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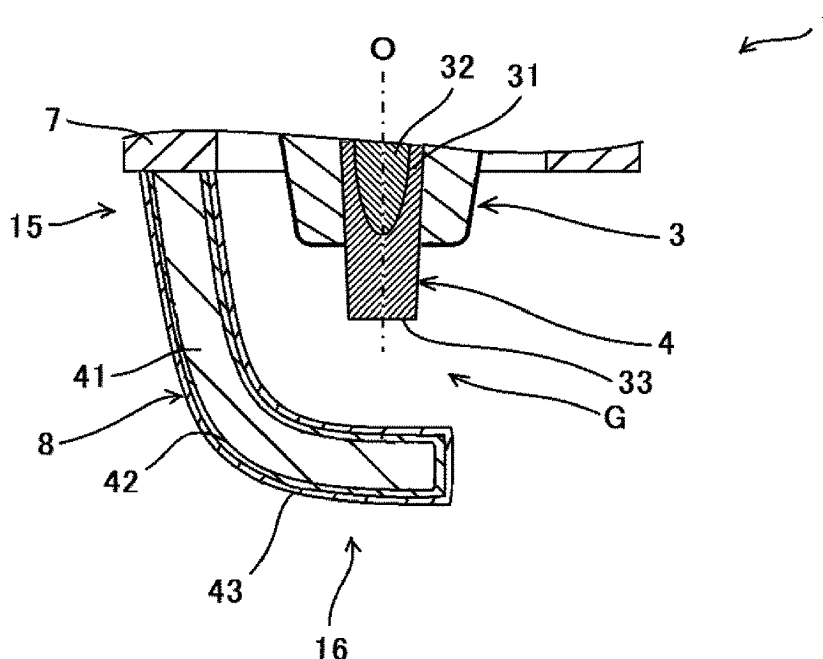
(54) **SPARK PLUG**

(57) [Object] It is an object of the present invention to provide a spark plug which includes a ground electrode and in which the occurrence of abnormal combustion and the dissolution loss of the ground electrode are suppressed by reducing a rise in a surface temperature of the ground electrode in a high-temperature environment.

[Solution] A spark plug includes a ground electrode that includes a base material containing Ni as a main component and having a Cr content of 14 mass% or more

and 33 mass% or less and an Al content of 0.3 mass% or more and 2.0 mass% or less, a Cr-poor layer disposed on a surface of the base material, having a lower Cr content and a higher Ni content than the base material, and having a thickness of 5 μm or more, and a Cr-rich layer disposed on a surface of the Cr-poor layer, having a higher Cr content than the base material, and having a thickness of 15 μm or less.

FIG. 2



Description**BACKGROUND OF THE INVENTION**

1. Field of the Invention

[0001] The present invention relates to a spark plug. In particular, the present invention relates to a spark plug which includes a ground electrode and in which a surface temperature rise of the ground electrode in a high-temperature environment is suppressed.

2. Description of the Related Art

[0002] Spark plugs are used in internal combustion engines such as automotive engines. In recent years, high-performance internal combustion engines have appeared, and an environment in a combustion chamber of such an internal combustion engine tends to become more severe. Some electrode materials have been proposed to overcome various problems posed in an electrode used in such a severe environment.

[0003] For example, PTL 1 discloses a spark plug produced by joining a noble metal tip to an electrode base material. The electrode base material has a Cr content of 10 to 20 wt% and an Al content of 1.5 to 5.5 wt% and the Cr content is at least three times the Al content. When the electrode base material is exposed to an environment in which 100 or more temperature changes from 300°C or lower to 1000°C or higher are caused in the air and the total time at 1000°C or higher due to the temperature changes is one hour or more, an oxide of Cr is formed on a surface of the electrode base material and an oxide of Al is formed on the inner side of the oxide of Cr. According to the invention described in PTL 1, the oxide of Cr is stably present on the surface of the electrode base material, and thus oxidation does not proceed into the electrode base material (paragraph 0011 in PTL 1). It is also disclosed that the oxide of Cr and the oxide of Al are formed during the operation of the spark plug in a high-temperature environment, which does not adversely affect the workability of the electrode base material, and furthermore the composition of the noble metal tip is not changed and thus the noble metal tip can be provided with resistance to spark erosion (paragraph 0014 in PTL 1).

[0004] PTL 2 discloses that an electrode material that has erosion resistance and is stable even when a combustion chamber is in a high-temperature severe environment is provided by controlling the electrical resistances of an electrode material and an oxide layer present on the surface of the electrode material to substantially the same value (e.g., paragraph 0007 in PTL 2).

[0005] PTL 3 discloses an electrode material for spark plugs, the electrode material containing Cr: 13% to 19% (hereafter "%" indicates "wt%"), Fe: 6% to 10%, and at least one of Nb, Re, Rh, and Ta in a total amount of more than 0.5% and less than 2.5%, the balance being Ni (Claim 1 in PTL 3). The electrode material in PTL 3 contains Cr, Fe, Nb, and the like in particular amounts. Therefore, when the spark plug is exposed to a high-temperature atmosphere, the electrode surface is oxidized and a multi-element composite porous oxide film is formed. Subsequently, selective oxidation starts in the porous oxide film, and a dense protective oxide film made of Cr₂O₃ is formed on the surface of a spark plug electrode. This improves the oxidation resistance of the electrode at high temperature and improves the durability of the electrode (paragraphs 0006 to 0008 in PTL 3).

Citation List

Patent Literature

[0006]

PTL 1: Japanese Patent No. 4375568

PTL 2: Japanese Unexamined Patent Application Publication No. 2013-508557

PTL 3: Japanese Unexamined Patent Application Publication No. 2004-247112

SUMMARY OF THE INVENTION

[0007] The temperature in a combustion chamber has been further increased with improved performance of internal combustion engines, and the surface temperature of the ground electrode sometimes reaches 1000°C or higher. An excessive increase in the surface temperature of the ground electrode sometimes causes abnormal combustion in which fuel is ignited by the ground electrode before generation of sparks by discharge and dissolution loss of the ground electrode that occurs at a temperature at which the ground electrode melts.

