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(54) ENHANCED SECONDARY SUBSTRATE FOR POLYCRYSTALLINE DIAMOND COMPACT CUTTING ELEMENTS

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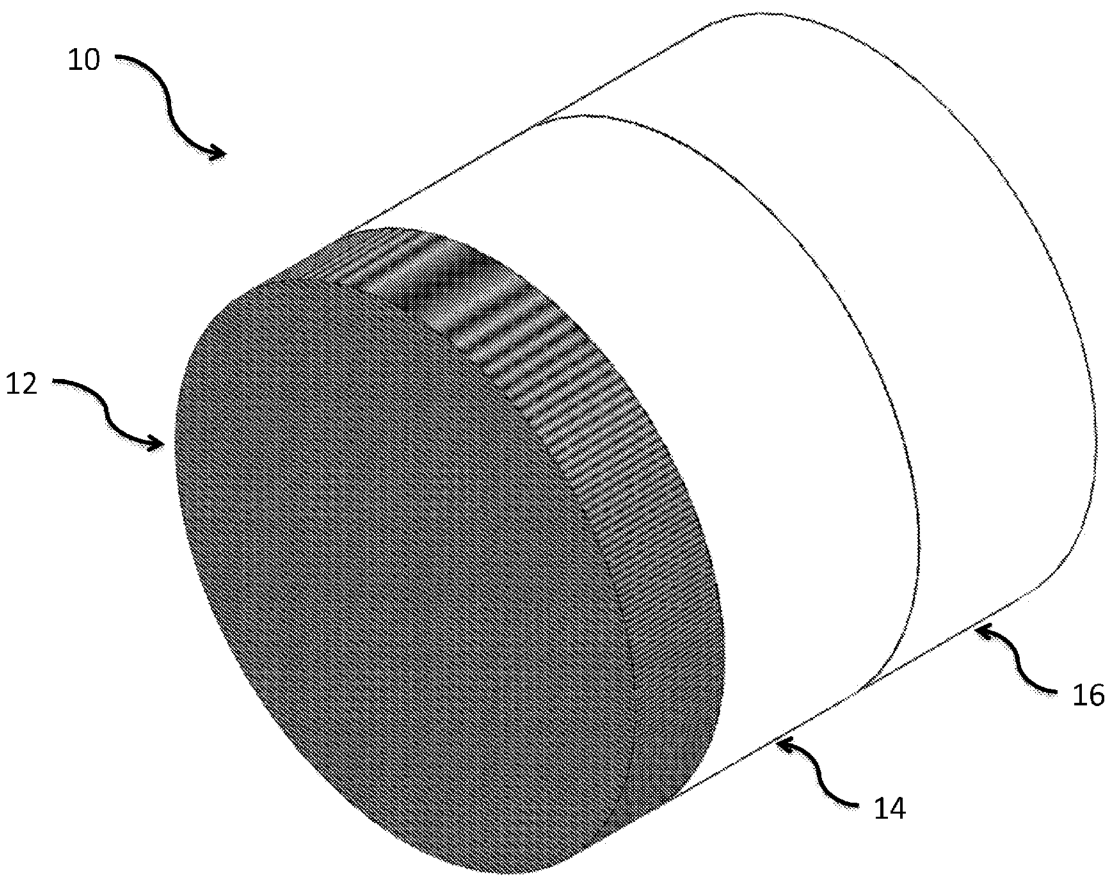
(57) **ABSTRACT**

A cutting structure for a drill bit includes a diamond table affixed to one end of a first substrate. A second substrate is affixed to the other end of the first substrate. The second substrate is made from a different material than the first substrate. The first and second substrates are substantially coaxial.



