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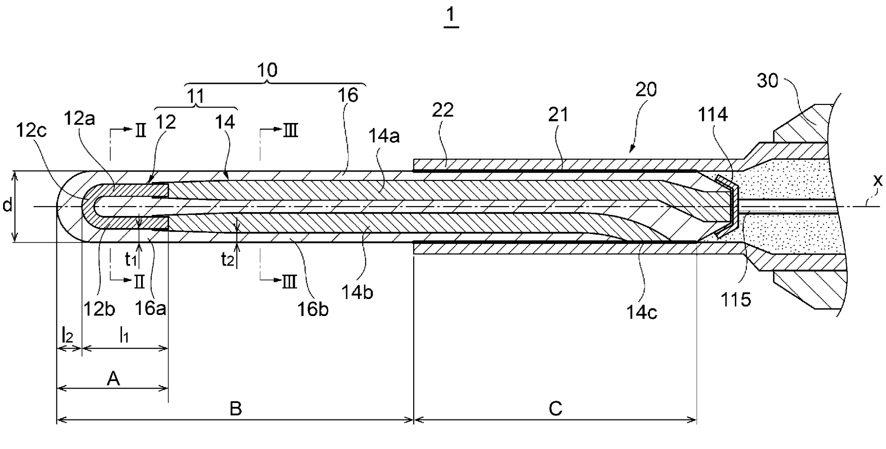
(54) GLOW PLUG

(57) [Abstract] A rapid temperature increase is achieved while power consumption is suppressed. A glow plug (1) according to the present invention includes a ceramic heater (10) that has a conductive ceramic (11) and an insulating ceramic (16) covering the conductive ceramic (11). The conductive ceramic (11) has: a heat generating section (12) that is arranged at a tip; and a lead (14) that is connected to a rear end of the heat generating section (12). In a cross section that is perpendicular to an axis of the ceramic heater (10), the insulating ceramic (16) has a thinnest portion (16a), where an outer circumferential surface thereof and the heat generating section (12) are closest to each other, in a thickness of 0.5 to 0.7 mm.

[FIG. 1]



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Description

Technical Field

[0001] The present invention relates to a glow plug that is used to aid starting an internal combustion engine such as a diesel engine.

Background Art

[0002] As a glow plug used to aid starting a diesel engine, a glow plug of a ceramic heater type has been known. Such a glow plug of the ceramic heater type includes: a ceramic heater; and an outer cylinder that accommodates a part of the ceramic heater such that at least a tip of the ceramic heater is exposed. The ceramic heater has: a heat generating section arranged at the tip of the heater; and a lead connected to a rear end of the heat generating section and having lower resistivity than the heat generating section. These heat generating section and lead are covered with an insulating ceramic. In addition, an outer circumferential surface of the ceramic heater and an inner circumferential surface of the outer cylinder are electrically connected via a joint section such as brazing (for example, see PTL 1).

Citation List

Patent Literature

[0003] PTL 1: JP-A-2002-334768

Summary of Invention

Technical Problem

[0004] By the way, in recent years, it has been desired to rapidly increase a temperature inside a combustion chamber at a start of the internal combustion engine. However, in order to rapidly increase a temperature of the ceramic heater, for example, a large current is made to flow through the heat generating section via the lead at an initial energization stage so as to rapidly increase the temperature of the heater. As a result, power is significantly consumed.

[0005] In regard to the conventional ceramic heaters, a thickness of the insulating ceramic between an outer circumferential surface of the insulating ceramic and a conductive ceramic embedded in the insulating ceramic is not concerned for purposes of a rapid temperature increase of the ceramic heater and a reduction in power consumption. It is considered that thinning of the insulating ceramic is effective for the rapid temperature increase. However, aging deterioration of the insulating ceramic possibly accelerates exposure of the heat generating section inside. Thus, simple thinning of the insulating ceramic is not sufficient.

[0006] The joint section between the ceramic heater and the outer cylinder is formed of a high thermal conducting brazing material, for example. Thus, heat is easily transferred from the ceramic heater to the outer cylinder. That is, the heat is likely to be released from the ceramic heater via the joint section. However, a position of the heat generating section in the ceramic heater, a joint range between the ceramic heater and the outer cylinder, and the like are not concerned from perspectives of the rapid temperature increase and the reduction in the power consumption.

[0007] The present invention has been made in view of the above problem and therefore has a purpose of providing a glow plug capable of achieving a rapid temperature increase while suppressing power consumption.

Solution to Problem

[0008] In order to achieve the above purpose, the present invention includes a ceramic heater that has a conductive ceramic and an insulating ceramic covering the conductive ceramic. The conductive ceramic has: a heat generating section that is arranged at a tip; and a lead that is connected to a rear end of the heat generating section. In a cross section that is perpendicular to an axis of the ceramic heater, the insulating ceramic has a thinnest portion, where an outer circumferential surface thereof and the heat generating section are closest to each other, in a thickness of 0.5 to 0.7 mm.

[0009] The thickness of the thinnest portion is preferably 0.57 to 0.66 mm.

[0010] The outer circumferential surface of the insulating ceramic is preferably in a cylindrical shape that has a diameter of 2.9 to 3.1 mm.

[0011] A length in an axial direction from a tip of the insulating ceramic to the rear end of the heat generating section is preferably equal to or shorter than 4.5 mm.

