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(54) GLOW PLUG

(57) [Object] To inhibit a metal of which a sheath tube is composed from diffusing into a heating coil.

[Solution] A heater (800) included in a glow plug (10) includes a sheath tube (810) and a heating coil (820). The heating coil contains at least one selected from tungsten (W) and molybdenum (Mo) as a main component and contains at least one additional element selected from potassium (K), aluminum (Al), silicon (Si), lanthanum (La), thorium (Th), and cerium (Ce). The sheath tube contains at least one metal selected from nickel (Ni) and iron (Fe). A melt portion (816) that is in contact with an outer surface of a front-end portion of the heating coil is formed at a front-end portion of the sheath tube. The additional element exists at a crystal grain boundary of the main component at least in a surface layer (825) of the front-end portion of the heating coil.

FIG. 9

No.	CONTENT OF ADDITIONAL ELEMENT (ppm)	ADDITIONAL ELEMENT	PRECIPITATE	DISCONNECTION CYCLE (cyc)	FRONT END OF DISCONNECTED PORTION	TUBE PENETRATION	DECISION
SAMPLE 1	2	Al	ABSENCE	9002	×	–	×
SAMPLE 2	4	Al	ABSENCE	9985	×	–	×
SAMPLE 3	5	K	PRESENCE	10053	○	+	◎
SAMPLE 4	8	K	PRESENCE	10949	○	+	◎
SAMPLE 5	11	Si	PRESENCE	11611	○	+	◎
SAMPLE 6	22	Al	PRESENCE	12479	○	+	◎
SAMPLE 7	30	Al	PRESENCE	13209	○	+	◎
SAMPLE 8	42	Ce	PRESENCE	13683	○	+	◎
SAMPLE 9	51	Si	PRESENCE	14111	○	+	◎
SAMPLE 10	62	K	PRESENCE	15054	○	+	◎
SAMPLE 11	73	K	PRESENCE	15401	○	+	◎
SAMPLE 12	80	K	PRESENCE	14982	○	+	◎
SAMPLE 13	91	Al	PRESENCE	14421	○	+	◎
SAMPLE 14	100	Si	PRESENCE	13974	○	+	◎
SAMPLE 15	122	Th	PRESENCE	13109	○	+	◎
SAMPLE 16	153	La	PRESENCE	12875	○	+	◎
SAMPLE 17	180	Si	PRESENCE	11629	○	+	◎
SAMPLE 18	191	La	PRESENCE	10824	○	+	◎
SAMPLE 19	197	K	PRESENCE	10263	○	+	◎
SAMPLE 20	200	K	PRESENCE	10033	○	+	◎
SAMPLE 21	205	K	PRESENCE	9788	○	–	○
SAMPLE 22	210	K	PRESENCE	9622	○	–	○
SAMPLE 23	222	Si	PRESENCE	8376	○	–	○

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a glow plug.

2. Description of the Related Art

[0002] A glow plug typically includes a heater, which is a heating element, at a front-end portion in an axial direction. A sheath heater is known as one of such heaters. The sheath heater includes a cylindrical sheath tube whose front-end portion is closed and a heating coil that is located in the sheath tube and that generates heat as a result of transmission of electricity. In such a sheath heater, the front-end portion of the heating coil is welded to the front-end portion of the sheath tube.

[0003] It has been known that a coil composed of, for example, an Fe-Cr-Al alloy is used for the heating coil. In the glow plug, the temperature of the heating coil becomes 1000°C or more during heating by the heater. At this time, there is a possibility that the heating coil melts and becomes disconnected when the temperature of the heating coil locally increases excessively. For this reason, the heating coil is formed of a metal having a higher melting point to inhibit the coil from becoming disconnected due to the melt of the heating coil and to improve the durability of the glow plug. Specifically, a glow plug including a heating coil whose main component is tungsten (W) or molybdenum (Mo), which is a metal having a high melting point is proposed (for example, see PTL 1 to PTL 4).

Citation List

Patent Literature

[0004]

PTL 1: Japanese Unexamined Patent Application Publication No. 2015-099008
PTL 2: Japanese Unexamined Patent Application Publication No. 2015-078784
PTL 3: International Publication No. 2011/162074
PTL 4: Japanese Unexamined Patent Application Publication No. 11-237045

SUMMARY OF THE INVENTION

[0005] However, in the case where the heating coil is composed of tungsten (W) or molybdenum (Mo), a metal, such as nickel (Ni) or iron (Fe), forming the sheath tube diffuses into the heating coil at a joint between the heating coil and the sheath tube during heating by the heater. At the location of the heating coil where the metal of which the sheath tube is composed diffuses, the melting point of the metal of which the heating coil is composed decreases, disconnection is likely to occur, and there is a possibility that the heat resistance of the heating coil decreases. In the case where the diffusion progresses, for example, there is a possibility that the melting point of the heating coil, which exhibits a melting point of about 3000°C, locally decreases to less than 1500°C. The diffusion of the metal of which the sheath tube is composed into the heating coil progresses mainly at a crystal grain boundary of the metal of which the heating coil is composed. Accordingly, the diffusion leads to grain boundary embrittlement in the heating coil. Consequently, the heating coil is likely to become disconnected at the location where the grain boundary embrittlement progresses when a stress is applied thereto, and there is a possibility that the durability of the heater and the glow plug further decreases.

[0006] The present invention has been accomplished to solve the above problems and can be achieved as the following aspects.

(1) According to an aspect of the present invention, a glow plug includes a heater including a tubular sheath tube that extends in an axial direction and that has a closed front end, a heating coil accommodated in the sheath tube with a front-end portion thereof joined to a front-end portion of the sheath tube, and an insulator filled in the sheath tube around the heating coil. In the glow plug, the heating coil contains at least one selected from tungsten (W) and molybdenum (Mo) as a main component and contains an additional element that is at least one element selected from potassium (K), aluminum (Al), silicon (Si), lanthanum (La), thorium (Th), and cerium (Ce). The sheath tube contains at least one metal selected from nickel (Ni) and iron (Fe). A melt portion that is in contact with an outer surface of the front-end portion of the heating coil and that contains at least the same material as that of a portion of the sheath tube other than the melt portion is formed at the front-end portion of the sheath tube. When a cross section of a wire forming the heating coil is viewed at the front-end portion of the heating coil, the additional element exists at a crystal grain boundary of the main component at least in a surface layer extending from the outer surface of the heating coil to a length of a quarter of a diameter of the wire. In the front-end portion of the heating coil of the glow plug according to the aspect, the additional element exists at the crystal grain boundary of the main component of which the heating coil is composed at least in the surface layer extending from the outer surface of the heating coil to a length of a quarter of the diameter of the wire. Accordingly, during heating by the heater, at least one metal selected from nickel (Ni) and iron (Fe) and contained in the melt portion can be inhibited from diffusing from the melt portion into the heating coil along the crystal grain boundary

of the main component of which the heating coil is composed. Consequently, the durability of the heater and the glow plug can be inhibited from decreasing due to diffusion of the metal of which the sheath tube is composed into the heating coil. In addition, the grain boundary embrittlement in the heating coil is inhibited from progressing, and the durability of the heater and the glow plug can be inhibited from decreasing. It is only necessary for the additional element to exist at the crystal grain boundary of the main component of which the heating coil is composed at least in the surface layer. The additional element may exist at the crystal grain boundary of the main component over the entire heating coil.

(2) In the glow plug according to the above aspect, the additional element may exist as an oxide at the crystal grain boundary. In the glow plug according to this aspect, the additional element that exists as an oxide is more stable than in the case where the additional element exists as a metal, and accordingly, the stability of the effect of inhibiting metal diffusion from the melt portion into the heating coil can be improved.

(3) In the glow plug according to the above aspect, a content of the additional element of the heating coil may be 5 ppm or more. In the glow plug according to this aspect, since the content of the additional element of the heating coil is 5 ppm more, the additional element can easily exist at the crystal grain boundary of the main component of which the heating coil is composed at least in the surface layer.

(4) In the glow plug according to the above aspect, a content of the additional element of the heating coil may be 200 ppm or less. In the glow plug according to this aspect, the additional element contained in the heating coil and the insulator filled around the heating coil are inhibited from reacting with each other, and the heating coil and the insulator can be inhibited from excessively adhering to each other. Accordingly, the heating coil can be inhibited from being damaged due to a difference in thermal expansion coefficient between the heating coil and the insulator.

(5) In the glow plug according to the above aspect, the heating coil may be joined to the sheath tube with the front-end portion of the heating coil embedded in the melt portion. In the glow plug according to this aspect, metal diffusion from the melt portion into the heating coil can be inhibited at the portion of the heating coil embedded in the melt portion.

(6) In the glow plug according to the above aspect, the sheath tube may include a tubular extension extending in the axial direction and a lid portion that is joined to the extension at a front-end portion of the extension and that closes the front-end portion of the sheath tube. The lid portion may include a protrusion protruding to an inside of the sheath tube. The heating coil may be joined to the protrusion with the front-end portion of the heating coil wound around the protrusion. In the glow plug according to this aspect, metal diffusion from the melt portion, which is formed in the protrusion included in the lid portion of the sheath tube, into the heating coil can be inhibited.

[0007] The present invention can be achieved as various aspects other than the above aspects. For example, the present invention can be achieved as aspects of a method of manufacturing the glow plug, a heater for the glow plug, and a method of manufacturing the heater for the glow plug.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008]

Fig. 1 is an explanatory view of a schematic structure of a glow plug.

Fig. 2 is an explanatory view of the structure of a sheath heater.

Fig. 3 is an enlarged schematic sectional view of the structure of a front-end portion of the sheath heater.

Fig. 4 is a flow chart illustrating a method of manufacturing the glow plug.

Figs. 5A and 5B illustrate a welding process.

Fig. 6 is an enlarged schematic sectional view of the structure of the front-end portion of the sheath heater.

Fig. 7 is an enlarged explanatory view of the structure of the front-end portion of the sheath heater.

Fig. 8 is an enlarged explanatory view of the structure of the front-end portion of the sheath heater.

Fig. 9 illustrates a summary of evaluation results of samples.

