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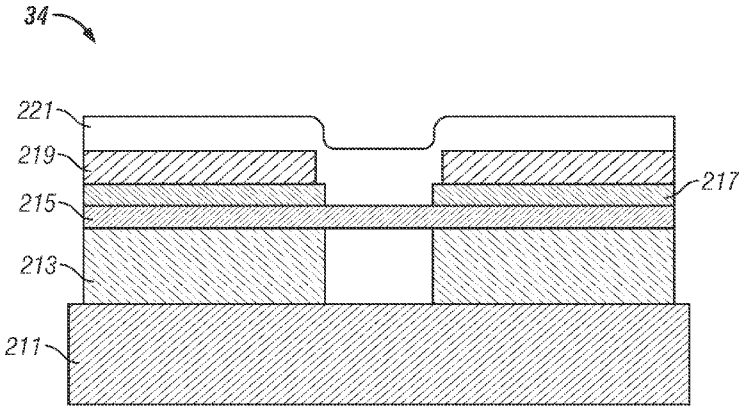


FIG. 2

(57) Abstract: A Polycrystalline Diamond Compact (PDC) cutter for a rotary drill bit is provided with an integrated sensor and circuitry for making measurements of a property of a fluid in the borehole and/or an operating condition of the drill bit. A method of manufacture of the PDC cutter and the rotary drill bit is discussed.

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PDC SENSING ELEMENT FABRICATION PROCESS AND TOOL

BACKGROUND OF THE DISCLOSURE

1. Field of the Disclosure

[0001] This disclosure relates in general to Polycrystalline Diamond Compact drill bits, and in particular, to a method of and an apparatus for PDC bits with integrated sensors and methods for making such PDC bits.

2. The Related Art

[0002] Rotary drill bits are commonly used for drilling bore holes, or well bores, in earth formations. Rotary drill bits include two primary configurations and combinations thereof. One configuration is the roller cone bit, which typically includes three roller cones mounted on support legs that extend from a bit body. Each roller cone is configured to spin or rotate on a support leg. Teeth are provided on the outer surfaces of each roller cone for cutting rock and other earth formations.

[0003} A second primary configuration of a rotary drill bit is the fixed-cutter bit (often referred to as a "drag" bit), which conventionally includes a plurality of cutting elements secured to a face region of a bit body. Generally, the cutting elements of a fixed-cutter type drill bit have either a disk shape or a substantially cylindrical shape. A hard, superabrasive material, such as mutually bonded particles of polycrystalline diamond, may be provided on a substantially circular end surface of each cutting element to provide a cutting surface. Such cutting elements are often referred to as "polycrystalline diamond compact" (PDC) cutters. The cutting elements may be fabricated separately from the bit body and are secured within pockets formed in the

outer surface of the bit body. A bonding material such as an adhesive or a braze alloy may be used to secure the cutting elements to the bit body. The fixed-cutter drill bit may be placed in a bore hole such that the cutting elements abut against the earth formation to be drilled. As the drill bit is rotated, the cutting elements engage and shear away the surface of the underlying formation.

[0004] During drilling operations, it is common practice to use measurement while drilling (MWD) and logging while drilling (LWD) sensors to make measurements of drilling conditions or of formation and/or fluid properties and control the drilling operations using the MWD/LWD measurements. The tools are either housed in a bottom hole assembly (BHA) or formed so as to be compatible with the drill stem. It is desirable to obtain information from the formation as close to the tip of the drill bit as is feasible.

[0005] The present disclosure is directed towards a drill bit having PDC cutting elements including integrated circuits configured to measure drilling conditions, properties of fluids in the borehole, properties of earth formations, and/or properties of fluids in earth formations. By having sensors on the drill bit, the time lag between the bit penetrating the formation and the time the MWD/LWD tool senses formation property or drilling condition is substantially eliminated. In addition, by having sensors at the drill bit, unsafe drilling conditions are more likely to be detected in time to take remedial action. In addition, pristine formation properties can be measured without any contamination or with reduced contamination from drilling fluids. For example, mud cake on the borehole wall prevents and/or distorts rock property measurements such as resistivity, nuclear, and acoustic measurements. Drilling fluid invasion into the formation contaminates the native fluid and gives erroneous results.

SUMMARY OF THE DISCLOSURE

[0006] One embodiment of the disclosure is a rotary drill bit configured to be conveyed in a borehole and drill an earth formation, The rotary drill bit includes: at least one polycrystalline diamond compact (PDC) cutter including: (i) at least one cutting element, and (ii) at least one transducer configured to provide a signal indicative of at least one of: (I) an operating condition of the drill bit, and (II) a property of a fluid in the borehole, and (III) a property of the surrounding formation.

[0007] Another embodiment of the disclosure is a method of conducting drilling operations. The method includes: conveying a rotary drill bit into a borehole and drilling an earth formation; and using at least one transducer on a polycrystalline diamond compact (PDC) cutter coupled to a body of the rotary drill bit for providing a signal indicative of at least one of: (I) an operating condition of the drill bit, and (II) a property of a fluid in the borehole, and (III) a property of the formation.

[0008] Another embodiment of the disclosure is a method of forming a rotary drill bit. The method includes: making at least one polycrystalline diamond compact (PDC) cutter including: (i) at least one cutting element, (ii) at least one transducer configured to provide a signal indicative of at least one of: (I) an operating condition of the drill bit, and (II) a property of a fluid in the borehole, and (III) a property of the formation and (iii) a protective layer on a side of the at least one transducer opposite to the at least one cutting element; and using the protective layer for protecting a sensing layer including the at least one transducer from abrasion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] For a detailed understanding of the present disclosure, reference should be made to the following detailed description of the disclosure, taken in conjunction with the accompanying drawings:

Fig. 1 is a partial cross-sectional side view of an earth-boring rotary drill bit that embodies teachings of the present disclosure and includes a bit body comprising a particle-matrix composite material;

Fig. 2 is an elevational view of a Polycrystalline Diamond Compact portion of a drill bit according to the present disclosure;

Fig. 3 shows an example of a pad including an array of sensors;

Fig. 4 shows an example of a cutter including a sensor and a PDC cutting element;

Figs. 5(a)-5(f) shows various arrangements for disposition of the sensor;

Fig. 6 illustrates an antenna on the surface of the PDC cutter;

Figs. 7 (a) – (e) illustrate the sequence in which different layers of the PDC cutter are made;

Figs. 8(a)-8(b) show the major operations needed to carry out the layering of Figs 7(a)-7(e);

Fig. 9 shows the basic structure of a pad including sensors of Fig. 3;

Figs. 10(a)-(b) show steps in the fabrication of the assembly of Fig. 3;

Figs. 11 (a)-(b) show steps in the fabrication of the assembly of Fig. 5 (f); and

Fig. 12 illustrates the use of transducers on two different cutting elements for measurement of acoustic properties of the formation.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0010] An earth-boring rotary drill bit **10** that embodies teachings of the present disclosure is shown in **FIG. 1**. The drill bit **10** includes a bit body **12** comprising a particle-matrix composite material **15** that includes a plurality of hard phase particles or regions dispersed throughout a low-melting point binder material. The hard phase particles or regions are "hard" in the sense that they are relatively harder than the surrounding binder material. In some embodiments, the bit body **12** may be predominantly comprised of the particle-matrix composite material **15**, which is described in further detail below. The bit body **12** may be fastened to a metal shank **20**, which may be formed from steel and may include an American Petroleum Institute (API) threaded pin **28** for attaching the drill bit **10** to a drill string (not shown). The bit body **12** may be secured directly to the shank **20** by, for example, using one or more retaining members **46** in conjunction with brazing and/or welding, as discussed in further detail below.

[0011] As shown in **Fig. 1**, the bit body **12** may include wings or blades **30** that are separated from one another by junk slots **32**. Internal fluid passageways **42** may extend between the face **18** of the bit body **12** and a longitudinal bore **40**, which extends through the steel shank **20** and at least partially through the bit body **12**. In some embodiments, nozzle inserts (not shown) may be provided at the face **18** of the bit body **12** within the internal fluid passageways **42**.

