May 2, 1967 KIYOSHI INOUE 3,317,773

SPARK PLUG HAVING AN ELECTRODE INCORPORATING AN ELECTRONEGATIVE MATERIAL

Filed May 17, 1963

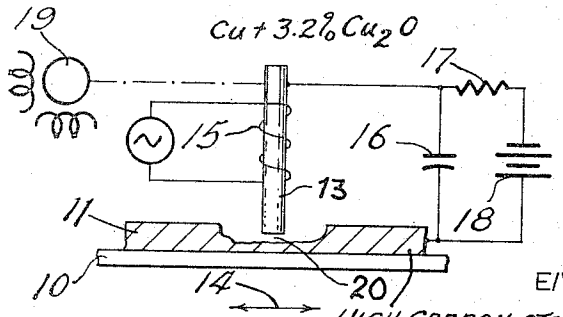


Fig. 1

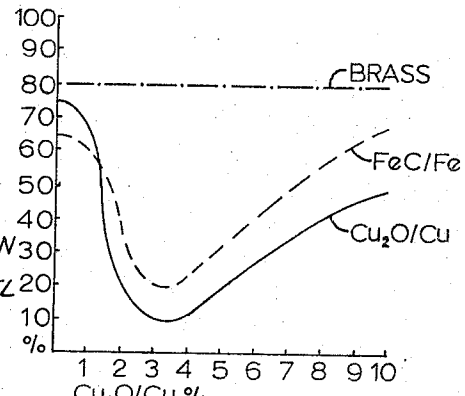


Fig. 6

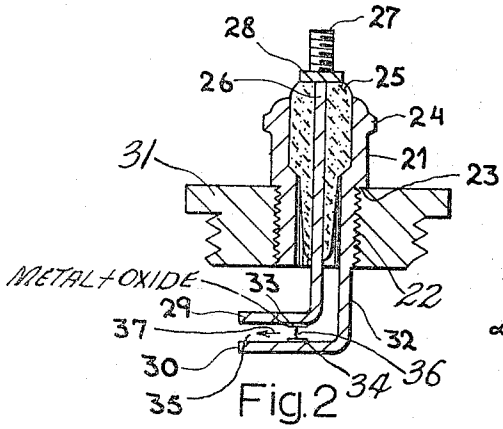


Fig. 2

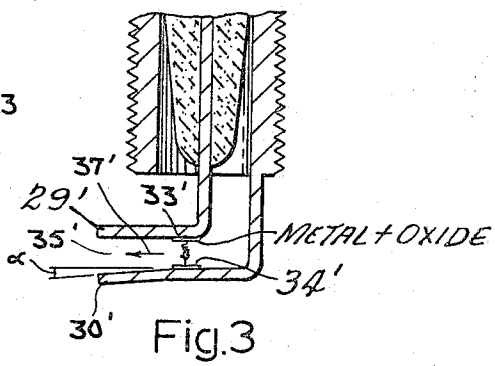


Fig. 3

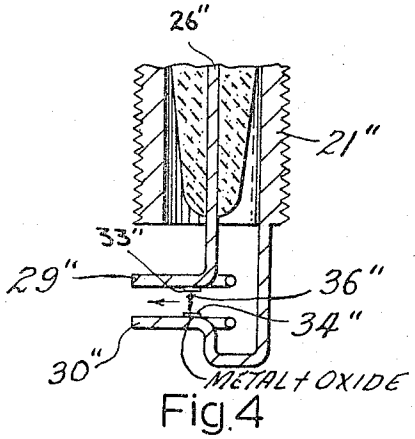


Fig. 4

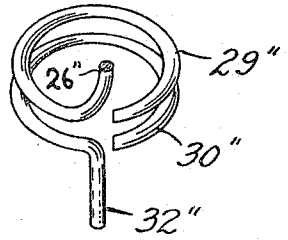


Fig. 5

KIYOSHI INOUE
INVENTOR.

