the intermediate layers can be adjusted accordingly as described below.

[0064] Typically, the composition of the intermediate layer can be tailored depending on the corresponding superabrasive layer. Thus, it has been found that the preferred superabrasive content of the intermediate layer will contain a mixture of superabrasive particles such that the composition includes more of the type of superabrasive particle which is contained in the adjacent working layer. For example, a CBN superabrasive layer would preferably have a corresponding intermediate layer having a mixture of diamond and cBN superabrasive particles wherein the volume content of cBN particles exceeds that of the diamond particles. Thus, in one detailed aspect, when the first and second polycrystalline layers are polycrystalline cubic boron nitride, the volume ratio of diamond to cubic boron nitride particles can be from about 0.005:1 to about 1:1, and preferably from about 0.05:1 to about 0.6:1. Unexpectedly, improved properties of the intermediate layer can also be realized when the ratio of diamond to cBN is extremely small such that only trace amounts of diamond are present. For example, ratios from about 0.0005:1 to about 0.05:1 have shown good results. A similar composition range would also apply to intermediate layers adjacent PCD polycrystalline working layers.

[0065] As mentioned previously, the precursor assembly **10a** further includes a first superabrasive layer **14** adjacent the first intermediate layer **13** and a second superabrasive layer **16** adjacent the second intermediate layer **15**. The superabrasive layers can include superabrasives of almost any size and suitable sizes can be chosen based on the intended application. As a general guideline, suitable superabrasive particles can have a size from about 0.1  $\mu\text{m}$  to about 70  $\mu\text{m}$ . For example, in one embodiment, the grain sizes can be from about 0.1  $\mu\text{m}$  to about 1.0  $\mu\text{m}$ . In a second embodiment, the grain sizes can be from about 1  $\mu\text{m}$  to about 2  $\mu\text{m}$ . In a third embodiment, the grain sizes can range from about 2  $\mu\text{m}$  to about 4  $\mu\text{m}$  or from about 4  $\mu\text{m}$  to about 6  $\mu\text{m}$ . For PCBN compacts, most commercial products tend to range from about 0.1  $\mu\text{m}$  to about 50  $\mu\text{m}$ . Further, coarse grits can be used in aggressive cutting applications, while bearing surfaces or fine polishing tools may require a finer particle size. Superabrasive particle sizes can range from 20 mesh to 400 mesh, although particle sizes outside this range can be used. Further, superabrasive particle sizes of from about 2  $\mu\text{m}$  to about 50  $\mu\text{m}$  are typical. Currently preferred superabrasive particle sizes range from about 1  $\mu\text{m}$  to about 50  $\mu\text{m}$ , and most preferred from about 2  $\mu\text{m}$  to about 35  $\mu\text{m}$ . Typically, the superabrasive particles used in the primary working layer have a relatively tight size distribution compared to the intermediate layers. For example, in some cases the ratio of largest to smallest particles can be from about 1 to about 10, and preferably ranges from about 1 to about 4.

[0066] In an additional alternative embodiment of the present invention, the first and second superabrasive particles can have different average particles sizes. For

example, the first superabrasive particles can have an average particle size of from about 1  $\mu\text{m}$  to about 10  $\mu\text{m}$  and the second superabrasive particles have an average particle size of from about 20  $\mu\text{m}$  to about 60  $\mu\text{m}$ .

[0067] Superabrasive particles suitable for use in the present invention can include diamond, cubic boron nitride (cBN), and mixtures thereof. Currently preferred superabrasive particles are cBN. However, the principles of the present invention can be applied using other superabrasive particles such as amorphous diamond and other known superabrasive materials. The superabrasive layers can further include a variety of other components known to those skilled in the art such as, but not limited to, metal binders, sintering aids, bonding mediums, organic binders, metal carbide, filler, and the like.

[0068] The relative dimensions of the polycrystalline layers and the intermediate layers can also be varied to optimize cost and performance of the double-sided tools of the present invention. For example, the first and second intermediate layers can have a thickness from about 0.2 to about 0.7 times a thickness of the first and second polycrystalline layers, respectively. However, the thickness of each layer can vary considerably depending on the particular application. Typically, the intermediate layers can range from about 0.1 mm to about 0.4 mm with polycrystalline layers from about 0.4 mm to about 0.8 mm such that the total double-sided compact thickness would be from about 0.8 mm to about 1.1 mm.

[0069] The superabrasive particles typically do not form a coherent mass suitable for mechanical applications without a metal binder or sintering aid such as cobalt, nickel, iron, manganese, or their alloys. Such sintering aids can be included in the substrate, e.g. cemented tungsten carbide. Alternatively, the metal binder or sintering aid can be physically mixed with the superabrasive particles prior to placement in the HPHT apparatus. Such metal binders can be any conventional infiltrant, sintering aid, carbon solvent, or other metal alloy used in producing coherent PCD or PCBN tools. For example, suitable metal binders can include carbide, nitride or boride forming metals such as nickel, cobalt, manganese, iron, silicon, aluminum, titanium, vanadium, chromium, zirconium, molybdenum, tungsten, and alloys thereof. Upon heating, the metal binder or sintering aid melts and/or flows throughout the superabrasive particles such that interstitial voids among particles are at least partially filled. The molten metal binder provides additional mechanical strength to the superabrasive layers and can provide additional strength through a reaction at a grain boundary between the metal binder and the superabrasives resulting in formation of carbide, boride, and/or nitride bonds. Depending on the additional components of the superabrasive layers, the superabrasive particles can be bound together by mechanical forces, chemical bonds as in the case of carbide, nitride, or boride forming metals, or the superabrasive particles can be sintered together as in the case of carbon solvent metals such as Co, Fe, Ni, Mn, Al, Si, Ti, V, Cr, Zr, Mo, W, and their alloys. Various alloys present differing melting temperatures and may be more or less appropriate for a particular application. Specific such alloys can be chosen by those skilled in the art.