[0012] The drill bit **10** may include a plurality of cutting elements on the face **18** thereof. By way of example and not limitation, a plurality of polycrystalline diamond compact (PDC) cutters **34** may be provided on each of the blades **30**, as shown in **Fig. 1.** The PDC cutters **34** may be provided along the blades **30** within pockets **36** formed in the face **18** of the bit body **12**, and may be supported from behind by

buttresses **38**, which may be integrally formed with the bit body **12**. During drilling operations, the drill bit **10** may be positioned at the bottom of a well bore and rotated while drilling fluid is pumped to the face **18** of the bit body **12** through the longitudinal bore 40 and the internal fluid passageways **42**. As the PDC cutters **34** shear or engage the underlying earth formation, the formation cuttings and detritus are mixed with and suspended within the drilling fluid, which passes through the junk slots **32** and the annular space between the well bore hole and the drill string to the surface of the earth formation.

[0013] Turning now to **Fig. 2**, a cross section of an exemplary PDC cutter **34** is shown. This includes a PDC cutting element **213**. This may also be referred to as part of the diamond table. A thin layer **215** of material such as Si_3N_4/Al_2O_3 is provided for passivation/adhesion of other elements of the cutter **34** to the cutting elements **213.** Chemical mechanical polishing (CMP) may be used for the upper surface of the passivation layer **215.** The cutting element may be provided with a substrate **211.**

[0014] The layer **217** includes metal traces and patterns for the electrical circuitry associated with a sensor. Above the circuit layer is a layer or plurality of layers **219** that may include a piezoelectric element and a p-n-p transistor. These elements may be set up as a Wheatstone bridge for making measurements. The top layer **221** is a protective (passivation) layer that is conformal. The conformal layer **221** makes it possible uniformly cover **217** and/or **219** with a protective layer**.** The layer **221** may be made of diamond like carbon (DLC).

[0015] The sensing material shown above is a piezoelectric material. The use of the piezoelectric material makes it possible to measure the strain on the cutter **34** during drilling operations. This is not to be construed as a limitation and a variety of sensors

may be incorporated into the layer **219.** For example, an array of electrical pads to measure the electrical potential of the adjoining formation or to investigate high-frequency (HF) attenuation may be used. Alternatively, an array of ultrasonic transducers for acoustic imaging, acoustic velocity determination, acoustic attenuation determination, and shear wave propagation may be used.

[0016] Sensors for other physical properties may be used. These include accelerometers, gyroscopes and inclinometers. Micro electro mechanical system (MEMS) or nano electro mechanical system (NEMS) style sensors and related signal conditioning circuitry can be built directly inside the PDC or on the surface. These are examples of sensors for a physical condition of the cutter and drillstem.

[0017] Chemical sensors that can be incorporated include sensors for elemental analysis: carbon nanotube (CNT), complementary metal oxide semiconductor (CMOS) sensors to detect the presence of various trace elements based on the principle of a selectively gated field effect transistors (FET) or ion sensitive field effect transistors (ISFET) for pH, H_2S and other ions; sensors for hydrocarbon analysis; CNT, DLC based sensors working on chemical electropotential; and sensors for carbon/oxygen analysis. These are examples of sensor for analysis of a fluid in the borehole.

[0018] Acoustic sensors for acoustic imaging of the rock may be provided. For the purposes of the present disclosure, all of these types of sensors may be referred to as transducers. The broad dictionary meaning of the term is intended: "a device actuated by power from one system and supplying power in the same or any other form to a second system." This includes sensors that provide an electric signal in response to a measurement such as radiation as well as a device that uses electric power to produce mechanical motion.

[**0019**] in one embodiment of the disclosure shown in **Fig. 3**, a sensor pad **303** provided with an array of sensing elements **305** is shown. The sensing elements may include pressure sensors, temperature sensors, stress sensors and/or strain sensors. Using the array of sensors, it is possible to make measurements of variations of the fence parameter across the face of the PDC element **301**. Electrical leads **307** to the sensing array are shown. The pad **303** may be glued onto the PDC element **301** as indicated by the arrow **309.**

[0020] In one embodiment of the disclosure shown in **Fig. 4**, a sensor **419** is shown on the cutter **34.** The sensor may be a chemical field effect transistor (FET). The PDC element **413** is provided with grooves to allow fluid and particle flow to the sensor **419.** In another embodiment of the disclosure, the sensor **419** may comprise an acoustic transducer configured to measure the acoustic velocity of the fluids and particles in the grooves. The acoustic sensors may be built from thin films or may be made of piezoelectric elements. The sensing layer can be built on top of the diamond table or below the diamond table or on the substrate surface, (either of the interfaces with the diamond table or with the drill bit matrix). In another embodiment of the disclosure, the sensor **419** may include an array of sensors of the type discussed above with reference to **Fig. 3.**

[0021] Referring to **Fig. 5a**, shown therein is a bit body **12** with cutters **34.** A sensor **501** is shown disposed in a cavity **503** in the bit body **12.** A communication (inflow) channel **505** is provided for flow of fluids and/or particles to the sensor **503**. The cavity is also provided with an outlet channel **507.** The sensor **501** is similar to the sensor shown in **Fig. 2** but lacks the cutting elements **213** but includes the circuit layer **215**, and the sensor layer **217**. The sensor may include a chemical analysis sensor, an

inertial sensor; an electrical potential sensor; a magnetic flux sensor and/or an acoustic sensor. The sensor is configured to make a measurement of a property of the fluid conveyed to the cavity and/or solid material in the fluid.

[0022] Fig. 5 (b) shows the arrangement of the sensor **217** discussed in **Fig. 2.** In **Fig. 5 (c),** the sensor **217** is in the cutting element **213. Fig. 5 (d)** shows the sensor **217** in the substrate and **Fig . 5 (e)** shows one sensor in the matrix **30** and one sensor in the substrate **211. Fig. 5f** shows an arrangement in which nanotube sensors **501** are embedded in the matrix. These nanotubes may be used to measure pressure force and/ or temperature.

[0023] Fig. 6 shows an antenna **601** on the cutter **34.** An electromagnetic (EM) transceiver **603** is located in the matrix of the bit body **12**. The transceiver is used to interrogate the antenna **601** and retrieve data on the measurements made by the sensor **219** in **Fig. 2.** The transceiver is provided with electrically shielded cables to enable communication with devices in the bit shank or a sub attached to the drill bit.

[0024] Referring to **Figs. 7(a) – (e),** the sequence of operations used to assemble the cutter **34** shown in **Fig. 2** are discussed. As shown in **Fig. 7(a),** PDC elements **213** are mounted on a handle wafer **701** to form a diamond table**.** Filler material **703** is added to make the upper surface of the subassembly shown in **Fig. 7(a)** planar.

[0025] As shown in a detail of **Fig.7a** in **Fig. 7b,** a "passivation layer" **705** comprising Si_3N_4 may be deposited on top of the cutter elements **213** and the filler **703.** The purpose of the thin layer is to improve adhesion between the cutter elements **213** and the layer above (discussed with reference to **Fig. 7a).** As suggested by the term "passivation", this layer also prevents damage to the layer above by the PDC cutting element **213.** Chemical mechanical polishing (CMP) may be needed for forming the passivation layer. It should be noted that the use of Si_3N_4 is for exemplary purposes

and not to be construed as a limitation. Equipment for chemical vapor deposition (CVD), Physical/Plasma Vapor Deposition (PVD), low pressure chemical vapor deposition (LPCVD), atomic layer deposition (ALD), and sol-gel spinning may be needed at this stage.