BY

Karl F. Ross
AGENT

United States Patent Office

3,317,773

Patented May 2, 1967

3,317,773

SPARK PLUG HAVING AN ELECTRODE INCORPORATING AN ELECTRONEGATIVE MATERIAL

Kiyoshi Inoue, 182 3-chome, Tamagawayoga-machi, Setagaya-ku, Tokyo-to, Japan

Filed May 17, 1963, Ser. No. 281,365

Claims priority, application Japan, June 11, 1962, 37/23,327; Oct. 19, 1962, 37/46,309; Nov. 30, 1962, 37/52,671; Jan. 25, 1963, 38/3,499; Feb. 15, 1963, 38/7,924

4 Claims. (Cl. 313—141)

My present invention relates to electrical-discharge electrodes and apparatus incorporating such electrodes as well as to methods of making improved electrode materials.

Spark-discharge electrodes of many types have been proposed hitherto and differ with the various applications of the electrode materials. It has been proposed, for example, to provide switch contacts, distributor points for internal-combustion engines and like bodies, adapted to form an electric-arc discharge, of tungsten or a like metal to limit erosion of the bodies. These considerations also enter into the design of electrode systems wherein spark (i.e. intermittent) or arc (i.e. continuous) discharges are not only to be expected but also desirable. Thus, for example, sparkplugs for internal-combustion engines are provided with juxtaposed electrodes composed of materials having a high thermal resistance or "refractory" character and designed for negligible erosion by the spark discharge. In newly developed methods of electric-discharge machining (as, for example, described in my Patent No. 3,054,931), wherein the impulsive nature of spark discharge is employed to erode and shape metal bodies, the composition of the electrode is of particular significance since certain electrode materials are subject to undue wear, thereby increasing the cost of such machining techniques. It is clear that improved contact materials, spark and arc electrodes, and even electrochemical machining electrodes must have in common the ability to withstand erosion under the high temperatures and impulsive pressures deriving from the discharge.

It is an object of the present invention to provide an improved electrode material of this character.

Another object of the invention is to provide an electrode system wherein high spark temperatures and impulsive pressures can be maintained for a large number of successive discharges without undue wear of the electrode.

A further object of this invention is to provide a unique and inexpensive method of producing such electrode materials.

Yet another object of the invention is to provide improved devices incorporating discharge electrodes of the general type mentioned above.

These and other objects, which will become apparent hereinafter, are attained, in accordance with the present invention, by forming an electrode system including at least one substance having a highly electronegative character as compared with the conductive materials constituting the electrode and capable of generating negative ions in the region of the spark discharge. This invention derives, at least in part, from the discovery that erosion of the electrode material in the presence of a spark or arc discharge, whether intentional or accidental, in large measure is a consequence of the formation of ions from the material constituting the electrodes by the discharge. The cathodic electrode is attacked by the positive ions formed in the impulsive discharge and becomes pitted as a result. I have found that the detrimental effects of these positive ions can be attenuated, if not entirely eliminated, by providing at least the cathodic electrode, but preferably both electrodes, with a highly electrogenative substance which is relatively easily ionized and nullifies the effect of the positive ions by neutralization thereof to some degree. In this connection it may be noted that exhaustive experiments have indicated that the substance should be atoms of elements selected from Groups 4, 5, 6 and 7 of the Periodic Table, with best results being obtained with those of Groups 6 and 7. The negative ions may, according to one aspect of the present invention, derive from a gas containing molecules of, say, oxygen, chlorine and bromine or binary compounds of these elements and/or carbon, sulphur, fluorine and iodine disposed in the region of the gap, although significantly better results are obtained with these substances in a solid state whereby they can be released upon discharge.