[0070] In an additional alternative embodiment, superabrasive particles can optionally be mixed with a carbon

source such as graphite in the formation of a PCD article or a nitrogen and/or boron source in the formation of PCBN. Under appropriate temperature and pressure conditions, the superabrasive particles can increase in size and additional superabrasive particles can be grown in situ using the provided carbon, nitrogen, and/or boron source. Such compositions and methods are known and U.S. Pat. No. 6,616,725, hereby incorporated by reference in its entirety, describes several such methods of producing PCD and PCBN materials suitable for use in the present invention.

[0071] In order to increase the workability of the precursor, an organic binder can be included in the superabrasive layers as is well known in the art. Typically, upon heating, the organic binder will be removed or otherwise decompose and is preferably not part of the final polycrystalline article.

[0072] In one alternative embodiment, the above described polycrystalline layers can be preformed layers, i.e. solid PCD or PCBN layers, which are then formed on the surface. Thus, the order of "forming" the coherent superabrasive layer is not crucial, although certain orders may be more or less desirable for processing convenience.

[0073] Further, the following discussion outlines several specific processes of forming the double-sided compacts of the present invention. However, it will be understood that other process steps, order of formation, modifications, and the like can be implemented by those skilled in the art based on the teachings provided herein and such are considered within the scope of the present invention.

[0074] FIGS. 2 through 10B illustrate several currently preferred approaches to forming precursor assemblies in accordance with the present invention. As shown in FIG. 2, a mixture 22a of superabrasive powder and metal binder can be prepared according to known techniques for use as the primary working layer. The mixture 22a can be poured into a reaction cup 24.

[0075] Importantly, at least one interface in the precursor assembly is contoured having a plurality of features. The contoured interface can be at least one interface being a first polycrystalline layer-first intermediate layer interface, a second polycrystalline layer-second intermediate layer interface, a first intermediate layer-first surface interface, or a second intermediate layer-second surface interface. In one currently preferred embodiment, each of these interfaces is contoured, as described herein.

[0076] The plurality of features can be formed using any convenient surface having corresponding pattern of features thereon. The plurality of features can be any number of shapes, sizes, orientations, distances apart, or the like. For example, non-limiting examples of suitable features can include pyramids, cones, mounds, divots, and variations thereof. As mentioned previously, the plurality of features allow for a significant increase in surface area contact between adjacent layers. This helps to increase the mechanical and chemical bonding over the same size compact, while also transferring stresses in different directions sufficient to reduce delamination problems. As a general guideline, the plurality of features can increase the surface area of the interface from about 1.4 to about 4  $\text{cm}^2$  per  $\text{cm}^2$  of non-contoured area. As additional guidance on suitable patterns of features, the plurality of features can be present at a concentration of from about 15 to about 1000 features per

cm<sup>2</sup>, and preferably from about 50 to about 300 features per cm<sup>2</sup>. In one embodiment, individual features can have a dimension from about 0.3 mm to about 1 mm, and most often about 0.5 mm to about 0.7 mm.

[0077] FIG. 3 illustrates a stamp 26 having an inverse pattern designed to create a desired pattern of features in the powdered particles. The stamp can be pressed into the mixture 22a to form the plurality of features 28 and then removed. The resulting layer of particles will eventually form a polycrystalline superabrasive working layer.

[0078] Referring now to FIG. 4, a mixture 22b of superabrasive particles, binder metal, and bonding medium can also be prepared for formation of the intermediate layer as discussed previously. This mixture 22b can be distributed over mixture 22a as shown.

[0079] A substrate can then be prepared as a solid sintered metal, partially sintered mass, or unsintered green body. The substrate can be preformed and then placed on the mixture 22b, or can be formed in situ by placing unsintered powder in the reaction cup 24. Additionally, as shown in FIG. 5A, the substrate 34a can also have a plurality of features on one or both opposing surfaces. Alternatively, as shown in FIG. 5B, the substrate 34b can be a standard substrate having substantially planar surfaces.

[0080] As shown in FIG. 6A, the substrate 34a can then be placed against the mixture 22b forming a portion of the precursor assembly. Similarly, as shown in FIG. 6B, the substrate 34b can be placed against the mixture 22b to form a portion of the precursor assembly. The process as described in connection with FIGS. 2 through 4 can be repeated to form a two layered assembly. The second two layered assembly can then be combined with the portion of FIGS. 6A or 6B to form a precursor assembly 10b and 10c, as shown in FIGS. 7A and 7B, respectively.

[0081] This process can also be repeated multiple times in order to form multi-layered compacts and tools as described herein. Additionally, the formation of the plurality of features at each interface can be tailored to a specific tool. Thus, some interfaces can be substantially planar. Typically, at least the interface between the working layer and the intermediate layer will be contoured. Alternatively, or in addition to, each contoured interface can differ from other contoured interfaces in shape, concentration, etc. Thus, for example, a first interface can have a plurality of pyramids, while a second interface can have a plurality of mounds.

[0082] Most preferably, the powdered mixtures used in formation of the precursor assembly are substantially free of organic material as such organic materials can interfere with formation of a high quality product through introduction of defects and weaker graphitic carbon deposits.