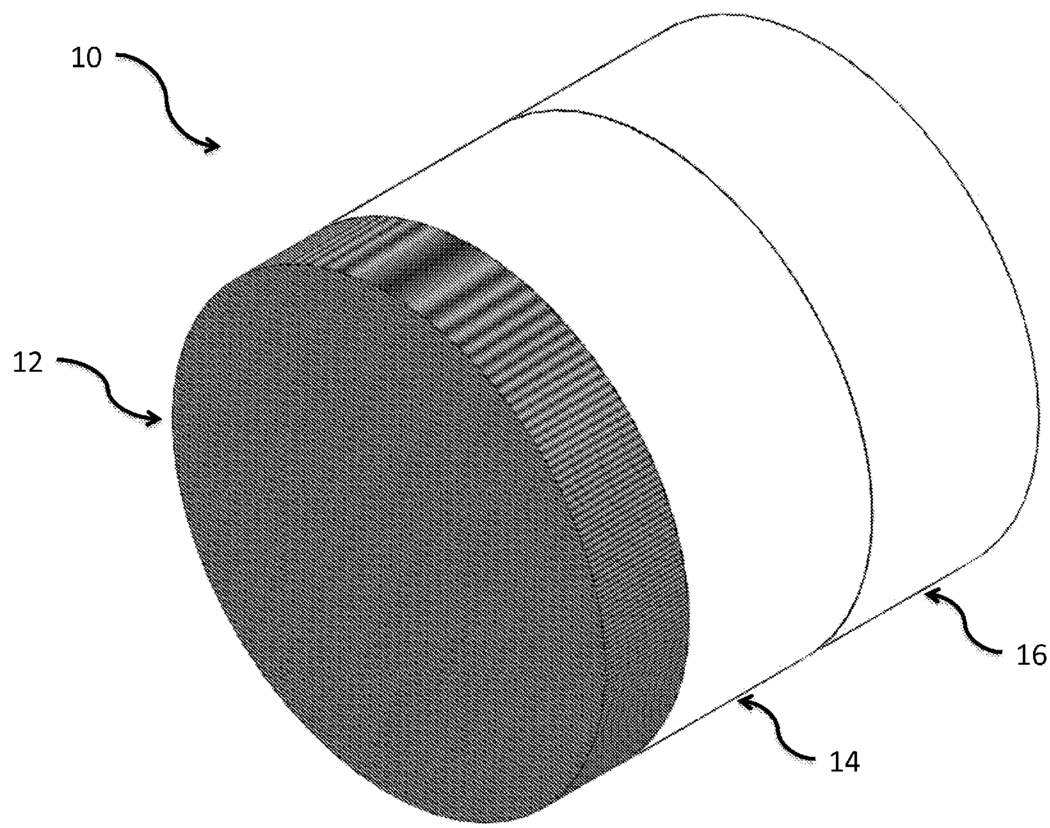


Fig. 1

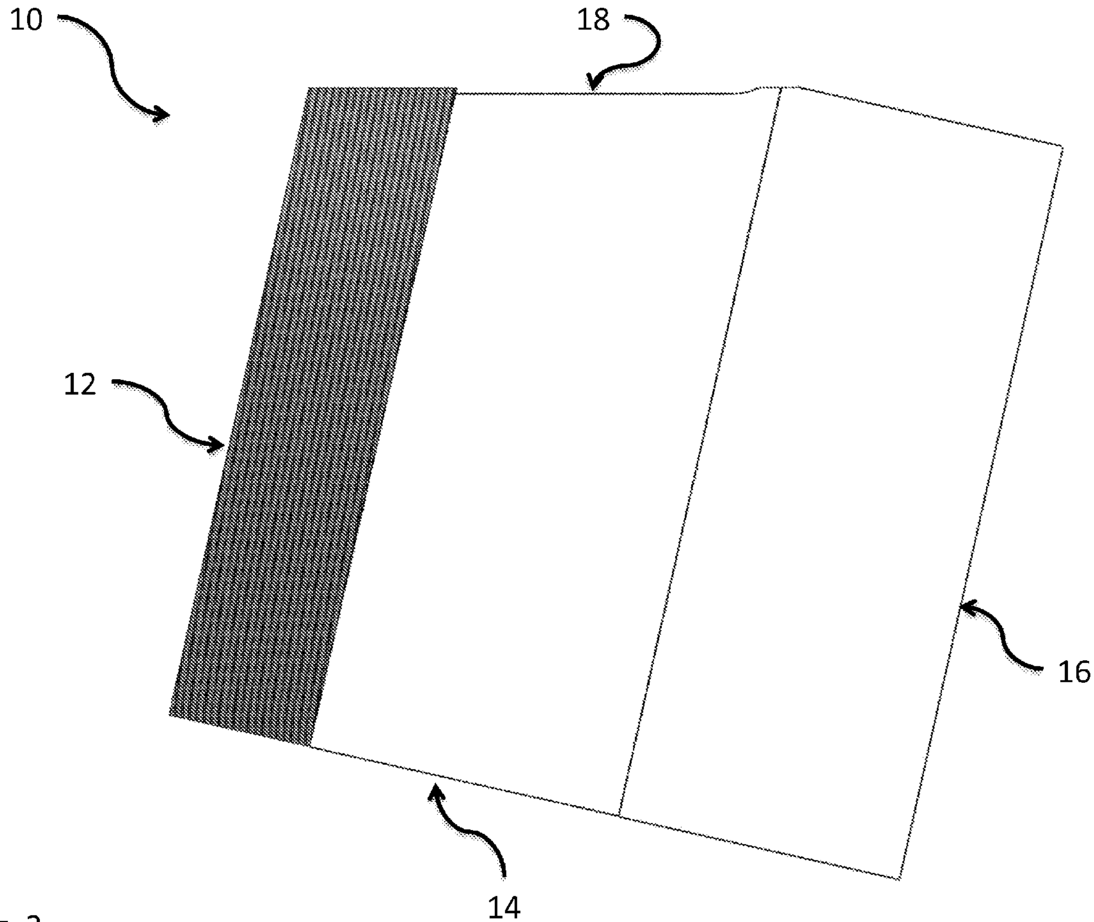


Fig. 2

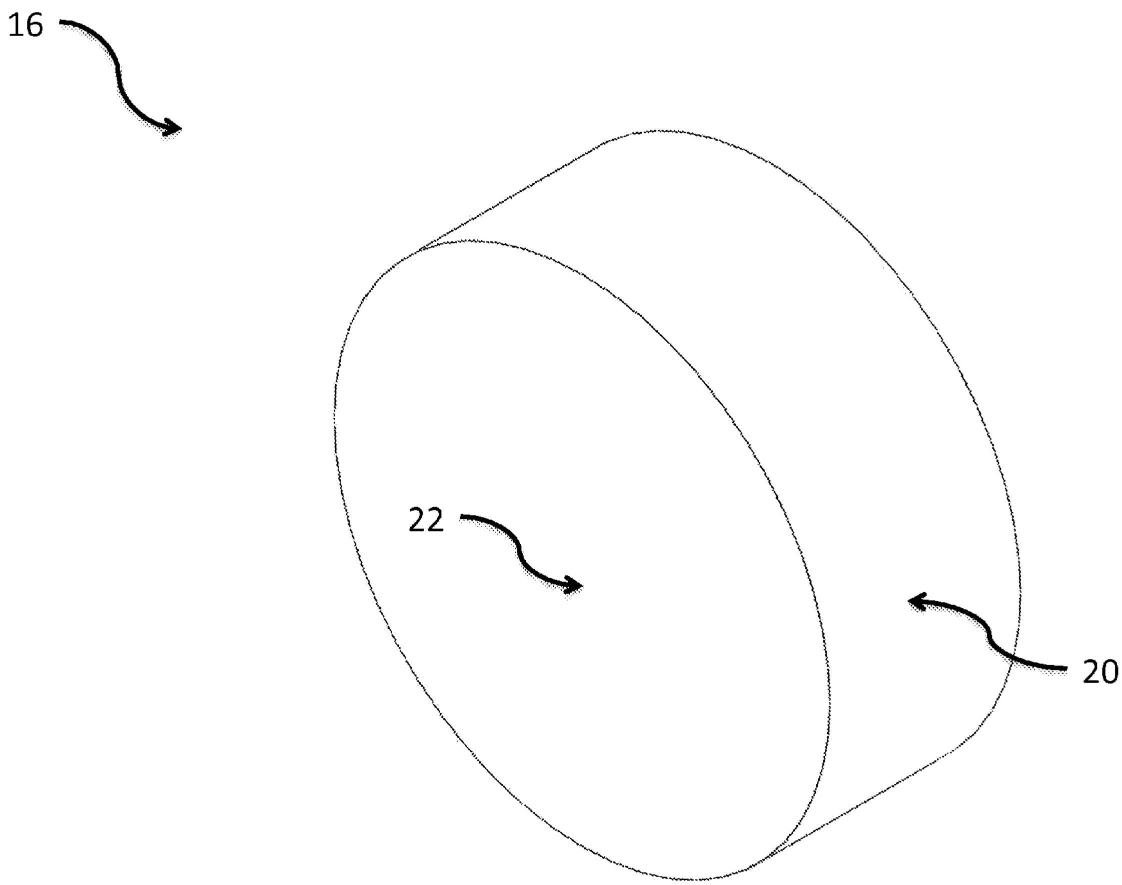


Fig. 3

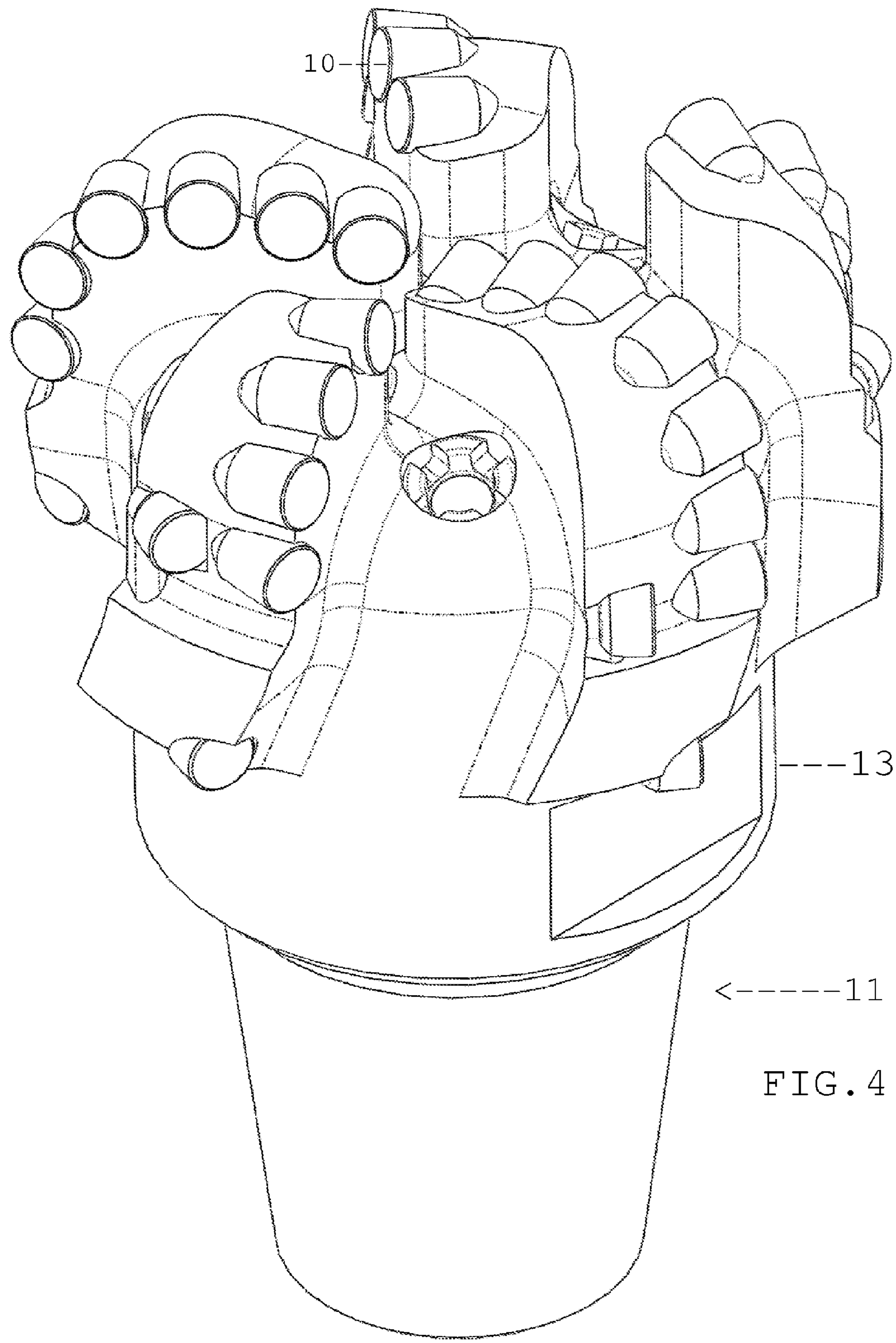


FIG. 4

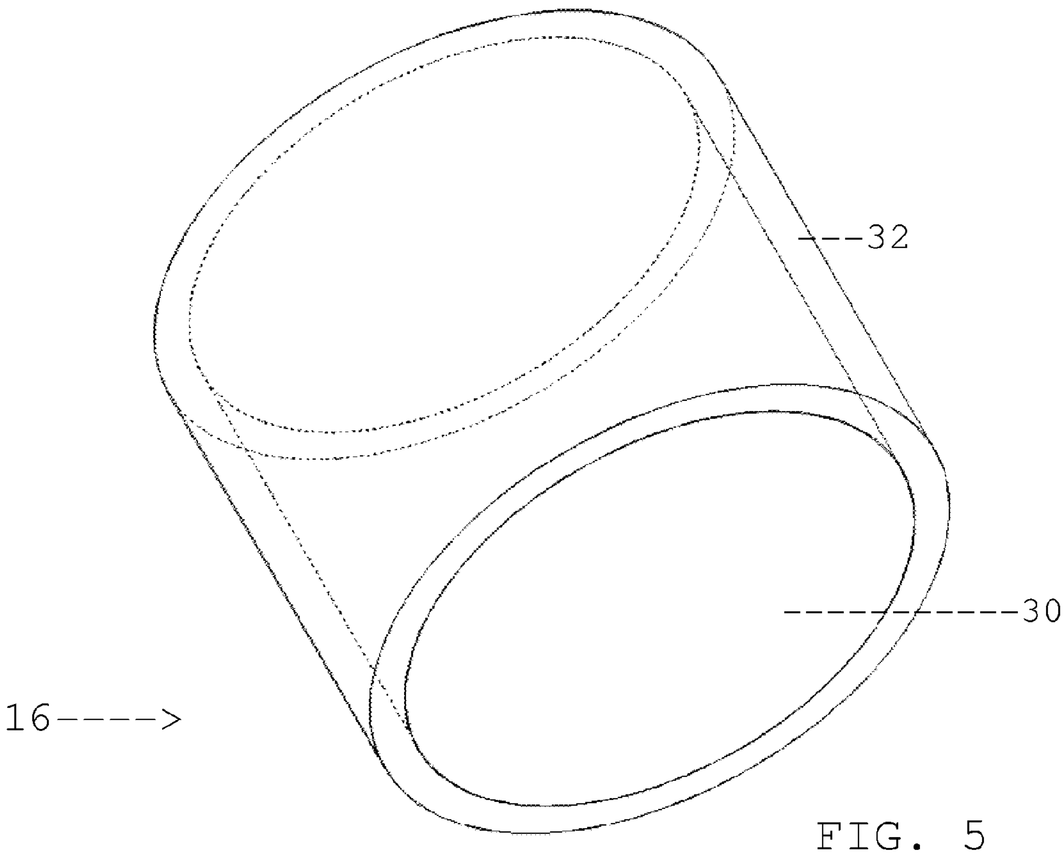


FIG. 5

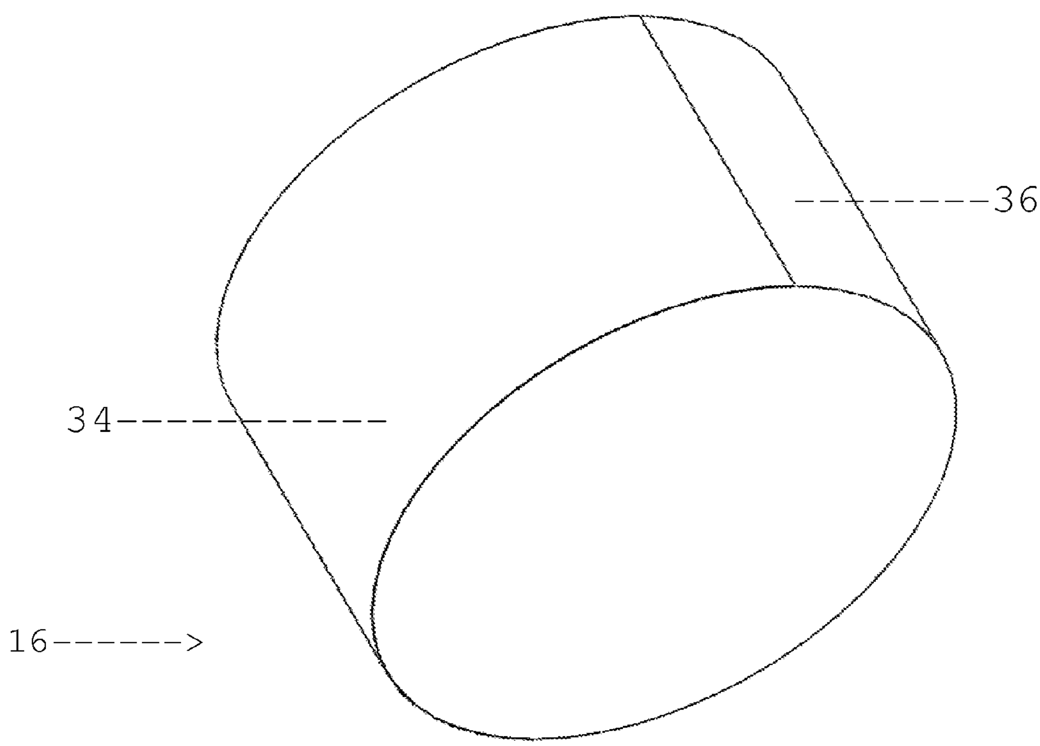


FIG. 6

ENHANCED SECONDARY SUBSTRATE FOR POLYCRYSTALLINE DIAMOND COMPACT CUTTING ELEMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Priority is claimed from U.S. Provisional Application No. 61/244,723 filed on 22 Sep. 2009.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND OF THE INVENTION

[0003] 1. Field of the Invention