Thus, according to a more important aspect of the invention, the electrogenative substance is incorporated directly within the electrode and uniformly distributed at least throughout the surface regions thereof. In this case, the electronegative substance may be a metal carbide, oxide, sulphide or halide, sintered into the electrode body or forming a solid solution with the base metal. To this end the metal to which the electronegative substance is chemically bound may be the same metal as that forming the base metal of the electrode body. Although several electronegative substances and compounds have been found to be effective in this connection, significant results were obtained with the oxides of copper, tin, manganese, aluminum, chromium and tungsten; the carbides of iron and molybdenum; and the sulphides of copper and iron. One can make the generalization, however, that alkali and alkaline-earth metals likewise form compounds which release electrogenative substances in this manner.

Experiments with many binary and ternary compounds containing electronegative substances from Groups 4 through 7 of the Mendelejeff Periodic Table and especially the elements thereof in the second and third periods have indicated that all of the halide salts of cuprous and cupric copper are suitable for the release of electronegative ions as well as the oxides and sulphides of this metal. While best results are, as mentioned above, obtained with these copper compounds, it must be pointed out that the following compounds of other metals are also suitable to a greater or lesser extent: magnesium oxide, carbonate, fluoride, chloride, bromide and iodide; silver, cadmium, zinc, lead and iron oxides, fluorides, chlorides, bromides and sulphides; antimony, aluminum, cobalt, titanium platinum and calcium oxides, chlorides, bromides, fluorides and iodides; tin, molybdenum and chromium chlorides, oxides, bromides and fluorides; gold oxide, chloride, bromide and iodide; manganese oxide and bromide; nickel oxide and iodide; bismuth oxide, chloride and iodide; and cesium oxide.

According to a more specific feature of the present invention, the electrode material is a solid solution of a compound containing one or more of the aforementioned electronegative materials in the base metal and constitutes at least part of the electrodes of a sparkplug serving for an internal-combustion engine. It has been discovered that a sparkplug incorporating such a substance and, desirably, containing from about 0.5% to 10% by weight copper oxide in solid solution can increase considerably the effective power of the engine when operation thereof is compared with that of an engine having similarly shaped sparkplugs with conventional electrode material and with all other conditions being more or less alike. The power gain has been found to be of the order of 10 to 15%. While the precise reason for such a power increase has not been determined, it is believed that, at least to some extent, the ionized elec-

tronegative constituents of the electrode act as catalysts or reaction promoters insuring more complete combustion of the fuel.

It is well known that one of the problems of conventional internal-combustion engines is that the completeness of combustion, even in the presence of excess of oxygen, is unsatisfactory, with a significant proportion of carbon monoxide being released into the atmosphere in the exhaust fumes. The present electrode material, when incorporated in a sparkplug, has been found to significantly decrease the proportion of incompletely burnt constituents in the exhaust. It is thus presumed that the negative oxygen ions produced by the discharge promote completeness of combustion. It is also possible, however, that the complete combustion of fuel with oxygen derives, at least in part, from a free-radical-type chain reaction initiated by high-energy oxygen atoms or radicals deriving from the electrode material.

According to yet another aspect of the instant invention, the power output of a conventional internal-combustion engine can be increased still further by appropriately designing the sparkplug. Investigations as to flame propagation within the internal-combustion-engine cylinder at the time of firing have indicated that significantly improved results can be obtained by producing a so-called "fat" spark whose duration and/or intensity is increased over the discharges of earlier sparkplugs. I have discovered that similarly improved results can be obtained by arranging the electrodes of a sparkplug so that the spark can bridge elongated generally parallel surfaces. By disposing the surfaces so that they diverge slightly away from their position of closest approach, it is possible to cause the spark to travel generally radially outwardly, thereby increasing the spark duration after decay of the energization pulse from the spark coil virtually only by self-induction. Even if the surfaces do not diverge, there is a noticeable tendency for the spark discharge to sweep therealong and physically clear the spark gap from soot particles which otherwise tend to accumulate on the electrodes. The surfaces forming a spark gap can, for compactness and to increase the inductive effect, be somewhat arcuate and may, according to a more specific feature of the invention, be more or less circular in planes perpendicular to the sparkplug axis.