[0008] It is an object of the present invention to provide a spark plug which includes a ground electrode and in which

the occurrence of abnormal combustion and the dissolution loss of the ground electrode are suppressed by reducing a rise in a surface temperature of the ground electrode in a high-temperature environment.

[0009] The object is achieved as follows.

[1] A spark plug includes an insulator having an axial hole extending along an axial line, a center electrode disposed in the axial hole on a front side of the axial hole, a cylindrical metal shell disposed on a periphery of the insulator, and a ground electrode having a base end portion fixed to a front end portion of the metal shell and a distal end portion facing the center electrode with a gap therebetween. The ground electrode includes a base material containing Ni as a main component and having a Cr content of 14 mass% or more and 33 mass% or less and an Al content of 0.3 mass% or more and 2.0 mass% or less; a Cr-poor layer disposed on a surface of the base material, having a lower Cr content and a higher Ni content than the base material, and having a thickness of 5 μm or more; and a Cr-rich layer disposed on a surface of the Cr-poor layer, having a higher Cr content than the base material, and having a thickness of 15 μm or less.

The preferred embodiments of [1] are as follow.

[2] The Cr-poor layer has a thickness of 10 μm or more and 15 μm or less.

[3] In the spark plug according to [1] or [2], the base material has an Al content of 0.3 mass% or more and 1.0 mass% or less, a Si content of 0.5 mass% or more and 1.3 mass% or less, and an Fe content of 6.0 mass% or more and 14 mass% or less.

[0010] The ground electrode according to the present invention includes a base material containing Ni as a main component and having a Cr content of 14 mass% or more and 33 mass% or less and an Al content of 0.3 mass% or more and 2.0 mass% or less. When a ground electrode is formed of only the base material having the above composition, the ground electrode has higher corrosion resistance but lower thermal conductivity than a ground electrode formed of an electrode material made of pure Ni. Consequently, the temperature of the ground electrode tends to rise. However, the ground electrode according to the present invention includes a Cr-rich layer disposed on an outer surface of the base material having the above composition, having a higher Cr content than the base material, and having a thickness of 15 μm or less. This cuts off heat from the outside, which suppresses a temperature rise due to receiving heat from the outside. Furthermore, a Cr-poor layer having a lower Cr content and a higher Ni content than the base material and having a thickness of 5 μm or more is disposed between the Cr-rich layer and the base material. The Cr-poor layer is believed to have higher thermal conductivity than the base material, and thus heat received by the Cr-rich layer can be immediately conducted to the base material, which suppresses a rise in the surface temperature of the ground electrode. Therefore, according to the present invention, a rise in the surface temperature of the ground electrode in a high-temperature environment can be suppressed. Thus, there can be provided a spark plug which includes a ground electrode and in which abnormal combustion in which fuel is ignited by the ground electrode before generation of sparks by discharge and dissolution loss of the ground electrode that occurs at a temperature at which the ground electrode melts are suppressed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011]

Fig. 1 is a partial sectional view for describing the entirety of a spark plug according to an embodiment of the present invention.

Fig. 2 is an enlarged sectional view near a ground electrode of the spark plug in Fig. 1.

Fig. 3 is a diagram for describing methods for measuring the composition of a base material of the ground electrode and the thicknesses of a Cr-poor layer and a Cr-rich layer.

Fig. 4 is a graph illustrating the relationship between distance and count per second obtained when a section of the ground electrode is subjected to line analysis.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] Fig. 1 is a partial sectional view for describing the entirety of a spark plug 1 according to an embodiment of the present invention. In Fig. 1, the downward direction in the plane, that is, the direction toward a ground electrode described later is referred to as a front direction of an axial line O, and the upward direction in the plane is referred to as a rear direction of the axial line O.

[0013] As illustrated in Fig. 1, the spark plug 1 includes a substantially cylindrical insulator 3 having an axial hole 2 extending along the axial line O, a substantially rod-shaped center electrode 4 disposed in the axial hole 2 on the front side of the axial hole 2, a metal terminal 5 disposed in the axial hole 2 on the rear side of the axial hole 2, a connector

6 disposed between the center electrode 4 and the metal terminal 5 inside the axial hole 2, a substantially cylindrical metal shell 7 that is disposed on a periphery of the insulator 3 and extends from the front side toward the rear side along the axial line O, and a ground electrode 8 having a base end portion fixed to a front end portion of the metal shell 7 and a distal end portion facing the center electrode 4 with a gap G therebetween.

[0014] The insulator 3 includes a rear trunk portion 11, a large-diameter portion 12, a front trunk portion 13, and a nose portion 14. The rear trunk portion 11 contains the metal terminal 5 and insulates the metal terminal 5 from the metal shell 7. The large-diameter portion 12 is disposed closer to the front side than the rear trunk portion 11 and protrudes outward in a radial direction. The front trunk portion 13 is disposed closer to the front side than the large-diameter portion 12, has a smaller outer diameter than the large-diameter portion 12, and contains the connector 6. The nose portion 14 is disposed closer to the front side than the front trunk portion 13, has a smaller outer diameter than the front trunk portion 13, and contains the center electrode 4. The insulator 3 is fixed to the metal shell 7 while the front end portion of the insulator 3 protrudes from the front end portion of the metal shell 7. The insulator 3 is formed of a material having mechanical strength, thermal strength, and electric insulation.

[0015] The connector 6 is disposed between the center electrode 4 and the metal terminal 5 inside the axial hole 2. The connector 6 fixes the center electrode 4 and the metal terminal 5 inside the axial hole 2 and electrically connects the center electrode 4 and the metal terminal 5.

[0016] The metal shell 7 has a substantially cylindrical shape and holds the insulator 3 inserted therein. A screw portion 24 is disposed on the peripheral surface of the metal shell 7 in the front direction. The spark plug 1 is installed to a cylinder head of an internal combustion engine (not illustrated) through the screw portion 24. The metal shell 7 includes a flange-shaped gas sealing portion 25 disposed on the rear side of the screw portion 24, a tool engagement portion 26 disposed on the rear side of the gas sealing portion 25 and used for engagement with a tool such as a spanner or a wrench, and a crimping portion 27 disposed on the rear side of the tool engagement portion 26. The metal shell 7 is formed of a conductive steel material such as a low-carbon steel.