[0004] The present invention is related to fixed cutter drill bits used for drilling wellbores in subsurface earthen formations. More particularly, the present invention relates to polycrystalline diamond compact ("PDC") cutters used to shear earthen formations in so-called "fixed cutter" drill bits.

[0005] 2. Background Art

[0006] Polycrystalline diamond compact ("PDC") cutting elements, called "cutters", used in wellbore drill bits are well known in the art. Generally, a PDC cutter is created in a high-temperature, high-pressure process. During the high-temperature, high-pressure process, called a "press cycle", a polycrystalline diamond "table" is created from synthetic diamond grit. During the press cycle the diamond table is also bonded to a substrate, usually formed from cemented tungsten carbide ("carbide"), forming the pieces into a cylinder with an integral carbide substrate.

[0007] In many cases, PDC cutters are manufactured with a short overall length to allow the making of multiple PDC cutters in a single press cycle. For cutters made with such short length substrates as above, in order to extend the length of the PDC cutter to an industry-acceptable dimension, a second cemented tungsten carbide substrate is bonded to the short length PDC cutter substrate in a separate process. Such processes include methods such as the "LS Bonding" process described in U.S. Pat. No. 4,225,322 issued to Knemeyer. Generally, the characteristics of the second carbide substrate are matched as closely as possible to the characteristics of the carbide substrate that is bonded to the diamond table (i.e., the short length substrate).

[0008] As is well known in the art, PDC cutters are generally attached to drill bit bodies, which can be either made from steel or a tungsten carbide 'matrix', through brazing. The extended length PDC cutter, for example, as created through the addition of the second carbide substrate to a short length substrate as explained above, is therefore required to provide sufficient surface area to make a reliable braze joint between the cutter and the bit body.