[0026] Referring next to **Fig. 7c,** metal traces and a pattern **709** for contacts and electronic circuitry are deposited. Equipment for sputter coating, evaporation, ALD, electroplating, and etching (plasma and wet) may be used. As shown in **Fig. 7d,** a piezoelectric material and a p-n-p semiconductor layer **709** are deposited. The output of the piezoelectric material may be used as an indication of strain when the underlying pattern on layer **707** includes a Wheatstone bridge. It should be noted that the use of a piezoelectric material is for exemplary purposes only and other types of sensor materials could be used. Equipment needed for this may include LPCVD, CVD, Plasma, ALD and RF sputtering.

[0027] A protective passivation layer that is conformal is added **711**. The term "conformal" is used to mean the ability to form a layer over a layer of varying topology. This could be made of diamond –like carbon (DLC). Process equipment needed may include CVD, sintering, and RF sputtering. Removal of the handle **701** and the filler material gives the PDC cutter **34** shown in **Fig. 2** that may be attached to the wing **30** in **Fig. 1.**

[0028] **Fig. 8a** shows the major operational units needed to provide the mounted PDC unit of **Fig. 7b.** This includes starting with the PDC elements **213** in step **801** and the handle wafer **701** in **803** to give the mounted and planarized unit **805**.

[0029] The mounted PDC unit is transferred to a PDC loading unit **811** and goes to a PDC wafer transfer unit **813.** The units are then transferred to the units identified as **815, 817** and **819. 815** is the metal processing chamber which may include CVD,

sputtering and evaporation. The thin film deposition chamber **819** may includes LPCVD, CVD, and plasma enhanced CVD. The DLC deposition chamber **817** may include CVD and ALD. Next, the fabrication of the array of **Fig. 3** is discussed.

[0030] Referring now to **Fig. 9,** tungsten carbide base **905** is shown with sensors **903** and a PDC table. One method of fabrication comprises deposition of the sensing layer **903** directly on top of the tungsten carbide base **905** and then forming the diamond table on top of the tungsten carbide base. Temperatures of 1500°C to 1700°C may be used and pressures of around 10^6 psi may be used.

[0031] Such an assembly can be fabricated by building a sensing layer **903** on the substrate **905** and running traces **904** as shown i**n Fig. 10(a).** The diamond table **901** is next deposited on the substrate. Alternatively, the diamond table **901** may be preformed, based on the substrate **905**, and brazed.

[0032] Fabrication of the assembly shown in **Fig. 5f** is discussed next with reference to **Figs. 11 (a)-(b).** The nanotubes **1103** are inserted into the substrate **905**. The diamond table **901** is next deposited on the substrate **905**.

[0033] Integrating temperature sensors in the assemblies of **Figs. 10-11** is relatively straightforward. Possible materials to be used are high-temperature thermocouple materials. Connection may be provided through the side of the PDC or through the bottom of the PDC.

[0034] Pressure sensors made of quartz crystals can be embedded in the substrate. Piezoelectric materials may be used. Resistivity and capacitive measurements can be performed through the diamond table by placing electrodes on the tungsten carbide substrate. Magnetic sensors can be integrated for failure magnetic surveys. Those versed in the art and having benefit of the present disclosure would recognize that magnetic material would have to be re-magnetized after integrating into the sensor

assembly. Chemical sensors may also be used in the configuration of **Fig.** 11. Specifically, a small source of radioactive materials is used in or instead of one of the nanotubes and a gamma ray sensor or a neutron sensor may be used in the position of another one of the nanotubes.

[0035] Those versed in the art and having benefit of the present disclosure would recognize that the piezoelectric transducer could also be used to generate acoustic vibrations. Such ultrasonic transducers may be used to keep the face of the PDC element clean and to increase the drilling efficiency. Such a transducer may be referred to as a vibrator. In addition, the ability to generate elastic waves in the formation can provide much useful information. This is schematically illustrated in **Fig. 12** that shows acoustic transducers on two different PDC elements **34**. One of them, for example **1201** may be used to generate a shear wave in the formation. The shear wave propagating through the formation is detected by the transducer **1203** at a known distance from the source transducer **1201**. By measuring the travel time for the shear wave to propagate through the formation, the formation shear velocity can be estimated. This is a good diagnostic of the rock type. Measurement of the decay of the shear wave over a plurality of distances provides an additional indication of the rock type. In one embodiment of the disclosure, compressional wave velocity measurements are also made. The ratio of compressional wave velocity to shear wave velocity (V_P/V_s ratio) helps distinguish between carbonate rocks and siliciclastic rocks. The presence of gas can also be detected using measurements of the V_P/V_s ratio. In an alternative embodiment, the condition of the cutting element may be determined from the propagation velocity of surface waves on the cutting element. This is an example of determination of the operating condition of the drill bit.

[0036] The shear waves may be generated using an electromagnetic acoustic transducer (EMAT). US patent 7697375 two *Reiderman* et al., having the same as in the as the present disclosure and the contents of which are incorporated herein by reference discloses a combined EMAT adapted to generate both SH and Lamb waves. Teachings such as those of *Reiderman* may be used in the present disclosure.

[0037] The acquisition and processing of measurements made by the transducer may be controlled at least in part by downhole electronics (not shown). Implicit in the control and processing of the data is the use of a computer program on a suitable machine readable-medium that enables the processors to perform the control and processing. The machine-readable medium may include ROMs, EPROMs, EEPROMs, flash memories and optical disks. The term processor is intended to include devices such as a field programmable gate array (FPGA).

CLAIMS

What is claimed is:

1. A rotary drill bit configured to be conveyed in a borehole and drill an earth formation, the rotary drill bit comprising:

at least one polycrystalline diamond compact (PDC) cutter including:

(i) at least one cutting element, and

(ii) at least one transducer configured to provide a signal indicative of at least one of: (I) an operating condition of the drill bit, and (II) a property of a fluid in the borehole, and (III) a property of the surrounding formation.

2. The rotary drill bit of claim 1 wherein the at least one PDC cutting element further comprises a protective layer on a side of the at least one transducer opposite to the at least one cutting element, the protective layer being

configured to safeguard a sensing layer including the transducer from abrasive elements.

3. The rotary drill bit of claim 1 wherein the at least one transducer further comprises an array of transducers disposed on a pad.

4. The rotary drill bit of claim 1 wherein the at least one transducer is selected from the group consisting of: (i) a strain sensor, (ii) an accelerometer, (iii) an inclinometer, (iv) a magnetometer, (v) a temperature sensor, (vi) a carbon nanotube sensor, (vii) an electropotential sensor, (viii) a sensor for carbon/oxygen analysis, (ix) an acoustic sensor, (x) a chemical field effect sensor, (xi) an ion-sensitive sensor, (xii) an angular rate sensor, (xiii) a nuclear sensor, (xiv) a pressure sensor, (xv) a vibrator and (xvi) an electromechanical acoustic transducer.

5. The rotary drill bit of claim 1 wherein the at least one PDC cutter further comprises a passivation layer disposed between the at least one cutting element and the at least one transducer.

6. The rotary drill bit of claim 5 further comprising electronic circuitry disposed between the passivation layer and the at least one transducer.

7. The rotary drill bit of claim 1 wherein the at least one cutting element is provided with a channel configured to allow flow of a fluid to the at least one transducer.

8. The rotary drill bit of claim 1 wherein the at least one transducer is disposed in at least one of: (i) a cavity in the body of the bit provided with a fluid flow channel, (ii) in the at least one cutting element, (iii) a substrate of the at least one cutting element, and (iv) in a matrix of a bit body.

9. The rotary drill bit of claim 1 further comprising:

an electromagnetic (EM) transceiver in the body of the bit; and

an antenna on the at least one PDC cutter;

wherein the EM transceiver is configured to interrogate the antenna and receive data relating to the signal.

10. The rotary drill bit of claim 1 wherein the at least one cutting element further comprises a first cutting element having a first transducer and a second cutting element having a second transducer responsive to a signal produced by the first transducer.

11. A method of conducting drilling operations, the method comprising:

conveying a rotary drill bit into a borehole and drilling an earth formation; and

using at least one transducer on a polycrystalline diamond compact (PDC) cutter coupled to a body of the rotary drill bit for providing a signal indicative of at least one of: (I) an operating condition of the drill bit, and (II) a property of a fluid in the borehole, and (III) a property of the formation.