[0017] The metal terminal 5 is inserted into the axial hole 2 and fixed by the connector 6 while a part of the metal terminal 5 is exposed on the rear side of the insulator 3. The metal terminal 5 is formed of a metal material such as a low-carbon steel.

[0018] The center electrode 4 includes a rear end portion 28 that is in contact with the connector 6 and a rod-shaped portion 29 extending from the rear end portion 28 toward the front side. The center electrode 4 is fixed inside the axial hole 2 of the insulator 3 while the tip end of the center electrode 4 protrudes from the tip end of the insulator 3. The rear end portion 28 and the rod-shaped portion 29 in the center electrode 4 are formed of a publicly known material used for the center electrode 4, such as a Ni alloy. The center electrode 4 has a two-layer structure including an outer layer and a core. The outer layer is formed of, for example, a Ni alloy. The core is formed of a material having a higher thermal conductivity than, for example, a Ni alloy for the outer layer, and is concentrically embedded in an axial portion located inside the outer layer. The core is formed of a material such as Cu, a Cu alloy, Ag, a Ag alloy, or pure Ni. The center electrode 4 may have a single-layer structure formed of a Ni alloy or the like. The center electrode 4 may include a tip on the tip-end surface of the rod-shaped portion 29. The tip is formed of, for example, a Pt alloy or an Ir alloy. The tip is joined to the rod-shaped portion 29 by, for example, resistance welding and/or laser beam welding.

[0019] Next, a ground electrode, which is a feature of the present invention, will be described.

[0020] As illustrated in Fig. 2, the ground electrode 8 has, for example, a substantially prismatic shape. The ground electrode 8 is disposed so that the base end portion 15 is fixed to the front end portion of the metal shell 7, the ground electrode 8 has a substantially L-shaped portion therein, and the distal end portion 16 faces a tip-end surface 33 of the center electrode 4 with a gap G therebetween. The gap G in this embodiment corresponds to a minimum distance between the tip-end surface 33 of the center electrode 4 and a side surface of the ground electrode 8 that faces the tip-end surface 33. The gap G is normally set to 0.3 to 1.5 mm. The ground electrode 8 may include a tip on a surface that faces the tip-end surface 33 of the center electrode 4. When the tip is disposed, the distance between the tip-end surface 33 of the center electrode 4 and the tip-end surface of the tip corresponds to the gap G. The tip is formed of a material such as a Pt alloy or an Ir alloy. The tip is joined to the distal end portion 16 of the ground electrode 8 by, for example, resistance welding and/or laser beam welding.

[0021] The ground electrode 8 includes a base material 41, a Cr-poor layer 42 that covers the surface of the base material 41, and a Cr-rich layer 43 that covers the surface of the Cr-poor layer 42.

[0022] The base material 41 is a metal material containing Ni as a main component and having a Cr content of 14 mass% or more and 33 mass% or less and an Al content of 0.3 mass% or more and 2.0 mass% or less. The Ni content is preferably 65 mass% or more and 85.7 mass% or less. When the ground electrode is formed of only the base material having the above composition, a chromium oxide film is formed on the surface of the ground electrode in a combustion chamber with an oxygen atmosphere and a high-temperature environment, which suppresses corrosion. However, the metal material has a lower thermal conductivity than Ni alloys having a high Ni content, and thus the surface temperature of the ground electrode tends to rise. This readily causes abnormal combustion in which fuel is ignited by the ground electrode before generation of sparks by discharge and dissolution loss of the ground electrode that occurs at a tem-

perature at which the ground electrode melts. On the other hand, the ground electrode 8 includes the Cr-poor layer 42 and the Cr-rich layer 43 in this order on the surface of the base material 41 having the above composition that the above phenomena are likely to occur. Therefore, a rise in the surface temperature of the ground electrode 8 in a high-temperature environment can be suppressed, which suppresses occurrence of abnormal combustion and dissolution loss of the ground electrode.

[0023] The base material 41 may contain, as an element other than Ni, Cr, and Al, at least one element selected from, for example, Si, Fe, Mn, and rare-earth elements. Examples of the rare-earth elements include Y, La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, and Lu. The base material 41 preferably contains Si and Fe as elements other than Ni, Cr, and Al. The base material 41 preferably contains Ni as a main component (a component with the highest content), and preferably has a Cr content of 14 mass% or more and 33 mass% or less, an Al content of 0.3 mass% or more and 1.0 mass% or less, a Si content of 0.5 mass% or more and 1.3 mass% or less, and an Fe content of 6.0 mass% or more and 14 mass% or less. Since a ground electrode formed of only the base material having such a composition is likely to cause the above phenomena, the ground electrode 8 including the Cr-poor layer 42 and the Cr-rich layer 43 in this order on the surface of the base material 41 having such a composition produces a large effect of suppressing the rise in the surface temperature of the ground electrode 8 in a high-temperature environment.

[0024] The Cr-rich layer 43 forms an outer surface of the ground electrode 8, has a higher Cr content than the base material 41, and has a thickness of 15 μm or less. A Cr-rich layer is formed by heat-treating an electrode material at a low partial pressure of oxygen as described later. As a result of diffusion of Cr contained in the electrode material toward the outer surface, a dense Cr-rich layer 43 is formed at an outer surface. The Cr-rich layer 43 is a dense layer with a small thickness of 15 μm or less and thus cuts off heat from the outside, which suppresses a temperature rise due to receiving heat from the outside. If the thickness of the Cr-rich layer 43 is more than 15 μm , the Cr-rich layer prevents cooling from the inside of the base material 41 rather than cuts off heat from the outside. Consequently, the rise in the surface temperature of the ground electrode 8 cannot be suppressed. The thickness of the Cr-rich layer is preferably 1.0 μm or more and more preferably 5.0 μm or more, and is preferably 11.0 μm or less. When the thickness of the Cr-rich layer is within the above range, the rise in the surface temperature of the ground electrode 8 can be further suppressed.

