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(71) Applicant: **Delphi Automotive Systems
Luxembourg SA
4940 Bascharage (LU)**

electrode (16) comprises a shell portion (12) receiving said tubular insulator member (20). The tubular insulator member (20) comprises a core (30) made from a dielectric material exhibiting a first dielectric constant and a peripheral layer (32) in a material exhibiting a greater dielectric constant that faces the shell (12) portion of the counter electrode.



Description

FIELD OF THE INVENTION

[0001] The present invention generally relates to gasoline engine ignition and in particular to a spark plug for a high frequency ignition system of such engine.

BACKGROUND OF THE INVENTION

[0002] As it is well known, ignition systems for gasoline internal combustion engines are conventionally built out of three main components: a spark plug, a transformer and a driving logic module. The primary function is to supply a spark, which allows to initiate a flame kernel and by this initiating the combustion process of gasoline engines. Creating a spark requires a very high voltage in an initial phase to provide the dielectric breakdown in form of an ionization path between two dedicated electrodes, named firing face, and subsequently a given amount of energy to sustain the dielectric breakdown for a certain time.

[0003] At leaner homogeneous gasoline mixtures using high exhaust gas recirculation rates and/or by injection of stratified gasoline mixtures the conventional ignition system reaches its limit. It was found that by applying a more stable and longer time spark the existing limitations in combustion stability could be moved further out to lower emissions and lower fuel consumption.

[0004] This is the purpose of recently developed high frequency ignition systems. They typically employ alternative, resonance based methods of generating high voltages. The outputs of such sources are typically alternating current and voltages; the smaller the electronics and resonators, the higher the operating frequency. Operating at high frequencies however brings some constraints, in particular due to a significant change in electric and dielectric properties of materials. Indeed, dielectric loss becomes a dominant factor. The dielectric loss represents a resistive electrical path through insulating materials, which decreases with increasing frequencies. This has two dramatic new consequences for an ignition system. The first is that the lower resistive loads are attenuating the power source output during its attempt to produce high voltages. The second consequence is malfunction due to the assembly air gaps at the electrode-insulator interfaces due to the conventional concentric arrangements of a spark plug (central insulator member housing the central electrode and surrounded by the counter (ground) electrode): the voltage drop across the air gaps may rise above the corona initiating threshold voltage.

[0005] To avoid such issues, it was suggested to fill in the air gaps with a dielectric material such as glass. However, implementing such measure at industrial scale may be difficult; and there is a risk of shear stresses appearing due to differential thermal expansions. Furthermore, the dielectric constant of glass may be too low for operation

at certain frequencies.

[0006] US 2009/0033194 discloses a spark plug for a high frequency ignition system, wherein the inner and outer surfaces of the ceramic insulator are metallized. As a result, each electrode sees a metallized surface opposite the air gap, which due to mounting is typically in electrical contact therewith. Since the surfaces facing each other across the air gap are at the same potential, the propagation of surface discharges is avoided.

OBJECT OF THE INVENTION

[0007] The object of the present invention is to provide an alternative spark plug design for high frequency ignition systems.

[0008] This object is achieved by a spark plug as claimed in claim 1.

SUMMARY OF THE INVENTION

[0009] According to the present invention, a spark plug for a high frequency ignition system comprises a centre electrode having a front end with a firing tip and a tubular insulator member having a front end and an axial bore accommodating the centre electrode such that the electrode firing tip protrudes out of the insulator front end. A counter electrode comprises a shell portion receiving the tubular insulator member.

[0010] It shall be appreciated that the tubular insulator member comprises a core made from a dielectric material exhibiting a first dielectric constant and an outer, peripheral layer made from a material exhibiting a greater dielectric constant than the insulator core that faces the shell portion of the counter electrode.