The term "electrode" as used herein should be considered to include contact materials forming mutually engaging switch members (e.g., in toggle switches, knife switches and rotary switches) as well as nonengaging members of the type often employed in vehicular distributors in addition to the electrode materials described above.

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description and examples, reference being made to the appended drawing in which:

FIG. 1 is a diagrammatic elevational view, partly in section, showing an electric-discharge machining apparatus incorporating an electrode according to the present invention;

FIGS. 2–4 are axial cross-sectional views through different sparkplugs according to the invention;

FIG. 5 is a perspective view of the electrode arrangement of FIG. 4, drawn to a larger scale; and

FIG. 6 is a graph showing a comparison between the present electrode material and earlier compositions employed for electric-discharge machining.

The apparatus shown in FIG. 1 is of the type illustrated in the above-mentioned patent and comprises basically a support **10** for a conductive workpiece **11**, with which is juxtaposed a vertically reciprocal electrode **13**. By the usual cross and longitudinal slides the table **10** can be displaced in the direction of arrow **14** to position the workpiece below the shaping electrode **13**. This electrode can be oscillated by a high-frequency alternating current

applied to the solenoid coil **15** substantially in step with the intermittent spark discharge across the spark gap **20**. The impulsive discharge is effected by a capacitor **16** charged through a resistor **17** by a direct-current source **18**. A servomotor **19**, responsive to an increase or decrease in the width of the gap **20**, can be provided to correct the position of the electrode **13** in the usual manner.

Example I

The electrode **13**, according to the present invention, is composed essentially of copper with 3.2% by weight of Cu_2O dissolved therein to form a solid solution. The electrode and the workpiece **11**, constituting the counter-electrode, are immersed in a dielectric liquid (kerosene) and a spark discharge with a pulse duration of 0.7 microsecond is carried out with a frequency of repetition of 22 kilocycles per second and with a discharge energy capable of eroding 1.48 grams of workpiece material per minute. The workpiece is composed of high-carbon steel. A total of 10 liters of the dielectric liquid is employed. A temperature rise of the liquid of about 10° C. and of the electrode **13** of about 20° C. is noted. By way of contrast, a conventional brass electrode of similar construction but not containing the oxygen-ion-releasing substance (Cu_2O) can be operated with a repetition frequency only of 10 kc./sec. with half the spark intensity and is capable of eroding only 0.6 gram of workpiece material per minute. After an identical operating time (15 min.), the temperature of the dielectric liquid surrounding the brass electrode rose 12° C. while the electrode temperature increased 22° C., thereby indicating a substantial loss of power as unusable heat generated in the course of discharge. The copper/copper-oxide electrode of the present invention was capable of sustaining discharge-repetition frequencies of up to 3 megacycles per second and thus was suitable for relatively fine machining operation while the brass electrode failed to sustain discharges much above 10 kc./sec. without undue deterioration of the electrode. In addition, the copper/copper-oxide electrode evidenced 40% less wear than the brass electrode and was capable of operating at 200% faster rates under the usual operating conditions. The improved electrode had many of the characteristics of many-times-more-expensive silver-containing electrodes which have not found widespread application as a consequence of their high costs.

It is believed that the rapid deterioration of the aforementioned conventional brass electrodes derives, in major part, from positive-ion bombardment of the electrode **13**. Negative oxygen ions released by the copper/copper-oxide electrode of the present invention are thought to reduce or nullify this bombardment by neutralization of the positive ions.

Referring now to FIG. 6, wherein the relative electrode wear (E) of a copper/copper-oxide electrode and workpiece wear (W) of a high-carbon-steel workpiece in percent are plotted against Cu_2O content of the electrode (solid line), it may be seen that of minimum of electrode wear is reached at about 3.2% by weight Cu_2O in solid solution in the copper base metal. At this minimum the ratio E/W is about 10%. In all cases where the Cu_2O content is below about 10%, the electrode wear of the copper/copper-oxide electrode is well below that of brass (dot-dash line).