[0025] The Cr-poor layer 42 has a lower Cr content and a higher Ni content than the base material 41, and has a thickness of 5 μm or more. The Cr-poor layer 42 is formed by heat-treating an electrode material at a low partial pressure of oxygen as described later. As a result of this heat treatment, Cr contained in the electrode material diffuses toward the outer surface. Thus, a metal layer having a lower Cr content and a higher Ni content than the base material 41 is formed between the base material 41 and the Cr-rich layer 43. Since the Cr-poor layer 42 has a lower Cr content and a higher Ni content than the base material 41, the Cr-poor layer 42 is believed to have a higher thermal conductivity than the base material 41. The Cr-poor layer 42 having high thermal conductivity is present between the Cr-rich layer 43 and the base material 41, and thus heat received by the Cr-rich layer 43 can be immediately conducted to the base material 41. This improves heat conduction, and the rise in the surface temperature of the ground electrode 8 can be suppressed. If the thickness of the Cr-poor layer 42 is 5 μm or less, heat received by the Cr-rich layer 43 is not immediately conducted to the base material 41. The thickness of the Cr-poor layer 42 is preferably 10 μm or more, and is preferably 30 μm or less and more preferably 15 μm or less. When the thickness of the Cr-poor layer 42 is within the above range, the rise in the surface temperature of the ground electrode 8 can be further suppressed.

[0026] The composition of the base material 41 and the Ni and Cr contents and thicknesses of the Cr-rich layer 43 and the Cr-poor layer 42 can be determined as follows. As illustrated in Fig. 3, the ground electrode 8 is cut along a plane that extends in a longitudinal direction through the center of the ground electrode 8 to obtain a section 40. The composition of the base material 41 is measured by performing point analysis at a position 2 mm from the tip end of the ground electrode 8 toward the base end portion 15, the position being located at the center of the ground electrode 8 in the width direction. This measurement is performed using an energy-dispersive X-ray spectrometer (EDS) included in a scanning electron microscope (SEM). For example, the Cr content is determined by calculating the amount of Cr relative to the total amount of all elements detected by the point analysis. The Cr contents of the Cr-rich layer 43 and the Cr-poor layer 42 are measured by performing line analysis on the section 40 in a portion near an edge on a line L that extends from the position at which the composition of the base material 41 is measured by point analysis toward the edge of the ground electrode 8 in the width direction. As a result of the line analysis, when a region having a higher Cr content than the base material 41 is present at an outer surface of the ground electrode 8, that is, near the edge on the section 40, the region is referred to as a Cr-rich layer 43. When a region having a lower Cr content than the base material 41 is present on the inner side of the Cr-rich layer 43, the region is referred to as a Cr-poor layer 42. Point analysis is performed at a plurality of positions in the Cr-poor layer 42 to measure the Ni content. In the Cr-poor layer 42, Cr diffuses toward the outer surface and the Cr content is lower than the base material 41. Therefore, the Ni content is normally higher than the base material 41. The thickness of the Cr-rich layer 43 is determined by measuring the length of the line L in the region having a higher Cr content than the base material 41. The thickness of the Cr-poor layer 42 is determined by measuring the length of the line L in the region having a lower Cr content than the base material 41.

[0027] It is sufficient that the Cr-rich layer 43 and the Cr-poor layer 42 cover at least a surface of the base material 41

in a portion that is easily heated to high temperature during the operation of the spark plug 1. Specifically, it is sufficient that the Cr-rich layer 43 and the Cr-poor layer 42 cover a surface of the distal end portion 16 of the base material 41. The Cr-rich layer 43 and the Cr-poor layer 42 preferably cover the entire surface other than a surface of the base material 41 that is joined to the metal shell 7. In this embodiment, as illustrated in Fig. 2, the Cr-rich layer 43 and the Cr-poor layer 42 cover the entire surface other than a surface of the base material 41 that is joined to the metal shell 7. When at least the surface of the base material 41 in a portion that is easily heated to high temperature is covered with the Cr-rich layer 43 and the Cr-poor layer 42, a temperature rise in the surface of the portion that is easily heated to high temperature is suppressed, and the occurrence of abnormal combustion and dissolution loss can be suppressed.

[0028] The spark plug 1 is produced by, for example, the following method. First, a method for producing the ground electrode 8, which is a feature of the present invention, will be described.

[0029] A Ni alloy containing Ni as a main component and having a Cr content of 14 mass% or more and 33 mass% or less and an Al content of 0.3 mass% or more and 2.0 mass% or less is prepared. The Ni alloy is appropriately subjected to wire drawing to adjust the shape and dimensions to a predetermined shape and predetermined dimensions. Thus, an electrode material is obtained. The obtained electrode material is heat-treated in an inert gas (e.g., Ar) atmosphere at a low partial pressure of oxygen of 0.01 ppm to 0.5 ppm at 800°C to 1100°C for 1 to 30 hours. As a result of the heat treatment, Cr diffuses from the inside of the electrode material toward the outer surface, and thus a ground electrode 8 including a base material 41, a Cr-poor layer 42, and a Cr-rich layer 43 can be provided.

[0030] After the heat treatment performed on the electrode material, a part of the surface of the ground electrode 8, such as an end face joined to a metal shell 7, is removed by performing cutting or the like. Thus, the Cr-poor layer 42 and the Cr-rich layer 43 can be disposed at a desired position on the surface of the base material 41. Furthermore, by appropriately changing the composition of the Ni alloy, the atmosphere in which the heat treatment is performed, the partial pressure of oxygen, the temperature, the time, and the like, the thicknesses of the Cr-poor layer 42 and the Cr-rich layer 43 can be controlled.

[0031] Then, one end portion of the ground electrode 8 is joined by, for example, electrical resistance welding or laser beam welding to an end face of a metal shell 7 formed into a desired shape by plastic working or the like. Zn plating or Ni plating is then performed on the metal shell 7 to which the ground electrode 8 has been joined. A trivalent chromate treatment may be performed after the Zn plating or Ni plating.

[0032] The center electrode 4 is formed as follows. An internal material made of a Cu alloy or the like and having a higher thermal conductivity than an external material made of a Ni alloy or the like and formed into a cup shape is inserted into the external material. By performing plastic working such as extrusion, a center electrode 4 including a core disposed inside an outer layer is formed.