[0009] Drill bits that use PDC cutters as their primary cutting elements are called 'PDC bits'. PDC bits were first used for drilling earth formations in the 1970's. Initially, PDC bits were primarily used for drilling low-strength formations because the PDC cutters could not withstand the forces created when drilling harder formations. More recently, however, PDC bit design and PDC cutter technology has improved substantially, thus enabling PDC bits to drill many tougher formations more effectively than other types of drill bits. However, there are still many formations that are too hard or too abrasive to be effectively drilled with PDC bits, and these formations result in the most expensive drilling in the industry because the speeds at which such formations can be drilled are very low, and drill bit life is very short.

[0010] Many attempts have been made to further increase the wear resistance of PDC bits, including the use of cylinder cutters comprised of a variety of thermally stable diamond pieces, such as is disclosed in U.S. Pat. No. 5,205,684 issued to Meskin et al., and the addition of diamond particles into the body of the bit or as separate inserts behind PDC cutters, such as is disclosed in U.S. Pat. No. 4,718,505 issued to Fuller. Unfortunately, in many cases, when the wear resistance of a PDC cutter is improved, the overall life of the bit may not increase in many drilling applications due to an increased susceptibility of such PDC cutters to impact damage. In most cases, when a PDC cutter is made more wear resistant, it often becomes more brittle and can fail more quickly when experiencing uneven loading in certain subsurface rock formations.

[0011] Another limiting factor for PDC bits in many drilling applications is excessive wear to the body of the PDC cutter resulting from erosion. In such situations, the carbide substrates wear relatively rapidly, thus accelerating the break down of the PDC cutter and, therefore, reducing the useful life of the PDC bit. U.S. Pat. No. 5,667,028 issued to Truax et al., for example discloses a PDC cutter that has a multitude of PDC segments all formed in the same PDC cutter body. Such arrangement has been observed to help prevent substrate erosion as the PDC material that is embedded in the carbide substrate helps to reduce wear.

[0012] Accordingly, there is a need for PDC cutters with increased longevity under different drilling conditions. A PDC cutter which has enhanced abrasion resistance but unreduced impact resistance will allow a drill bit fitted with those cutters to drill longer sections in hard formations, and a PDC cutter with enhanced erosion resistance will allow a bit fitted with those cutters to drill longer sections in highly abrasive environments.

SUMMARY OF THE INVENTION

[0013] One aspect of the invention is an improved PDC cutter created by bonding a substrate (secondary substrate') of dissimilar material to an integral carbide substrate of a PDC cutter. The material composition of the secondary substrate can be adjusted to enhance the performance of the PDC cutter in accordance with the requirements of the particular drilling conditions to be encountered. The integral carbide substrate and the secondary substrate are substantially coaxial.

[0014] A drill bit according to another aspect of the invention includes a bit body and at least one polycrystalline diamond compact (PDC) cutter affixed to the bit body. The PDC cutter includes at least a diamond table affixed to one end of a first substrate and a second substrate affixed to the other end of the first substrate. The second substrate is made from a different material than the first substrate. The first and second substrates are substantially coaxial.

[0015] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** shows an example PDC cutter according to the invention.

[0017] FIG. **2** shows a recessed section being formed in the integral substrate of a PDC cutter.

[0018] FIG. **3** shows an example of a secondary substrate having different material characteristics at different places within the secondary substrate.

[0019] FIG. **4** shows an example fixed cutter drill bit having at least one cutter made according to the invention.

[0020] FIG. **5** shows an example secondary substrate including a steel center pressed or brazed inside a carbide cylinder.

[0021] FIG. **6** shows an example partially coated secondary substrate, leaving an exposed surface for attachment to a bit body.

DETAILED DESCRIPTION

[0022] FIG. **1** shows an example polycrystalline diamond compact ("PDC") cutting element or "cutter" **10** having a diamond table **12**, a carbide substrate **14** integrally formed with the diamond table (the integral substrate), and a secondary substrate **16** bonded to the integral substrate **14**. While the present example is shown in FIG. **1** and is described herein as a cylinder-shaped cutter, the invention is equally applicable to any shape of PDC cutter. In the present example, the secondary substrate **16** is comprised of a material dissimilar to the material of the integral substrate **14** in order to enhance the performance of the cutter **10**, and can be attached to the integral substrate **14** in a variety of methods that are known in the art. In the invention, while the shape of the cutter is not limited, the integral substrate **14** and the secondary substrate **16** are substantially coaxial.

[0023] The material composition of the secondary substrate **16** can be selected to enhance the performance of the PDC cutter **10** in a variety of different drilling conditions. In situations where PDC cutters tend to experience rapid abrasive wear to the diamond table, the secondary substrate **16** can be formed from highly abrasion resistant material, such as a mixture of tungsten carbide particles with a low metal content, to increase the overall wear resistance of the PDC cutter **10**.