[0011] As it will be understood by those skilled in the art, equipotential voltage lines will be moved out of the peripheral layer of the insulator with higher dielectric constant, and will be proportionally denser inside the core. Hence, most of the electric field resides in the core portion of the insulator member, which has a comparatively lower dielectric constant. As a result, the difference of potential between the outer surface of the insulator and the counter electrode is reduced, hence reducing potential surface discharge effects. Therefore, although a small air gap may exist at the interface between the ground electrode and the insulator due to mounting play (assembly air gap), electrical breakdown through this air gap may be avoided by the layered insulator structure.

[0012] It may be noted that the term "dielectric constant" is used herein as equivalent to the frequency-dependent relative permittivity $\epsilon_r(\omega)$, i.e. the ratio of the complex frequency-dependent absolute permittivity $\epsilon(\omega)$ of a material over the vacuum permittivity ϵ_0 .

[0013] It is also clear that comparisons made herein between dielectric constants are made for same or comparable frequencies.

[0014] In practice, the axial extent of the insulator may be chosen so that it separates the centre electrode from

the shell on overlapping lengths thereof.

[0015] In one embodiment, the centre electrode comprises a rod-shaped element that terminates with a firing tip outside the insulator. For an improved operation, the insulator comprises an inner dielectric layer such that the insulator core is radially sandwiched between this inner dielectric layer and the outer peripheral layer, the inner dielectric layer having a greater dielectric constant than said core. With such structure, most of the electrical flux is concentrated in the core portion, away from electrode/insulator interfaces. Preferably, a metal deposit layer is formed on the surface of the axial bore of the insulator member in such a way that the insulator inner surface is at the same potential as the centre electrode.

[0016] In another embodiment, the centre electrode comprises: a hollow shaft portion in the insulator member formed as a metallic layer on the inner, axial bore surface of the insulator member; and a firing tip member mounted from the front end of the insulator member and in electrical contact with the metallic layer. In this variant, there is no inner rod-type electrode. The electrode is formed as a hollow shaft directly on the insulator axial bore. As a result, there is no air gap.

[0017] Conventionally, the counter electrode (normally connected to ground in the engine cylinder head) may include a counter electrode element bonded to the shell portion and cooperating with the firing tip to define a discharge gap. However, in the context of high frequency ignition systems, it has been found that such an electrode element is not required and that the cylindrical shell portion may itself act as electrical return path from the firing face tip to the ground. The ionizing path would then exist over at least part of the circumference of the counter electrode.

[0018] The insulator member may be typically made from appropriate ceramic materials, selected in particular for their dielectric properties in order to build the desired structure. Although in the above described embodiments the insulator member consists of two or three different layers, it may be made from a plurality of layers to create a gradient of dielectric constants, as may be devised by those skilled in the art. However the insulator member is preferably manufactured as a single, coherent part where all layers are bonded together.

[0019] Preferably, the dielectric constant of the peripheral layer, respectively of the inner layer, is at least 2 times the dielectric constant of the insulator core.

[0020] For application in a plasma spark plug operating at frequencies in the range of 1MHz to 42MHz, the core may be made from a material having a dielectric constant between 3 and 10 at frequencies between 1 and 42 MHz.

[0021] The dielectric constant of the core (ϵ_{r-core}) and of the peripheral layer ($\epsilon_{r-periph}$) can be characterized therefore by

$$3 < \epsilon_{r-core} < 10$$

$$\epsilon_{r-core} < \epsilon_{r-periph} \quad \text{and} \quad \epsilon_{r-periph} > \epsilon_{r-core} * 2$$

for operating frequencies ranging from 1 MHz to 42 MHz.

[0022] Preferred materials of choice for the core range from beta-alumina ceramics to boron-nitrides. Materials for the peripheral layer may comprise a variety ceramic coatings modified such that a higher dielectric constant in comparison to the core is achieved.