[0012] In order to achieve the above purpose, the present invention further includes: a ceramic heater that has a conductive ceramic and an insulating ceramic covering the conductive ceramic; and an outer cylinder that accommodates a part of the ceramic heater such that at least a tip is exposed and an inner circumferential surface of which is joined to an outer circumferential surface of the ceramic heater via a joint section. The conductive ceramic has: a heat generating section that is arranged at a tip; and a lead that is connected to a rear end of the heat generating section. When a length in an axial direction from a tip of the insulating ceramic to the rear end of the heat generating section is set as a first length A, a length in the axial direction from the tip of the insulating ceramic to a tip of the joint section is set as a second length B, and a length in the axial direction of the joint section is set as a third length C, following Formula 1 and Formula 2 are satisfied.
[Formula 1]

$$\frac{A}{B} < 0.55 \quad \text{(Formula 1)}$$

[Formula 2]

$$\frac{C}{B+C} < 0.55 \quad \text{(Formula 2)}$$

[0013] Following Formula 3 and Formula 4 are preferably satisfied.
[Formula 3]

$$\frac{A}{B} < 0.5 \quad \text{(Formula 3)}$$

[Formula 4]

$$\frac{C}{B+C} < 0.5 \quad \text{(Formula 4)}$$

Advantageous Effects of Invention

[0014] According to the present invention, it is possible to achieve a rapid temperature increase while suppressing power consumption.

Brief Description of Drawings

[0015]

Fig. 1 is a cross-sectional view for illustrating a configuration of a glow plug according to this embodiment.
Fig. 2 is a cross-sectional view that is taken along line II-II in Fig. 1.
Fig. 3 is a cross-sectional view that is taken along line III-III in Fig. 1.

Description of Embodiments

[0016] A description will be made on a preferred embodiment of the present invention with reference to the drawings. Note that the embodiment, which will be described below, is merely one example and various embodiments can be implemented within the scope of the present invention. Fig. 1 is a cross-sectional view for illustrating a configuration of a glow plug. Fig. 2 is a cross-sectional view that is taken along line II-II in Fig. 1. Fig. 3 is a cross-sectional view that is taken along line III-III in Fig. 1.
[0017] A glow plug 1 is a glow plug of a ceramic heater type, for example, and includes, as illustrated in Fig. 1: a ceramic heater 10; a metallic outer cylinder 20 that accommodates a part of the ceramic heater 10 such that at least a tip thereof is exposed and an inner circumferential surface of which is joined to an outer circumferential surface of the ceramic heater 10 via a joint section 21; and a housing 30.

[0018] The ceramic heater 10 aids starting an internal combustion engine, has the tip that is inserted in a combustion chamber (a pre-combustion chamber in the case of the internal combustion engine of a pre-combustion type or the combustion chamber of the internal combustion engine in the case of the internal combustion engine of a direct-injection type), and is fixed to the housing 30 via the outer cylinder 20. The ceramic heater 10 is formed of a ceramic.

[0019] The ceramic heater 10 has a conductive ceramic 11 and an insulating ceramic 16 that covers the conductive ceramic 11.

[0020] The conductive ceramic 11 is heated by energization in the glow plug 1, and has: a heat generating section 12 that is arranged at a tip and is molded in a U-shape; and a lead 14 that is connected to a rear end of the heat generating section 12. In a cross-sectional view that is perpendicular to an axis x of the ceramic heater 10, the heat generating section 12 is not limited to have a particular shape but can have any one of various shapes such as a circle, an oval, an elongated circle, and a polygon.

[0021] The heat generating section 12 has: a pair of extending sections 12a, 12b that extend in parallel with each other along the axis x of the ceramic heater 10; and a curved section 12c that couples the extending sections 12a, 12b. The heat generating section 12 is located within a range of 4.5 mm from a tip of the insulating ceramic 16, and is dimensioned to have a length l_1 of 3.5 mm along the axis x of the ceramic heater 10.

[0022] The heat generating section 12 is a heat generating resistance element having high resistivity against the lead 14, and is formed of the conductive ceramic. For example, the heat generating section 12 is formed of a material that has, as a primary component, a carbide, a nitride, or a silicide containing tungsten (W), molybdenum (Mo), titanium (Ti), or the like. The heat generating section 12 is particularly preferred to have high thermal resistance and contain tungsten carbide (WC) that has inorganic conductivity from a point of having low specific resistance.

[0023] In addition to the above primary component, the heat generating section 12 contains silicon nitride (Si_3N_4), and percentage of a silicon nitride (Si_3N_4) content is preferably equal to or higher than 20% by mass. For example, compared to silicon nitride (Si_3N_4) in the insulating ceramic 16 that contains a silicon nitride ceramic, a conductor component that serves as the heat generating section 12 has a high coefficient of thermal expansion, and thus is usually in a state of being applied with tensile stress. However, by adding silicon nitride (Si_3N_4) to the heat generating section 12, the coefficient of thermal expansion is made to approximate the coefficient of thermal expansion of the insulating ceramic 16. In this way, it is possible to alleviate stress generated by a difference in the coefficient of thermal expansion at a time of a temperature increase and a time of a temperature decrease of the ceramic heater 10.

[0024] In the case where the percentage of the silicon nitride (Si_3N_4) content contained in the heat generating section 12 is equal to or lower than 40% by mass, a resistance value of the heat generating section 12 can be reduced to be small and stabilized. Thus, the percentage of the silicon nitride (Si_3N_4) content in the heat generating section 12 is preferably 20 to 40% by mass. The percentage of the silicon nitride (Si_3N_4) content is further preferably 25 to 35% by mass.

[0025] As a similar additive to the heat generating section 12, boron nitride (BN) of 4 to 12% by mass may be added instead of silicon nitride (Si_3N_4). Furthermore, the heat generating section 12 may contain at least one type of elements (titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), and iron (Fe)) in groups 4, 5, 6, 7, 8 of period 4 in a periodic table of elements.

[0026] For example, percentage of a content of each of the elements including titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), and iron (Fe) in the heat generating section 12 is preferably equal to or lower than 0.5 mol%.