Fig. 10 illustrates a summary of evaluation results of samples.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A. First Embodiment

(A-1) Entire Structure of Glow Plug

[0009] Fig. 1 is an explanatory view of a glow plug 10 according to a first embodiment of the present invention. The glow plug 10 according to the first embodiment functions as a heat source that assists ignition, for example, when internal combustion engines including a diesel engine start. As illustrated in Fig. 1, the glow plug 10 includes a sheath heater 800 that generates heat as a result of transmission of electricity, a metal shell 500, and a center rod 200 as main components. In Fig. 1, the exterior structure of the glow plug 10 is illustrated on the right-hand side of an axial line O of the glow plug 10, and the sectional structure thereof is illustrated on the left-hand side of the axial line O. In the description, the side of the sheath heater 800 in an axial direction OD parallel to the axial line O of the glow plug 10 is referred to as a "front-end side", and the side of the center rod 200 in the axial direction OD is referred to as a "rear-end side".

[0010] The metal shell 500 is a member obtained by forming a metallic material such as carbon steel into a tubular shape. The metal shell 500 holds the sheath heater 800 at the end portion thereof on the front-end side. The metal shell 500 holds the center rod 200 at the end portion thereof on the rear-end side with an insulating member 410 and an O-ring 460 interposed therebetween. The position of the insulating member 410 in the direction of the axial line O is fixed in a manner in which a ring 300 in contact with the rear end of the insulating member 410 is crimped along with the center rod 200. The insulating member 410 electrically insulates the metal shell 500 and the center rod 200 from each other. The metal shell 500 accommodates a portion of the center rod 200 extending from the insulating member 410 to the sheath heater 800. The metal shell 500 includes a tool engagement portion 520 and an external thread portion 540. An axial hole 510 is formed inside the metal shell 500.

[0011] The axial hole 510 is a through-hole formed along the axial line O and has a diameter larger than the diameter of the center rod 200. A gap for electrically insulating the periphery of the axial hole 510 and the center rod 200 from each other is formed between the periphery of the axial hole 510 and the center rod 200 with the position of the center rod 200 with respect to the axial hole 510 set. The sheath heater 800 is press-fitted in and joined to the axial hole 510 on the front-end side. The external thread portion 540 is to be screwed into an internal thread formed on an internal combustion engine (not illustrated) and attached thereto. The tool engagement portion 520 is to engage a tool (not illustrated) used to attach and detach the glow plug 10.

[0012] The center rod 200 is a member obtained by forming a conductive material into a cylindrical shape (rod shape). The center rod 200 is assembled along the axial line O with the center rod 200 inserted in the axial hole 510 of the metal shell 500. A center rod front-end portion 210, which is a front-end portion of the center rod 200, is inserted in the sheath heater 800. An external thread portion 290 is formed at the rear end of the center rod 200. The external thread portion 290 protrudes from the metal shell 500 on the rear-end side and is fitted in an engagement member 100.

(A-2) Structure of Sheath Heater

[0013] Fig. 2 is an explanatory view of the detailed structure of the sheath heater 800. The sheath heater 800 includes a sheath tube 810, a heating coil 820 serving as a heating element, a control coil 830, and an insulator 870.

[0014] In Fig. 2, components other than the heating coil 820, the control coil 830, and the center rod 200 are illustrated by their section.

[0015] The sheath tube 810 is a tubular member that extends in the axial direction OD and has a closed front end. Inside the sheath tube 810, the heating coil 820, the control coil 830, and the insulator 870 are accommodated. The sheath tube 810 includes a side surface portion 814, a sheath tube front-end portion 813, and a sheath tube rear-end portion 819. The side surface portion 814 is a portion that extends in the axial direction OD and that is formed such that the outer diameter of the cross section (section perpendicular to the axial line O) is constant over the entire length in the axial direction OD. The sheath tube front-end portion 813 is a portion that is formed on the front-end side of the side surface portion 814 such that the diameter gradually decreases and the sheath tube front-end portion 813 is rounded toward the outside. The sheath tube rear-end portion 819 is an opened end portion on the rear-end side of the sheath tube 810. The center rod front-end portion 210 is inserted in the sheath tube 810 from the sheath tube rear-end portion 819. The sheath tube 810 is electrically insulated from the center rod 200 by using a packing 600 and the insulator 870. The packing 600 is an insulating member interposed between the center rod 200 and the sheath tube 810. The sheath tube 810 is electrically connected to the metal shell 500 in a manner in which the outer surface thereof is in contact with the metal shell 500.

[0016] The sheath tube 810 contains at least one metal selected from nickel (Ni) and iron (Fe). More specifically, the sheath tube 810 may be composed of a metallic material containing nickel (Ni) or iron (Fe) as a main component. For example, the sheath tube 810 may be composed of a nickel-based alloy such as inconel 601 ("inconel" is a registered trademark) or Alloy 602, or stainless steel such as SUS310S.

[0017] The heating coil 820 is a spiral coil formed of a conductive material. The heating coil 820 is located inside the sheath tube 810 so as to extend in the axial direction OD and generates heat as a result of transmission of electricity. The heating coil 820 includes a coil front-end portion 822, which is the end portion on the front-end side, a spiral portion 823 spirally wound, and a heating coil rear-end portion 829, which is the end portion on the rear-end side. The heating coil 820 is electrically connected to the sheath tube 810 in a manner in which the coil front-end portion 822 is welded to the sheath tube 810.

[0018] The heating coil 820 contains at least one selected from tungsten (W) and molybdenum (Mo) as a main component. The phrase "to contain at least one selected from tungsten (W) and molybdenum (Mo) as a main component" means that the content percentage (mass%) of at least one selected from tungsten (W) and molybdenum (Mo) is 50 mass% or more. With this structure, the melting point of the metal of which the heating coil 820 is composed can be increased, and the durability of the heating coil 820 can be improved. In addition, the resistance of the heating coil 820 at a high temperature can be decreased, and the amount of current flowing therethrough can be ensured. The main component of the heating coil 820 is preferably tungsten (W). The content percentage of the main component of the heating coil 820 is preferably 80 mass% or more, more preferably 90 mass% or more, further preferably 99 mass% or more. In the case where at least one selected from tungsten (W) and molybdenum (Mo) is the main component as above, the melting point of the heating coil 820 can be increased.

[0019] The heating coil 820 contains additional elements, each of which is at least one element selected from potassium (K), aluminum (Al), silicon (Si), lanthanum (La), thorium (Th), and cerium (Ce), in addition to the main component. According to the first embodiment, the additional elements exist at the crystal grain boundary of the main component at least in a surface layer including at least the outer surface of the coil front-end portion 822. The additional elements that exist in the coil front-end portion 822 will be described in detail later.

[0020] The control coil 830 is located on the rear-end side of the heating coil 820 and formed of a conductive material having a larger temperature coefficient of electrical resistivity than the temperature coefficient of the material of which the heating coil 820 is formed. Specifically, the control coil 830 can be formed of, for example, a nickel-based alloy such as a nickel (Ni)-chrome (Cr) alloy or an iron (Fe)-chrome(Cr)-aluminum (Al) alloy. The control coil 830 formed of such a material controls power supplied to the heating coil 820. The control coil 830 includes a control coil front-end portion 831, which is the end portion on the front-end side, and a control coil rear-end portion 839, which is the end portion on the rear-end side. The control coil front-end portion 831 is welded to the heating coil rear-end portion 829 of the heating coil 820 and is thereby electrically connected to the heating coil 820. The control coil rear-end portion 839 is joined to the center rod front-end portion 210 of the center rod 200 and is thereby electrically connected to the center rod 200.

[0021] The insulator 870 is formed of powder of an electrically insulating material. Examples of the powder of the insulating material of which the insulator 870 is composed include powder of a magnesium oxide (MgO). The insulator 870 is filled inside the sheath tube 810 and electrically insulates the sheath tube 810, the heating coil 820, the control coil 830, and the center rod 200 from each other in spaces therebetween.

(A-3) Structure of Front-End Portion of Sheath Heater

[0022] Fig. 3 is an enlarged schematic sectional view of the structure of the front-end portion of the sheath heater 800. The section in Fig. 3 is the section of the sheath heater 800 cut along a line crossing the axial line O, and the spiral portion 823 and coil front-end portion 822 of the heating coil 820, the sheath tube 810, and the insulator 870 are illustrated. According to the first embodiment, the central axis of the sheath heater 800 coincides with the axial line O of the glow plug 10.

[0023] According to the first embodiment, the coil front-end portion 822 is formed on the axial line O so as to extend linearly along the axial line O. According to the first embodiment, a melt portion 816 is formed at the sheath tube front-end portion 813. The melt portion 816 is in contact with the outer surface of the coil front-end portion 822. The composition of the melt portion 816 is the same as a portion of the sheath tube 810 other than the melt portion 816. Specifically, the melt portion 816 is a portion whose composition has been changed when the heating coil 820 has been welded to the sheath tube 810 and the front-end portion of the sheath tube 810 has melted once. According to the first embodiment, during welding, the heating coil 820 having a higher melting point does not substantially melt, and only a tubular member, which will be the sheath tube 810, melts. Accordingly, as illustrated in Fig. 3, the coil front-end portion 822 is surrounded by and embedded in the melt portion 816.

[0024] According to the first embodiment, the additional elements exist at the crystal grain boundary of the main component of which the heating coil 820 is composed at least in a surface layer 825 including at least the outer surface of the coil front-end portion 822 (specifically, the surface layer including the outer surface in contact with the melt portion 816), as described above. Each additional element is at least one element selected from potassium (K), aluminum (Al), silicon (Si), lanthanum (La), thorium (Th), and cerium (Ce), as described above. In the case where the additional elements thus exist at the crystal grain boundary of the main component of which the heating coil 820 is composed, the metal of which the sheath tube 810 is composed can be inhibited from diffusing into the heating coil 820 from the melt portion 816 via the crystal grain boundary. The elements of which the sheath tube 810 is composed diffuse at the coil front-end portion 822 via the crystal grain boundary faster than when the elements pass through the inside of a crystal grain. Accordingly, in the case where the additional elements exist at the crystal grain boundary, the metal of which the sheath tube 810 is composed can be inhibited from diffusing into the heating coil 820.

[0025] The cross section of a wire forming the heating coil 820 is a section perpendicular to the direction in which the wire forming the heating coil 820 extends. According to the first embodiment, the cross section of the wire forming the heating coil 820 is substantially circular, and the cross section of the coil front-end portion 822 extending in the axial direction OD is substantially constant. According to the first embodiment, the surface layer 825 extends from the outer circumference of a side edge surface toward the center of the cross section up to a distance R (R=1/4D), where D represents the diameter of the cross section. Thus, when the cross section of the wire at the coil front-end portion 822 is viewed, the additional elements exist at the crystal grain boundary of the main component of which the heating coil 820 is composed in the surface layer 825. In the case where the cross section of the wire forming the heating coil 820 is not circular, the diameter D of the cross section corresponds to the length of the longest line segment of line segments, each of which passes through the center of gravity of the cross section and has endpoints that are on the outer circumference of the cross section.