[0023] These and other aspects of the present invention are recited in the appended dependent claims 2-13.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1: a) is a principle diagram of a first embodiment of the present spark plug, showing the firing face of the spark plug; and b) is a principle section view through the insulator;

FIG. 2: a) is a principle diagram of a second embodiment of the present spark plug, also showing the firing face; and b) is a principle section view through the insulator.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

[0025] A first variant of a spark plug 10 (or plasma plug) for a high frequency ignition system is schematically represented in part (socket side with firing face only) in Fig. 1, as a longitudinal section view. It comprises, similar to conventional spark plugs, a generally cylindrical shell 12 (also referred to as socket) that is normally linked to the ground and bonded to an optional electrode element 14, shell 12 and element 14 being globally indicated 16 in Fig. 1 and referred to as counter electrode or more simply as ground electrode hereinafter. The shell 12 has an outer thread 18 for mounting in an engine cylinder head (not shown) or any equivalent mounting feature.

[0026] Reference sign 20 indicates a tubular insulator having a central or axial bore 22 housing a centre electrode 24. The insulator 20 is received in the ground electrode 16 and is thus surrounded, at least partially, by the shell 12. In other words, the insulator 20 is held by the ground electrode 16 and separates the latter from the centre electrode 24.

[0027] The axial bore 22 in the insulator 20 is preferably open at both ends. On the socket side of the plug 10, the insulator 20 has a front end 26 in which the axial bore 22 opens so that a centre electrode front end with a firing tip 28 protrudes out of this insulator front end 26. The ground electrode 16 with its optional electrode element 14 cooperates with the firing tip 28 to form a discharge

gap. Classically, the not shown portion of the plug 10 comprises an elongate, insulated portion with a terminal end for connection to a drive circuit, the terminal end being electrically connected with the centre electrode 24.

[0028] It shall be appreciated that the tubular insulator 20 comprises a tubular core portion 30 made from a first dielectric material and an outer, peripheral layer 32 (surrounding the core 30) in a second dielectric material, wherein the dielectric constant ϵ_{r2} of the second dielectric material is greater than that ϵ_{r1} of the first material. This outer, peripheral layer 32 made from a material having a greater dielectric constant has a (radial) thickness t_2 corresponding to: $t_2=R_4-R_3$ (referring to radiuses shown in Fig.1b) and extends over the axial length of the insulator 20. The radial thickness of the core is $t_1=R_3-R_2$.

[0029] As it will be understood, the peripheral insulator region 32 has, due to its higher dielectric constant, the ability to move the equipotential voltage lines out of its zone into core portion 30 of the insulator member 20. Hence, most of voltage drop occurs inside the core 30. As a consequence, the difference of potential between the outermost surface of the insulator 20 (i.e. outer surface of layer 32) and the ground electrode 24 is reduced, and so is the potential risk of corona.

[0030] Hence, although a small assembly air gap 34, say of a few hundredths to a few tenths of a millimetre, may typically exist at the interface between the ground electrode 16 and insulator 20 due to mounting play, electrical breakdown through this air gap 34 may be avoided by the layered insulator structure.

[0031] Similarly, the insulator 20 advantageously comprises an inner region or layer 36 made from a dielectric material having a greater dielectric constant ϵ_{r3} than that ϵ_{r1} of the core material. As both the inner 36 and outer 32 layers extend axially along the insulator 20, the core portion 30 is radially sandwiched between two layers having greater dielectric constants (see Fig.1b). The thickness of the inner layer 36 is $t_3=R_2-R_1$.

[0032] Preferably, a metal layer (not shown) is provided on the inner surface of bore 22 to avoid surface discharges at the remaining inherent air gaps 38 between the center electrode 24 and the inner surface of the inner layer 36.

[0033] Preferably, the respective thicknesses of each portion of the insulator 20 is such that $t_1 > t_2$, and $t_1 > t_2 + t_3$.

[0034] The insulator member 20 is preferably manufactured as a multilayer part, i.e. as a cohesive part of various layers that are bonded together. The dielectric materials of the insulator may typically be ceramics, including crystalline, part-crystalline and amorphous ceramics, and in particular oxides and nonoxides, as appropriate for the application. As it has been understood, a main criterion of choice is the dielectric constant to be able to build desired layered insulator structure. But ruggedness and thermal sensitivity are further parameters of choice, considering the application in a spark plug.