[0027] The tip of the lead 14 is connected to the rear end of the heat generating section 12, and a rear end thereof is exposed from the insulating ceramic 16. The lead 14 includes a positive electrode-side lead 14a and a negative electrode-side lead 14b.

[0028] Each of the positive electrode-side lead 14a and the negative electrode-side lead 14b is formed of the conductive ceramic having low resistivity against the heat generating section 12. The positive electrode-side lead 14a and the negative electrode-side lead 14b extend in parallel with each other along the axis x of the ceramic heater 10. The positive electrode-side lead 14a and the negative electrode-side lead 14b are respectively connected to ends of the extending sections 12a, 12b of the heat generating section 12 extending in the U-shape.

[0029] A tip of the positive electrode-side lead 14a is connected to the extending section 12a of the heat generating section 12. In the insulating ceramic 16, the positive electrode-side lead 14a extends to a rear end of the insulating ceramic 16. At a rear end of the ceramic heater 10, the positive electrode-side lead 14a is exposed from the insulating ceramic 16 and is electrically connected to a lead wire 115 via a cap-shaped connection section 114.

[0030] A tip of the negative electrode-side lead 14b is connected to the extending section 12b of the heat generating section 12, and a rear end thereof has an exposed section 14c where a part of the negative electrode-side lead 14b is exposed to an outer circumferential surface of the insulating ceramic 16. The exposed section 14c of the lead 14 is joined to an inner circumferential surface of the outer cylinder 20 via the joint section 21, which will be described later, by brazing or the like. The lead 14 is electrically connected to the outer cylinder 20, which is formed of a metallic material having conductivity, via the exposed section 14c. The exposed section 14c of the lead 14 functions as a negative electrode-side electrode.

[0031] The lead 14 contains, as a primary component, tungsten carbide (WC) that is an inorganic conductor, and silicon nitride (Si_3N_4) is preferably added thereto such that percentage of the silicon nitride (Si_3N_4) content becomes equal to or higher than 15% by mass. As the percentage of the silicon nitride (Si_3N_4) content is increased, a coefficient of thermal expansion of each of the positive electrode-side lead 14a and the negative electrode-side lead 14b can approximate a coefficient of thermal expansion of silicon nitride (Si_3N_4) that is contained in the insulating ceramic 16.

[0032] In the case where the percentage of the silicon nitride content is equal to or lower than 40% by mass, a resistance value of each of the positive electrode-side lead 14a and the negative electrode-side lead 14b is reduced to be small and stabilized. Thus, the percentage of the silicon nitride (Si_3N_4) content is preferably 15 to 40% by mass. The percentage of the silicon nitride (Si_3N_4) content is further preferably 20 to 35% by mass.

[0033] Furthermore, the lead 14 may contain an oxide and/or a nitride containing at least one type of elements (titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), and iron (Fe)) in groups 4, 5, 6, 7, 8 of period 4 in the periodic table of elements. For example, the percentage of the content of each of the elements including titanium (Ti), vanadium (V), chromium (Cr), manganese (Mn), and iron (Fe) in the lead 14 is preferably equal to or lower than 0.5 mol%.

[0034] For example, the lead 14 is preferably a mixture that contains a rare earth element compound such as chromium oxide (Cr_2O_3) of about several tens of ppm, and is a sintered body formed by sintering.

[0035] The lead 14 is formed of the same material as that for the heat generating section 12, but contains a larger amount of the forming material than the heat generating section 12 and has a larger cross-sectional area than the heat generating section 12, for example. In this way, the lead 14 has the smaller resistance value per unit length than the heat generating section 12.

[0036] The insulating ceramic 16 is a sintered body which is formed by sintering and the outer circumferential surface of which has a cylindrical shape, for example. The insulating ceramic 16 covers the conductive ceramic 11. More specifically, the insulating ceramic 16 covers the heat generating section 12 and the lead 14. In other words, the heat generating section 12 and the lead 14 are embedded in the insulating ceramic 16.

[0037] The insulating ceramic 16 has a diameter d of 2.9 to 3.1 mm and the cylindrical outer circumferential surface. In particular, the diameter d is preferably 2.9 mm. Here, the "diameter d of the insulating ceramic 16" is not a diameter of a dome-shaped portion but is a diameter of a cylindrical portion of the outer circumferential surface. A distance (length) l_2 between a tip of the curved section 12c of the heat generating section 12 and the tip of the insulating ceramic 16 is about 0.97 mm.

[0038] In the cross section that is perpendicular to the axis x, in the insulating ceramic 16, a thickness t_1 of a thin portion (the thinnest portion) 16a where the outer circumferential surface of the insulating ceramic 16 is closest to each of the extending sections 12a, 12b of the heat generating section 12 falls within a range from 0.5 to 0.7 mm. The thickness t_1 of the thin portion 16a is preferably 0.57 to 0.66 mm.

[0039] Here, the "closest" in this embodiment means that the thickness t_1 of the thin portion 16a of the insulating ceramic 16 between the outer circumferential surface of the insulating ceramic 16 and each of the extending sections 12a, 12b of the heat generating section 12 (here, each of outer circumferential surfaces of the extending sections 12a, 12b) falls within the range from 0.5 to 0.7 mm. As illustrated in Fig. 2, in the cross section that is perpendicular to the axis x, the thin portion 16a is a portion whose thickness t_1 that is the shortest distance from the outer circumferential surface of the insulating ceramic 16 to the outer circumferential surface of the heat generating section 12 is 0.5 to 0.7 mm. However, a portion other than the thin portion 16a may be 0.5 to 0.7 mm in thickness.

[0040] The insulating ceramic 16 has a thin portion 16b in a region covering the lead 14. In the thin portion 16b, a thickness t_2 of insulating ceramic 16 between each of the positive electrode-side lead 14a and the negative electrode-side lead 14b and the outer circumferential surface of the insulating ceramic 16 falls within a range from 0.25 to 0.4 mm. The thin portion 16b is preferably 0.25 to 0.35 mm in thickness.