[0026] The content of the additional elements of the heating coil 820 is preferably 5 ppm or more so that the additional elements thus exist at the crystal grain boundary of the main component in the surface layer 825. In this way, it is easy for the additional elements to exist at the crystal grain boundary of the main component of which the heating coil 820 is composed at least in the surface layer 825 of the coil front-end portion 822 of the heating coil 820. In the case where the additional elements thus exist at the crystal grain boundary, the content of the additional elements of the heating coil 820 is preferably 10 ppm or more, more preferably 30 ppm or more, further preferably 50 ppm or more, from the viewpoint of an improvement in the effect of inhibiting metal diffusion into the heating coil 820.

[0027] The content of the additional elements of the heating coil 820 is preferably 200 ppm or less. In the glow plug 10 according to the first embodiment, the insulator 870, for example, powder of a magnesium oxide (MgO), is filled in the space between the heating coil 820 and the sheath tube 810, as described above. In the case where the heating coil 820 of the glow plug 10 contains the additional elements, the additional elements and MgO can react with each other in the sheath tube 810. The reaction between the additional elements and MgO increases adhesion between the heating coil 820 and the insulator 870. Accordingly, when the content of the additional elements of the heating coil 820 is, for example, more than 200 ppm, the content of the additional elements is excessive, and there is a possibility that the heating coil 820 and the insulator 870 excessively adhere to each other. The thermal expansion coefficient of tungsten (W) or molybdenum (Mo) of which the heating coil 820 is composed is lower than the thermal expansion coefficient of MgO. Accordingly, there is a possibility that during heating by the sheath heater 800, a large stress due to a difference in the thermal expansion coefficient is produced at a location at which the additional elements and MgO react with each other and the adhesion between the heating coil 820 and the insulator 870 is increased. At such a location at which a large stress is produced, the heating coil 820 is likely to become disconnected. Accordingly, the content of the additional elements of the heating coil 820 is preferably 180 ppm or less, more preferably 150 ppm or less, further preferably 120 ppm or less, from the viewpoint of an improvement in the effect of inhibiting the heating coil 820 from becoming disconnected due to the reaction between the additional elements and MgO and the effect of inhibiting the durability of the glow plug 10 from decreasing due to the disconnection.

[0028] When the heating coil 820 is manufactured, the additional elements may be added to and mixed with the material of the heating coil 820 in advance so that the heating coil 820 contains the additional elements. In the case where several kinds of additional elements are used, the content of the additional elements means the total content of the several kinds of additional elements.

[0029] In order to identify whether the additional elements exist at the crystal grain boundary of the main component of which the heating coil 820 is composed in the surface layer 825 of the heating coil 820, the cross section of the coil front-end portion 822 may be subjected to mirror polishing and subsequently thermal etching, and the resulting surface may be observed with a scanning transmission electron microscope (STEM) to check whether a precipitate exists. The kind of the additional elements that exist may be identified in a manner in which the concentration of the additional elements is measured near the crystal grain boundary in an image obtained by the STEM with an energy dispersive X-ray spectrometer (EDS). A magnification during the observation with the STEM may be 5000 times or more.

[0030] The content of the additional elements of the heating coil 820 that the glow plug 10 includes can be measured in the following manner. That is, after the heating coil 820 is detached from the sheath heater 800 and the insulator 870 is mechanically removed, the content may be measured by ICP atomic emission spectroscopy (high frequency inductively coupled plasma atomic emission spectroscopy). In the case where the content of the additional elements in the coil front-end portion 822 located in the melt portion 816 is measured, a component of the sheath tube 810 may be removed from the surface of the wire by using a mechanical method or an acid before the measurement.

[0031] The additional elements that exist at the crystal grain boundary in the surface layer 825 of the heating coil 820 may exist in a state of a reduced metal or a state of an oxide. The majority of the additional elements typically exist in a state of an oxide because the additional elements are exposed to a high temperature during manufacturing processes of the glow plug 10. In the case where the additional elements exist in a state of an oxide at the grain boundary, the additional elements, which exist as an oxide, are more stable than in the case where the additional elements exist as a metal, and the stability of the effect of inhibiting metal diffusion from the melt portion into the heating coil can be improved. That is, in the case where the additional elements exist in a state of a reduced metal, the grain of a metallic precipitate grows when the metallic precipitate is exposed to a high temperature during the use of the glow plug 10. This causes the additional elements dispersed at the crystal grain boundary to aggregate, the locations at which metal diffusion is prevented by the additional elements at the crystal grain boundary decrease, and the effect of inhibiting metal diffusion gradually decreases. In the case where at least some of the additional elements exist as an oxide, which is more stable (more unlikely to aggregate) than a metal, the effect of inhibiting metal diffusion can be stable for a longer period of time.

[0032] Whether the additional elements exist as an oxide can be checked by measurement with the EDS, that is, by measurement of the concentration of the additional elements and oxygen atoms near the crystal grain boundary.

(A-4) Method of Manufacturing Glow Plug

[0033] Fig. 4 is a flow chart illustrating a method of manufacturing the glow plug 10. The manufacture of the glow plug 10 begins with welding of the heating coil 820, the control coil 830, and the center rod 200 (step T100). Specifically, the heating coil 820 and the control coil 830 are welded to each other, and the control coil rear-end portion 839 and the center rod front-end portion 210 are welded to each other. Subsequently, the coil front-end portion 822 and the front-end portion of the sheath tube 810 are welded to each other (step T110). In the step T110, a process of welding the coil front-end portion 822 and the front-end portion of the sheath tube 810 is also referred to as a "welding process".

[0034] Figs. 5A and 5B illustrate the welding process in the step T110. In Figs. 5A and 5B, the front-end portions of the sheath tube 810 and the heating coil 820 are illustrated, and the sheath tube 810 is illustrated by its section. In the welding process, an extension 810p that is a tubular member extending in the axial direction OD is first prepared as a member for forming the sheath tube 810. The extension 810p includes a front-end portion 813p having an opening 815 and is formed such that the diameter gradually decreases toward the opening 815. The coil front-end portion 822 is inserted into the front-end portion 813p (opening 815) of the prepared extension 810p and located there (Fig. 5A). Subsequently, the front-end portion 813p is melted by, for example, arc welding from the outside of the front-end portion 813p and solidified to close the opening 815, and the coil front-end portion 822 and the sheath tube front-end portion 813 are welded to each other (Fig. 5B). In this way, the coil front-end portion 822 is surrounded by and embedded in the melt portion 816. At this time, in the case where welding is performed under conditions in which the heating coil 820 does not melt, the melt portion 816, which does not substantially contain the component of the heating coil 820, is formed.

[0035] After the welding process in the step T110 is finished, the insulator 870 is filled in the sheath tube 810 (step T120). The insulator 870 covers the heating coil 820, the control coil 830, and the center rod 200 and is filled in the gap formed in the sheath tube 810. The assemble of the sheath heater 800 is finished.

[0036] After the sheath heater 800 is assembled, the sheath heater 800 is subjected to a swaging process (step T130). The swaging process is a process of applying a striking force to the sheath heater 800 to decrease the diameter of the sheath heater 800 and densifying the insulator 870 filled in the sheath tube 810. When a striking force is applied to the sheath heater 800 by swaging, the striking force is transmitted to the inside of the sheath heater 800, and the insulator 870 is densified.

[0037] After the sheath heater 800 is subjected to the swaging process, the sheath heater 800 and the metal shell 500 are assembled together, and the glow plug 10 is assembled (step T140) to complete the glow plug 10. Specifically, the sheath heater 800 integrated with the center rod 200 is press-fitted into the axial hole 510 of the metal shell 500 and secured thereto, the O-ring 460 and the insulating member 410 are engaged with the center rod 200 at the rear-end portion of the metal shell 500, and the engagement member 100 is tightened with the external thread portion 290 of the center rod 200 formed at the rear end of the metal shell 500. In the step T140, the glow plug 10 is subjected to an aging process. Specifically, transmission of electricity to the assembled glow plug 10 causes the sheath heater 800 to generate heat, and an oxide film is formed on the outer surface of the sheath heater 800.

[0038] In the glow plug 10 with the above structure according to the first embodiment, the additional elements exist at the crystal grain boundary of the main component of which the heating coil 820 is composed at least in the surface layer 825 of the coil front-end portion 822 of the heating coil 820 containing at least one selected from tungsten (W) and molybdenum (Mo) as the main component. Accordingly, during heating by the sheath heater 800, at least one metal selected from nickel (Ni) and iron (Fe) and contained in the melt portion 816 can be inhibited from diffusing from the melt portion 816 into the heating coil 820 along the crystal grain boundary of the main component of which the heating coil 820 is composed. Consequently, the melting point of the heating coil 820 can be inhibited from decreasing due to diffusion of the metal of which the sheath tube 810 is composed into the heating coil 820. Accordingly, the heating coil 820 is inhibited from melting and becoming disconnected when the glow plug 10 is used, and the durability of the glow plug 10 can be improved. In addition, in the case where the additional elements exist at the crystal grain boundary of the main component in the surface layer 825, the grain boundary embrittlement in the heating coil 820 is inhibited from progressing, and the durability of the sheath heater 800 and the glow plug 10 can be inhibited from decreasing.

[0039] In particular, the temperature of the front-end portion (for example, a portion about 2 mm from the front-end portion of the sheath heater 800 toward the rear-end side in the axial direction OD) of the heating coil 820 becomes high during heating by the sheath heater 800. According to the first embodiment, Ni or Fe of which the sheath tube 810 is composed can be greatly inhibited from diffusing at such a high-temperature portion, and accordingly, the heating coil 820 can be greatly inhibited from becoming disconnected.

B. Second Embodiment

[0040] Fig. 6 is an enlarged schematic sectional view of the structure of the front-end portion of a sheath heater 800a according to a second embodiment as in Fig. 3. The sheath heater 800a according to the second embodiment is used with the sheath heater 800a installed in the glow plug 10 instead of the sheath heater 800 according to the first embodiment. In the second embodiment, components shared with the first embodiment are designated by like reference numbers, and a detailed description thereof is omitted.