12. The method of claim 11 further comprising using a drill bit having a protective layer on a side of the at least one transducer opposite to the at least one cutting element, and using the protective layer to safeguard a sensing layer including the at least one transducer from external abrasion.

13. The method of claim 11 further comprising using, for the at least one transducer, a transducer selected from the group consisting of: (i) a strain sensor, (ii) an accelerometer, (iii) an inclinometer, (iv) a magnetometer, (v) a temperature sensor, (vi) a carbon nanotube sensor, (vii) an electropotential sensor, (viii) a sensor for carbon/oxygen analysis, (ix) an acoustic sensor, (x) a chemical field effect sensor, (xi) an ion-sensitive sensor, (xii) an angular rate sensor, (xiii) a nuclear sensor, and (xiv) a pressure sensor.

14. The method of claim 11 further comprising using, for the at least one PDC cutter, a PDC cutter including a passivation layer disposed between the at least one cutting element and the at least one transducer.

15. The method of claim 14 further comprising conveying the signal to electronic circuitry disposed between the protective layer and the at least one transducer.

16. The method of claim 11 further comprising providing a channel for conveying fluid from the borehole to the at least one transducer.

17. The method of claim 11 further comprising positioning the at least one transducer at a location selected from: (i) a cavity in the body of the bit provided with a fluid flow channel, (ii) in the at least one cutting element, (iii) a substrate of the at least one cutting element, (iv) a matrix of a bit body.

18. The method of claim 11 further comprising:

providing an electromagnetic (EM) transceiver in the body of the bit;

providing an antenna on the at least one PDC cutter; and

using the EM transceiver for interrogating the antenna and receiving data relating to the signal.

19. The method of claim 11 further comprising generating a signal using a transducer on a first cutting element of the rotary drill bit and receiving a signal indicative of a property of the Earth formation using a transducer on a second cutting element of the Rotary drill bit.

20. A method of forming a rotary drill bit, the method comprising:

making at least one polycrystalline diamond compact (PDC) cutter including at least one cutting element;

coupling a sensing layer including at least one transducer on the cutting element and

coupling the at least one PDC cutter to a body of the drill bit.

21. The method of forming a rotary drill bit claim 20 wherein coupling the sensing layer further comprises depositing the sensing layer.

22. The method of claim 20 wherein the at least one transducer is configured to provide a signal indicative of at least one of: (i) an operating condition of the drillbit, (ii) a property of a fluid in the borehole, and (iii) a property of the formation.

23. The method of claim 20 further comprising depositing a protective layer for protecting the sensing layer from abrasion during drilling operations.

24. The method of claim 20 wherein making the at least one polycrystalline diamond compact (PDC) cutter further comprises:

mounting a plurality of cutting elements to a handle wafer;

adding a filler material to gaps between the plurality of cutting elements;

depositing a passivation layer on top of the filler material and the plurality of cutter elements;

depositing electronic circuitry on top of the passivation layer;

positioning a transducer above the electronic circuitry and coupling an output of the transducer to the electronic circuitry;

forming a protective layer above the transducer;

removing the handle wafer; and

removing the filler material.

25. The method of claim 24 wherein depositing the passivation layer further comprises using Si_3N_4.

26. The method of claim 24 wherein depositing the passivation layer further comprises at least one of: (i) chemical vapor deposition (CVD), (ii) Low pressure chemical vapor deposition (LPCVD), (iii) atomic layer deposition (ALD), and (iv) using a sol-gel.

27. The method of claim 24 wherein depositing electronic circuitry on top of the passivation layer further comprises at least one of: (i) sputter coating, (ii) evaporation, (ii) atomic layer deposition (ALD), (iii) electroplating, (iv) plasma etching, and (iv) wet etching.

28. The method of claim 24 wherein positioning a transducer above the electronic circuitry further comprises at least one of: (i) chemical vapor deposition (CVD), (ii) low pressure CVD, (iii) plasma etching, (iv) atomic layer deposition, and (v) radio frequency (RF) sputtering.

29. The method of claim 24 wherein forming the protective layer above the transducer further comprises hard materials like diamond-like carbon (DLC).

30. The method of claim 24 wherein forming the protective layer above the transducer further comprises using a conformal material.

31. The method of claim 24 wherein forming the protective layer above the transducer further comprises using at least one of: (i) chemical vapor deposition, (ii) sintering, (iii) sputtering, (iv) evaporation, and (v) screen printing and curing.