[0041] As illustrated in Fig. 3, in the cross section that is perpendicular to the axis x, the thin portion 16b is a portion whose thickness t_2 that is the shortest distance from the outer circumferential surface of the insulating ceramic 16 to the outer circumferential surface of the lead 14 is 0.25 to 0.4 mm.

[0042] A length (a first length) A in an axis x direction from the tip of the insulating ceramic 16 to the rear end of the heat generating section 12, more specifically, to the rear end of each of the extending sections 12a, 12b of the heat generating section 12 is about 4.5 mm. A length (a second length) B in the axis x direction from the tip of the insulating ceramic 16 to a tip of the joint section 21, which will be described later, is 12 to 20 mm, and a length (a third length) C in the axis x direction of the joint section 21 is 2.8 to 10.8 mm.

[0043] The length A with respect to the length B of the insulating ceramic 16 satisfies the following formula (Formula 1).

[Formula 5]

$$\frac{A}{B} < 0.55$$

[0044] The length A with respect to the length B of the insulating ceramic 16 preferably satisfies the following formula (Formula 3).

[Formula 6]

$$\frac{A}{B} < 0.5$$

[0045] The length C with respect to a total length (B + C) of the length B and the length C of the insulating ceramic 16 satisfies the following formula (Formula 2).

[Formula 7]

$$\frac{C}{B+C} < 0.55$$

[0046] The length C with respect to the total length (B + C) of the length B and the length C of the insulating ceramic 16 preferably satisfies the following formula (Formula 4).

[Formula 8]

$$\frac{C}{B+C} < 0.5$$

[0047] The length ($l_1 + l_2 = A$) in the axis x direction from the tip of the insulating ceramic 16 to the rear end of the heat generating section 12, more specifically, to the rear end of each of the extending sections 12a, 12b of the heat generating section 12 is equal to or shorter than 4.5 mm. The entire heat generating section 12 is located within the range of 4.5 mm from the tip of the insulating ceramic 16 along the axis x.

[0048] With the insulating ceramic 16 that is formed of the ceramic, it is possible to provide the ceramic heater 10 with high reliability during a rapid temperature increase. Specific examples of ceramics are ceramics having electric insulation properties such as an oxide ceramic, a nitrogen ceramic, and a carbide ceramic.

[0049] In particular, silicon nitride as the primary component of the silicon nitride ceramic is superior in terms of high strength, high toughness, the high insulation property, and thermal resistance. This silicon nitride ceramic is obtained by mixing, as sintering additives, a rare earth oxide, an aluminum oxide (Al_2O_3), a content of which is 0.5 to 3% by mass, and a silicon dioxide (SiO_2) with silicon nitride and by hot pressing, for example. Examples of the rare earth oxide are an yttrium oxide (Y_2O_3), an ytterbium oxide (Yb_2O_3), and an erbium oxide (Er_2O_3), a content of each of which is 3 to 12% by mass. Silicon dioxide (SiO_2) is contained in such an amount that the sintered body contains 1.5 to 5% of a silicon dioxide (SiO_2) content by mass.

[0050] In the case where the insulating ceramic 16 that is formed of the silicon nitride ceramic is used, molybdenum disilicide ($MoSi_2$) , tungsten disilicide (WSi_2), and the like are preferably mixed and dispersed. In this case, a coefficient of thermal expansion of the silicon nitride ceramic as a base material can approximate the coefficient of thermal expansion of the heat generating section 12. In this way, durability of the ceramic heater 10 can be improved.

[0051] The outer cylinder 20 is formed of stainless steel such as SUS 430 in a cylindrical shape, for example. As illustrated in Fig. 1, the outer cylinder 20 accommodates the ceramic heater 10 in a state where a tip portion of the ceramic heater 10 is exposed. In the state of accommodating the ceramic heater 10, the inner circumferential surface of the outer cylinder 20 is formed with the joint section 21 for a specified length along the axis x of the ceramic heater 10. For example, in the joint section 21, the ceramic heater 10 and the outer cylinder 20 are joined by brazing using a brazing material such as a silver filler.

[0052] The joint section 21 is formed by metalizing the outer circumferential surface of the insulating ceramic 16 with the brazing material such as the silver filler, and is formed for the specified length (corresponding to the length C.) between the outer circumferential surface of the ceramic heater 10 and the inner circumferential surface of the outer cylinder 20 along the axis x of the ceramic heater 10. In this embodiment, the joint section 21 is formed from a tip of the outer cylinder 20 to a position where the rear end side of the insulating ceramic 16 contacts an inner circumferential surface of a tip portion 22 of the outer cylinder 20. Here, on the axis x, a tip of the joint section 21 may be located in front of the outer cylinder 20 or inside the outer cylinder 20.

[0053] The housing 30 is an attachment jig to a cylinder head of the engine, which is not illustrated, and, as illustrated in Fig. 1, accommodates the ceramic heater 10 and the outer cylinder 20.

[0054] The housing 30 is formed of a thermally conductive metallic material with a superior heat dissipation property. The housing 30 is formed in a cylindrical shape, for example. A rear end side of the ceramic heater 10 is partially supported by the outer cylinder 20, and the outer cylinder 20 is arranged in the housing 30. In this state, the tip side of the ceramic heater 10 is projected to the outside from a tip of the housing 30.

Examples

[0055] A description will hereinafter be made on comparative examples based on the conventional glow plug and specific examples of the glow plug 1 according to the embodiment. The present invention is not particularly limited to these examples. Numerical values described below are numerical values obtained in simulations.