Example II

The copper/copper-oxide electrode of Example I is replaced by an iron/iron-carbide electrode wherein about 3.5% carbon in the form of the carbide is in solid solution within the iron base metal. Again, a reduction in the electrode wear (dash line in FIG. 6), when compared with brass, is observed. The iron/iron-carbide electrode is, however, somewhat less suitable than the copper/copper-oxide electrode as can be seen from this graph.

Example III

A pair of contact members for a knife switch of a conventional type and across which a cut-off spark with an intensity of 0.5 joule developed upon open-circuiting was prepared by dissolving about 8% by weight of Cu_2O in copper. The copper/copper-oxide contacts had an operable life more than 300% greater than conventional copper contacts under identical conditions. The effective range of copper-oxide content in the improved composition was found to be between 1 and 8% by weight. Lesser and greater amounts of copper oxide were shown to decrease the operable life.

Example IV

A set of distributor contacts or "points" for an automotive vehicle were prepared from a solid solution of tungsten oxide in tungsten (2% by weight tungsten oxide) and compared with distributor points commercially available in an automotive engine under actual motor-vehicle operating conditions. The conventional points required replacement five times before any deterioration of the tungsten/tungsten-oxide contacts was observed. The improved contacts were found to be free from surface scale during their operating life.

Example V

Another set of distributor contacts were prepared from a solid solution of copper oxide in a copper/tungsten alloy whose total tungsten content was about one-tenth that of the points of Example IV. The contact material consisted of 5.5% by weight Cu_2O, 10% by weight tungsten and 84.5% copper. The test was similar to that of Example IV with, however, the improved points and conventional contacts being incorporated in a common vehicle distributor. After the conventional points had been replaced several times as a consequence of erosion by spark discharge, the improved points were removed and subjected to microscopic examination. No pitting of the copper/copper-oxide/tungsten contacts was observed.

Example VI

A pair of mutually engageable contacts for a rotary switch were produced by spark-sintering a mixture consisting of 2% by weight tungsten-oxide particles and 98% by weight copper particles in the manner described and claimed in my copending application Ser. No. 247,387, filed Dec. 26, 1962. The particles had a size of several microns. The resulting contacts were capable of withstanding the pitting effect of open-circuiting discharges of about 0.5 joule three times longer than copper contacts in similar applications and about twice as long as tungsten contacts.

Example VII

A contact material having an effective life about twice that of a copper contact under similar operating conditions was produced by dissolving about 4% by weight of calcium oxide in molten copper. Between 2 and 10% by weight of calcium oxide was found to increase contact life while reducing pitting, although addition of the oxide-containing substance was seen to reduce the utility of the electrode in concentrations above this range by mechanically weakening it and increasing its electrical resistance.

Example VIII

A contact material consisting essentially of a base metal in solid solution with a metal compound of an electronegative element is formed by dissolving a binary compound of elements from Groups 4–7 of the Periodic Table in the base metal. About 5% by weight of sulphur hexafluoride (SF_6) is dissolved in molten copper and yields stoichiometric equivalents of copper sulphide and copper fluoride in solid solution in the copper base metal. Contacts composed of the copper/copper-sulphide/copper-fluoride solid solution formed in this manner were compared with copper contacts under similar switching conditions and found to have significantly less pitting. Between 1 and 15% by weight SF_6 was indicated to yield satisfactory results.