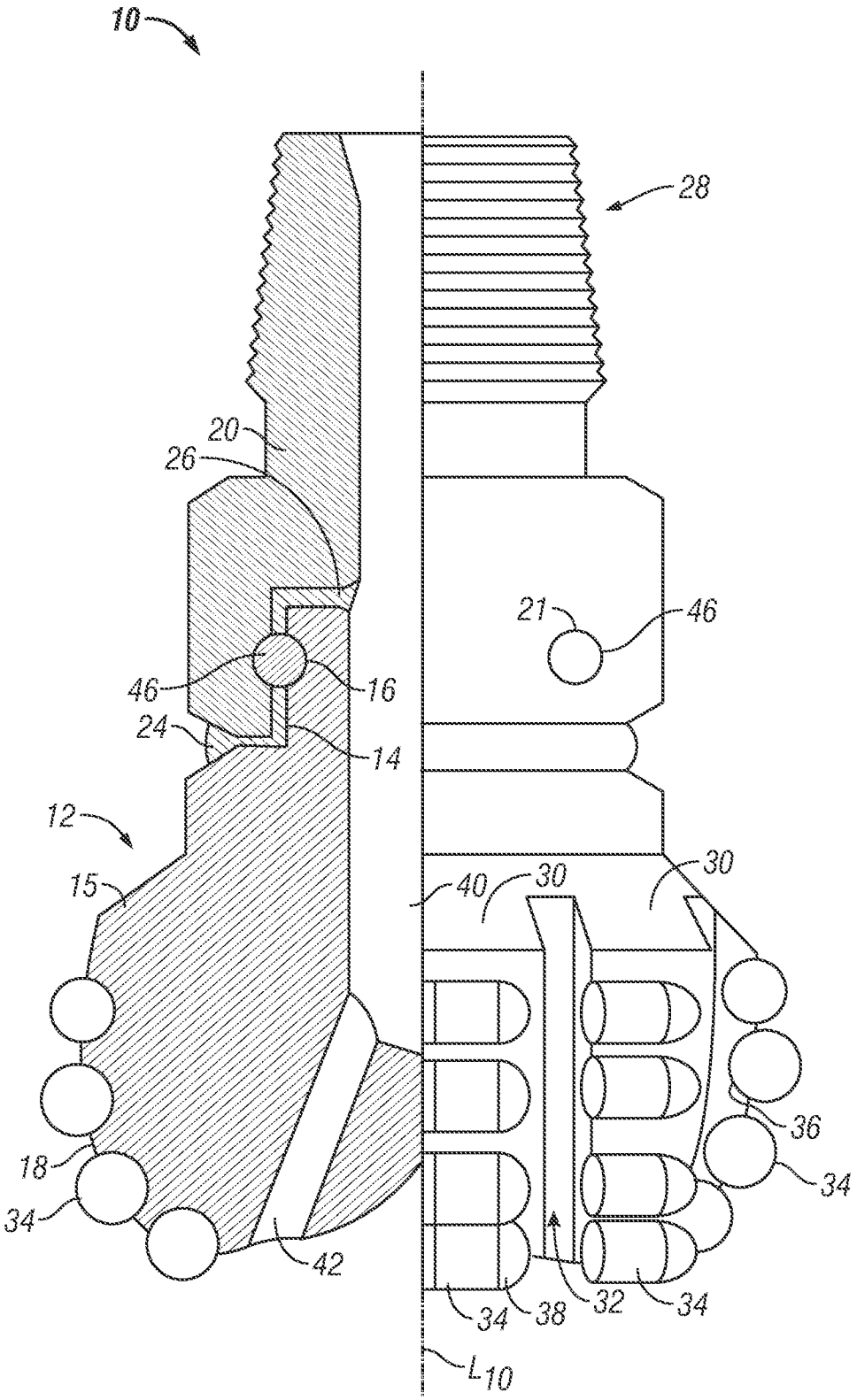

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FIG. 1

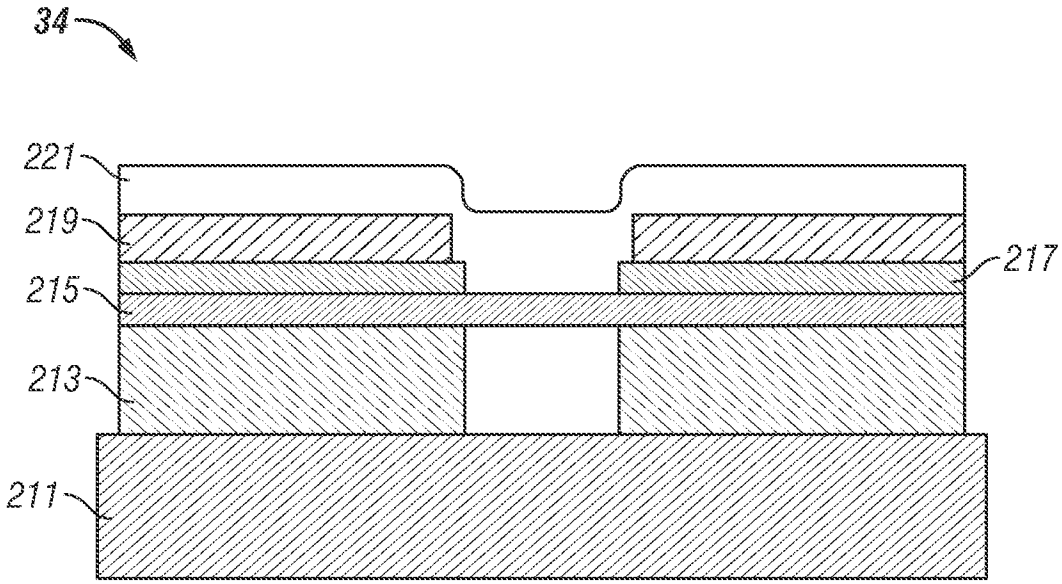


FIG. 2

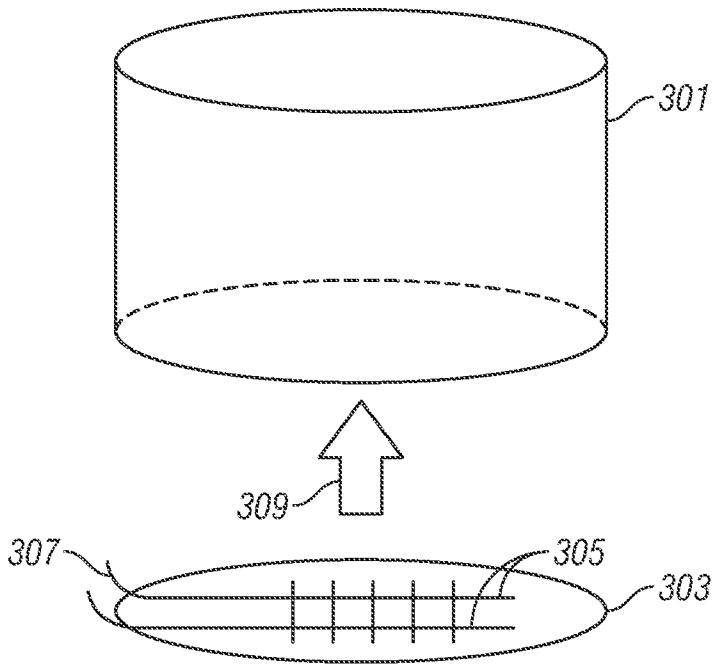


FIG. 3

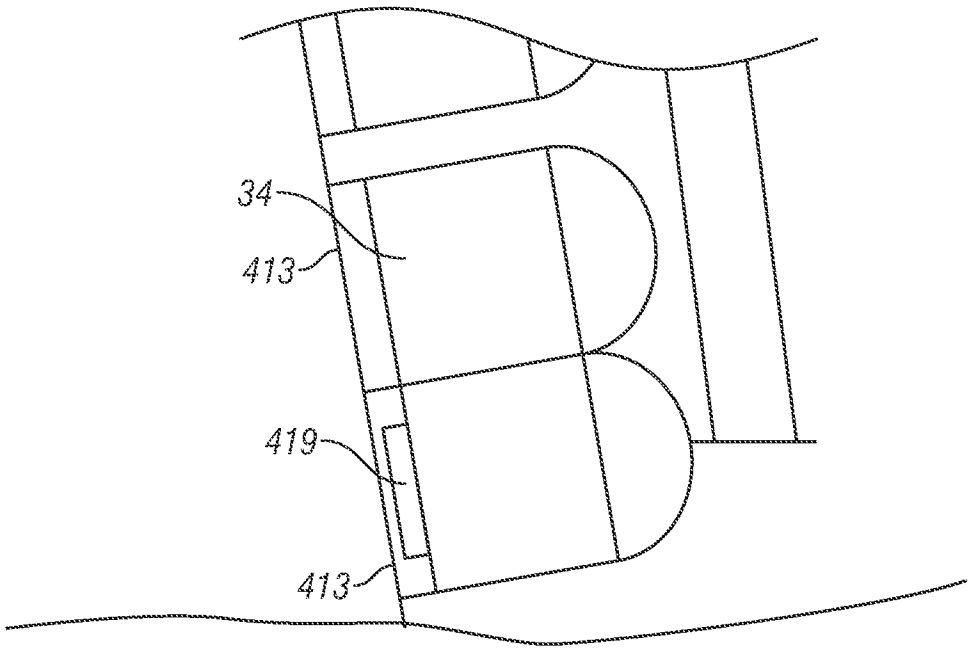


FIG. 4

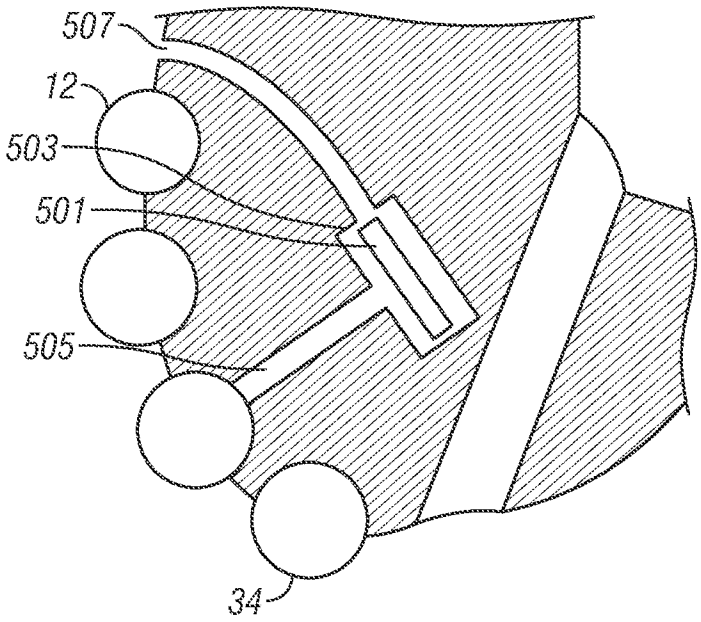


FIG. 5A

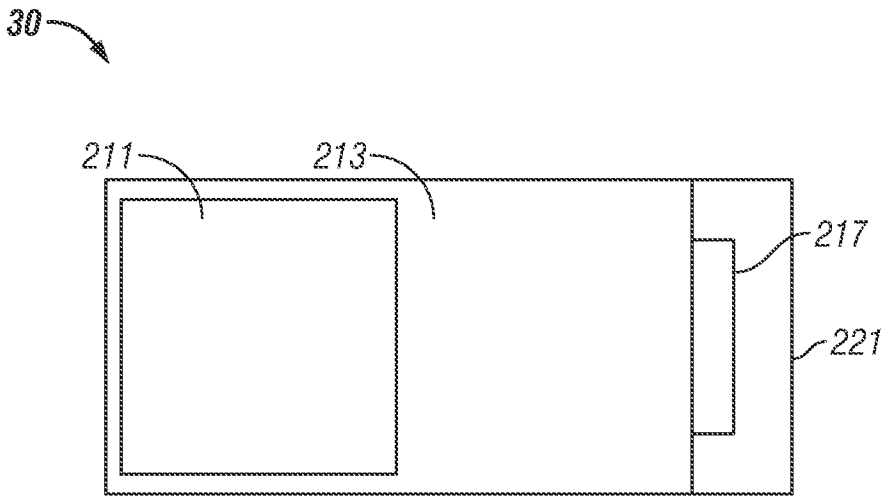


FIG. 5B

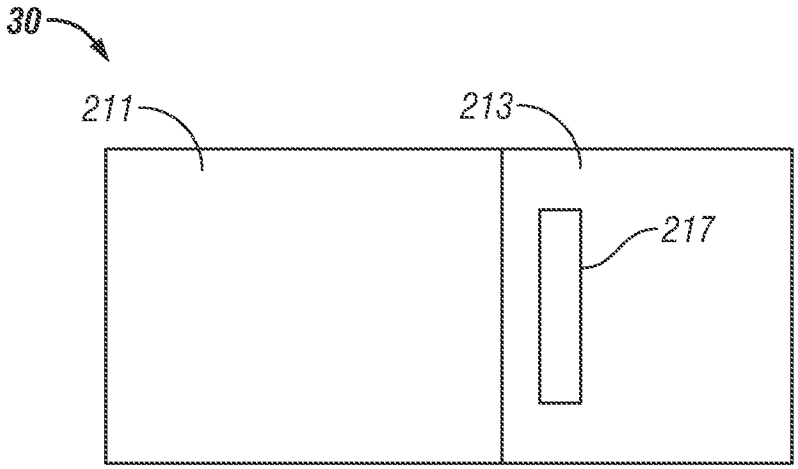