[0033] An insulator 3 is produced by sintering a ceramic or the like into a desired shape. The center electrode 4 is inserted into an axial hole 2 of the insulator 3, and the axial hole 2 is filled with a composition for forming a connector 6 while the composition is preliminarily compressed. The composition is then compressed under heating while a metal terminal 5 is subjected to press-in through the rear end portion of the axial hole 2. Thus, the composition is sintered into a connector 6. Subsequently, the insulator 3 to which the center electrode 4 and the like have been fixed is assembled to the metal shell 7 to which the ground electrode 8 has been joined. Finally, the distal end portion 16 of the ground electrode 8 is bent toward the center electrode 4 so that the side surface of the distal end portion 16 of the ground electrode 8 faces the tip-end surface 33 of the center electrode 4. Thus, a spark plug 1 is produced.

[0034] The spark plug 1 according to the present invention is used as an ignition plug for automotive internal combustion engines such as gasoline engines. The screw portion 24 is screwed into a tapped hole disposed in a head (not illustrated) that defines and forms a combustion chamber of an internal combustion engine. Thus, the spark plug 1 is fixed at a predetermined position. The spark plug 1 according to the present invention can be used for any internal combustion engine. The spark plug 1 according to the present invention includes the ground electrode 8 whose surface temperature is prevented from rising in a high-temperature environment. Therefore, the spark plug 1 is particularly suitable for internal combustion engines whose combustion chamber is easily heated to high temperature.

[0035] The spark plug 1 according to the present invention is not limited to the above embodiment, and various modifications can be made as long as the object of the present invention can be achieved.

EXAMPLES

Production of ground electrode

[0036] Ni alloys each having a composition described in "Composition of base material" in Tables 1 and 2 were appropriately subjected to wire drawing to produce prismatic electrode materials having a length of 1.3 mm, a width of 2.7 mm, and a height of 13 mm. In Test Nos. 1 and 21, the following heating test was performed using the electrode material as a ground electrode. In Test Nos. 2, 3, 6 to 12, and 24 to 31, the electrode material was heat-treated in an Ar gas atmosphere at a low partial pressure of oxygen of 0.02 ppm at 800°C to 1000°C for 1 to 30 hours to produce a

ground electrode. In Test Nos. 4 and 22, the electrode material was heat-treated in a hydrogen atmosphere at a low partial pressure of oxygen of 0.02 ppm at 1000°C for 1 hour to produce a ground electrode. In Test Nos. 5 and 23, the electrode material was heat-treated in a vacuum at a low partial pressure of oxygen of 0.02 ppm at 1000°C for 1 hour to produce a ground electrode.

Measurement of composition of base material and thicknesses of Cr-poor layer and Cr-rich layer

[0037] The compositions of the base material, Cr-rich layer, and Cr-poor layer in the ground electrode were measured using an EDS included in a SEM (manufactured by JEOL Ltd.). As illustrated in Fig. 3, the produced ground electrode 8 was cut along a plane that extends in a longitudinal direction through the center of the ground electrode 8 to obtain a section 40.

[0038] The composition of the base material 41 was measured by performing point analysis on the section 40 at an acceleration voltage of 20 kV with a spot size of 70 μm at a position 2 mm from the tip end of the ground electrode 8 in the longitudinal direction, the position being located at the center of the ground electrode 8 in the width direction. Tables 1 and 2 show the results. In Tables 1 and 2, for example, "Ni-23Cr-1.5Al" refers to a Cr content of 23 mass% and an Al content of 1.5 mass%, with the balance being Ni.

[0039] Subsequently, line analysis was performed on the section 40 in a portion near an edge of the ground electrode 8 on a line L that extends from the position at which the composition of the base material 41 was measured by point analysis toward the edge of the ground electrode 8 in the width direction. Fig. 4 illustrates the results of the line analysis in Test No. 29. As illustrated in Fig. 4, a region (Cr-rich layer 43) having a higher Cr content than the base material 41 was present at an outer surface of the ground electrode 8, that is, near the edge on the section 40, and a region (Cr-poor layer 42) having a lower Cr content than the base material 41 was present on the inner side of the Cr-rich layer 43. The region having a lower Cr content than the base material 41 was regarded as the Cr-poor layer 42, and point analysis was performed at three positions in this region to measure the Ni content. At all the positions, the Ni content was higher than the Ni content of the base material 41 ("%" in Fig. 4 indicates "mass%"). In all of Test Nos. 2 to 12 and 22 to 31, the line analysis results showed that the Cr-poor layer 42 and the Cr-rich layer 43 were present on the surface of the base material 41.

[0040] The thickness of the Cr-rich layer 42 was determined by measuring the length of the line L in the region having a higher Cr content than the base material 41.

[0041] The thickness of the Cr-poor layer 42 was determined by measuring the length of the line L in the region having a lower Cr content than the base material 41.

Heating test

[0042] The produced ground electrode was heated with a burner for two minutes and the surface temperature of the ground electrode was measured with a thermocouple. Tables 1 and 2 show the temperature differences $\Delta T (= T - T_0)$ between temperatures (T) at which the surface temperatures of the ground electrodes in Test Nos. 2 to 12 and 22 to 31 reached constant temperatures and reference temperatures (T_0) at which the surface temperatures of the ground electrodes in Test Nos. 1 and 21 reached constant temperatures.

[0043] Test Nos. 2 to 12 were evaluated in the heating test on the basis of the following criteria using the temperature difference ΔT , which is a difference between the surface temperature of the ground electrode in each of Test Nos. 2 to 12 and the surface temperature of the ground electrode in Test No. 1. Table 1 shows the results.

- A: The temperature difference ΔT was -20°C or less.
- B: The temperature difference ΔT was more than -20°C and -10°C or less.
- C: The temperature difference ΔT was more than -10°C .

[0044] Test Nos. 22 to 31 were evaluated in the heating test on the basis of the following criteria using the temperature difference ΔT , which is a difference between the surface temperature of the ground electrode in each of Test Nos. 22 to 31 and the surface temperature of the ground electrode in Test No. 21. Table 2 shows the results.

- A: The temperature difference ΔT was -40°C or less.
- B: The temperature difference ΔT was more than -40°C and -20°C or less.
- C: The temperature difference ΔT was more than -20°C .

