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(71) Applicant (*for all designated States except BR, CA, CG, CM, CN, CZ, FR, GA, GB, IN, JP, LT, MA, NE, NL, SD, TD, TR, TT, US, VN*): **SCHLUMBERGER TECHNOLOGY B.V. (STBV)** [NL/NL]; Parkstraat 83-89, NL-2514 JG The Hague (NL).

(71) Applicant (*for FR only*): **SERVICES PETROLIERS SCHLUMBERGER (SPS)** [FR/FR]; 42, rue Saint Dominique, F-75007 Paris (FR).

(71) Applicant (*for CN only*): **SCHLUMBERGER OVERSEAS S.A. (SOSA)** [PA/PA]; 8 Calle Aquilino de la Guardia, Panama City (PA).

(71) Applicant (*for GB, JP, NL only*): **SCHLUMBERGER HOLDINGS LIMITED (SHL)** [—/—]; P.O. Box 71, Graigmuir Chambers, Road Town, Tortola (VG).

(71) Applicant (*for BR only*): **SCHLUMBERGER SURENCO S.A. (SURENCO)** [PA/PA]; 8 Calle Aquilino de la Guardia, Panama City (PA).

(71) Applicant (*for CA only*): **SCHLUMBERGER CANADA LIMITED (SCL)** [CA/CA]; 24th floor, Monenco Place, 801 6th Avenue, S.W., Calgary, Alberta T2P 3W2 (CA).

(71) Applicant (*for CG, CM, CZ, GA, IN, LT, MA, NE, TD, VN only*): **PETROLEUM RESEARCH & DEVELOPMENT N.V. (PRAD NV)** [NL/NL]; De Ruyterkade 62, Willemstad, Curacao (AN).

(71) Applicant (*for SD, TR only*): **SCHLUMBERGER OILFIELD ASSISTANCE LIMITED (SOAL)** [PA/PA]; 8 Calle Aquilino de la Guardia, Panama City (PA).

(71) Applicant (*for TT only*): **SCHLUMBERGER SERVICES LIMITED (SSL)** [—/—]; P.O. Box 438, Tortola (VG).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): **SAENGER, Richard** [FR/FR]; 15, rue de l'Epargne, F-92320 Chatillon (FR).

(74) Agent: **HYDEN, Martin**; Etudes & Productions Schlumberger, 1, rue Henri Becquerel, Boîte postale 202, F-92142 Clamart Cedex (FR).

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(54) Title: AN ELECTRODE SUITABLE FOR PERFORMING MEASUREMENTS IN AGGRESSIVE MEDIA

(57) Abstract: The invention relates to an electrode suitable for taking measurements in aggressive media, the electrode being made of diamond that includes a dopant that makes said diamond electrically conductive. The invention also provides apparatus for measuring resistivity and including at least one electrode possessing said characteristics.

AN ELECTRODE SUITABLE FOR PERFORMING MEASUREMENTS IN AGGRESSIVE MEDIA

The invention relates to an electrode suitable for taking measurements in aggressive media. Particularly suitable applications for the electrode of the invention relate to taking measurements in boreholes for oil wells.

Boreholes for oil wells give rise to numerous measurements for the purposes of estimating, amongst other things, the nature of the geological formation and the composition of the formation fluids and of the drilling muds. For example, resistivity measurements are performed, it being understood that the resistivity of a formation depends essentially on the fluid it contains and that consequently a formation which contains conductive salt water has much lower resistivity than a formation filled with hydrocarbons. Thus, resistivity measurements are of great value in locating and tracking hydrocarbon deposits.

Resistivity is measured by electrical conduction using devices having electrodes. For example such measurements can be based on causing a current to flow from injection electrodes to return electrodes. The injection electrodes and the return electrodes are far enough apart to enable current to circulate into the geological formations through which the well passes. It is then a question of evaluating the current in circulation: at a given level, this current increases with increasing conductivity of the formation surrounding the well at this level.

Electrode devices are lowered to the bottom of the well and they are then raised progressively so as to perform resistivity measurements over the entire length of the borehole. Usually, the electrodes come directly into contact with the geological formation itself. Under such circumstances, as the electrodes are raised they become scratched and damaged by the rocks of the formation and also the extreme conditions of temperature, pressure, and a particularly corrosive environment. The electrodes thus wear progressively to such an extent that their contact impedance changes, thereby falsifying resistivity measurements and requiring them to be replaced very frequently, which is particularly expensive.

In other cases, resistivity measurements are performed after metal casing has already been put into place and then cemented against the walls of the well. Unfortunately, the conditions inside the well are such that the metal casing rusts very quickly. To ensure good electrical contact, the electrode must pass through the layer of rust which can be several tenths of a millimeter thick. It will readily be understood that this causes electrodes to wear rapidly, thereby affecting the results of measurements, particularly since the magnitudes to be detected are very small.