[0035] Possible materials for the core portion 30 is beta-alumina, conventionally used in spark plugs, and hav-

ing a dielectric constant of about 10 at 1MHz-42MHz. Alternative materials are SiO₂ boron-nitrides or aluminium-nitride ceramics. Considering the present application to radiofrequency ignition systems, ceramics having a dielectric constant between 3 and 10 at frequencies between 1 MHz and 42 MHz may be considered for the core portion 30

[0036] The inner 36 and outer 32 layers may be made from material having substantially same dielectric constant, i.e. $\epsilon_{r2} \approx \epsilon_{r3}$. Preferably, the dielectric constant of the inner and/or outer layers is/are at least 100% greater than that of the core material 30 (considered at the same frequency).

[0037] Here again, beta-alumina may be used, however doped to reach the desired value of dielectric constant, for example Al₂O₃/TiO₂

[0038] Such ceramic materials are well known to those skilled in the art, as well as their manufacture. Suitable processing techniques are chemical or physical vapor deposition as well as spraying coatings, dip coating, paint coatings.

[0039] It remains to be noted that the ground electrode element 14 is represented in the drawings in dashed-lines, because it is considered optional, although conventionally used in spark plugs. Indeed, it has been found that, in the context of high frequency ignition, the shell portion 12 concentrically surrounding the centre electrode may act as electrical return path from the firing face tip 28 to the ground.

[0040] Turning now to Fig.2, another embodiment of the present spark plug 100 is shown. Similarly to Fig. 1, a ground electrode 116 comprises a shell 112 with outer thread 118 and an optional electrode element. The insulator member 120 with axial bore 122 comprises a core portion 130 and an outer peripheral layer 132 that faces the shell 112 of the ground electrode 116.

[0041] A peculiarity of this embodiment is that the inner electrode 124 comprises a hollow shaft 125 inside the insulator 120, which is formed by a metal deposit on the inner surface of the axial bore 122. A firing tip 128 is mounted at the front face 126 of the insulator 120 and is in electrical connection with the hollow shaft portion 125. By forming the centre electrode 124 directly onto the insulator bore 122, there is no air gap at the interface between the centre electrode 124 and the insulator 120. Therefore also, no inner insulator layer with increased dielectric constant is required. Contrary to the embodiment of Fig.1, there is no rod-shaped electrode member inside the insulator 120, only the firing tip 128.

[0042] The wall thickness of the metal layer forming hollow shaft 125 may be in the range of 5 to 500 μ m. Typically, the remaining inner diameter of the insulator 120 bearing the hollow electrode shaft 125 may be between 0.1 and 3 mm.

[0043] Here again, the thickness of the core ($t'_1=R'_3-R'_1$) is substantially greater than that of the peripheral layer ($t'_2=R'_4-R'_3$): $t'_1 > t'_2$.

[0044] The materials for the insulator member 120 may

be selected as explained before.

Claims

1. A spark plug for a high frequency ignition system comprising:

a centre electrode (24; 124) having a front end with a firing tip;
a tubular insulator member (20; 120) having a front end (26; 126)) and an axial bore (22; 122) accommodating said centre electrode, said electrode firing tip protruding beyond said insulator front end;

a counter electrode (16; 116) comprising a shell portion (12; 112) receiving said tubular insulator member (20; 120);

characterized in that said tubular insulator member (20; 120) comprises a core (30; 130) made from a dielectric material exhibiting a first dielectric constant and a peripheral layer (32; 132) in a material exhibiting a greater dielectric constant that faces said shell portion (12; 112) of said counter electrode.

2. The spark plug according to claim 1, wherein said insulator member (20; 120) extends axially over at least overlapping lengths of said central electrode (24; 124) and shell (12; 112).