Table 1

Test No.	Composition of base material (mass%)	Heat treatment conditions			Thickness of Cr-poor layer (μm)	Thickness of Cr-rich layer (μm)	Surface temperature ($^{\circ}\text{C}$)	Temperature difference ΔT ($^{\circ}\text{C}$)	Evaluation result
		Atmosphere	Temperature ($^{\circ}\text{C}$)	Holding time (hour)					
1	Ni-23Cr-1.5Al	-	-	-	0.0	0.0	1033	-	-
2	Ni-14Cr-0.3Al	Ar	900	1	8.4	3.2	1014	-19	B
3	Ni-33Cr-2.0Al	Ar	900	1	7.5	2.8	1017	-16	B
4	Ni-23Cr-1.5Al	H ₂	1000	1	1.8	0.3	1035	2	C
5	Ni-23Cr-1.5Al	Vacuum	1000	1	3.8	0.7	1031	-2	C
6	Ni-23Cr-1.5Al	Ar	800	1	5.1	1.0	1019	-14	B
7	Ni-23Cr-1.5Al	Ar	900	1	8.1	3.0	1015	-18	B
8	Ni-23Cr-1.5Al	Ar	900	5	10.0	6.2	1011	-22	A
9	Ni-23Cr-1.5Al	Ar	1000	10	15.0	10.6	1005	-28	A
10	Ni-23Cr-1.5Al	Ar	1000	12	15.8	11.6	1014	-19	B
11	Ni-23Cr-1.5Al	Ar	1000	30	29.8	14.8	1021	-12	B
12	Ni-23Cr-1.5Al	Ar	1000	35	30.4	15.2	1025	-8	C

Table 2

Test No.	Composition of base material (mass%)	Heat treatment conditions			Thickness of Cr-poor layer (μm)	Thickness of Cr-rich layer (μm)	Surface temperature (°C)	Temperature difference ΔT (°C)	Evaluation result
		Atmosphere	Temperature (°C)	Holding time (hour)					
21	Ni-23Cr-0.5Al-0.9Si-9.0Fe	-	-	-	0.0	0.0	1073	-	-
22	Ni-23Cr-0.5Al-0.9Si-9.0Fe	H ₂	1000	1	1.5	0.3	1074	1	C
23	Ni-23Cr-0.5Al-0.9Si-9.0Fe	Vacuum	1000	1	4.2	0.6	1075	2	C
24	Ni-23Cr-0.5Al-0.9Si-9.0Fe	Ar	800	1	5.0	1.0	1051	-22	B
25	Ni-23Cr-0.5Al-0.9Si-9.0Fe	Ar	900	1	7.1	2.2	1035	-38	B
26	Ni-23Cr-0.5Al-0.9Si-9.0Fe	Ar	1000	1	10.2	9.8	1033	-40	A
27	Ni-23Cr-0.5Al-0.9Si-6.0Fe	Ar	900	1	8.4	2.0	1041	-32	B
28	Ni-23Cr-0.5Al-1.3Si-14.0Fe	Ar	900	1	9.8	3.2	1035	-38	B
29	Ni-23Cr-0.5Al-1.3Si-14.0Fe	Ar	1000	3	12.8	9.3	1030	-43	A
30	Ni-23Cr-0.5Al-1.3Si-14.0Fe	Ar	1000	10	13.5	13.1	1028	-45	A
31	Ni-23Cr-0.5Al-0.9Si-9.0Fe-0.1Y	Ar	1000	10	14.1	12.5	1026	-47	A

[0045] As shown in Tables 1 and 2, the ground electrodes in Test Nos. 2, 3, 6 to 11, and 24 to 31, which are within the scope of the present invention, were given an evaluation result of "B" or "A". The rise in the surface temperature of the ground electrode in each of Test Nos. 2, 3, 6 to 11, and 24 to 31 was suppressed compared with the ground electrode in Test No. 1 or 21 in which the Cr-poor layer and the Cr-rich layer were not formed. In contrast, the ground electrodes in Test Nos. 4, 5, 12, 22, and 23, which are outside the scope of the present invention, were given an evaluation result of "C". The surface temperature of the ground electrode in each of Test Nos. 4, 5, 12, 22, and 23 was equal to or higher than the surface temperature of the ground electrode in Test No. 1 or 21 in which the Cr-poor layer and the Cr-rich layer were not formed.

[0046] As shown in Table 1, the ground electrodes in Test Nos. 2, 3, 6, 7, 10, and 11 in which the Cr-poor layer had a thickness of 5 μm or more and less than 10 μm or more than 15 μm and 30 μm or less were given an evaluation result of "B" whereas the ground electrodes in Test Nos. 8 and 9 in which the Cr-poor layer had a thickness of 10 μm or more and 15 μm or less were given an evaluation result of "A". When the Cr-poor layer had a thickness of 10 μm or more and 15 μm or less, the rise in the surface temperature of the ground electrode could be further suppressed.

[0047] The surface temperature of the ground electrode in Test No. 21 that contained Ni, Cr, Al, Si, and Fe was higher than the surface temperature of the ground electrode in Test No. 1 that contained Ni, Cr, and Al.

[0048] As shown in Table 2, the same tendency was observed between the ground electrodes in Test Nos. 1 to 12 that included a base material containing only Ni, Cr, and Al and the ground electrodes in Test Nos. 21 to 31 that included a base material containing Ni, Cr, Al, and other elements. That is, the ground electrodes in Test Nos. 26 and 29 to 31 in which the Cr-poor layer had a thickness of 10 μm or more and 15 μm or less were given an evaluation result of "A" whereas the ground electrodes in Test Nos. 24, 25, 27, and 28 in which the Cr-poor layer had a thickness of 5 μm or more and less than 10 μm were given an evaluation result of "B". When the Cr-poor layer had a thickness of 10 μm or more and 15 μm or less, the rise in the surface temperature could be further suppressed.