[0024] Another possible advantage to the PDC cutter structure of the invention can be observed in FIG. **2**. As a PDC cutter wears, the self-sharpening action of a PDC cutter, which is well documented in the literature, produces a recessed section **18** in the surface of the integral substrate **14**, located generally between the diamond table **12** and the secondary substrate **16**. This recessed section **18** allows drilling fluid to flow into the void space created by the recessed section **18**, helping to keep the diamond table **12** cool while the secondary substrate **16** inhibits further wear. It will be appreciated by those skilled in the art that the material composition of the secondary substrate **16** can vary widely and yet still have abrasion resistance that is much higher than that of the integral carbide substrate **14**. Such differential abrasion resistance may enhance formation of the recessed section **18**, which may prove advantageous in certain drilling conditions.

[0025] The material composition of the integral carbide substrate **14** is a critical factor in the manufacturing of an effective PDC cutter. The material composition of the integral carbide substrate **14** must be very uniform throughout its cross section in order to properly form the diamond table and handle residual stresses created during the pressing operation. The secondary substrate **16**, however, is under no such limitations, and can therefore have substantially different material properties throughout its cross section. This enables creation of a secondary substrate **16** with, for example, varying abrasion resistance along the cross section.

[0026] Referring to FIG. **3**, in another example the secondary substrate **16** can be made from varying material composition so as to have highest abrasion resistance at the periphery of the substrate structure, as shown at **20**, to help inhibit wear to the diamond table (**12** in FIG. **1**). Conversely, the secondary substrate **22** can also have higher material strength toward the center of the substrate structure, as shown at **22**, to help inhibit breakage of the PDC cutter (**10** in FIG. **1**) under high loading. In other words, unlike the integral carbide substrate (**14** in FIG. **1**), the secondary substrate **16** can be both highly abrasion resistant and highly impact resistant by varying the material properties across the cross section of the secondary substrate (**16** in FIG. **1**).

[0027] A drill bit made using one or more cutters according to any of the examples explained herein is shown in FIG. **4**, wherein the drill bit **11** includes a bit body **13** of types well known in the art for affixing thereto a plurality of PDC cutters **10**. Any or all of the cutters shown in the example bit **11** in FIG. **4** may be made according to any of the examples explained herein, and it is to be clearly understood that the bit body and cutter configuration shown in FIG. **4** is only meant to serve as an example of a drill bit made using cutters according to the invention. Accordingly, the bit and cutter structure and numbers of cutters on the bit as shown in FIG. **4** are in no way intended to limit the scope of the present invention.

[0028] In drilling situations where PDC cutters tend to experience severe impact damage, using a secondary substrate formed from highly abrasion resistant material can allow the use of a more impact resistant diamond table without sacrificing overall wear resistance. As is well known in the art, PDC cutters that are more abrasion resistant tend to be less resistant to impact. As a result, compromises are typically made in the overall design of PDC bits that use highly abrasion resistant cutters in order to minimize impact loading of the cutters and therefore limit impact damage to or breakage of the PDC cutters. Such design considerations may result in a bit that drills less efficiently. However, in the present invention, a diamond table and integral substrate that are inherently more impact resistant, and therefore less abrasion resistant, can be joined with a highly abrasion resistant secondary substrate, and can therefore provide a PDC cutter that is both highly abrasion resistant and highly impact resistant.

[0029] In a further example, in drilling conditions where PDC cutters tend to experience severe impact damage, using a secondary substrate with higher ductility, such as steel, can cushion the force of the impact on the cutters, thus improving the impact resistance of the overall PDC cutter structure. This configuration can also provide a PDC cutter that is both highly abrasion resistant, due to the use of a diamond table that is inherently more abrasion resistant and less impact resistant, and highly impact resistant due to the use of a secondary substrate that cushions the impact loading on the cutter.

[0030] In yet a further example, in drilling conditions where the body of the PDC cutter tends to experience rapid erosive wear, the secondary substrate can be formed with a highly erosion resistant outer layer, as can be provided, for example with many different types of ceramics.

[0031] A secondary substrate can also be made wherein the secondary substrate may be made from a very erosion resistant material layer on the outer surface, for example a material even more erosion resistant that traditional carbides, but may include a material in the center that is tougher and stronger than the erosion resistant material on the outer layer.

[0032] Examples of materials for a secondary substrate that would be more erosion resistant than carbide substrate materials known in the art may include the following:

[0033] a) a made-for-purpose layer of carbide that is formulated to have higher erosion resistance yet lower structural strength than a typical integral substrate would have, as can be achieved by reducing the percentage of metal (typically cobalt) in the carbide substrate;

[0034] b) a substrate wherein the outer layer (OD) has been coated in selected regions with diamond through chemical vapor deposition (CVD) or physical vapor deposition (PVD), yet leaving some of the outer surface uncoated to enable brazing the cutter to the bit body, an example of which is shown in FIG. **6**, wherein a coated portion of the outer surface of the secondary substrate **16** is shown at **34**, and an uncoated portion for affixing the secondary substrate **16** to a bit body is shown at **36**;

[0035] c) a substrate where the outer layer is made from highly erosion resistant ceramic, for example, cubic boron nitride (CBN), while having an inner layer made from stronger, tougher material, including, for example, steel;

[0036] d) a substrate where, again, the material composition across the cross-section varies, but in the present example the substrate may include a very tough/strong center (e.g., much tougher than typically carbides) and an outer layer that conforms to industry standards for erosion resistance. An example of the foregoing would include a steel core pressed or brazed into an annular carbide cylinder. An example of a steel core pressed or brazed into an annular carbide cylinder is shown in FIG. **5**, wherein the core is shows at **30** and the annular cylinder is shown at **32**.