3. The spark plug according to claim 1 or 2, wherein said insulator (20) comprises an inner dielectric layer (36) such that said insulator core (20) is sandwiched between said inner dielectric layer (36) and outer peripheral layer (32), said inner dielectric (36) layer having a greater dielectric constant than said core (30).

4. The spark plug according to any one of the preceding claims, wherein said centre electrode (24) comprises a rod-shaped element.

5. The spark plug according to claim 4, wherein a metal deposit covers the axial bore surface (22) of said insulator member (20).

6. The spark plug according to claim 1 or 2, wherein said centre electrode comprises:

a hollow shaft portion (125) in said insulator member (20) formed as a metallic layer on the inner, axial bore (22) surface of said insulator member; and

a firing tip member (128) in electrical contact with said hollow shaft portion (125).

7. The spark plug according to claim 6, wherein said

hollow shaft portion (125) has a wall thickness in the range of 5 to 500 μm .

8. The spark plug according to claim 6 or 7, wherein said axial bore (122) of said insulator member (120) with said hollow shaft portion (125) has a remaining diameter between 0.1 and 3 mm.

9. The spark plug according to claim 6, 7 or 8, wherein said hollow shaft portion (125) consists of a metal selected from the group consisting of: Cr, Ni, Co and Al, and alloys of one or more of said metals.

10. The spark plug according to any one of the preceding claims, wherein the ratio of the peripheral layer (32; 132) dielectric constant to the insulator core (30; 130) dielectric constant is at least 2.

11. The spark plug according to the preceding claim, wherein said insulator core (30; 130) has a dielectric constant between 3 and 12, preferably about 10, at frequencies between 1 MHz and 42 MHz.

12. The spark plug according to any one of the preceding claims, comprising an assembly air gap (34; 134) between said counter electrode (16; 116) and said insulator member (20; 120).

13. The spark plug according to any one of the preceding claims, wherein said counter electrode (16) comprises a counter electrode element (14) bonded to said shell portion (12) and cooperating with said firing tip (28) to define a discharge gap.

14. An internal combustion engine comprising a cylinder head having mounted therein, for each cylinder, a spark plug according to any one of the preceding claims, wherein each spark plug is connected to a high frequency ignition system of said engine, the counter electrode of said spark plug being linked to ground.