[0083] Referring again to FIGS. 1A, 7A, and 7B, the precursor assembly 10a, 10b, and 10c, respectively, can be placed in an HPHT apparatus such as a belt-type press, multi-anvil apparatus, bar-type apparatus, toroid apparatus, or any other HPHT apparatus capable of achieving pressures and temperatures sufficient to cause superabrasive bonding and/or growth. Upon heating at high pressures, the superabrasive particles in the superabrasive layers are bonded together to form polycrystalline layers. In one aspect of the present invention, the polycrystalline layers include superabrasives bonded together by sintering. The final sintered

polycrystalline layers will have a thickness which, of course, will be slightly thinner than the pre-sintered thickness. Those skilled in the art are well acquainted with taking these changes in dimension into account in designing appropriate molds and determining appropriate thicknesses of each layer in the precursor to achieve desired final dimensions.

[0084] Once placed in the HPHT apparatus, the precursor assembly can be consolidated to form a polycrystalline compact. Typically, consolidation can include sintering, growth, and/or bonding of the particles to form a polycrystalline compact. The sintering process of the present invention can occur at a temperature of from about 1,200° C. to about 1,500° C. and a pressure of from about 1 GPa to about 7 GPa, although conditions outside this range can be used depending on the HPHT apparatus and particular superabrasive particles chosen. As the pressure is increased, even lower temperatures can be used to achieve sintering of superabrasive particles. For polycrystalline compacts of fine grained PCD or PCBN, lower temperatures and thus higher pressures, are often preferred in order to minimize grain growth. Significant grain growth results in cleavage planes which can lead to premature cracking and failure of the material under applied forces. However, almost any pressure can be used, provided it is sufficient to prevent conversion of diamond to graphite or the conversion of CBN to hexagonal boron nitride.

[0085] Various additional known processes can be utilized in the present invention. For example, a wide variety of catalyst removal processes can be used such as acid leaching or other processes known to those skilled in the art. Removal of the catalyst, i.e. sintering aid or carbon solvent, can help to improve the high temperature performance of the final PCD material by removing the lower melting temperature metals from the tool.

[0086] The polycrystalline compact thus produced can have at least two polycrystalline layers. The polycrystalline layers can be substantially parallel as shown in FIGS. 1A and 7A through 10A, although this orientation is not always required. In an alternative embodiment of the present invention, the polycrystalline layers can be contoured to provide specific cutting or abrading characteristics to the final tool. Such contoured polycrystalline layers are considered within the scope of the present invention.

[0087] In one alternative embodiment of the present invention, a polycrystalline layer can be formed on one side of a substrate as discussed above. A second polycrystalline layer can be formed on one side of a separate second substrate. The two substrates can then be attached along non-polycrystalline surfaces, i.e. the surfaces opposite the polycrystalline layer, by brazing, gluing, welding, clamping, HPHT welding as explained below, or the like, to form a double-sided polycrystalline compact similar to that shown in FIG. 1A. Thus, in this embodiment, the substrate 12 is comprised of two separate materials bonded together.

[0088] The polycrystalline layers of the present invention can be formed in a variety of configurations and shapes which can be tailored to any number of abrasive applications. In one embodiment, the polycrystalline layers can have a thickness of from about 0.05 mm to about 3 mm and can also range from about 0.1 mm to about 1.6 mm. Many commercial products such as SYNDITE cutting tool blanks (available from Element Six Co.) can effectively utilize

polycrystalline layers having a thickness of from about 0.40 mm to about 0.90 mm. As mentioned above, thicknesses greater than about 1.6 mm to about 2 mm can often result in polycrystalline structure which is non-homogenous and is subject to premature failure, depending on the superabrasive particle size. As explained above, increased thicknesses of up to about 5 mm can be achieved by using larger particle sizes. One of the advantages of the present invention is to make possible polycrystalline compacts having effective thicknesses greater than 2 mm with minimal or no suffering of microstructure homogeneity, regardless of the superabrasive particle size. For example, although the substrate can have almost any practical thickness, a substrate having a thickness of from about 1 mm to about 10 mm can be used to produce a polycrystalline compact having a total thickness of from about 1 mm to about 14 mm, and preferably from about 0.5 mm to about 5 mm. Further, such tools can incorporate superabrasive particles having an average particle size, i.e. diameter, of from about 0.5  $\mu\text{m}$  to about 0.5 mm without a reduction in the homogeneity and quality of the polycrystalline layers.

[0089] Accordingly, the methods of the present invention can further include forming a polycrystalline compact wherein an effective thickness of the polycrystalline compact or insert is extended using a non-superabrasive intermediate material, e.g., substrate as discussed above or other suitable material. The effective thickness **18** is measured as the overall thickness of the polycrystalline compact or insert as shown in **FIGS. 8A and 8B**. This effective thickness corresponds to what would typically be a single polycrystalline layer. Such multi-layered polycrystalline compacts typically have at least two external polycrystalline layers separated by at least a substrate as described above, although additional layers can be formed if desired, as shown in **FIG. 10A** which is described more fully below. In addition to avoiding problems associated with forming thick polycrystalline layers such as those shown in **FIG. 1B**, the resulting polycrystalline compact of the present invention localizes the use of expensive superabrasive primarily at surfaces of the compact or insert which will be used in abrading or otherwise cutting into a work piece, as shown in **FIGS. 1A and 7A** through **10A**.