[0041] According to the second embodiment, a coil front-end portion 822a, which is the front-end portion of a heating coil 820a, is joined to the sheath tube 810 with the coil front-end portion 822a embedded in the melt portion 816, as in the first embodiment. According to the second embodiment, however, the coil front-end portion 822a is not formed so as to extend linearly in the axial line O, but the entire heating coil 820a is spirally wound as in the case of the spiral portion 823 according to the first embodiment. In the case where the sheath heater 800a is manufactured, when the extension 810p and the heating coil 820a are welded to each other, as illustrated in Fig. 5A and Fig. 5B, the spiral coil front-end portion 822a may be inserted into the opening 815 of the front end of the extension 810p. The front-end portion 813p may be melted by, for example, arc welding from the outside of the front-end portion 813p and solidified to close the opening 815, and the coil front-end portion 822a and the sheath tube front-end portion 813 may be welded to each other.

[0042] With this structure, the additional elements exist at the crystal grain boundary of the main component of the heating coil 820a at least in the surface layer 825 of the coil front-end portion 822a embedded in the melt portion 816, and accordingly, the same effects as in the first embodiment can be achieved.

C. Third Embodiment

[0043] Fig. 7 is an enlarged explanatory view of the structure of the front-end portion of a sheath heater 800b according to a third embodiment. The sheath heater 800b according to the third embodiment is used with the sheath heater 800b installed in the glow plug 10 instead of the sheath heater 800 according to the first embodiment. In the third embodiment, components shared with the first embodiment are designated by like reference numbers, and a detailed description thereof is omitted. In Fig. 7, a sheath tube 810b and the insulator 870 are illustrated by their section.

[0044] The sheath tube 810b forming the sheath heater 800b includes an extension 811 and a lid portion 812b. The extension 811 is a cylindrical member that extends in the axial direction OD and that forms the entire side surface of the sheath tube 810b. The lid portion 812b is located at the front end of the extension 811 such that an outer surface thereof is exposed to the outside of the sheath tube 810b and closes the front-end portion of the sheath tube 810b. The coil front-end portion 822 is joined to the lid portion 812b by welding. Specifically, the lid portion 812b and the coil front-end portion 822 are connected to each other with the melt portion 816 interposed therebetween. According to the third embodiment, the extension 811 and the lid portion 812b are joined to each other by welding, and a joint 817 is formed between the extension 811 and the lid portion 812b. According to the third embodiment, a discoid member having a constant thickness is used as the lid portion 812b, and the joint 817 is formed in an annular shape extending through the sheath tube 810b in the thickness direction.

[0045] The melt portion 816 is a joint at which the lid portion 812b has melted. The joint 817 is a joint at which at least one of the lid portion 812b and the extension 811 has melted. The extension 811 can be formed of the same material as the sheath tube 810 according to the first embodiment. The compositions of the extension 811 and the lid portion 812b may be the same or different. The lid portion 812b, however, contains at least one metal selected from nickel (Ni) and iron (Fe). Accordingly, the melt portion 816 also includes at least one metal selected from nickel (Ni) and iron (Fe).

[0046] When the sheath heater 800b is manufactured, the coil front-end portion 822 and the lid portion 812b are first welded to each other to form the melt portion 816 in the step T110 in Fig. 4. At this time, the lid portion 812b may have at the central portion a through-hole or a recessed portion for inserting and welding the coil front-end portion 822. In the welding process, the coil front-end portion 822 does not substantially melt, and the lid portion 812b melts, so that the melt portion 816 is formed. The heating coil 820 the front end of which is welded to the lid portion 812b may be inserted into the extension 811, and the lid portion 812b may be welded to the front end of the extension 811 to form the joint 817.

[0047] With this structure, the additional elements exist at the crystal grain boundary of the main component of the heating coil 820 at least in the surface layer 825 of the coil front-end portion 822 embedded in the melt portion 816, and accordingly, the same effects as in the first embodiment can be achieved.

[0048] The lid portion 812b can be formed in various shapes other than a discoid shape. The joint 817 that joints the lid portion 812b and the extension 811 to each other may be formed in a shape other than an annular shape extending through the sheath tube 810b in the thickness direction. For example, the melt portion 816 and the joint 817 may at least partially overlap.

D. Fourth Embodiment

[0049] Fig. 8 is an enlarged explanatory view of the structure of the front-end portion of a sheath heater 800c according to a fourth embodiment. The sheath heater 800c according to the fourth embodiment is used with the sheath heater 800c installed in the glow plug 10 instead of the sheath heater 800 according to the first embodiment. In the fourth embodiment, components shared with the first to third embodiments are designated by like reference numbers, and a detailed description thereof is omitted. In Fig. 8, components other than the heating coil 820a are illustrated by their section.

[0050] A sheath tube 810c forming the sheath heater 800c includes the extension 811 and a lid portion 812c. The lid portion 812c is formed in a cylindrical shape with a step including a thinner closing portion 840 and a thicker protrusion 842, that is, in a rivet shape. The closing portion 840 closes the front-end portion of the sheath tube 810c while the front-end surface thereof is exposed to the outside. The protrusion 842 is formed so as to protrude from the closing portion 840 to the inside of the sheath tube 810c and is joined to the coil front-end portion 822a of the heating coil 820a by welding. Specifically, the protrusion 842 and the coil front-end portion 822a are connected to each other with the melt portion 816 interposed therebetween. According to the fourth embodiment, the extension 811 and the closing portion 840 are also joined to each other by welding, and the joint 817 is formed between the extension 811 and the closing portion 840. The joint 817 is formed in an annular shape extending through the sheath tube 810c in the thickness direction.

[0051] The melt portion 816 is a joint at which the lid portion 812c (protrusion 842) has melted. The joint 817 is a joint at which at least one of the lid portion 812c (closing portion 840) and the extension 811 has melted. The extension 811 can be formed of the same material as the sheath tube 810 according to the first embodiment. The compositions of the extension 811 and the lid portion 812c may be the same or different. The lid portion 812c, however, contains at least one metal selected from nickel (Ni) and iron (Fe). Accordingly, the melt portion 816 also includes at least one metal selected from nickel (Ni) and iron (Fe).

[0052] According to the fourth embodiment, the coil front-end portion 822a is not embedded in the melt portion 816 formed in the sheath tube 810c but is wound around the outer circumference of the protrusion 842. The melt portion 816 is formed in a region including the outer surface of the protrusion 842 in contact with the coil front-end portion 822a of the heating coil 820a. The additional elements exist at the crystal grain boundary of the main component of the heating coil 820a at least in the surface layer 825 of the coil front-end portion 822a in contact with the melt portion 816 at the protrusion 842, as in the first embodiment.

[0053] When the sheath heater 800c is manufactured, the coil front-end portion 822a is first wound around and welded to the protrusion 842 of the lid portion 812c to form the melt portion 816 in the step T110 in Fig. 4. In the welding process, the coil front-end portion 822a does not substantially melt, and the protrusion 842 melts, so that the melt portion 816 is formed. The heating coil 820a the front end of which is welded to the lid portion 812c may be inserted into the extension 811, and the closing portion 840 of the lid portion 812c may be welded to the front end of the extension 811 to form the joint 817.

[0054] With this structure, the additional elements exist at the crystal grain boundary of the main component of the heating coil 820a at least in the surface layer 825 of the coil front-end portion 822a in contact with the melt portion 816 formed at the protrusion 842, and accordingly, the same effects as in the first embodiment can be achieved.

[0055] The joint 817 that joints the lid portion 812c and the extension 811 to each other may be formed in a shape other than an annular shape extending through the sheath tube 810c in the thickness direction. For example, the joint 817 may be formed of the whole of a portion of the closing portion 840 that is exposed to the outside of the sheath tube 810c. Alternatively, the joint 817 may be formed so as to extend to at least a part of the protrusion 842.

E. Modification

First Modification

[0056] According to the above embodiments, the melt portion 816 is formed as a result of the sheath tube 810, 810b, or 810c only being melted and does not substantially contain the material of which each heating coil is composed. However, a different structure may be used. For example, a mixed layer containing the material of which each heating coil is composed may be formed in a region (region including the boundary with the coil front-end portion) of the melt portion 816 near the surface of the heating coil. That is, the melt portion 816 may contain the material of which each heating coil is composed, provided that the melt portion 816 contains the same material as a portion of the sheath tube other than the melt portion 816. Also, in this case, it is only necessary for the additional elements to exist at the crystal grain boundary of the main component of the heating coil at least within the range in which the distance from the above boundary in the cross section of the coil front-end portion is equal to a length of a quarter of the diameter of the wire forming the coil front-end portion. Second Modification

[0057] According to the above embodiments, the sheath heaters 800 and 800a to 800c have the heating coils 820 and 820a and the control coil 830. However, a different structure may be used. For example, a single coil in which the rear-end portion of the heating coil is connected to the center rod front-end portion 210 may be provided. Alternatively, three or more coils connected to each other in series may be provided. Also in this case, it is only necessary for the additional elements to exist at the crystal grain boundary at least in the surface layer 825 of the coil front-end portion of the heating coil that is located at the front-end portion and that is welded to the sheath tube.

Third Modification

[0058] According to the third and fourth embodiments, the extension 811 and the lid portions 812b and 812c are joined to each other by welding with the joint 817 interposed therebetween. However, a different structure may be used. For example, the extension 811 and the lid portions 812b and 812c may be joined by, for example, a crimping method.

EXAMPLE

[0059] Various glow plugs were manufactured as samples having different kinds of additional elements added to the heating coil 820 and different contents of the additional elements of the heating coil 820. The presence or absence of a precipitate at the crystal grain boundary and the durability of the glow plugs were evaluated. The results will be described below.

[0060] Fig. 9 and Fig. 10 illustrate the summary of the kind of the additional elements, the content of the additional elements, and the evaluation results of the samples. When the samples were manufactured, the heating coils 820 formed of different tungsten (W) wires having a diameter of 0.2 mm and containing different contents of various kinds of additional elements other than tungsten were prepared, and the sheath heaters 800 were manufactured, and the glow plugs 10 were assembled. At this time, regarding the samples in which the compositions of the heating coils 820 are different from each other, the heating coils 820 were manufactured under the same conditions, and the glow plugs 10 were assembled. Regarding some of the heating coils 820 of the samples, which were manufactured under the same conditions, after the glow plugs 10 were assembled, the content of the additional elements contained in each heating coil 820 was investigated. Regarding other heating coils 820 of the samples, which were manufactured under the same conditions, after the glow plugs 10 were assembled, whether the additional elements existed at the crystal grain boundary at least in the surface layer of the coil front-end portion of each heating coil was investigated. Regarding the samples, after the glow plugs 10 were assembled, the other heating coils 820, which were manufactured under the same conditions, were used for operational durability tests of the glow plugs 10.