It is also known to make resistivity measurements during production within the effluent itself, in order to determine the water/hydrocarbon ratio. Unfortunately, the effluent contains solid particles, in particular particles of sand, which are entrained together with the liquids along the production tubing. These particles then strike and erode the electrodes. As in the other cases, the measurement devices cease to be reliable after they have been used for a certain length of time.

The invention seeks to solve the problem of the variation over time in the contact impedance of measurement electrodes subjected to conditions that are particularly abrasive and corrosive.

To this end, the invention provides an electrode that is adapted to taking measurements in aggressive media that is made of diamond that has been doped to make said diamond electrically conductive.

This type of electrode is particularly suited to corrosive or abrasive media. Since diamond is particularly hard and resists erosion particularly well, the fact of making it electrically conductive by associating it with a metallic element that acts as a "dopant", gives results that are particularly satisfactory in terms of electrode head lifetime. Such electrodes thus make it possible to guarantee contact impedance that is substantially stable over time. There is therefore no need to replace electrodes after each measurement, thus reducing the cost of such measurements.

In an advantageous embodiment of the resistivity, the electrically conductive diamond is a diamond that has been doped with cobalt.

Cobalt penetrates into and bonds strongly with the crystal lattice of diamond, thereby making it electrically conductive. The association of cobalt with diamond is known in composite materials manufactured from diamond powder and tungsten carbide enriched with cobalt and used in the manufacture of the cutting pieces of drill bits. Cobalt is known to diffuse in the crystal lattice of diamond and to provide not only good cohesion between particles of the powder, but also between diamond and the tungsten carbide support.

The electrode of the invention thus makes it possible to combine the mechanical and physical properties of diamond with electrical properties. This guarantees stability over time for the contact impedance of the electrodes.

In an advantageous embodiment of the invention, the electrode is made of a polycrystalline diamond composite including a dopant that makes said diamond electrically conductive.

The use of a polycrystalline diamond composite increases the mechanical and physical strength of the electrode. The electrode is thus much stronger, thereby enabling it to be used in media that are particularly difficult: abrasive, corrosive, at high temperature, under pressure, ...

In another advantageous embodiment of the invention, a layer of gold covers the electrode.

This particular embodiment serves to increase the conductivity of the electrodes and thus the effectiveness of the measurements. This is particularly advantageous when the electrodes are to measure magnitudes that are very small compared with the order of magnitude of interfering values.

In another particularly advantageous embodiment of the invention, the electrode is beveled in shape.

This particular shape makes the electrode sharp and thus enables it to penetrate well into the medium being prospected. It is also advantageous when measurements are performed in an oil well that already possesses a metal casing, where it is necessary for the electrode to get through the initial layer of rust or of scale.

The invention also provides apparatus for measuring resistivity that includes at least one electrode implementing the above characteristics.

Other advantages and characteristics of the invention appear more clearly from the following description given with reference to the accompanying drawing, in which:

- Figure 1 is a section view of an electrode constituting an embodiment of the invention; and
- Figure 2 shows an example of how an electrode of the invention can be used.

Figure 1 shows an embodiment of an electrode 1 of the invention that is included in an insulating sleeve 2, e.g. made of polyether ether ketone (PEEK). The base of the electrode is securely bonded, e.g. by brazing, to a support 13 that co-operates with a spring 30. The spring 30 serves to press the electrode continuously against the measurement surface. Finally, the assembly comprising the electrode 1, the insulating sleeve 2, and the support 3 is itself carried by a pad 4.

By way of example, the electrode is beveled in shape. This embodiment is particularly advantageous when an electrode of the invention is used to perform measurements that require deep penetration into the medium being prospected, as is the case for measurements in an oil well borehole that possesses metal casing. Because of the particularly corrosive conditions inside the well, the metal casing becomes covered very quickly in a layer of rust which must be penetrated in order to ensure that the measurements performed by the electrode are correct. The beveled shape is sufficiently sharp to pierce said layer.

Nevertheless, in other embodiments, the electrode head can have any other shape that is found to be more suitable, such as a spike that can be used under circumstances such as taking measurements within an effluent coming from an oil borehole. It is also possible to envisage giving it a pad shape as would be appropriate for measurements in uncased wells where the electrodes come directly into contact with the geological formations. By way of example, all such shapes can be obtained easily and at low cost by electroerosion.

The electrode is made of a composite material which is constituted by a fine layer of polycrystalline diamond compact (PDC) bonded to an amalgamated tungsten carbide support, enriched with about 7% cobalt.