[0090] The polycrystalline articles of the present invention can be used to form a polycrystalline tool for use in a wide variety of applications. The polycrystalline articles of the present invention can be incorporated directly into a polycrystalline tool or can be cut into various shapes. Exemplary polycrystalline tools include, without limitation, drill bits, cutting inserts, saw blades, wire drawing dies, wire saws, and any other tool known to those skilled in the art, e.g., indexable inserts and throw-away PCD/PCBN tools. The polycrystalline articles of the present invention can be formed using a wide variety of superabrasive particle sizes and can range from about 0.5  $\mu\text{m}$  to about 0.5 mm, although larger sizes may be desirable in some highly abrasive applications. Typical applications can use superabrasive particles having an average particle size of from about 1  $\mu\text{m}$  to about 60  $\mu\text{m}$ . Further, the polycrystalline layers can have a superabrasive particle content of from about 50% by volume to about 95% by volume. Additionally, the presence of a non-superabrasive substrate placed between polycrystalline layers results in improved mechanical strength and increased service life of the tool. The polycrystalline articles of the present invention can be formed having specific

shapes during preparation of the precursor assembly. Alternatively, the polycrystalline articles of the present invention can be cut and shaped to predetermined specifications subsequent to HPHT processing. For example, polycrystalline inserts can be designed for cutting, grooving, milling, turning, finishing, polishing, threading, and the like. Further, such inserts can be contoured to produce specific profiles in a work piece, such contours being known to those skilled in the art.

[0091] In order to reduce waste of polycrystalline material, the polycrystalline articles of the present invention can be cut such that a plurality of polycrystalline tool inserts are formed. The polycrystalline article can be cut using any known technique, e.g., laser and wire EDM. **FIG. 8A** shows a rectangular double-sided polycrystalline insert **20a** cut from the polycrystalline compact of **FIG. 1A**. Similarly, **FIG. 8B** shows a triangular double-sided polycrystalline insert **20b** cut from the polycrystalline compact of **FIG. 1A**.

[0092] The polycrystalline articles, i.e. compacts or solid articles, or polycrystalline inserts formed therefrom can be attached to a tool body to produce an abrasive polycrystalline tool. Attachment to a tool body can be accomplished by any known method such as brazing, gluing, welding, clamping, interference fitting, or other similar methods. The polycrystalline article or polycrystalline inserts can be attached along at least a portion of the substrate to the tool body. Thus, as can be seen in **FIG. 9**, polycrystalline inserts **20b** can be attached along a side of the insert such that a portion of the substrate and the edges of each polycrystalline layer are in contact with the tool body **30**. Although any known braze can be used, it is often preferable to utilize a braze which contains a carbide, boron, or nitride former in order to strengthen the bond between the substrate and the edge of the polycrystalline layers which contact the tool body **30**, as shown in **FIG. 9** at **32**. For polycrystalline compacts or inserts wherein the superabrasive is diamond, carbide formers such as such as nickel, cobalt, manganese, iron, silicon, aluminum, titanium, vanadium, chromium, zirconium, molybdenum, tungsten, alloys thereof, and the like can be used. Those skilled in the art will recognize various factors which affect the composition of the braze chosen for a particular purpose and such braze materials can be chosen by those skilled in the art. For example, carbide formers such as iron, aluminum, nickel and others have a low melting point which may reduce the strength of the braze bond at high temperatures associated with many cutting applications. Similarly, if the superabrasive is cBN, the braze can include boride or nitride formers such as tantalum, titanium, aluminum, zirconium, silicon, and alloys thereof.

[0093] Alternatively, the double-sided polycrystalline compacts of the present invention can be attached to an additional substrate **40**, as shown in **FIG. 10A**. **FIG. 10A** illustrates a drill bit having two polycrystalline layers **14** and **16**. **FIG. 10B** illustrates a drill bit produced by conventional methods having a single polycrystalline layer **42**. The substrate layers **12** and **40** shown in **FIG. 10A** can be formed simultaneously with the polycrystalline layers **14** and **16**. For example, a cup assembly can be formed by placing layers of superabrasive and substrate materials as either solid or powder to form a precursor assembly. The assembly can then be subjected to HPHT conditions. Alternatively, each layer can be formed in separate steps and the substrate **40** can be attached as discussed above.

[0094] Extending the effective thickness of the polycrystalline layers in accordance with the principles of the present invention allows production of polycrystalline tools having a thickness or effective thickness greater than about 1.6 mm to about 2 mm, without regard to superabrasive particle size. An additional benefit of the polycrystalline compacts and inserts of the present invention includes extended tool life. Specifically, traditional PCD and PCBN inserts are single sided and can be attached to a tool body. Upon wear of the polycrystalline surface the insert is typically removed and replaced. The polycrystalline compacts and inserts of the present invention include at least two abrading or cutting surfaces, thus at least doubling the useful life the tool. Further, having polycrystalline superabrasive on two opposing edges of the compact or insert allows for applications such as reversible cutting and abrading, and other applications made possible by having a double-sided PCD/PCBN which are difficult or not possible using traditional single sided compacts.

[0095] The polycrystalline layers of the present invention can be joined to one another or to a substrate using a HPHT welding process in order to manufacture the various embodiments of the present invention. The HPHT welding process is a method, in accordance with one aspect of the present invention, of joining two surfaces, at least one of which can be a polycrystalline layer. As an illustration of this process, a polycrystalline layer and a substrate can be joined as described below. A substrate can be provided having a contact surface. The substrate can be formed as described above in connection with other embodiments of the present invention. The contact surface can be any surface, or portion of a surface, of the substrate which is configured to be joined to a polycrystalline layer. Generally, this contact surface is a flat surface, however contoured and shaped surfaces can also be suitable for use in the HPHT welding process of the present invention. At least one polycrystalline layer can also be provided having a surface configured for joining to the contact surface. The polycrystalline layer can be a solid PCD or PCBN or can be a layered polycrystalline article such as a double-sided compact, described previously, or a sandwich segment, described below. These polycrystalline layers are preferably HPHT sintered products produced in a prior separate step.