[0037] It is believed in the wellbore drilling industry that drill bits made using PDC cutters affixed to steel bit bodies tend to suffer less impact damage because the steel bit body absorbs the energy from impacts better than matrix bit bodies (as matrix is much harder than steel). To the extent such belief is correct, the same effect could be obtained by making the secondary substrate primarily made from steel to absorb the impact loading on the cutter. One possible additional benefit of making the secondary substrate out of steel is that it becomes possible to weld (instead of braze) the cutter onto a bit. Welding creates a much stronger bond than brazing and may make possible certain bit designs that are not possible using conventionally braze connected cutters.

[0038] In still other examples, the secondary substrate may contain thermally stable polycrystalline diamond ("TSP") segments to enhance wear resistance. The TSP may be in the form of a TSP included in a coating over parts of the secondary substrate or may be included in the material of all or part of the secondary substrate. Certain sections of the secondary substrate should exclude the use of TSP so as to maintain the capability of attaching the cutter to the bit body, such as by brazing.

[0039] In still other examples, it is possible to vary the properties of the secondary substrate along its length rather than across its diameter. For example, a secondary substrate can have a harder and softer portion separated longitudinally. The harder portion could be disposed toward the end where it attaches to the PDC cutter, that is, to substantially match the properties of the integral substrate of the PDC cutter. A softer/tougher material may be disposed longitudinally toward the end of the cutter where it attaches to the drill bit body to enhance braze strength. Such longitudinally varying properties may be made by layering or by gradationally varying the substrate material properties during manufacture.

[0040] PDC cutter bits made according to the various aspects of the invention may enable more flexibility in designing bits to perform optimally under more widely varying drilling conditions than PDC cutter bits known in the art prior to the present invention.

[0041] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

What is claimed is:

1. A cutting structure for a drill bit, comprising:

a diamond table affixed to one end of a first substrate; and

a second substrate affixed to the other end of the first substrate, the second substrate made from a different material than the first substrate, the first and second substrates being substantially coaxial.

2. The cutting structure of claim **1** wherein the diamond table comprises polycrystalline diamond and the first substrate comprises tungsten carbide.

3. The cutting structure of claim **1** wherein the second substrate comprises a material composition having higher abrasion resistance proximate a periphery thereof and higher strength proximate a center thereof.

4. The cutting structure of claim **1** wherein the second substrate comprises an erosion resistant outer layer.

5. The cutting structure of claim **4** wherein the erosion resistant outer layer is disposed except on portions of the second substrate to be affixed to a bit body.

6. The cutting structure of claim **4** wherein the erosion resistant outer layer comprises thermally stable polycrystalline diamond.

7. The cutting structure of claim **1** wherein the second substrate comprises steel.

8. The cutting structure of claim **1** wherein a material composition of the first substrate is substantially uniform.

9. The cutting structure of claim **1** wherein the second substrate comprises a material composition having higher abrasion resistance proximate a first longitudinal end thereof and higher strength proximate a second longitudinal end thereof.

10. The cutting structure of claim **1** wherein the second substrate material comprises thermally stable polycrystalline diamond.

11. A drill bit, comprising:

a bit body; and

at least one polycrystalline diamond compact cutter affixed to the bit body, the cutter comprising at least

a diamond table affixed to one end of a first substrate and

a second substrate affixed to the other end of the first substrate, the second substrate made from a different material than the first substrate, the first and second substrates being substantially coaxial.

12. The drill bit of claim **11** wherein the diamond table comprises polycrystalline diamond and the first substrate comprises tungsten carbide.

13. The drill bit of claim **11** wherein the second substrate comprises a material composition having higher abrasion resistance proximate a periphery thereof and higher strength proximate a center thereof.

14. The drill bit of claim **11** wherein the second substrate comprises an erosion resistant outer layer.

15. The drill bit of claim **14** wherein the erosion resistant outer layer is disposed except on portions of the second substrate to be affixed to a bit body.

16. The drill bit of claim **14** wherein the erosion resistant outer layer comprises thermally stable polycrystalline diamond.

17. The drill bit of claim **14** wherein the second substrate comprises steel.

18. The drill bit of claim **11** wherein a material composition of the first substrate is substantially uniform.

19. The drill bit of claim **11** wherein the second substrate comprises a material composition having higher abrasion resistance proximate a first longitudinal end thereof and higher strength proximate a second longitudinal end thereof.

20. The drill bit of claim **10** wherein the bit body comprises a material affixable to the second substrate by welding.

21. The drill bit of claim **19** wherein the bit body comprises steel.

22. The drill bit of claim **11** wherein the second substrate material comprises thermally stable polycrystalline diamond.

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