Typically, such an assembly is made by placing diamond powder (advantageously of the finest grain size) in a refractory metal mold generally of zirconium or of molybdenum. The shape of the mold determines the shape of the composite. Thereafter, a tungsten carbide support is placed over the diamond powder and the mold is sealed hermetically. The assembly is then placed in a press at a temperature of about 1400°C and at a pressure of about 69,000 bars (1,000,000 pounds per square inch (psi)), for a length of time that is too short to affect the diamond. Under such conditions, some of the cobalt diffuses into the diamond which, acting as a cement, gives rise to a total bond with the tungsten carbide base. Furthermore, the mixture of cobalt in the crystal lattice of the diamond makes the diamond electrically conductive. At the end of the process, a composite is thus obtained possessing a PDC layer that is doped with cobalt and that is of a thickness lying in the range 1 mm to 2 mm, together with a layer of cobalt-enriched tungsten carbide having a thickness lying in the range 4 mm to 10 mm.

The presence of cobalt in the diamond makes the diamond electrically conductive. As a result, the electrode makes it possible to combine electrical properties with the excellent mechanical properties of diamond. In another embodiment of the invention, the proportions of cobalt in the tungsten could be different. Similarly, tungsten could be associated with some other element in order to make the diamond electrically conductive. It is also possible to replace the tungsten carbide with some other support material, providing it presents the same compatibility with diamond powder and cobalt or some other element for making diamond conductive.

In a variant embodiment of the invention, the PDC electrode is covered in a layer of gold, e.g. deposited by physical vapor deposition (PVD) and having a thickness that is typically of the order of a few micrometers. It has been shown that the covering of gold adheres strongly and durably to the PDC. The layer of gold thus makes it possible significantly to increase the conductivity of the electrodes.

PDC thus combines the excellent mechanical properties of diamond, in particular its hardness and its resistance both to shock and also to temperature (it remains chemically stable up to about 720°C), with electrical properties due to cobalt doping, possibly assisted by a deposit of gold. This makes the electrodes particularly good at withstanding shock, temperature, and also corrosive media.

Figure 2 shows an example of an electrode of the invention in use. In this example, resistivity measurements are performed inside an uncased hydrocarbon well. The electrodes of the measurement device thus come directly into contact with the geological formation 5. Current is caused to flow from the injection electrodes 6 towards so-called "return" electrodes 7 which are far enough away to enable a current to circulate, which current is evaluated. The measurement device is raised progressively up the well so as to perform resistivity measurements over the entire length of the borehole.

The increased mechanical strength of electrodes of the invention make it possible to perform such measurements without modifying the contact impedance between the electrodes and the formation. The electrodes erode much less easily than electrodes of the kind known in the state of the art. This guarantees that measurements are reliable over the entire length of the operation and greatly decreases the frequency with which electrodes need to be replaced, thereby reducing the cost of taking measurements.

CLAIMS

1/ An electrode adapted for taking measurements in aggressive media, the electrode being made of diamond that includes a dopant that makes said diamond electrically conductive.

2/ An electrode according to claim 1, characterized in that the electrically conductive diamond is diamond that has been doped with cobalt.

3/ An electrode according to claim 1 or 2, made of composite polycrystalline diamond material including a dopant that makes said diamond electrically conductive.

4/ An electrode according to claim 3, characterized in that the composite material has a dopant-enriched tungsten carbide support.

5/ An electrode according to claim 4, characterized in that a portion of the dopant has migrated into the polycrystalline diamond from the support.

6/ An electrode according to any preceding claim, and covered in a layer of gold.

7/ An electrode according to any preceding claim, that is bevel-shaped.

8/ Apparatus for measuring resistivity and comprising at least one electrode according to any preceding claim.

9/ The use of apparatus for measuring resistivity according to claim 8 in a hydrocarbon well that possesses casing.

10/ The use of apparatus for measuring resistivity according to claim 8, within the effluent from an oil borehole.

FIG.1

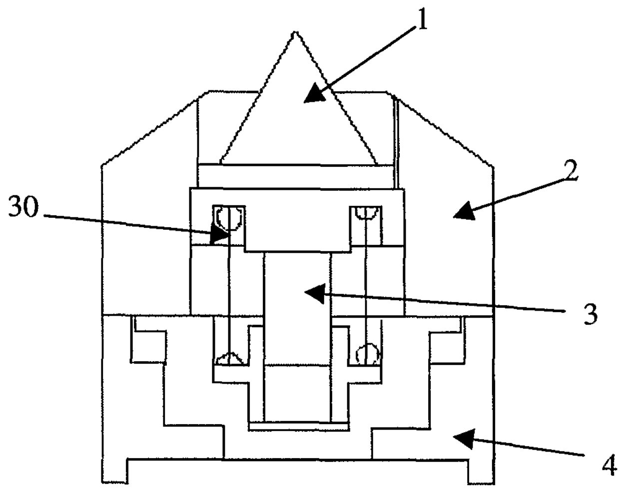

FIG.2