[0096] One or both of the polycrystalline surfaces and the substrate contact surfaces can be coated with a coupling agent. The coupling agent can be any material capable of acting as a sintering aid under HPHT conditions. Suitable coupling agents can include, without limitation, cobalt, titanium, nickel, manganese, iron, silicon, aluminum, vanadium, chromium, zirconium, molybdenum, tungsten, tantalum, and alloys thereof. Currently preferred coupling agents include cobalt and titanium. Titanium and several other coupling agents such as tantalum, aluminum, zirconium, silicon, and alloys of these metals can act as both carbide and nitride formers. Coating of the coupling agent can be performed by a wide variety of processes. Several suitable coating processes include, but are not limited to, sputtering, electrodeposition, electroless deposition, spot-welding, and combinations thereof. In one embodiment, coating of the coupling agent can be performed by sputtering. The coating can be applied at various thicknesses depending on the final tool desired. However, the coating typically can have a thickness of from about 1  $\mu\text{m}$  to about 0.5 mm, and preferably from about 3  $\mu\text{m}$  to about 20  $\mu\text{m}$ . One consideration in

determining an appropriate thickness for the coating layer is that a thinner layer can result in a more uniform boundary in the final tool from one joined layer to an adjacent layer. Further, extremely thick layers may result in a multi-layer polycrystalline article having excess coupling agent. The presence of excess coupling agent or excessive amounts of metal binder can weaken the final article at high operating temperatures.

[0097] After the coating is formed on either or both of the surfaces to be joined, the surfaces can be placed in contact with one another in a predetermined orientation to form a polycrystalline precursor. The polycrystalline precursor can then be placed in a HPHT apparatus and subjected to high pressure and high temperature sufficient to bond surfaces having a coupling agent coated therebetween. During this HPHT welding process the coupling agent acts to sinter adjacent layers together. As mentioned in connection with previous discussions of HPHT processes, typical temperatures can range from about 1,200° C. to about 1,500° C. and pressures can range from about 1 GPa to about 7 GPa, although conditions outside these ranges can be used.

[0098] The above HPHT welding process can also be applied to joining two or more polycrystalline layers to form a multi-layered polycrystalline article. Referring now to FIG. 11, a multi-layered polycrystalline precursor is shown generally at 50. Polycrystalline layers 52a, 52b, 52c, and 52d can be formed in accordance with either the principles previously described herein or traditional methods. These polycrystalline layers typically include superabrasives bonded together by sintering. Between each contacting layer is placed a layer of a coupling agent 54a, 54b, and 54c. It will be understood that each polycrystalline layer can have independently selected thicknesses, superabrasive particle sizes, and contours. Similarly, the layers of coupling agent 54 can each have differing characteristics. The coupling agent can be any metal binder which acts to create chemical bonds between the polycrystalline layers as discussed above. The coupling agent can be coated on either or both of the surfaces of adjacent polycrystalline layers 52 which are placed in proximity to one another. The coupling agent can be coated on a surface of the polycrystalline layers using any known technique such as, but not limited to, sputtering, electrodeposition, electroless deposition, spot-welding, applying as a paste, applying as a thin foil, and the like. The polycrystalline layers 52 can be placed in a predetermined orientation with respect to one another corresponding to a desired final tool configuration to produce the multi-layered polycrystalline precursor 50. Typically this configuration is substantially parallel layers as shown in FIG. 11; however other orientations could also be used.

[0099] The multi-layered precursor assembly 50 can then be placed in an HPHT apparatus and subjected to high pressure and high temperature sufficient to bond adjacent polycrystalline layers together. The resulting interface between layers is typically a sintered layer of polycrystalline particles which approaches the strength and stability of a solid polycrystalline material formed in a single step. Further, by bonding polycrystalline layers in accordance with the present invention, almost any thickness can be achieved regardless of the superabrasive particle size. Conceivably, the only limitation on thickness is the size of the HPHT apparatus available for processing.

**[0100]** The above described HPHT welding process enables economic production of a wide variety of products which were either difficult or impossible to produce using conventional methods. For example, often it is desirable to form a sandwich segment for drill bit inserts and the like. These sandwich segments include a polycrystalline layer having a metal substrate on either side. In accordance with the present invention, such sandwich segments can be produced by providing two traditional polycrystalline compacts having a single polycrystalline layer each bonded to a substrate. At least one of the polycrystalline surfaces can then be coated with a coupling agent and joined using the HPHT welding process of the present invention. Alternatively, one or more additional polycrystalline layers can be HPHT welded between the two compacts to form a sandwich segment of almost any thickness and particle size. Thus, the methods of the present invention allow for a significantly increased gamut of polycrystalline tool dimensions and grain sizes.

**[0101]** In an additional alternative embodiment, PCD and PCBN layers can be joined by HPHT welding. A suitable coupling agent can be used which form both carbide and nitride bonds which allows for multi-layered articles having adjacent PCD and PCBN layers sintered and joined together. Non-limiting examples of such coupling agents include titanium, tantalum, aluminum, zirconium, silicon, and alloys thereof.