FIG. 5C

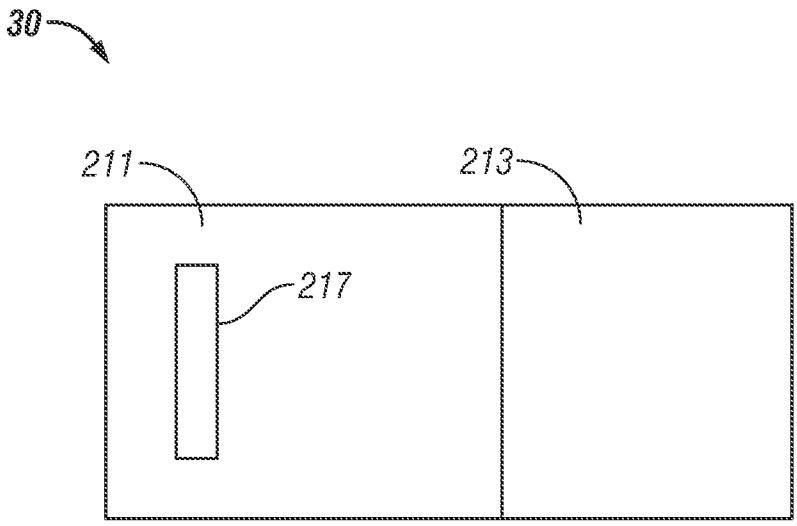


FIG. 5D

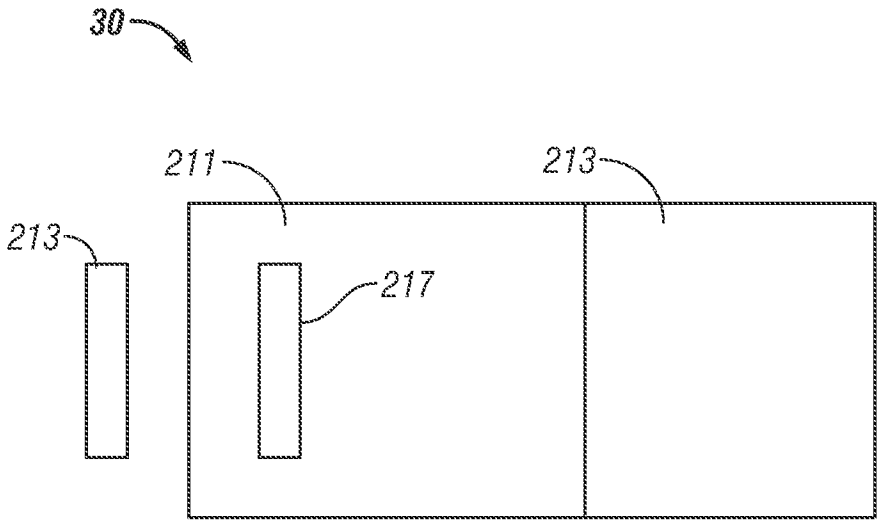


FIG. 5E

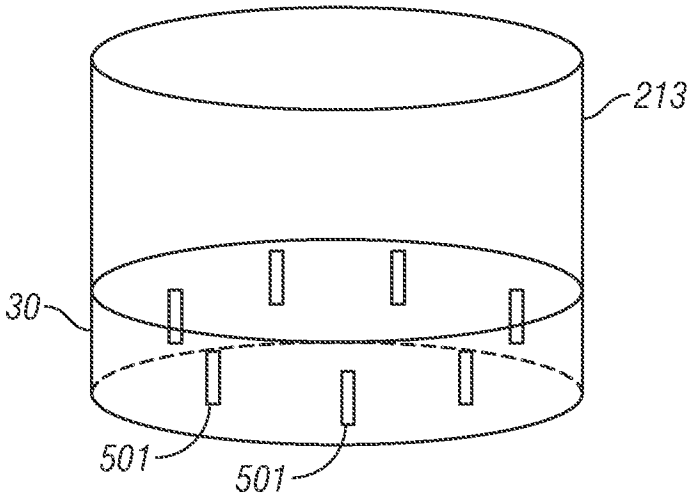


FIG. 5F

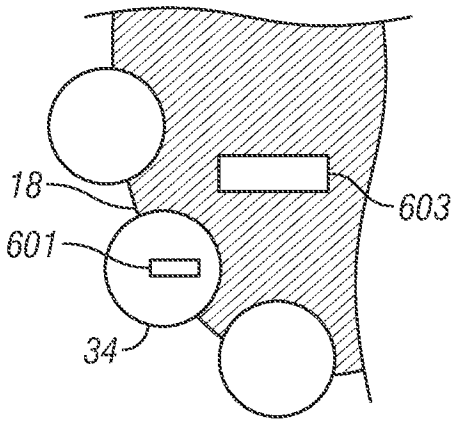


FIG. 6

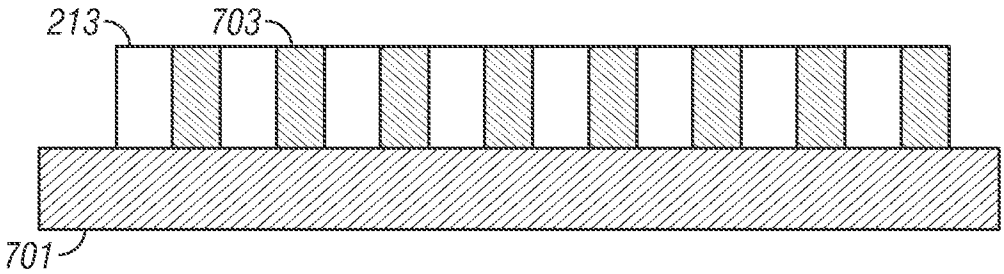


FIG. 7A

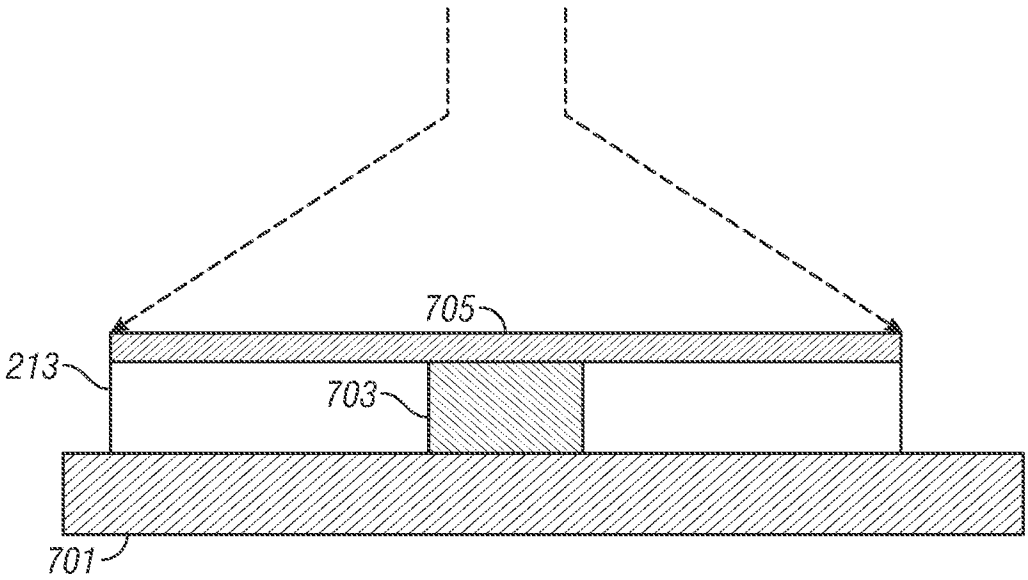


FIG. 7B

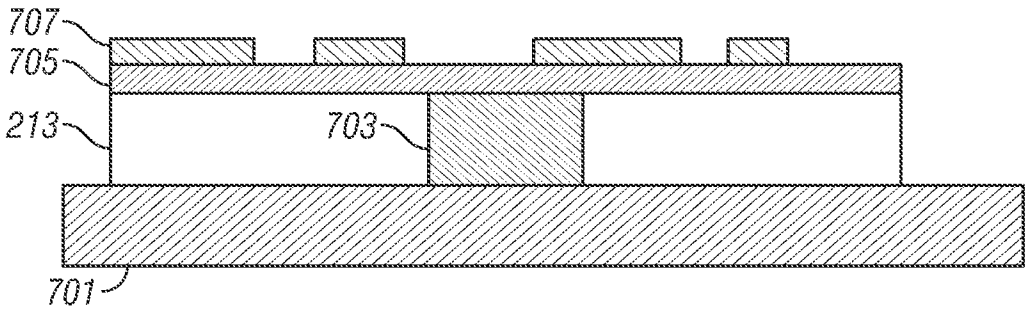