[0061] Among samples 1 to 29 illustrated in Fig. 9 and Fig. 10, the samples 1 to 23 illustrated in Fig. 9 contain only one kind of additional elements. In contrast, the samples 24 to 29 illustrated in Fig. 10 contain several kinds of additional elements selected from potassium (K), aluminum (Al), silicon (Si), lanthanum (La), thorium (Th), and cerium (Ce). Specifically, the heating coils 820 of the samples 24 to 29 were manufactured in a manner in which two kinds of additional elements were added in the same amount.

[0062] The sheath heaters and the glow plugs were manufactured in accordance with the first embodiment (for example, Fig. 2). The front-end portion of each heating coil 820 was welded directly to the sheath tube. The kind and content of the additional elements of the heating coil 820 of each sample are illustrated in Fig. 9 and Fig. 10. The other conditions (shape of the components and the material of each component other than the heating coil) are the same in all of the samples.

Measurement of Content of Additional Elements

[0063] Each sample glow plug 10 was disassembled, and each heating coil 820 was detached from the sheath heater. After the insulator 870 was mechanically removed, the content of the additional elements of the heating coil 820 was measured by ICP atomic emission spectroscopy (high frequency inductively coupled plasma atomic emission spectroscopy). The content of the additional elements thus measured was substantially equal to the amount of the additional elements added to a raw material (tungsten) when the heating coil 820 was manufactured.

Check of Additional Elements at Crystal Grain Boundary

[0064] It was determined whether the additional elements existed at the crystal grain boundary of the main component (tungsten) of which the heating coil 820 was composed in the surface layer 825 of the heating coil 820 of each sample. For this purpose, the cross section of the coil front-end portion 822 was subjected to mirror polishing and subsequently thermal etching, and the resulting surface was observed with a scanning transmission electron microscope (STEM) to check whether a precipitate existed at the crystal grain boundary. The concentration of the additional elements at the crystal grain boundary in an image obtained by the STEM was measured with an energy dispersive X-ray spectrometer (EDS), and it was thereby confirmed that the additional elements caused the observed precipitate to be produced. The magnification during the observation by the STEM was 5000 times. In Fig. 9, the column of "PRECIPITATE" includes the term "PRESENCE" in the case where the presence of the additional elements at the crystal grain boundary of the main component was confirmed. The column of "PRECIPITATE" includes the term "ABSENCE" in the case where the presence of the additional elements at the crystal grain boundary of the main component was not confirmed. Regarding the samples in which the presence of the additional elements at the crystal grain boundary of the main component was confirmed, it was confirmed from the result of the EDS that at least some of the additional elements existed as an oxide at the crystal grain boundary.

Condition of Operational Durability Test

[0065] An operational test was conducted by using each sample glow plug 10 to evaluate the durability thereof. Specifically, a process having a cycle of the following procedures 1 to 3 was repeatedly performed on each sample, and the number of the cycles (number of disconnection cycles) the heating coil 820 of each sample became disconnected was measured. (Procedure 1) Electricity was transmitted to each sample glow plug such that the temperature of the sheath heater at a location 2 mm from the front-end portion of the outer surface of the sheath heater in the axial direction OD became 1200°C. (Procedure 2) After the temperature of the sheath heater at the above location became 1200°C, the transmission of electricity to the glow plug 10 was continued for 10 minutes while a state where the temperature of the sheath heater at the above location was 1200°C was maintained. (Procedure 3) The transmission of electricity to the glow plug was stopped after the state where the temperature of the sheath heater at the above location was 1200°C was maintained for 10 minutes, and the sheath heater was cooled for 2 minutes in a manner in which air was sent thereto (air at a wind speed of 10 mm/s).

Determination of Location of Disconnection

[0066] During the operational durability test of each sample glow plug, after the heating coil 820 became disconnected, the location of the disconnection was checked. The location of the disconnection was checked with an X-ray CT apparatus. Specifically, the location of the disconnection of the heating coil 820 was identified in an X-ray CT image enlarged 1000 times. The location of the disconnection was measured by using as a criterion the location of the rear end of a region of the heating coil 820 in which the component of the sheath tube 810 existed on the surface. The location (also referred to below as the "tube component rear-end location") of the rear end of the region of the heating coil 820 in which the component of the sheath tube 810 existed on the surface refers to the location of a region of the surface of the heating coil 820 in contact with the melt portion 816 on the rear-end side in the axial direction OD.

[0067] In Fig. 9, the column of "FRONT END OF DISCONNECTED PORTION" includes the symbol "×" in the case where the location of the disconnection was a location within 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD. The column of "FRONT END OF DISCONNECTED PORTION" includes the symbol "○" in the case where the location of the disconnection was further away than the location 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD. In the case where the location of the disconnection is the location within 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD (in the case where the evaluation of "FRONT END OF DISCONNECTED PORTION" is "×"), it is thought that the cause of the disconnection of the heating coil 820 is that the metal of which the sheath tube 810 is composed diffuses into the heating coil 820 and that the melting point of the heating coil 820 locally decreases. In the case where the location of the disconnection is further away than the location 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD (in the case where the evaluation of "FRONT END OF DISCONNECTED PORTION" is "○"), it is thought that the cause of the disconnection of the heating coil 820 is not that the metal of which the sheath tube 810 is composed diffuses into the heating coil 820 and that the melting point of the heating coil 820 locally decreases.

Presence or Absence of Sheath Tube Penetration

[0068] When each sample was observed with the X-ray CT apparatus, whether a through-hole was formed in the side surface portion 814 of the sheath tube 810 was also checked. In Fig. 9, the column of "TUBE PENETRATION" includes the symbol "+" in the case where a through-hole was formed in the side surface portion 814 of the sheath tube 810, and the column of "TUBE PENETRATION" includes the symbol "-" in the case where no through-hole was formed.

[0069] As the transmission of electricity to each glow plug 10 was repeated, oxidation in the sheath tube 810 gradually progresses, and there is a possibility that a through-hole is finally formed. In the case where the through-hole is formed in the sheath tube 810, oxygen enters the sheath heater via the through-hole. When oxygen enters the sheath heater, tungsten (W) of which the heating coil 820 is composed is oxidized, and the melting point of the heating coil 820 locally decreases. Accordingly, it is thought that, in the case where the through-hole is formed in the sheath tube 810, the cause of the disconnection of the heating coil 820 is the oxidation of tungsten due to oxygen that enters via the through-hole.

[0070] As illustrated in Fig. 9, in the samples 1 and 2 in which the content of the additional elements was less than 5 ppm, specifically, 2 ppm and 4 ppm, the presence of the additional elements at the crystal grain boundary of tungsten in the surface layer 825 of the heating coil 820 was not confirmed. In the samples 1 and 2, the location of the disconnection of the heating coil 820 was the location within 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD. Accordingly, it is thought that, in the samples 1 and 2, the metal of which the sheath tube 810 was composed was not inhibited from diffusing into the heating coil 820, and the heating coil 820 became disconnected near the tube component rear-end location, because the presence of the additional elements at the crystal grain boundary of tungsten in the surface layer 825 of the heating coil 820 was not confirmed. The disconnection cycle of the samples 1 and 2 was less than ten thousand cycles. From the above result, in Fig. 9, the column of "DECISION" for the samples 1 and 2 includes the symbol "×".

[0071] As illustrated in Fig. 9, in the samples 3 to 20 in which the content of the additional elements was no less than 5 ppm and no more than 200 ppm, the presence of the additional elements at the crystal grain boundary of tungsten in the surface layer 825 of the heating coil 820 was confirmed. In the samples 3 to 20, the location of the disconnection of the heating coil 820 was further away than the location 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD. The presence of the through-hole in the sheath tube 810 of the samples 3 to 20 was confirmed. Accordingly, it is thought that the cause of the disconnection of the heating coil 820 of the samples 3 to 20 was not diffusion of the metal of which the sheath tube 810 was composed into the heating coil 820 but was the oxidation of the heating coil 820 (tungsten) due to oxygen that entered via the through-hole. The disconnection cycle of the samples 3 to 20 was more than ten thousand cycles. From the above result, in Fig. 9, the column of "DECISION" for the samples 3 to 20 includes the symbol "⊙".

[0072] As illustrated in Fig. 9, in the samples 21 to 23 in which the content of the additional elements was more than 200 ppm, the presence of the additional elements at the crystal grain boundary of tungsten in the surface layer 825 of the heating coil 820 was confirmed. In the samples 21 to 23, the location of the disconnection of the heating coil 820 was further away than the location 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD. The presence of a through-hole in the sheath tube 810 of the samples 21 to 23 was not confirmed.

[0073] The location of the disconnection was further away than the location 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD, as described above. For this reason, it is thought that the cause of the disconnection of the heating coil 820 of the samples 21 to 23 was not diffusion of the metal of which the sheath tube 810 was composed into the heating coil 820. Since the presence of a through-hole in the sheath tube 810 was not confirmed, it is thought that the cause of the disconnection of the heating coil 820 of the samples 21 to 23 was not oxidation of the heating coil 820 due to oxygen that entered via the through-hole. It is however thought that, in the samples 21 to 23, the content of the additional elements of the heating coil 820 was large, the additional elements and the insulator 870 (MgO) reacted with each other and excessively adhered to each other, and the heating coil 820 became disconnected due to a stress caused by a difference in the thermal expansion coefficient between the heating coil 820 and the insulator 870.

[0074] With the samples 21 to 23, an effect of the present invention, that is, inhibiting disconnection due to diffusion of the metal of which the sheath tube 810 was composed was achieved. However, there was a tendency that the additional metal reacted with MgO selected as the material of which the insulator 870 was composed, and the disconnection cycle was thereby less than in the case where the content of the additional elements was 200 ppm or less (specifically, the disconnection cycle was less than ten thousand cycles). From the above result, in Fig. 9, the column of "DECISION" for the samples 21 to 23 includes the symbol "○".

[0075] As illustrated in Fig. 10, in the samples 24 to 28 among samples containing two kinds of additional elements in which the content of the additional elements was no less than 5 ppm and no more than 200 ppm, the presence of the additional elements at the crystal grain boundary of tungsten in the surface layer 825 of the heating coil 820 was confirmed. The location of the disconnection of the heating coil 820 was further away than the location 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD. The presence of the through-hole in the sheath tube 810 was confirmed. Accordingly, it is thought that the cause of the disconnection of the heating coil 820 of the samples 24 to 28 was not diffusion of the metal of which the sheath tube 810 was composed into the heating coil 820 but was the oxidation of the heating coil 820 (tungsten) due to oxygen that entered via the through-hole, as in the case of the samples 3 to 20. The disconnection cycle of the samples 24 to 28 was more than ten thousand cycles. From the above result, in Fig. 10, the column of "DECISION" for the samples 24 to 28 includes the symbol "⊙".