**[0102]** In an additional aspect of the present invention, any of the embodiments disclosed herein can include polycrystalline layers having superabrasive particles of different average particle size. By adjusting the superabrasive particle size in each layer, the abrasiveness, cutting speed, and cutting quality can be tailored to obtain specific abrasive and/or cutting characteristics. Thus, an outer surface can have a coarse superabrasive for initial cutting and abrading, while a second or later contact surface can have a finer superabrasive for improving the surface finish of a workpiece. This tailored polycrystalline structure reduces the necessity for extensive finishing steps and can help to remove debris and rough edges. For example, the double-sided polycrystalline compacts of **FIGS. 1A and 7A** through **10A** can include polycrystalline layers having different average particle sizes. Likewise, the polycrystalline layers of **FIG. 11** can include superabrasive particles having different particle sizes depending on the intended application. In one embodiment, a first contact surface of a polycrystalline layer can have superabrasive particles with an average particle size of from about 1  $\mu\text{m}$  to about 10  $\mu\text{m}$  and a contact surface of a second polycrystalline layer can have superabrasive particles with an average particle size of from about 20  $\mu\text{m}$  to about 60  $\mu\text{m}$ . Preferably, the first polycrystalline layer can have superabrasive particles with an average particle size of from about 2  $\mu\text{m}$  to about 4  $\mu\text{m}$  and the second polycrystalline layer can have second superabrasive particles with an average particle size of from about 30  $\mu\text{m}$  to about 50  $\mu\text{m}$ . It will be understood that these ranges are merely exemplary and other ranges can be used depending on the specific abrading application. Additional layers can also be included each having a tailored superabrasive particle size designed for a specific abrading application.

**[0103]** As an illustration of applying several of the principles of the present invention, **FIG. 12** shows a wire drawing die for forming a wire. The wire drawing die **60** can

include a substrate **62**. Although any of the aforementioned substrate materials can be used, tungsten carbide is currently preferred. It should be noted that **FIG. 12** is a side cross-sectional view, while an overhead view would show a circular cross-section having annular layers of substrate and polycrystalline material. On the inner surface of the substrate **62** is formed at least two polycrystalline layers. Initial drawing layer **64** can be formed from superabrasive particles having a coarse size such as from about 30  $\mu\text{m}$  to about 50  $\mu\text{m}$ . Finishing layer **66** can be formed from superabrasive particles having a finer size such as from about 2  $\mu\text{m}$  to about 4  $\mu\text{m}$ . The above ranges can be adjusted depending on the application and are merely provided as an illustration of the initial coarse abrading followed by a finer finishing abrading step. Thus, as a rough wire **68** is drawn through the annular opening, the wire passes through the initial drawing layer **64** and then out of the drawing die through finishing layer **66**.

**[0104]** In one embodiment, the drawing die can be formed by HPHT welding two solid polycrystalline layers, as discussed above in connection with **FIG. 11**. The bonded layers can then be shrink fit inside a metal sleeve substrate. Finally, a wire EDM, laser or the like can be used to cut a wire drawing profile in the die. Other methods of forming such a multi-layered wire drawing die are also considered within the scope of the present invention.

#### EXAMPLES

**[0105]** The following examples illustrate various methods of making double-sided PCD and PCBN tools, as well as, multi-layered polycrystalline articles in accordance with the present invention. However, it is to be understood that the following are only exemplary or illustrative of the application of the principles of the present invention. Numerous modifications and alternative compositions, methods, and systems can be devised by those skilled in the art without departing from the spirit and scope of the present invention. The appended claims are intended to cover such modifications and arrangements. Thus, while the present invention has been described above with particularity, the following Examples provide further detail in connection with several specific embodiments of the invention.

##### Example 1

**[0106]** A layer of CBN particles was mixed with titanium carbide metal and ceramic binder having an average particle size of about 3  $\mu\text{m}$ . The mixture was then placed in a tantalum cup having an inner diameter of 51 mm to a thickness of about 1.5 mm. A cylindrical cobalt cemented tungsten carbide substrate having a thickness of 3 mm was then placed over the layer of CBN. A second layer of CBN having an average particle size of about 3  $\mu\text{m}$  was mixed with TiC and TiN powders was then placed on top of the substrate to a thickness of about 1.5 mm to form a precursor assembly. The precursor assembly was then placed in a HTHP belt apparatus and pressed to about 5 GPa and heated to about 1,400° C. for about 30 minutes. The mixture of CBN and titanium carbide was sintered under HPHT to form chemical bonds between CBN particles and TiC particles. The PCBN sintered mass was then allowed to cool and removed from the apparatus. The sintered PCBN was finished by conventional grinding and lapping processes into a final PCBN of 50.8 mm diameter and 4.8 mm thick with a

PCBN layer of 1.0 mm thick on each side. This double-side PCBN was wire EDM cut into squares and rounds for use as a PCBN insert tool.

#### Example 2

[0107] A layer of diamond particles having an average particle size of about 30  $\mu\text{m}$  was placed in a tantalum cup having an inner diameter of 35 mm to a thickness of about 1.5 mm. A cylindrical cobalt cemented tungsten carbide substrate having a thickness of 1.0 mm was then placed over the layer of diamond. A second layer of diamond also having an average particle size of about 4  $\mu\text{m}$  was then placed on top of the substrate to a thickness of about 1.5 mm and then another piece of cylindrical cobalt cemented tungsten carbide substrate having a thickness of about 11 mm was placed on the second layer of diamond to form a precursor assembly. The precursor assembly was then placed in a HPHT belt apparatus and pressed to about 5 GPa and heated to about 1,400° C. for about 30 minutes. The cobalt infiltrated from each of the cemented tungsten carbide substrates to sinter each diamond layers together, thus attaching the layers to the adjacent substrates to form a PCD having multiple PCD layers. The sintered mass was then allowed to cool and removed from the apparatus. The PCD was then finished into a final product of 34 mm diameter and 13mm tall with two diamond layers on top of the PCD, similar to FIG. 10A. A PCD of 19 mm in diameter and 13mm tall was cut out of this product resulting in similar physical dimensions to conventional drill-bit PCD cutters.