Claims

1. A spark plug (1) comprising:

an insulator (3) having an axial hole (2) extending along an axial line (O);
 a center electrode (4) disposed in the axial hole (2) on a front side of the axial hole (2);
 a cylindrical metal shell (7) disposed on a periphery of the insulator (3); and
 a ground electrode (8) having a base end portion (15) fixed to a front end portion of the metal shell (7) and a distal end portion (16) facing the center electrode (4) with a gap (G) therebetween,

wherein the ground electrode (8) includes:

a base material (41) containing Ni as a main component and having a Cr content of 14 mass% or more and 33 mass% or less and an Al content of 0.3 mass% or more and 2.0 mass% or less,
 a Cr-poor layer (42) disposed on a surface of the base material (41), having a lower Cr content and a higher Ni content than the base material (41), and having a thickness of 5 μm or more, and
 a Cr-rich layer (43) disposed on a surface of the Cr-poor layer (42), having a higher Cr content than the base material (41), and having a thickness of 15 μm or less.

2. The spark plug 1 according to Claim 1, wherein the Cr-poor layer (42) has a thickness of 10 μm or more and 15 μm or less.

3. The spark plug 1 according to Claim 1 or 2, wherein the base material (41) has an Al content of 0.3 mass% or more and 1.0 mass% or less, a Si content of 0.5 mass% or more and 1.3 mass% or less, and an Fe content of 6.0 mass% or more and 14 mass% or less.