[0076] As illustrated in Fig. 10, in the sample 29 among the samples containing two kinds of additional elements in which the content of the additional elements was more than 200 ppm, the presence of the additional elements at the crystal grain boundary of tungsten in the surface layer 825 of the heating coil 820 was confirmed. The location of the disconnection of the heating coil 820 was further away than the location 10 mm from the tube component rear-end location on the rear-end side in the axial direction OD. The presence of a through-hole in the sheath tube 810 was not confirmed. Accordingly, it is thought that the cause of the disconnection of the heating coil 820 of the sample 29 was that the additional elements and the insulator 870 (MgO) reacted with each other and excessively adhered to each other, as in the samples 21 to 23. With the sample 29, an effect of the present invention, that is, inhibiting disconnection due to diffusion of the metal of which the sheath tube 810 was composed was achieved. However, the additional elements and the insulator 870 (MgO) reacted with each other, and the disconnection cycle was thereby less than ten thousand cycles. Accordingly, the column of "DECISION" includes the symbol "○".

[0077] The present invention is limited neither to the above embodiments, the example, nor the modifications and can be achieved with various structures without departing from the concept of the present invention. For example, the technical features in the embodiments, the example, and the modifications corresponding to the technical features in the aspects described in the summary of the invention can be appropriately replaced or combined in order to solve part or all of the above problems or in order to achieve part or all of the above effects. Technical features described as unessential features can be appropriately removed.

Claims

1. A glow plug (10), comprising:

    a heater including a tubular sheath tube (810, 810b, 810c) that extends in an axial direction and that has a closed front end, a heating coil (820, 820a) accommodated in the sheath tube (810, 810b, 810c) with a front-end portion (822, 822a) thereof joined to a front-end portion of the sheath tube (810, 810b, 810c), and an insulator (870) filled in the sheath tube (810, 810b, 810c) around the heating coil (820, 820a),
    wherein the heating coil (820, 820a) contains at least one selected from tungsten (W) and molybdenum (Mo) as a main component and contains an additional element that is at least one element selected from potassium (K), aluminum (Al), silicon (Si), lanthanum (La), thorium (Th), and cerium (Ce),
    wherein the sheath tube (810, 810b, 810c) contains at least one metal selected from nickel (Ni) and iron (Fe),
    wherein a melt portion (816) that is in contact with an outer surface of the front-end portion (822, 822a) of the heating coil (820, 820a) and that contains at least the same material as that of a portion of the sheath tube (810, 810b, 810c) other than the melt portion (816) is formed at the front-end portion of the sheath tube (810, 810b, 810c), and
    wherein, when a cross section of a wire forming the heating coil (820, 820a) is viewed at the front-end portion (822, 822a) of the heating coil (820, 820a), the additional element exists at a crystal grain boundary of the main component at least in a surface layer (825) extending from the outer surface of the heating coil (820, 820a) to a length of a quarter of a diameter of the wire.

2. The glow plug (10) according to Claim 1, wherein the additional element exists as an oxide at the crystal grain boundary.

3. The glow plug (10) according to Claim 1 or Claim 2, wherein a content of the additional element of the heating coil (820) is 5 ppm or more.

4. The glow plug (10) according to any one of Claims 1 to 3, wherein a content of the additional element of the heating coil (820) is 200 ppm or less.

5. The glow plug (10) according to any one of Claims 1 to 4, wherein the heating coil (820, 820a) is joined to the sheath tube (810, 810b) with the front-end portion (822, 822a) of the heating coil (820, 820a) embedded in the melt portion (816).

6. The glow plug (10) according to any one of Claims 1 to 4,
    wherein the sheath tube (810c) includes a tubular extension (811) extending in the axial direction and a lid portion (812c) that is joined to the extension (811) at a front-end portion of the extension (811) and that closes the front-end portion of the sheath tube (810c),
    wherein the lid portion (812c) includes a protrusion (842) protruding to an inside of the sheath tube (810c), and
    wherein the heating coil (820a) is joined to the protrusion (842) with the front-end portion (822a) of the heating coil (820a) wound around the protrusion (842).

FIG. 1

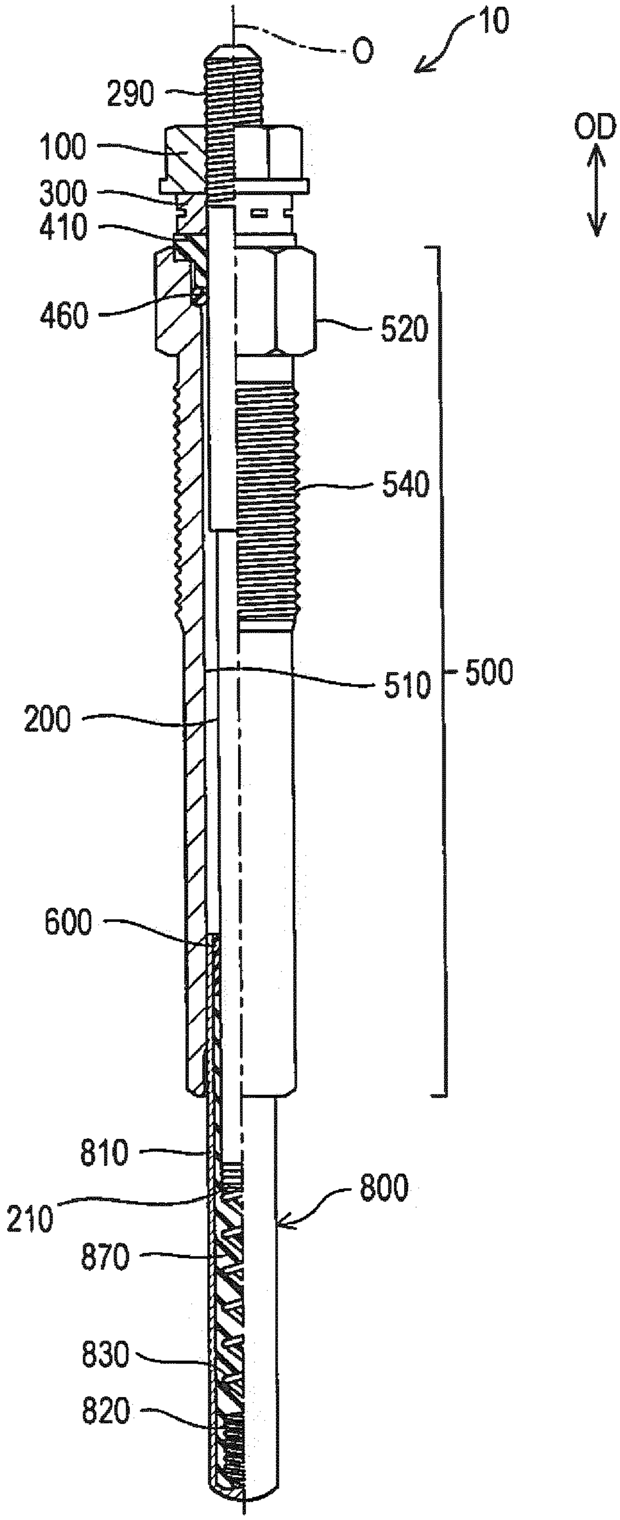
10
O
OD
290
100
300
410
460
520
540
510
500
200
600
810
210
870
830
820
800

FIG. 2

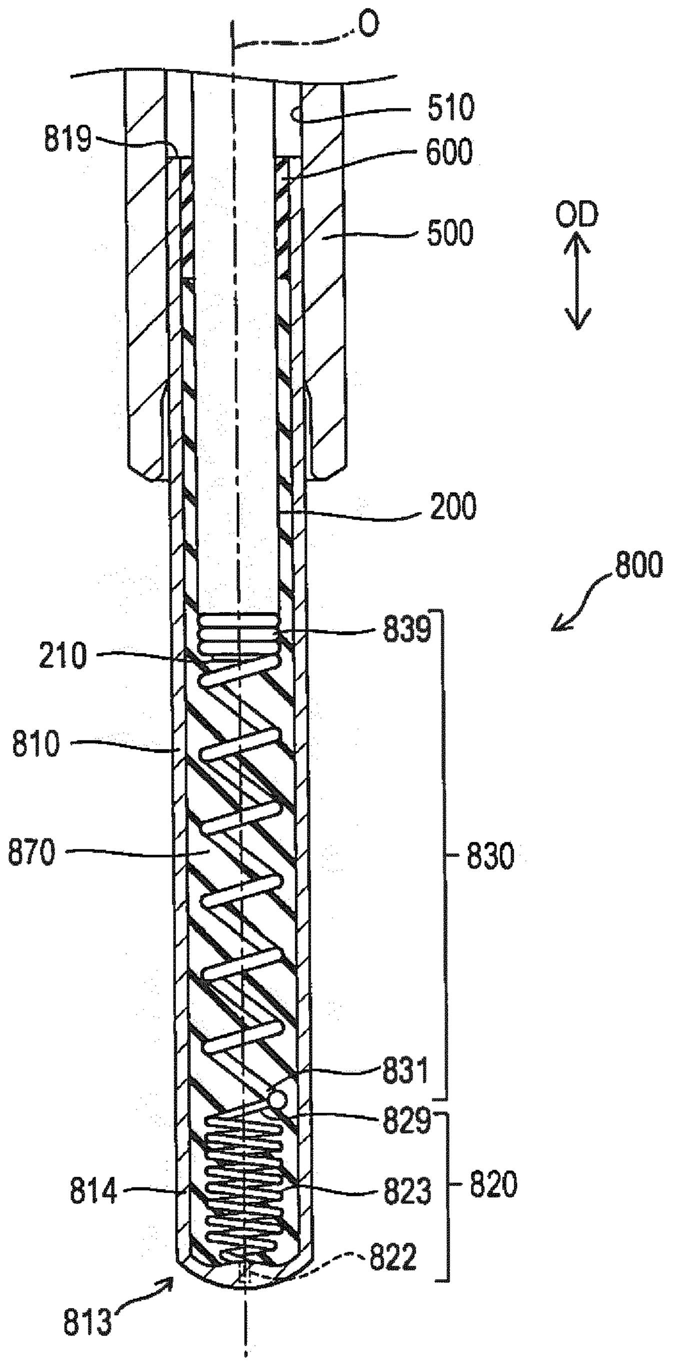
O
510
819
600
OD
500
200
800
839
210
810
870
830
831
829
814
823
820
822
813