[0056] Table 1 shows various specifications and various simulation results of Examples 1, 2 and Comparative Example 1. In Examples 1, 2, in the ceramic heater 10, the diameter d (mm) of the insulating ceramic 16, the thickness t_1 (mm) of the thin portion 16a between the heat generating section 12 and the outer circumferential surface of the insulating ceramic 16, and the thickness t_2 (mm) of the thin portion 16b between the lead 14 and the outer circumferential surface of the insulating ceramic 16 are within the numerical ranges in the above embodiment. In Comparative Example 1, the numerical values do not fall within the numerical ranges in the above embodiment.

[Table 1]

	Diameter d of heater element (mm)	Thickness t_1 of thin portion between heat generating section and insulating member (mm)	Thickness t_2 of thinnest portion between lead and insulating member (mm)	Consumed power after 60 seconds (W)	Temperature increase duration up to 1000 °C at position 2 mm from tip of heater element (s)	Temperature of heat generating section after energization for 2 seconds (°C)
Example 1	3.1	0.66	0.35	35.2	1.23	1453.8
Example 2	2.9	0.57	0.25	34.5	0.94	1548.2
Comparative Example 1	3.22	0.72	0.41	35.6	1.39	1401.1

[0057] After initiation of the simulations, a current with a voltage of 11 V was applied to the glow plugs 1 according to Examples 1, 2 and Comparative Example 1 for first two seconds, and thereafter the current with the voltage of 7 V was applied thereto.

[0058] As a result, as understood from Table 1, it was found that the consumed power in Examples 1, 2 after 60 seconds from the initiation of the simulations were 35. 2 W and 34.5 W, respectively, and thus were lower than the consumed power 35.6 W in Comparative Example 1.

[0059] In addition, in each of Examples 1, 2 in which the diameter d of the ceramic heater 10 was smaller than 3.2 mm and the thickness t_1 of the thin portion 16a was less than 0.7 mm, temperature increase duration up to 1000 °C was shorter than that in Comparative Example 1 in which the diameter d was larger than 3.2 mm and the thickness t_1 of the thin portion 16a exceeded 0.7 mm. In particular, in Example 2 in which the diameter d was 2.9 mm and the thickness t_1 was 0.57 mm, the temperature increase duration up to 1000 °C was shorter than 1 second, and thus a superior temperature increase property was exhibited.

[0060] Furthermore, it was found that the temperature of the heat generating section 12 after energization for two seconds in each of Examples 1, 2 was higher than the temperature in Comparative Example 1, the temperature exceeds 1500 °C in Example 2, and thus the superior temperature increase property was exhibited in Example 2.

[0061] As a volume of the insulating ceramic 16 is increased, more heat is diffused from the heat generating section 12. Thus, it was found that, when the thickness t_1 of the thin portion 16a satisfied a condition of 0.5 to 0.7 mm as in Examples 1, 2, the superior temperature increase property was exhibited. The diameter d further preferably satisfies a condition of 2.9 to 3.1 mm.

[0062] Note that, in the case where the thickness t_1 is less than 0.5 mm and corrosion of the insulating ceramic 16 progresses over a period of time, the heat generating section 12 is possibly exposed early. When the heat generating section 12 is exposed, tungsten (W) contained in the material for the heat generating section 12 is oxidized, which possibly destroys the heat generating section 12. In Example 2, the early exposure of the heat generating section 12 is avoided to achieve a long life span of the glow plug 1 and also to achieve the rapid temperature increase and the reduced power consumption.

[0063] Next, Table 2 shows various specifications and various simulation results of Examples 3 to 5 and Comparative Examples 2, 3. In Examples 3 to 5, the diameter d (mm) of the insulating ceramic 16, the thickness t_1 (mm) of the thin portion 16a between the heat generating section 12 and the outer circumferential surface of the insulating ceramic 16, and the thickness t_2 (mm) of the thin portion 16b between the lead 14 and the outer circumferential surface of the insulating ceramic 16 are the same as those in Example 2 but the length B in the axial direction from the tip of the insulating ceramic 16 to the tip of the joint section 21 and the length C in the axial direction of the joint section 21 differ. Note that the length A in the axial direction from the tip of the insulating ceramic 16 to the rear end of the heat generating section 12 is the same in Examples 3 to 5 and Comparative Examples 1, 2.

[Table 2]

	Length A in axial direction from tip of insulating ceramic to rear end of heat generating section (mm)	Length B in axial direction from tip of insulating ceramic to tip of joint section (mm)	Length C in axial direction of joint section (mm)	A/B	C/(B + C)	Temperature after 60 seconds at position 2 mm from tip of heater element (°C)	Consumed power after 60 seconds (W)	Temperature in contact section between negative electrode-side lead and outer cylinder (°C)
Example 3	4.5	12	10.8	0.375	0.47368	1199	29	434
Example 4	4.5	14	8.8	0.32143	0.38597	1208	28.98	419.54
Example 5	4.5	20	2.8	0.225	0.12281	1219	28.6	378
Comparative Example 2	4.5	8	14.8	0.5625	0.64912	1166	29.5	466
Comparative Example 3	4.5	10	12.8	0.45	0.5614	1186	29.2	450

[0064] As understood from Table 2, it was found that the temperature at a point of 2 mm from the tip of the ceramic heater 10 after 60 seconds from the initiation of the simulations was increased as a ratio of the exposure of the ceramic heater 10 from the outer cylinder 20 was increased, that is, a region of the ceramic heater 10 brazed to the outer cylinder 20 was reduced.

[0065] More specifically, as in Examples 3 to 5, the temperature of the ceramic heater 10 satisfying conditions that a ratio (A/B) of the length A to the length B in the insulating ceramic 16 was 0.2 to 0.4 and that a ratio (C/B + C) of the length C to the length B + C in the insulating ceramic 16 was 0.1 to 0.5 after 60 seconds reached about 1200 °C.