In FIG. 2 I show a sparkplug for an internal-combustion engine which comprises a shell **21** of conductive material whose threads **22** permit it to be seated in a cylinder block or cylinder head in the conventional manner. A shoulder **23** on this shell is adapted to bear against a sealing ring while a prismatic head **24** is engageable by a wrench or the like for tightening the sparkplug. Shell **21** surrounds an insulating body **25** of ceramic (e.g. porcelain) material through which passes a central member **26** whose threaded extremity **27** is designed to receive an electrical connector coupling this sparkplug with the distributor. A washer **28** serves as an abutment for the contact nut not shown. The central member **26** has its electrode extremity **29** bent at right angles to the axis of the sparkplug body and substantially parallel to but spaced from a counterelectrode **30** lying in a plane perpendicular to the sparkplug axis and axially spaced from electrode **29**. Since electrodes **29** and **30** extend radially beyond the periphery of shell **21**, the latter may be received within a bushing **31** which, in turn, is received in a wall of the engine block. The electrode **30** is integral with or welded to the conductive shell **21** making electrical contact with the cylinder block. This electrode **30** has a shank portion **32** extending parallel to the central member **26**. In the region of the axis of the sparkplug, each of the electrodes **29** and **30** is provided with a respective layer **33, 34** of my improved material as will be more readily apparent hereafter. The layer of electrode material can be spark-sintered to the respective electrode by the technique described in the aforementioned copending application. The layers or blocks **33, 34** are disposed on opposite sides of the spark gap **35** which extends generally radially.

When a spark discharge is initiated by a pulse from the induction coil, a spark **36** develops at the improved electrode material which is disposed at the location of closest approach of the two electrodes as will be apparent from FIG. 2. It has been found that the spark then travels radially along the electrodes **29, 30**, as indicated by arrow **37**, to sweep the spark gap and the electrodes clear of any accumulation of soot, scale or grime. Surprisingly, it was observed that the spark continues to travel in this manner even after the pulse from the induction coil has been terminated. This effect is believed due to a self-induction by means of which current continues to bridge the gap in form of a spark. As previously noted, the result is a spark of longer duration than those of conventional sparkplugs, with consequent improvements in flame propagation and fuel utilization within the cylinder.

The sparkplug of FIG. 3 is generally similar to that of FIG. 2, with the exception that the electrodes **29′, 30′**, together defining the spark gap **35′**, diverge radially outwardly in an axial plane of the sparkplug by an angle α of approximately 4° so as to produce a Jacob's-ladder effect, whereby the "fattness" of the spark increases as it sweeps outwardly in the direction of arrow **37′**. Again blocks **33′** and **34′** of my improved electrode material are juxtaposed across the spark gap upon the respective electrodes **29′, 30′**. According to another feature of the invention, such deposits of electrode material are avoided and the electrodes **29′** and **30′** are composed of a copper/copper-oxide material as described hereinafter. Since the electrodes **29′, 30′** diverge outwardly, they will have a common location of closest approach in the central region of the sparkplug at which spark discharge is initiated.

In the modification of FIGS. 4 and 5 the electrode extremities **29″** and **30″**, respectively integral with the central member **26″** and the shell **21**, are arcuately bent in respective axially spaced planes perpendicular to the axis of the sparkplug. As indicated in FIG. 5, the electrode

members 29", 30" can be of circular configuration in their respective planes while their shank portions 26", 32" lie along the axis of the sparkplug. In the central region thereof, each of the electrodes is provided with a respective layer 33", 34" of the improved electrode material and forms a position of closest approach at which the spark 36" is developed. The spark tends to travel arcuately along the electrodes to sweep them clear of foreign matter. In this connection it may be noted that the arcuate configuration of the electrodes increases the self-induction effect mentioned above so that the spark duration of the sparkplug of FIGS. 4 and 5 is greater than that of the plug of FIG. 2. It is evident that the spark-promoting layers 33" and 34" may be dispensed with and the electrodes 29", 30" composed entirely, or at least in their region of closest approach, of the improved material. In this case it is desirable to arrange the electrodes 29", 30" so that they diverge slightly away from this region of closest approach.