FIG. 7C

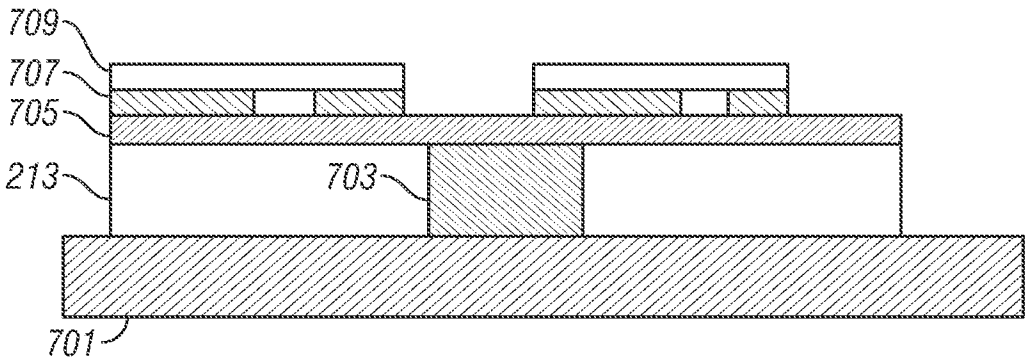


FIG. 7D

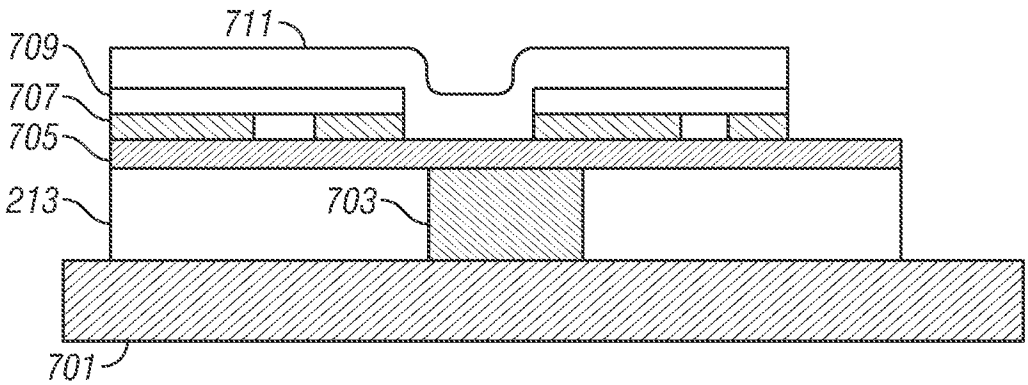


FIG. 7E

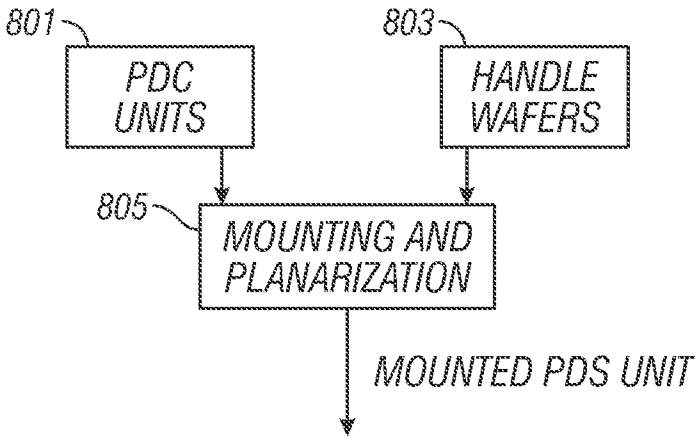

801
PDC UNITS
803
HANDLE WAFERS
805
MOUNTING AND PLANARIZATION
MOUNTED PDS UNIT

FIG. 8A

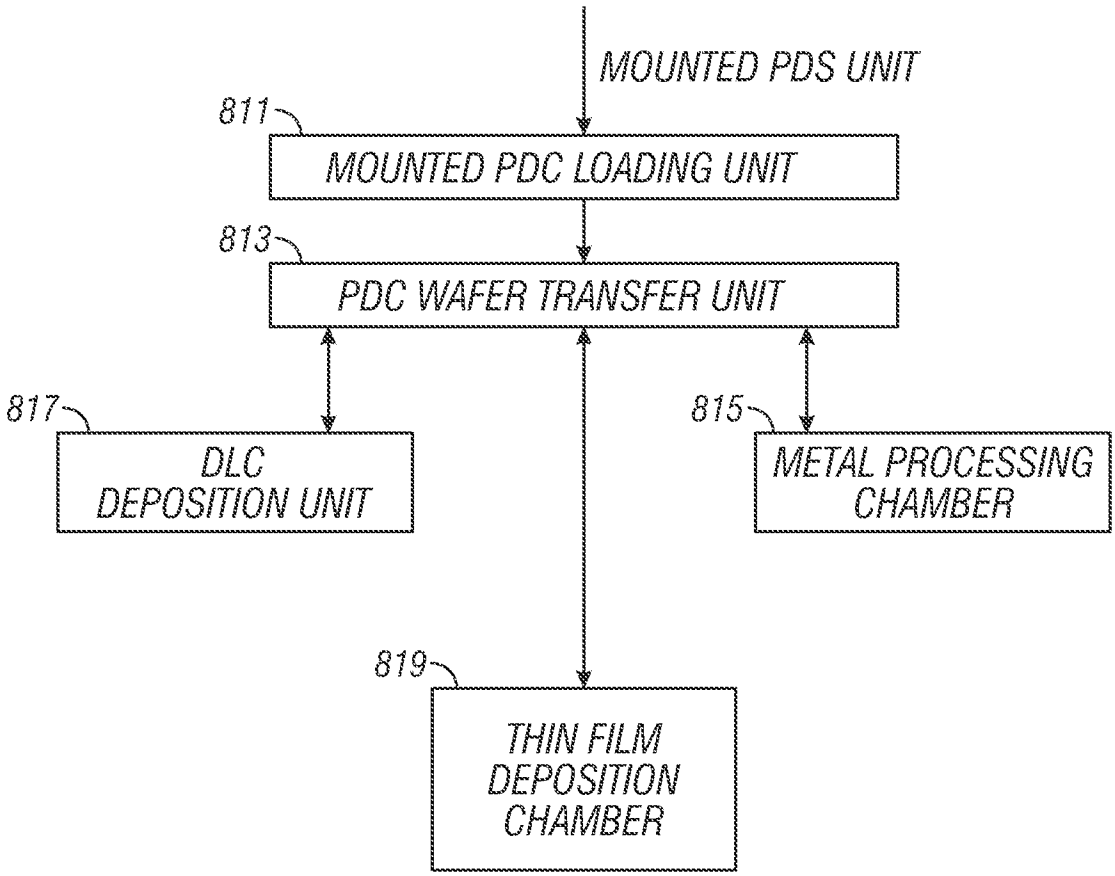

MOUNTED PDS UNIT
811
MOUNTED PDC LOADING UNIT
813
PDC WAFER TRANSFER UNIT
817
DLC DEPOSITION UNIT