[0066] In Example 3, a value of A/B was 0.375, and a value of C/B + C was about 0.474. In Example 4, the value of A/B was about 0.321, and the value of C/B + C was about 0.386. In Example 5, the value of A/B was 0.225, and the value of C/B + C was about 0.123. In the case where Comparative Examples 2,3 in which none of the conditions of the ratios was satisfied were compared to Examples 3 to 5, it was found that the superior temperature increase property was exhibited in Examples 3 to 5.

[0067] Furthermore, it was found that the consumed power after 60 seconds from the initiation of the simulations was equal to or lower than 29 W in the case where the above conditions of the ratios were satisfied as in Examples 3 to 5 and that the consumed power in Examples 3 to 5 was lower than the consumed power in Comparative Examples 2, 3.

[0068] Moreover, in Examples 3 to 5, a joint area between the joint section 21, which is formed by the silver filler with high thermal conductivity, and the ceramic heater 10 is suppressed to be small. In this way, it is configured that heat from the ceramic heater 10 is unlikely to be released. Thus, a superior heat retaining property can be exhibited near the heat generating section 12.

[0069] In particular, in Examples 3 to 5, the temperature near the heat generating section 12 could be kept high. Thus, a temperature of the joint section 21 between the negative electrode-side lead 14b and the outer cylinder 20, that is, a temperature of the exposed section 14c of the lead 14 could be suppressed below 450 °C. On the contrary, in Comparative Examples 2, 3, the temperature of the exposed section of the lead was equal to or higher than 450 °C. From what have been described so far, it was found that, in Examples 3 to 5, a negative impact on the brazing material for the joint section 21 by heat could be suppressed to be small.

[0070] Next, Table 3 shows various specifications and various simulation results of Example 6 and Comparative Example 4 in which the diameter d (mm) of the insulating ceramic 16, the thickness t_1 (mm) of the thin portion between the heat generating section 12 and the outer circumferential surface of the insulating ceramic 16, and the thickness t_2 (mm) of the thin portion 16a between the lead 14 and the outer circumferential surface of the insulating ceramic 16 are the same as those in Example 2 but the length l_1 of the heat generating section 12 differs and Comparative Example 5 in which the diameter d (mm), the thickness t_1 (mm), and the thickness t_2 (mm) are the same as those in Comparative Example 1 and the length l_1 of the heat generating section 12 is the same as that in Example 6.

[Table 3]

	Diameter dmax Of heater element (mm)	Distance l_2 from tip of insulating member to tip of heat generating section (mm)	Length l_1 of heat generating section (mm)	Condition for voltage (V)	Temperature increase duration up to 1000 °C at position 2 mm from tip of heater element (s)	Temperature of position 2 mm from tip of heater element after 60 seconds (°C)
Example 6	2.9	0.97	3.5	First 1.4 seconds: 11 V Thereafter: 6.3 V	0.98	1187
Comparative Example 4	2.9	0.97	4.5	First 2 seconds: 11 V Thereafter: 7 V	1.08	1259
Comparative Example 5	3.22	0.97	3.5	First 1.8 seconds: 11 V Thereafter: 6.8 V	1.32	1181

[0071] As understood from Table 3, in Example 6 in which the length A in the axis x direction from the tip of the insulating ceramic 16 to the rear end of the heat generating section 12 became equal to or shorter than 4.5 mm ($A \leq 4.5$ (mm)), the temperature increase duration up to 1000 °C was 0.98 second and thus was shorter than 1 second.

[0072] On the contrary, in Comparative Example 4 in which the length A in the axial direction from the tip of the insulating ceramic 16 to the rear end of the heat generating section 12 exceeded 4.5 mm ($A > 4.5$ (mm)), the temperature increase duration up to 1000 °C was 1.08 seconds and thus exceeded 1 second.

[0073] Also from this, it was found that, when the length A in the axis x direction from the tip of the insulating ceramic 16 to the rear end of the heat generating section 12 was equal to or shorter than 4.5 mm, the temperature increase duration up to 1000 °C in the ceramic heater 10 was reduced.

[0074] It was found that, in the case where the diameter d was 3.22 mm (exceeded 2.9 mm) even when the length A in the axial direction from the tip of the insulating ceramic 16 to the rear end of the heat generating section 12 was equal to or shorter than 4.5 mm ($A \leq 4.5$ (mm)) as in Comparative Example 5, the temperature increase duration up to 1000 °C was 1.32 seconds and thus the temperature increase property was inferior to that in Example 6.

[0075] According to the glow plug 1 that has been described so far, the thickness t_1 of the thin portion 16a where the outer circumferential surface of the insulating ceramic 16 is adjacent to the heat generating section 12 falls within the range from 0.5 to 0.7 mm. As a result, compared to the glow plug in which the thin portion 16a falls out of the above range, it is possible to significantly improve the temperature increase property and suppress the power consumption. The thickness t_1 of the thin portion 16a is preferably 0.57 to 0.66 mm, and the diameter d of the insulating ceramic 16 is further preferably 2.9 to 3.1 mm.

[0076] Since the length A in the axis x direction from the tip of the insulating ceramic 16 to the rear ends of the extending sections 12a, 12b of the heat generating section 12 is equal to or shorter than 4.5 mm, in other words, the entire heat generating section 12 is located within the range of 4.5 mm from the tip of the insulating ceramic 16, it is possible to shorten the duration until reaching 1000 °C in comparison with the case where the length A in the axis x direction from the tip of the insulating ceramic 16 to the rear ends of the extending sections 12a, 12b of the heat generating section 12 exceeds 4.5 mm.