Example IX

A sparkplug having the configuration shown in FIG. 4 and provided with layers 33", 34" composed of a solid solution of 5.5% by weight copper oxide in 94.5% by weight copper was inserted into a single cylinder of a four-cycle internal-combustion engine of the air-cooled type whose displacement was 125 cc. The average spark gap was 0.3 mm. and the sparkplug was energized by an induction coil having an output pulse of 700 volts. Between 10 and 15% more power (16 h.p.) was obtained from the engine employing this sparkplug than could be derived from the identical engine utilizing a conventional sparkplug. Moreover, the conventional sparkplug required an induction coil having an output of 1300 volts and yielded a spark whose duration was 400 μsec. The spark of the improved electrode, by contrast, had a duration of 500 μsec. Analysis of the exhaust gases indicated that the combustion utilizing the improved electrode was 3% more complete than combustion with the conventional sparkplug. The electrode material was found to be free from scaling even after several hours of operation.

Example X

The tests described in Example IX were carried out with tin oxide, zinc oxide, iron sulphide, ferric and ferrous oxide, iron carbide, managanese dioxide, chromium oxide, aluminum oxide and molybdenum carbide. In all cases the proportions were the same as those given in Example IX. The results of these tests demonstrated that improved electrode materials were obtained by all of the above compounds, with copper oxide proving to be the best adjuvant and aluminum oxide next best. Iron carbide and iron oxide were both found to have slightly less effect while molybdenum carbide, iron sulphide, zinc oxide, tin oxide and chromium oxide had still less ability to reduce pitting. Manganese dioxide was the worst in this connection of the compounds tested. Between 1 and 8% of the electronegative material was required for satisfactory results.

The invention described and illustrated is believed to admit of many modifications within the ability of persons skilled in the art, all such modifications being considered within the spirit and scope of the appended claims.

I claim:

1. A sparkplug for an internal-combustion engine, comprising a generally cylindrical insulating body and a pair of spaced-apart electrodes mounted upon said body, said electrodes having extremities extending codirectionally generally transversely to the axis of said body to form therebetween an elongated spark gap transverse to said axis, said electrodes including a first electrode extending generally centrally through said body and a second electrode outwardly from said first electrode, said extremities having a region of closest approach in the vicinity of said axis and diverging outwardly therefrom, at least one of said electrodes consisting essentially, at least in said region, of a copper sparking element having between 1 and 10 weight percent cuprous oxide in solid solution therein.

2. A sparkplug for an internal-combustion engine, comprising an insulating body and a pair of spaced-apart electrodes each having an end mounted on said body and connected to a source of voltage for developing a spark discharge across a gap defined by said electrodes at a point of closest approach intermediate the respective ends thereof, said electrodes having generally parallel free ends with increased separation beyond said point to an extent consistent with maintenance of a spark propagating from said gap toward said ends, at least one of said electrodes being provided at said gap with a metallic portion incorporating an electronegative compound capable of decomposition for releasing negative ions of said compound in the region of said gap to limit erosion of an electrode surface under bombardment from positive ions by neutralizing at least some of said positive ions.

3. A sparkplug as defined in claim 2 wherein said free ends are substantially circularly curved in two axially separated planes.

4. A sparkplug as defined in claim 2 wherein said free ends progressively diverge from said point outwardly.

References Cited by the Examiner

UNITED STATES PATENTS

462,540	11/1891	Edison	29—25.17
869,317	10/1907	Marshall	29—25.17
2,022,140	11/1935	Michel	123—169
2,088,945	8/1937	Xardell	123—169
2,298,504	10/1942	Ost	313—138
2,545,438	3/1951	Stumbock	313—141.1 X

FOREIGN PATENTS

19,082	4/1910	Great Britain.

DAVID J. GALVIN, *Primary Examiner.*

GEORGE N. WESTBY, D. E. SRAGOW,
Assistant Examiners.