FIG. 3

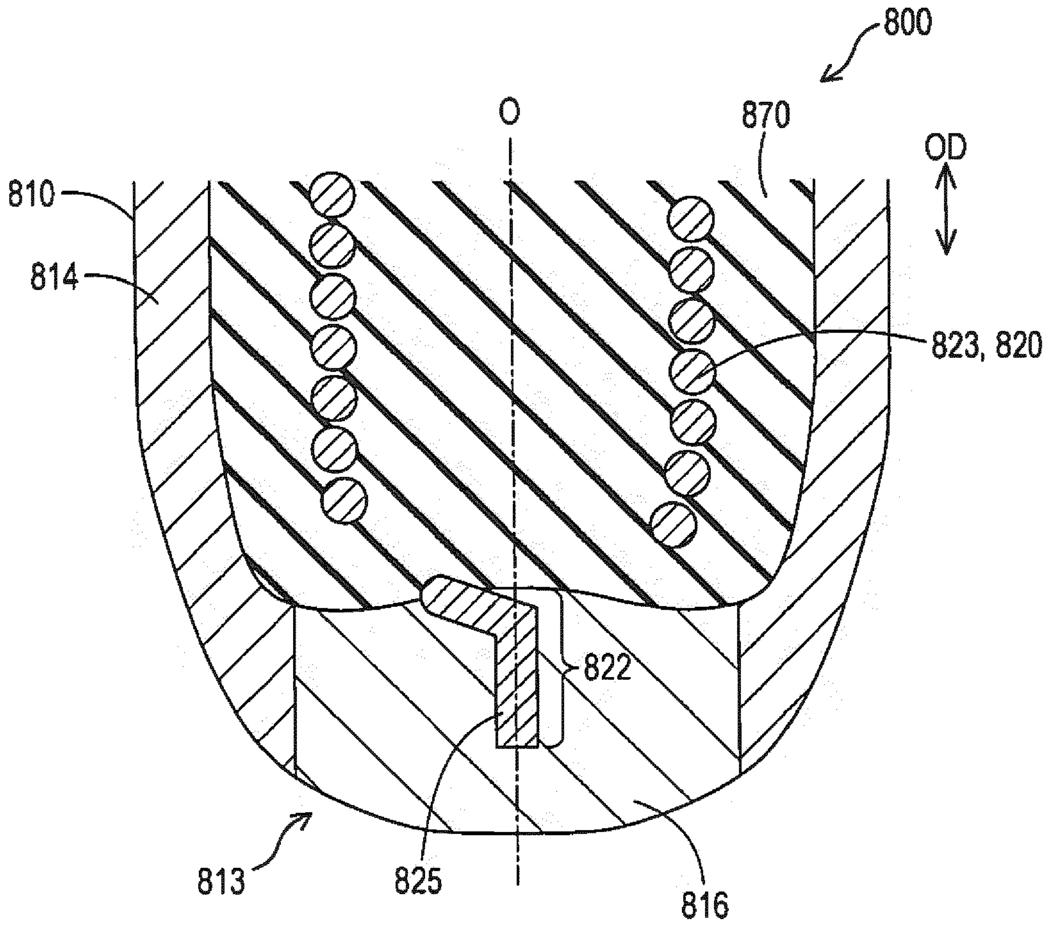

FIG. 4

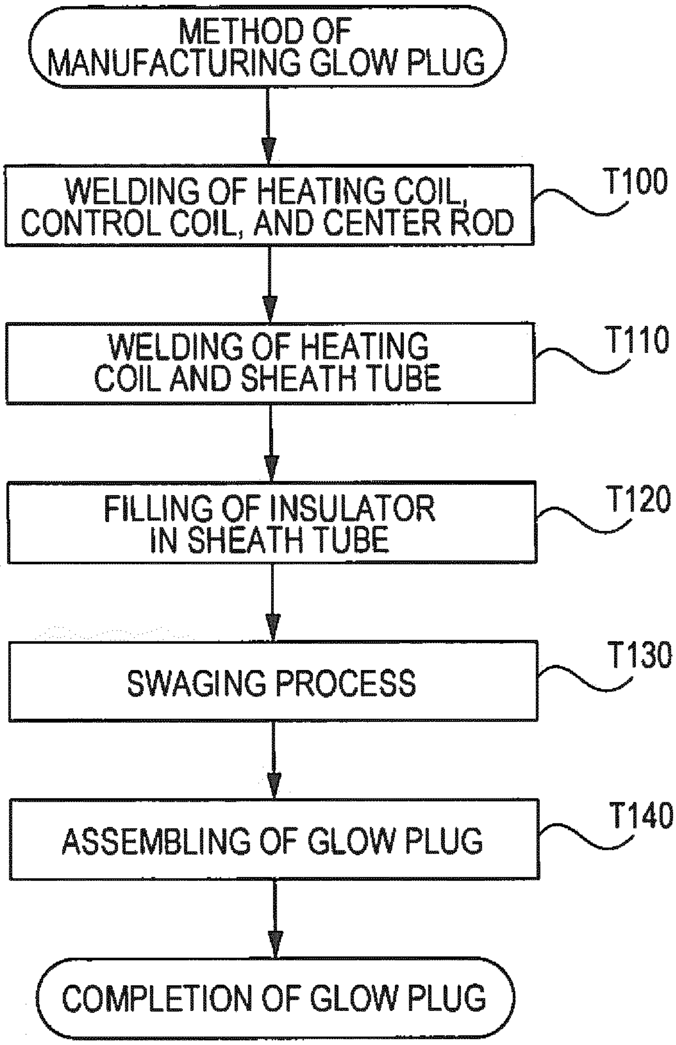
METHOD OF MANUFACTURING GLOW PLUG
WELDING OF HEATING COIL, CONTROL COIL, AND CENTER ROD
T100
WELDING OF HEATING COIL AND SHEATH TUBE
T110
FILLING OF INSULATOR IN SHEATH TUBE
T120
SWAGING PROCESS
T130
ASSEMBLING OF GLOW PLUG
T140
COMPLETION OF GLOW PLUG