[0077] In addition, according to the glow plug 1, when the length A in the axis x direction from the tip of the insulating ceramic 16 to the rear ends of the extending sections 12a, 12b of the heat generating section 12, the length B in the axis x direction from the tip of the insulating ceramic 16 to the tip of the joint section 21, and the length C in the axis x direction of the joint section 21 satisfy following Formula 1 and Formula 2,

[Formula 9]

$$\frac{A}{B} < 0.55 \quad \text{(Formula 1)}$$

[Formula 10]

$$\frac{C}{B+C} < 0.55 \quad \text{(Formula 2)}$$

in addition to the temperature increase property and the reduction in the power consumption, it is possible to lower the temperature of a contact section between the exposed section 14c of the negative electrode-side lead 14b and the outer cylinder 20. In this way, it is possible to reduce a load by the heat to the brazing material for the joint section 21 that joins the ceramic heater 10 and the outer cylinder 20.

[0078] In addition, satisfying following Formula 3 and Formula 4

[Formula 11]

$$\frac{A}{B} < 0.5 \quad \text{(Formula 3)}$$

[Formula 12]

$$\frac{C}{B+C} < 0.5 \quad \text{(Formula 4)}$$

is further preferred from perspectives of the temperature increase property and the reduction in the power consumption.

<Others>

[0079] The present invention is not limited to the above embodiment. For example, a cross-sectional shape of the ceramic heater 10 that is perpendicular to the axis x is not limited to a circular shape but may be another shape such as an oval shape or a polygonal shape. In addition, a cross-sectional shape of each of the heat generating section 12 and the lead 14 is not limited to the oval shape as illustrated in FIGs. 2, 3 but may be another shape such as the circular shape or the polygonal shape including a rectangular shape.

Claims

1. A glow plug comprising:

a ceramic heater that has a conductive ceramic and an insulating ceramic covering the conductive ceramic, wherein
the conductive ceramic has: a heat generating section that is arranged at a tip; and a lead that is connected to a rear end of the heat generating section, and
in a cross section that is perpendicular to an axis of the ceramic heater, the insulating ceramic has a thinnest portion where an outer circumferential surface thereof and the heat generating section are closest to each other in a thickness of 0.5 to 0.7 mm.

2. The glow plug according to claim 1, wherein
the thickness of the thinnest portion is 0.57 to 0.66 mm.

3. The glow plug according to claim 1 or 2, wherein
the outer circumferential surface of the insulating ceramic is in a cylindrical shape that has a diameter of 2.9 to 3.1 mm.

4. The glow plug according to any one of claims 1 to 3, wherein
a length in an axial direction from a tip of the insulating ceramic to a rear end of the heat generating section is equal to or shorter than 4.5 mm.

5. A glow plug comprising:

a ceramic heater that has a conductive ceramic and an insulating ceramic covering the conductive ceramic; and
an outer cylinder that accommodates a part of the ceramic heater such that at least a tip is exposed and an inner circumferential surface of which is joined to an outer circumferential surface of the ceramic heater via a joint section, wherein
the conductive ceramic has: a heat generating section that is arranged at a tip; and a lead that is connected to a rear end of the heat generating section, and
when a length in an axial direction from a tip of the insulating ceramic to the rear end of the heat generating section is set as a first length A,
a length in the axial direction from the tip of the insulating ceramic to a tip of the joint section is set as a second length B, and
a length in the axial direction of the joint section is set as a third length C,
following Formula 1 and Formula 2 are satisfied.
[Formula 1]

$$\frac{A}{B} < 0.55 \quad \text{(Formula 1)}$$

[Formula 2]

$$\frac{C}{B+C} < 0.55 \quad \text{(Formula 2)}$$

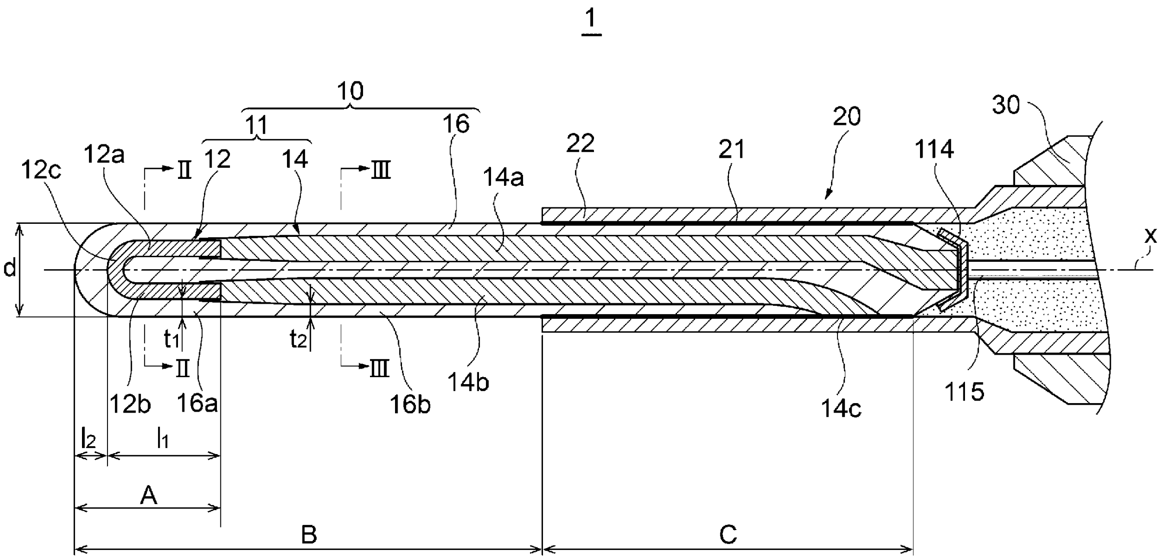
6. The glow plug according to claim 5 satisfying following Formula 3 and Formula 4.
[Formula 3]

$$\frac{A}{B} < 0.5 \quad \text{(Formula 3)}$$

[Formula 4]

$$\frac{C}{B+C} < 0.5 \quad \text{(Formula 4)}$$

[FIG. 1]