#### Example 3

[0108] A layer of CBN particles having an average particle size of about 1.0  $\mu\text{m}$  mixed with titanium nitride was placed in a tantalum cup having an inner diameter of 51 mm to a thickness of about 1.5 mm. A cobalt cemented tungsten carbide substrate having a thickness of 1.2 mm was then placed over the layer of CBN particles. A second layer of CBN particles having an average particle size of about 1.0  $\mu\text{m}$  mixed with titanium carbide and titanium nitride sintering aids was then placed on top of the substrate to a thickness of about 1.5 mm to form a precursor assembly. The precursor assembly was then placed in a HPHT belt apparatus and pressed to about 5 GPa and heated to about 1,300° C. for about 20 minutes. The CBN particles sintered together in the presence of the sintering aids to form a double-sided PCBN compact. The sintered mass was then allowed to cool and removed from the apparatus. The PCBN compact was then finished into several 3.2 mm diameter double-sided PCBN blanks having a PCBN thickness of 1.0 mm on each side.

#### Example 4

[0109] The PCBN compact of Example 3 is cut into several triangular inserts (similar to those shown in FIG. 8B) measuring 60 degrees with a 5.0 mm leg length and 3.2 mm thick using a wire EDM. The triangular inserts are then brazed to two opposing ends of a tungsten carbide milling insert tool (similar to that shown in FIG. 9) using a either a typical braze alloy (Easy-Flo No.45 available from Handy & Harman Co.) or a Pd—Cr—B alloy that melts at 1,000° C. that is heated locally in order to prevent the PCD or PCBN from thermal degradation.

#### Example 5

[0110] A layer of micron-diamond having an average particle size of about 5  $\mu\text{m}$  is placed in a 34 mm diameter

tantalum cup to a thickness of about 1.5 mm. A cobalt cemented tungsten carbide substrate of 3.0 mm thickness was first spot-welded with a 0.15 mm thick cobalt foil placed at each side of substrate and then placed against the 5  $\mu\text{m}$  diamond layer. Another second layer of diamond having a particle size of about 40  $\mu\text{m}$  is then placed over the tungsten carbide layer to a thickness of 1.5 mm. The assembled tool precursor is then placed in a HPHT apparatus and pressed to about 5 GPa and heated to about 1,450° C. for about 30 minutes. The cobalt infiltrates thru both diamond layers to produce a sintered PCD compact. The sintered double-sided PCD is then removed from the apparatus and finished thru conventional PCD finishing operations. The final double-sided PCD of 4.8 mm blank thickness and 1.0 mm PCD layer thickness was obtained with two different PCD grades, i.e. one side is fine grained and the other side is coarse grained PCD.

#### Example 6

[0111] Four HPHT sintered solid PCD discs (34 mm diameter and 1.0 mm thick made with about 2 micrometer diamond grains) were prepared by cleaning the exposed surfaces. One of the surfaces, i.e. top or bottom, of each disc was coated with cobalt by an ion beam sputter method to a depth of about 5  $\mu\text{m}$ . All four solid PCD discs with cobalt coated on one side were assembled in the tantalum cup assembly per FIG. 11 and processed under typical HPHT conditions (5 GPa and 1450 ° C. for 20 minutes). The sintered multi-layered PCD was recovered from the HPHT press and finished per standard grinding and lapping operations. The finished solid multi-layered PCD was obtained as a solid round PCD of 33 mm diameter and 3.5 mm thick. The solid round PCD was wire EDM cut into several small round PCD articles of 8.0 mm diameter and 3.5 mm thick. The individual small round solid PCD was shrink fit into a tungsten carbide jacket for use as a wire drawing die with fine grain. The wire drawing die can also be treated in acid to remove substantially all of the metallic phases from the PCD layers to produce a more thermally stable die.

[0112] It was also noted that coating of materials other than Co such as Ni, Fe, Mo, Ta, and the like would be suitable. Likewise, the coating method can be other than sputtering such as electroplate, electroless, spot-welding of metal on the surface, etc.

#### Example 7

[0113] Several HPHT sintered solid PCBN discs (35 mm diameter and 1.0 mm thick) were prepared by coating titanium on one side of each disc to about 5  $\mu\text{m}$  by an ion sputtering method. Five of these titanium coated discs were assembled in the tantalum cup assembly similar to FIG. 11 to form a multi-layered precursor assembly. This precursor was then placed in a HPHT apparatus and pressed to 5 GPa and heated to 1,350° C. for about 25 minutes. The titanium coating at the interface of both discs reacts with both CBN and non-CBN phases (TiC, TiN, etc) to form chemical bonding through formation of TiN, TiC, TiB, etc. at the interface of both surfaces. The resultant PCBN was a single piece of hard solid PCBN from multi-layers. Another similar test was also conducted with different grades of solid PCBN discs resulting in a solid PCBN of tailored microstructure, i.e. finer and coarser particles in each layer, for use in machining.

[0114] Of course, it is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention and the appended claims are intended to cover such modifications and arrangements. Thus, while the present invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function and manner of operation, assembly and use may be made without departing from the principles and concepts set forth herein.