FIG. 5B

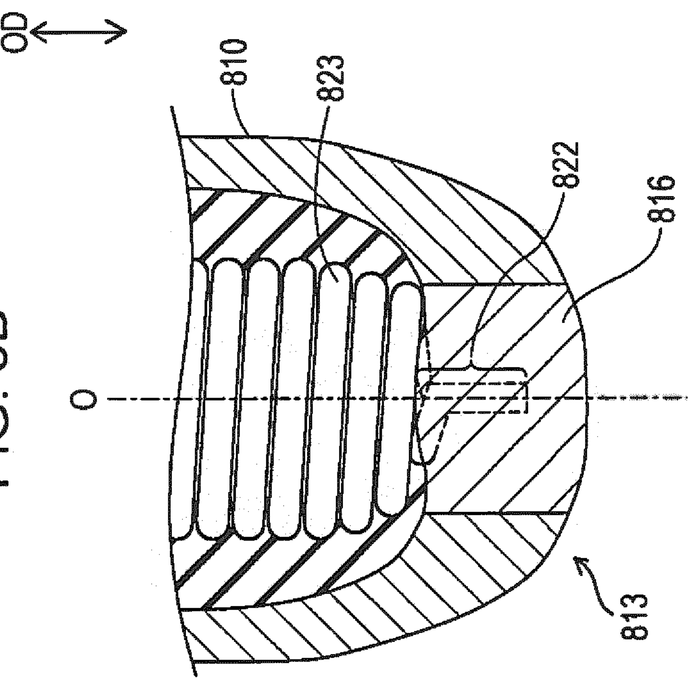

FIG. 5A

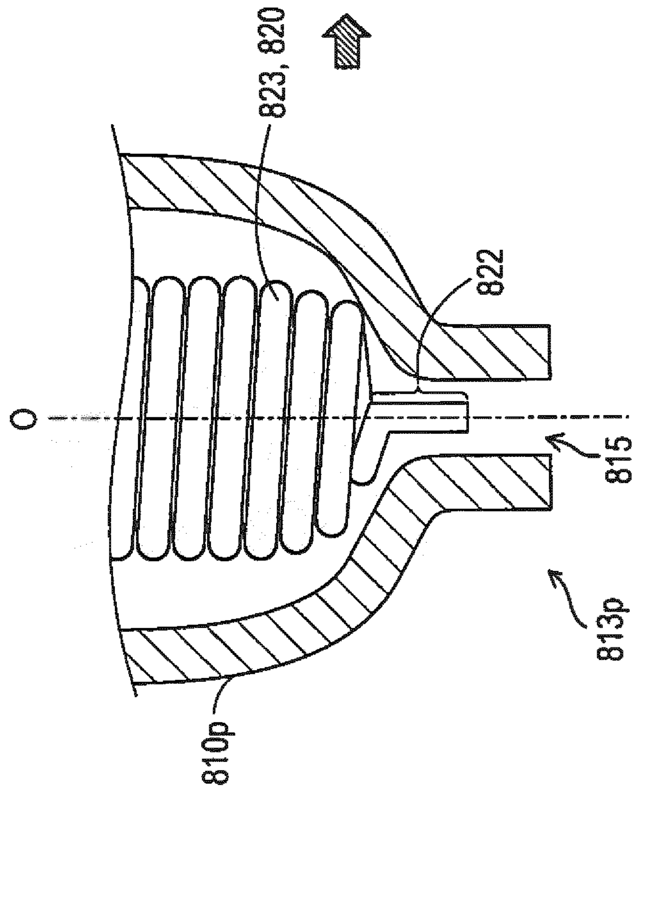

FIG. 6

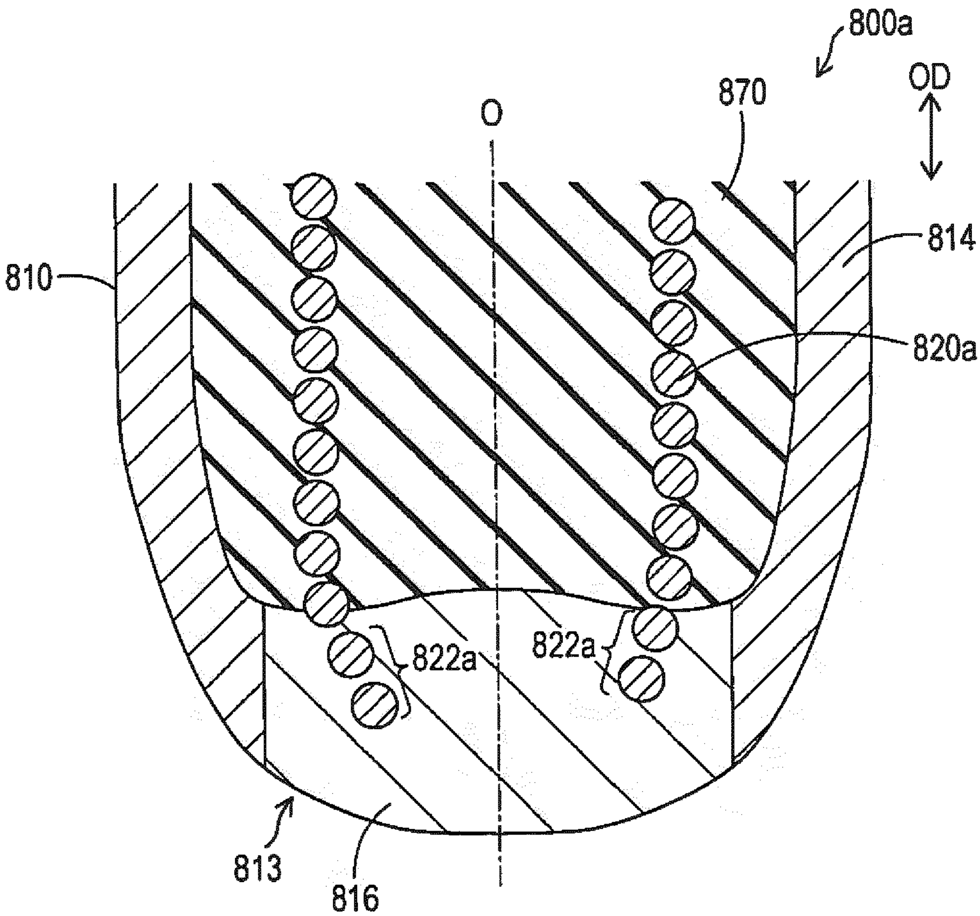

FIG. 7

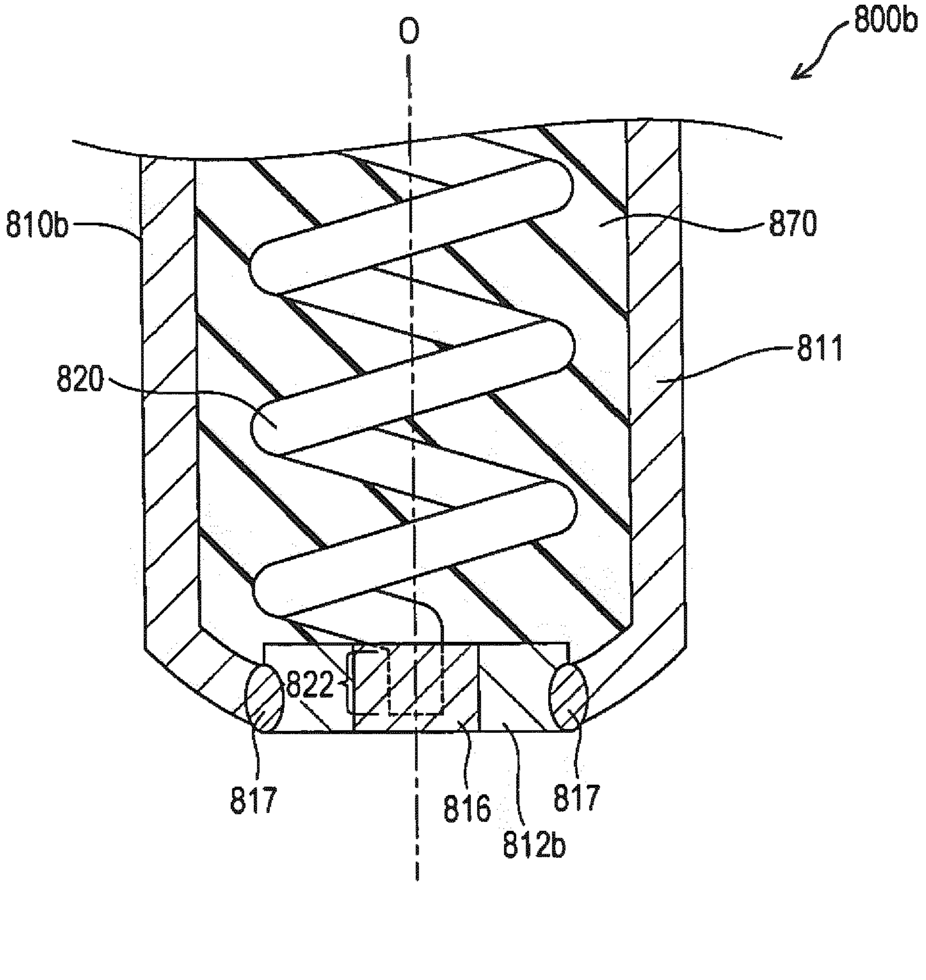

FIG. 8

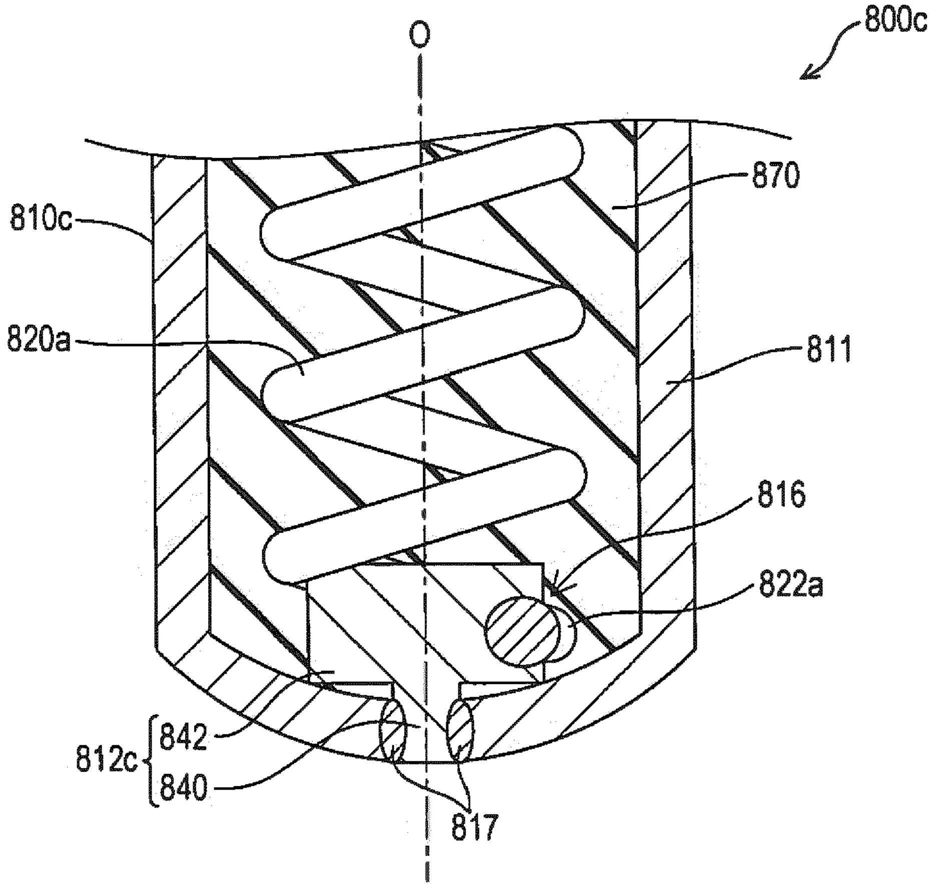

FIG. 9

No.	CONTENT OF ADDITIONAL ELEMENT (ppm)	ADDITIONAL ELEMENT	PRECIPITATE	DISCONNECTION CYCLE (cyc)	FRONT END OF DISCONNECTED PORTION	TUBE PENETRATION	DECISION
SAMPLE 1	2	Al	ABSENCE	9002	×	−	×
SAMPLE 2	4	Al	ABSENCE	9985	×	−	×
SAMPLE 3	5	K	PRESENCE	10053	○	+	◎
SAMPLE 4	8	K	PRESENCE	10949	○	+	◎
SAMPLE 5	11	Si	PRESENCE	11611	○	+	◎
SAMPLE 6	22	Al	PRESENCE	12479	○	+	◎
SAMPLE 7	30	Al	PRESENCE	13209	○	+	◎
SAMPLE 8	42	Ce	PRESENCE	13683	○	+	◎
SAMPLE 9	51	Si	PRESENCE	14111	○	+	◎
SAMPLE 10	62	K	PRESENCE	15054	○	+	◎
SAMPLE 11	73	K	PRESENCE	15401	○	+	◎
SAMPLE 12	80	K	PRESENCE	14982	○	+	◎
SAMPLE 13	91	Al	PRESENCE	14421	○	+	◎
SAMPLE 14	100	Si	PRESENCE	13974	○	+	◎
SAMPLE 15	122	Th	PRESENCE	13109	○	+	◎
SAMPLE 16	153	La	PRESENCE	12875	○	+	◎
SAMPLE 17	180	Si	PRESENCE	11629	○	+	◎
SAMPLE 18	191	La	PRESENCE	10824	○	+	◎
SAMPLE 19	197	K	PRESENCE	10263	○	+	◎
SAMPLE 20	200	K	PRESENCE	10033	○	+	◎
SAMPLE 21	205	K	PRESENCE	9788	○	−	○
SAMPLE 22	210	K	PRESENCE	9622	○	−	○
SAMPLE 23	222	Si	PRESENCE	8376	○	−	○

FIG. 10

No.	CONTENT OF ADDITIONAL ELEMENT (ppm)	ADDITIONAL ELEMENT	PRECIPITATE	DISCONNECTION CYCLE (cyc)	FRONT END OF DISCONNECTED PORTION	TUBE PENETRATION	DECISION
SAMPLE 24	45	Ce, K	PRESENCE	13784	○	+	⊙
SAMPLE 25	84	Si, K	PRESENCE	14721	○	+	⊙
SAMPLE 26	136	Al, K	PRESENCE	12932	○	+	⊙
SAMPLE 27	172	La, K	PRESENCE	11893	○	+	⊙
SAMPLE 28	190	Th, Al	PRESENCE	11992	○	+	⊙
SAMPLE 29	219	Si, K	PRESENCE	8544	○	−	○

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EUROPEAN SEARCH REPORT

Application Number
EP 17 17 6803

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F23Q

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	11 October 2017	Theis, Gilbert

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