1
10
11
12c
12a
II
12
14
III
16
14a
22
21
20
30
114
x
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14c
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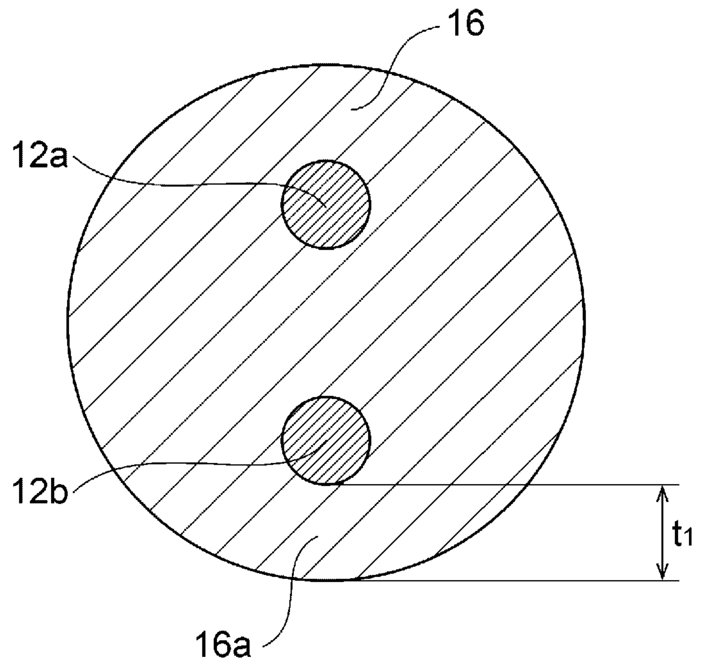
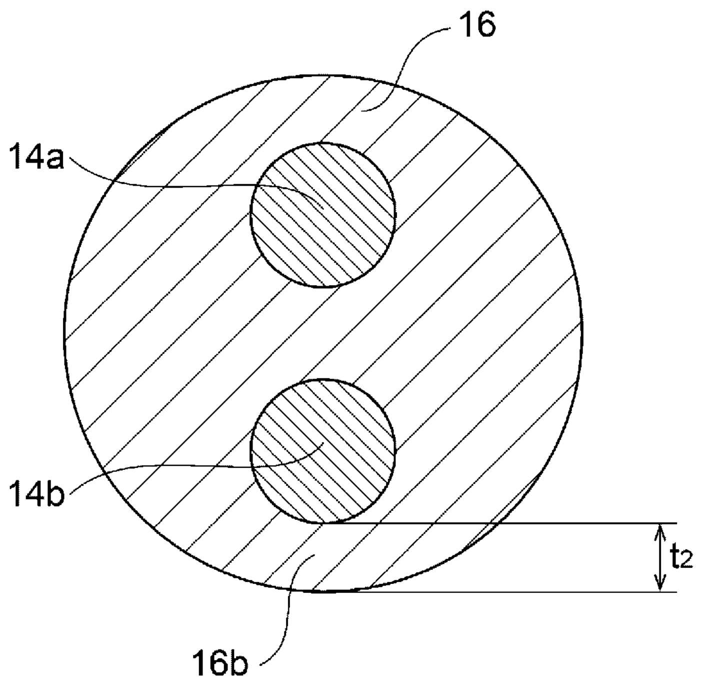
l2
l1
A
B
C

[FIG. 2]



[FIG. 3]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2018/035539

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. F23Q7/00(2006.01)i, H05B3/48(2006.01)i
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. F23Q7/00, H05B3/48

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP 2009-287920 A (NGK SPARK PLUG CO., LTD.) 10 December 2009, claims, paragraphs [0008], [0014]-[0078], fig. 1-11 (Family: none)	1, 3-4 1-6
X Y	JP 07-151332 A (KYOCERA CORP.) 13 June 1995, claims, paragraphs [0004], [0009], [0010]-[0038], fig. 1-3 & US 5750958 A, claims, column 19, line 25 to column 29, line 65, fig. 10-16 & DE 4433505 A1	1-2 1-6
X Y	JP 07-220859 A (KYOCERA CORP.) 18 August 1995, claims, paragraphs [0004], [0010], [0013]-[0044], fig. 1-3 & US 5750958 A, claims, column 29, line 66 to column 41, line 63, fig. 17-28 & DE 4433505 A1	1-2 1-6

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2018/035539

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 098603/1988 (Laid-open No. 020293/1990) (NGK SPARK PLUG CO., LTD.) 09 February 1990, specification, page 1, line 5 to page 16, table 1, fig. 1-5 & DE 3924777 A1	1-2 1-6
Y	JP 2004-061041 A (KYOCERA CORP.) 26 February 2004, paragraph [0021] (Family: none)	4-6
Y	JP 62-000731 A (JIDOSHA KIKI CO., LTD.) 06 January 1987, page 3, upper left column, line 12 to page 5, lower right column, line 13, fig. 1-2 & US 4742209 A, column 3, line 29 to column 7, line 31, fig. 1-2 & DE 3621216 A	5-6
Y	WO 2017/038694 A1 (KYOCERA CORP.) 09 March 2017, paragraphs [0008]-[0047], fig. 9-12 (Family: none)	5-6
A	JP 2005-315447 A (KYOCERA CORP.) 10 November 2005, entire text, all drawings (Family: none)	1-6
A	JP 2001-227744 A (DENSO CORP.) 24 August 2001, entire text, all drawings (Family: none)	1-6

Form PCT/ISA/210 (continuation of second sheet) (January 2015)

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