FIG. 1

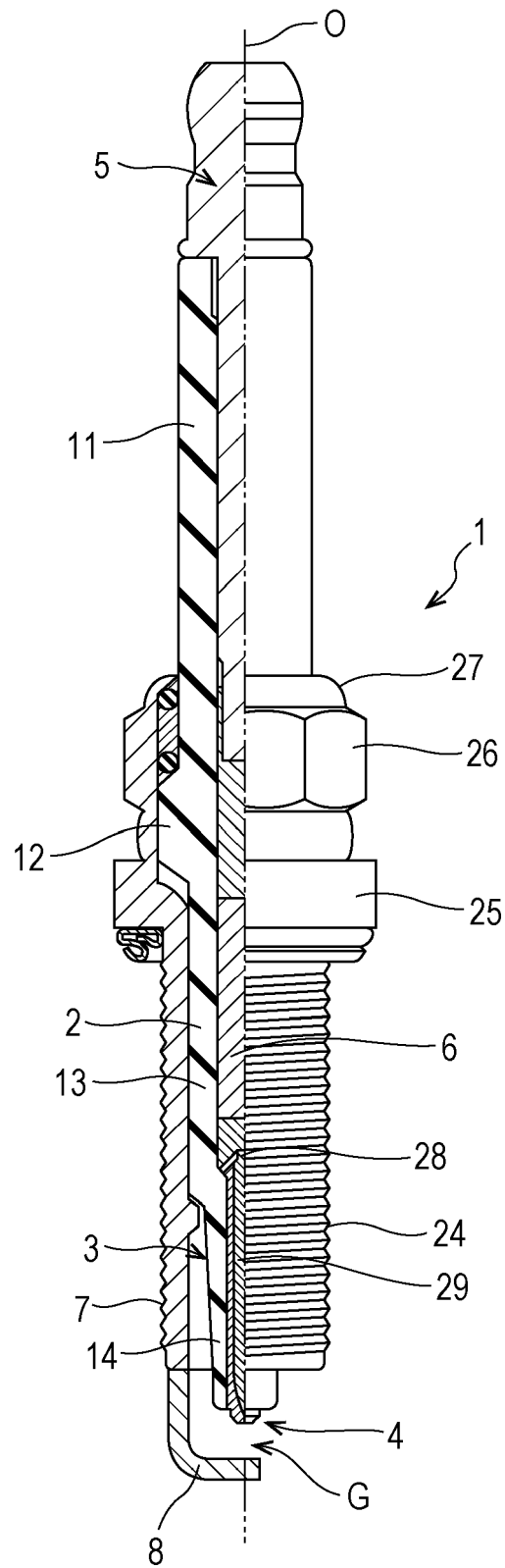


FIG. 2

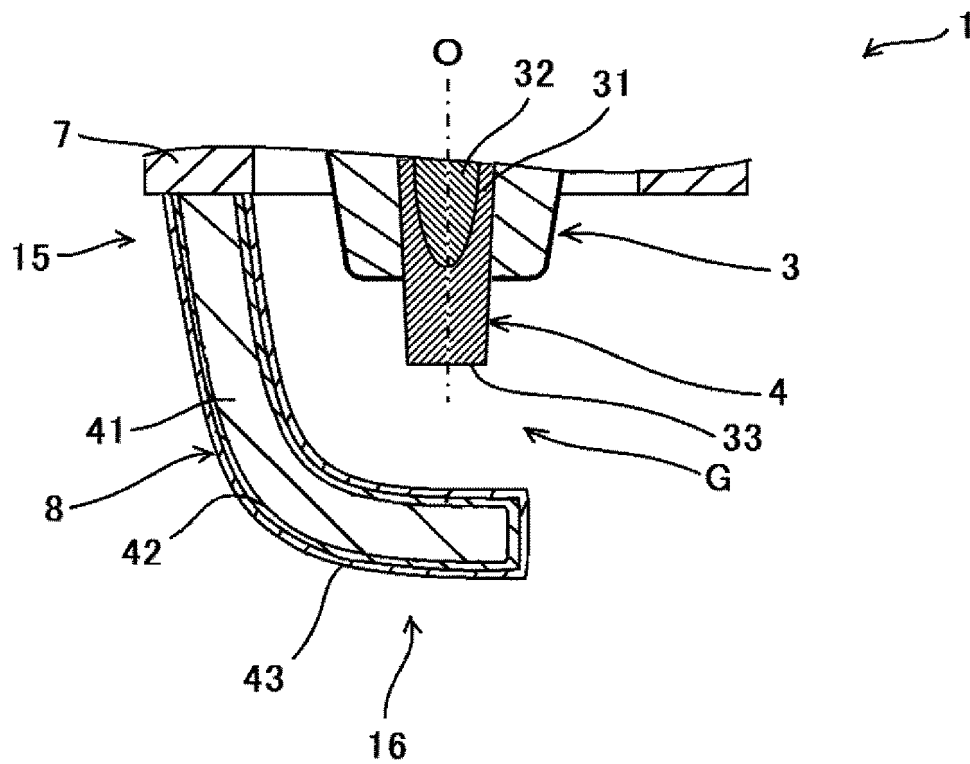


FIG. 3

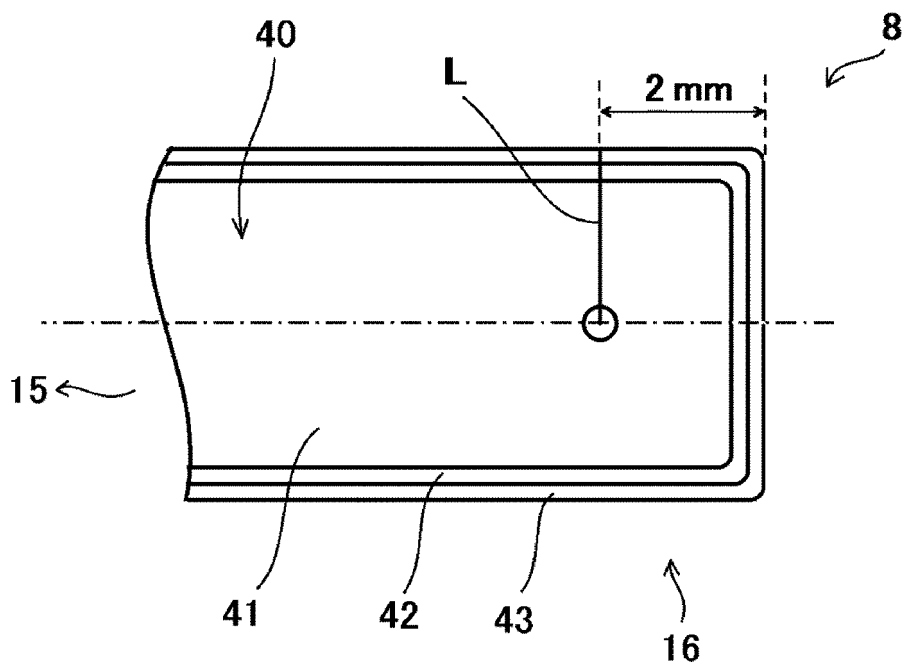
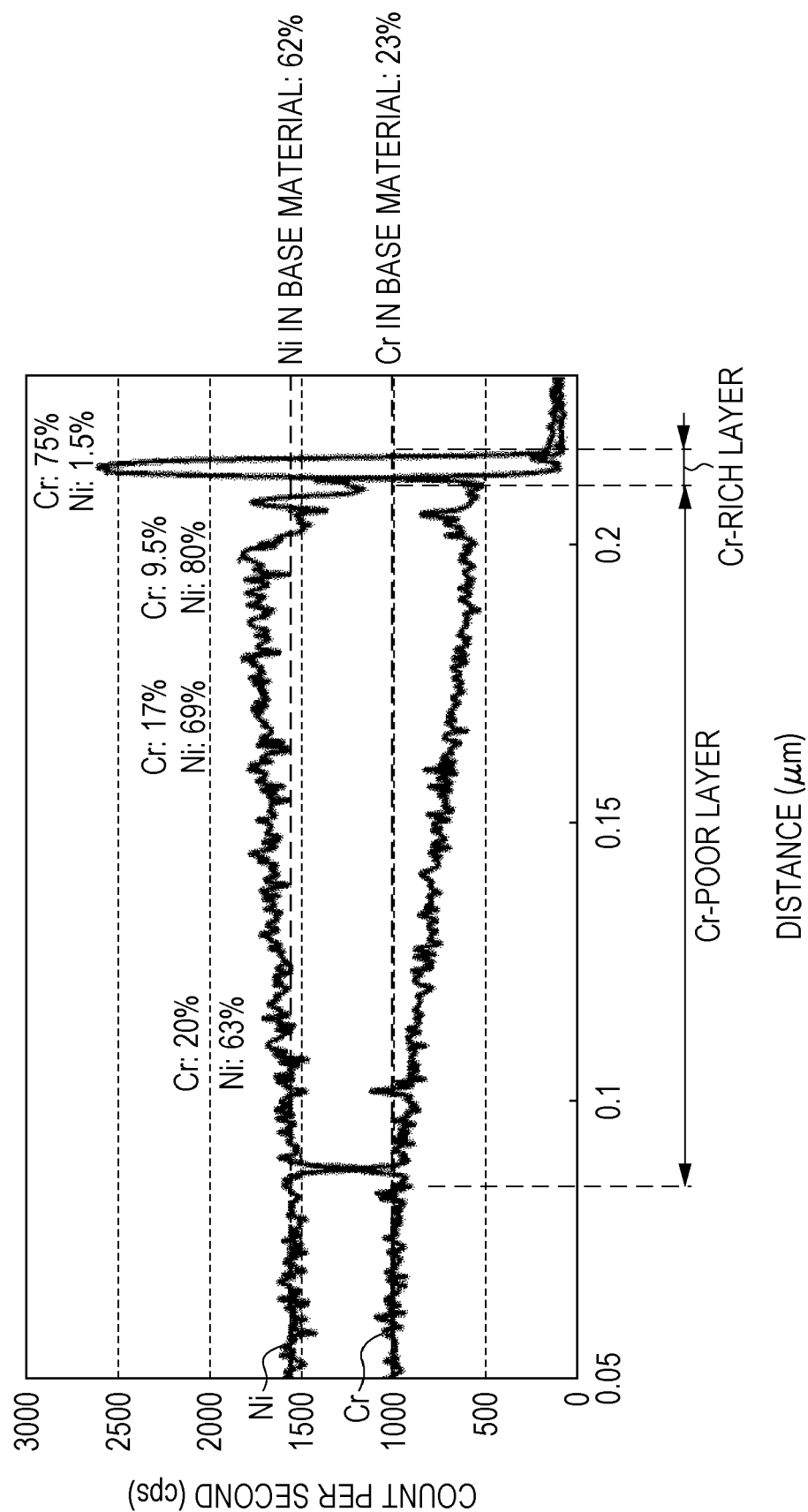


FIG. 4





EUROPEAN SEARCH REPORT

Application Number
EP 17 15 1471

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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			TECHNICAL FIELDS SEARCHED (IPC) H01T
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 15 May 2017	Examiner Marti Almeda, Rafael
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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