815
METAL PROCESSING CHAMBER
819
THIN FILM DEPOSITION CHAMBER

FIG. 8B

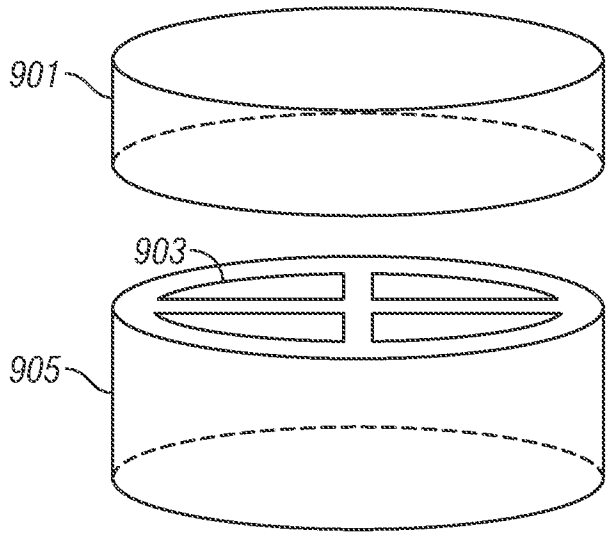


FIG. 9

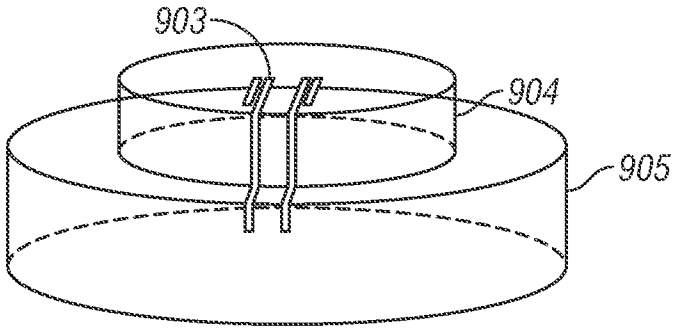


FIG. 10A

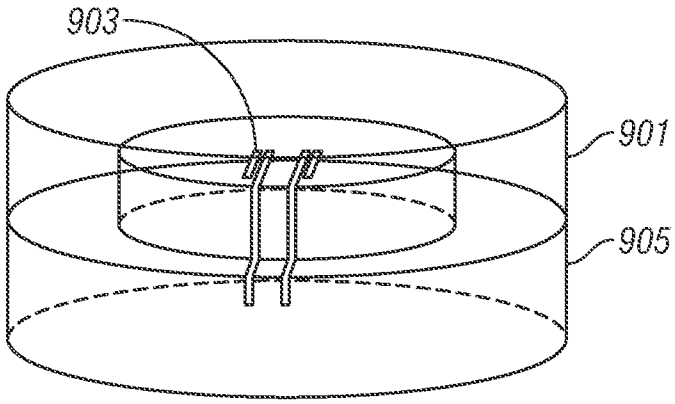


FIG. 10B

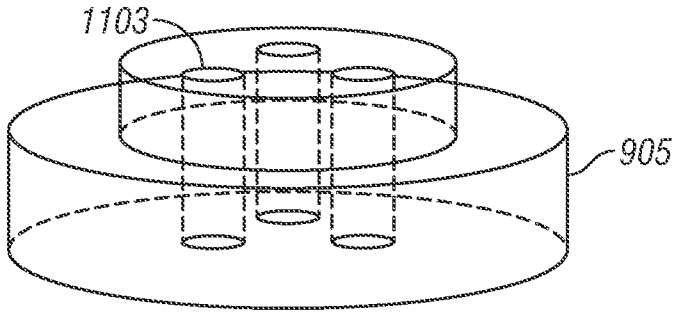


FIG. 11A

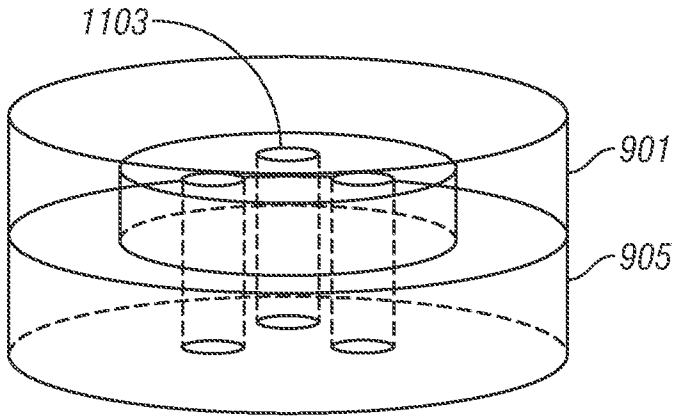


FIG. 11B

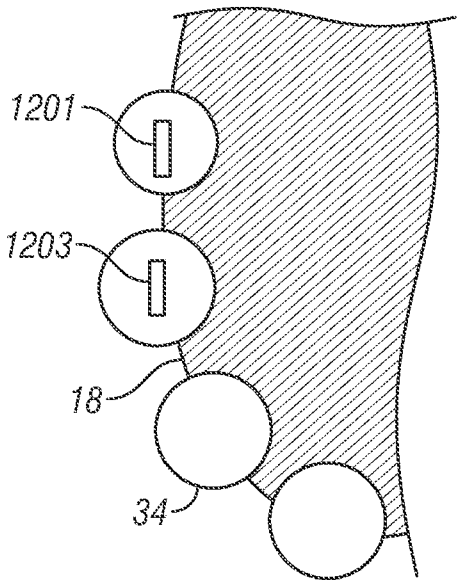


FIG. 12