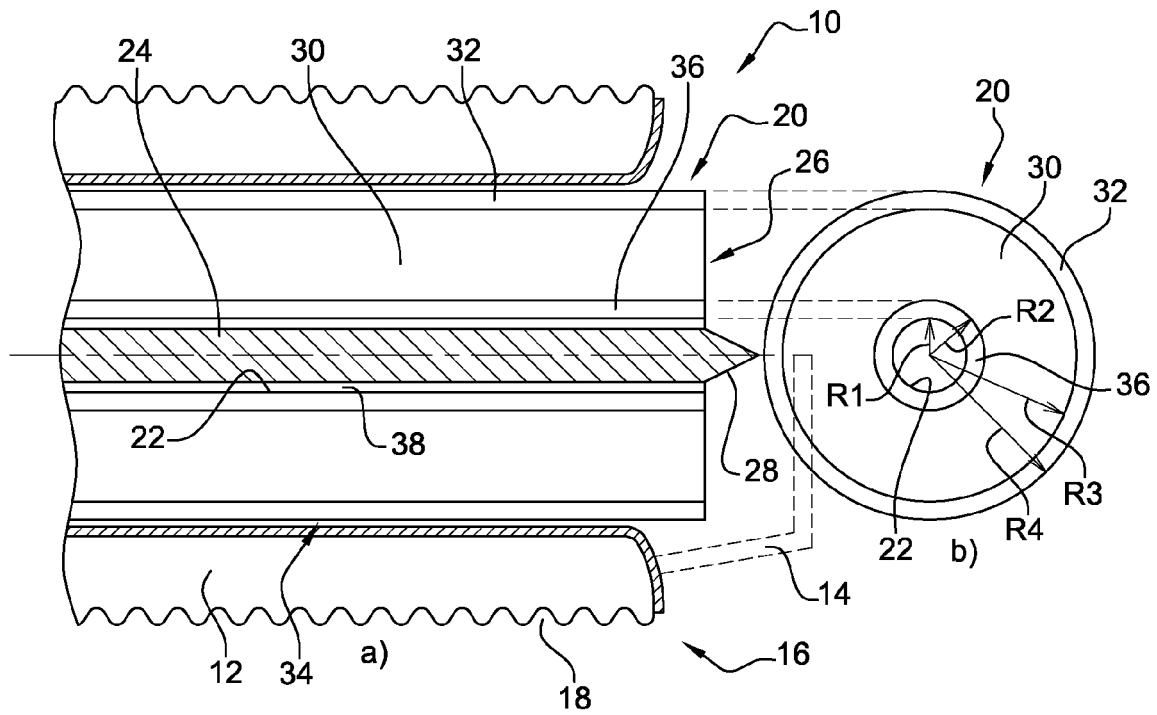


Fig. 1

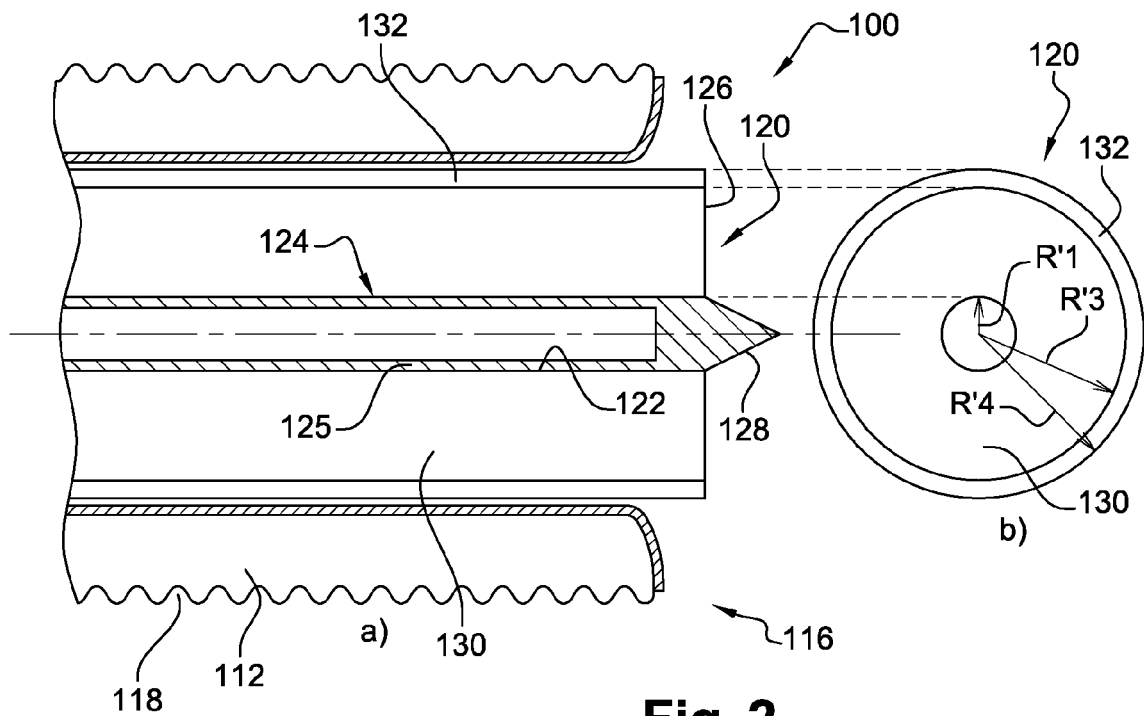


Fig. 2



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Application Number
EP 11 18 5285

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EUROPEAN SEARCH REPORT

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