What is claimed is:

1. A polycrystalline compact, comprising:
  - a) a metal substrate having a first surface and a second surface, wherein the first and second surfaces are non-contiguous;
  - b) a first polycrystalline layer attached to the first surface using a first intermediate layer, said first polycrystalline layer including first superabrasive particles bonded together and said first intermediate layer including a consolidated mixture of first intermediate superabrasive particles and a first binder metal; and
  - c) a second polycrystalline layer attached to the second surface using a second intermediate layer, said second polycrystalline layer including second superabrasive particles bonded together and said second intermediate layer including a consolidated mixture of second intermediate superabrasive particles and a second binder metal.
2. The polycrystalline compact of claim 1, wherein the first and second intermediate superabrasive particles are a mixture of diamond and cubic boron nitride particles.
3. The polycrystalline compact of claim 2, wherein first and second polycrystalline layers are polycrystalline cubic boron nitride and the volume ratio of diamond to cubic boron nitride particles is from about 0.0005:1 to about 0.05:1.
4. The polycrystalline compact of claim 1, wherein the first and second intermediate layers each comprise from about 50 to about 99 vol % superabrasive particles.
5. The polycrystalline compact of claim 1, wherein the first and second binder metals are a member selected from the group consisting of Co, WC, Al, Ti, Ni, and alloys thereof.
6. The polycrystalline compact of claim 1, wherein the first and second intermediate layers comprise from about 5 vol % to about 25 vol % binder metal.
7. The polycrystalline compact of claim 1, wherein the first and second binder metal have an average particle size which is smaller than an average particle size of the first and second intermediate superabrasive particles, respectively.
8. The polycrystalline compact of claim 1, wherein the first and second intermediate layers further include a first and second bonding medium, respectively, and are each a member selected from the group consisting of TiC, TiN, TiCN, AlN, TiB<sub>2</sub>, SiO<sub>2</sub>, Si<sub>3</sub>N<sub>4</sub>, and combinations thereof.
9. The polycrystalline compact of claim 8, wherein the first and second intermediate layers comprise from about 5 vol % to about 25 vol % bonding medium.
10. The polycrystalline compact of claim 1, wherein at least one interface is contoured having a plurality of features, said at least one interface being a first polycrystalline layer-first intermediate layer interface, a second polycrystalline layer-second intermediate layer interface, a first intermediate layer-first surface interface, or a second intermediate layer-second surface interface.
11. The polycrystalline compact of claim 9, wherein the plurality of features are pyramids.
12. The polycrystalline compact of claim 9, wherein a surface area of the at least one interface is from about 1.2 to about 2 cm<sup>2</sup> per cm<sup>2</sup> of non-contoured area.
13. The polycrystalline compact of claim 9, wherein the plurality of features are present at a concentration of from about 50 to about 300 features per cm<sup>2</sup>.
14. The polycrystalline compact of claim 1, wherein the first and second intermediate superabrasive particles have a ratio of largest to smallest particles which is from about 1 to about 500.
15. The polycrystalline compact of claim 1, wherein the first and second superabrasive particles have different average particles sizes.
16. The polycrystalline compact of claim 1, wherein the first and second superabrasive particles have a ratio of largest to smallest particles which is from about 1 to about 10.
17. The polycrystalline compact of claim 1, wherein the first and second intermediate layers have a thickness from about 0.2 to about 0.7 times a thickness of the first and second polycrystalline layers, respectively.
18. A polycrystalline tool formed from the polycrystalline compact of claim 1, wherein the polycrystalline tool is a member selected from the group consisting of drill bit, cutting insert, wire drawing die, and saw blade.
19. A method of forming a polycrystalline compact, comprising steps of:
  - a) forming a first superabrasive layer in a reaction assembly, said first superabrasive layer including first superabrasive particles and an optional first binder metal;
  - b) forming a first intermediate layer adjacent the first superabrasive layer, said first intermediate layer including a mixture of first intermediate superabrasive particles and a first binder metal;
  - c) forming a metal substrate layer adjacent the first intermediate layer;
  - d) forming a second intermediate superabrasive layer opposite the first intermediate layer, said second intermediate layer including a mixture of intermediate second superabrasive particles and a second binder metal;
  - e) forming a second superabrasive layer adjacent the second intermediate layer, said second superabrasive layer including second superabrasive particles and an optional second binder metal; and
  - f) heating said first and second superabrasive layers such that superabrasive particles of each layer are bonded together to form a multilayer polycrystalline compact.
20. The method of claim 19, wherein the substrate is a fully sintered, partially sintered, or unsintered preform mass.

**21.** The method of claim 19, wherein the first and second intermediate superabrasive particles are a mixture of diamond and cubic boron nitride particles.

**22.** The method of claim 21, wherein first and second polycrystalline layers are polycrystalline cubic boron nitride and the volume ratio of diamond to cubic boron nitride particles is from about 0.05:1 to about 1:1.

**23.** The method of claim 19, wherein the first and second intermediate layers each comprise from about 50 to about 99 vol % superabrasive particles.

**24.** The method of claim 19, wherein the first and second intermediate layers comprise from about 5 vol % to about 25 vol % binder metal.

**25.** The method of claim 19, wherein the first and second intermediate layers further comprise from about 5 vol % to about 25 vol % of a bonding medium.

**26.** The method of claim 19, further comprising the step of stamping a surface of at least one of said layers with a pattern of features.

**27.** The method of claim 26, wherein the plurality of features are pyramids.

**28.** The method of claim 26, wherein every interface between differing layers is stamped with the pattern of features.

**29.** The method of claim 19, wherein the first and second superabrasive particles have different average particles sizes.

**30.** The method of claim 19, further comprising the step of cutting the polycrystalline compact such that a plurality of polycrystalline tool inserts are formed having at least two polycrystalline surfaces.

**31.** The method of claim 30, further comprising the step of attaching at least one of the plurality of polycrystalline tool inserts to a tool body, wherein at least a portion of the substrate is attached to the tool body.

**32.** The method of claim 30, further comprising the step of attaching at least one of the plurality of polycrystalline tool inserts to a tool body, wherein only one of the first and second polycrystalline layers is attached to the tool body.

\* \* \* \* \*