US 20150362177A1

(19) **United States**

(12) **Patent Application Publication**

KRICHTAFOVITCH et al.

(10) **Pub. No.: US 2015/0362177 A1**

(43) **Pub. Date: Dec. 17, 2015**

(54) **FLAME POSITION CONTROL ELECTRODES**

(71) Applicant: **ClearSign Combustion Corporation**, SEATTLE, WA (US)

(72) Inventors: **IGOR A. KRICHTAFOVITCH**, KIRKLAND, WA (US); **JOSEPH COLANNINO**, BELLEVUE, WA (US)

(21) Appl. No.: **14/736,562**

(22) Filed: **Jun. 11, 2015**

Related U.S. Application Data

(60) Provisional application No. 62/010,931, filed on Jun. 11, 2014.

Publication Classification

(51) **Int. Cl.**
F23C 99/00 (2006.01)

(52) **U.S. Cl.**
CPC *F23C 99/001* (2013.01)

(57) **ABSTRACT**

A method and apparatus for stabilizing a flame in a combustion volume is disclosed. The present method and device may include a burner nozzle configured to support the flame, a halo electrode configured to anchor the flame, and electrodes disposed in top and bottom regions of the flame configured to apply voltage difference above or below the halo electrode that may assist in anchoring of the flame to the halo electrode while also controlling a shape and position of the flame. Effects of different electrical configurations within the combustion volume for stabilizing the flame are also disclosed.

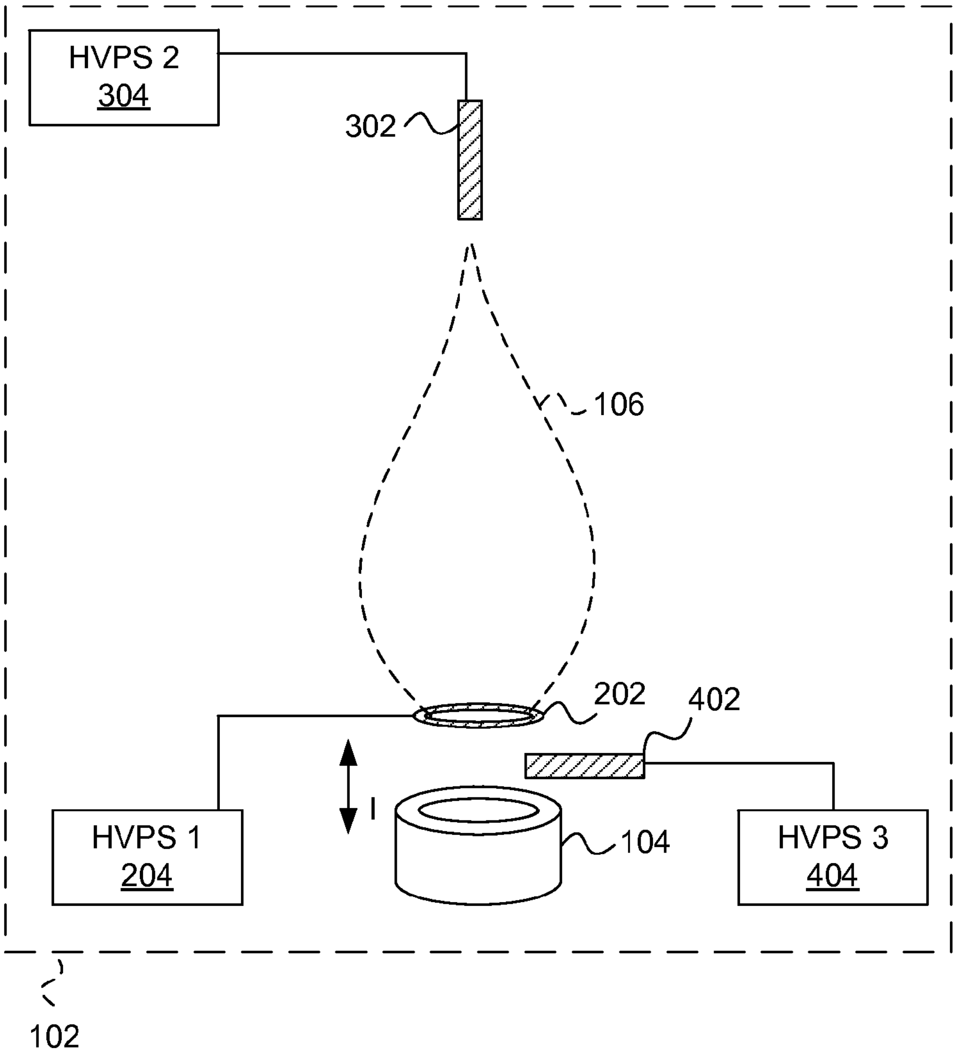


FIG. 1A

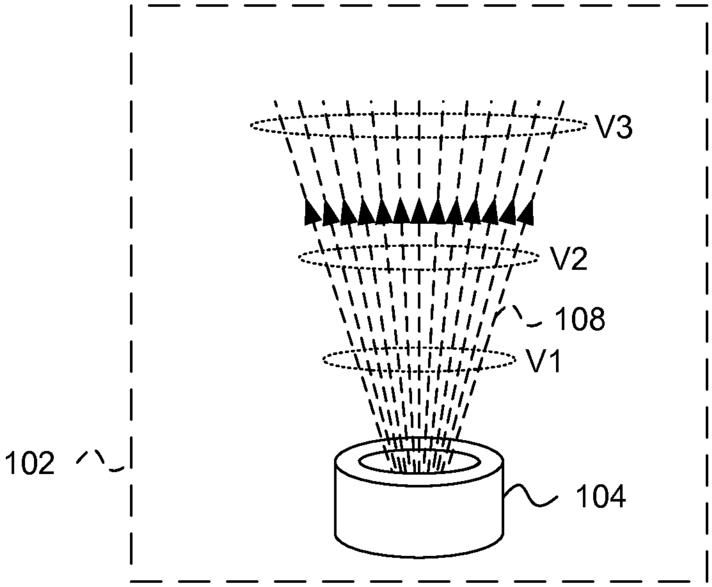


FIG. 1B

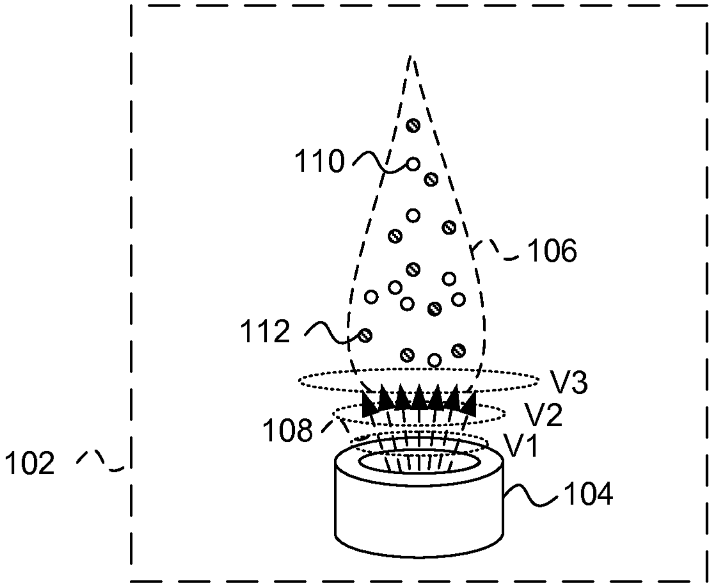


FIG. 2

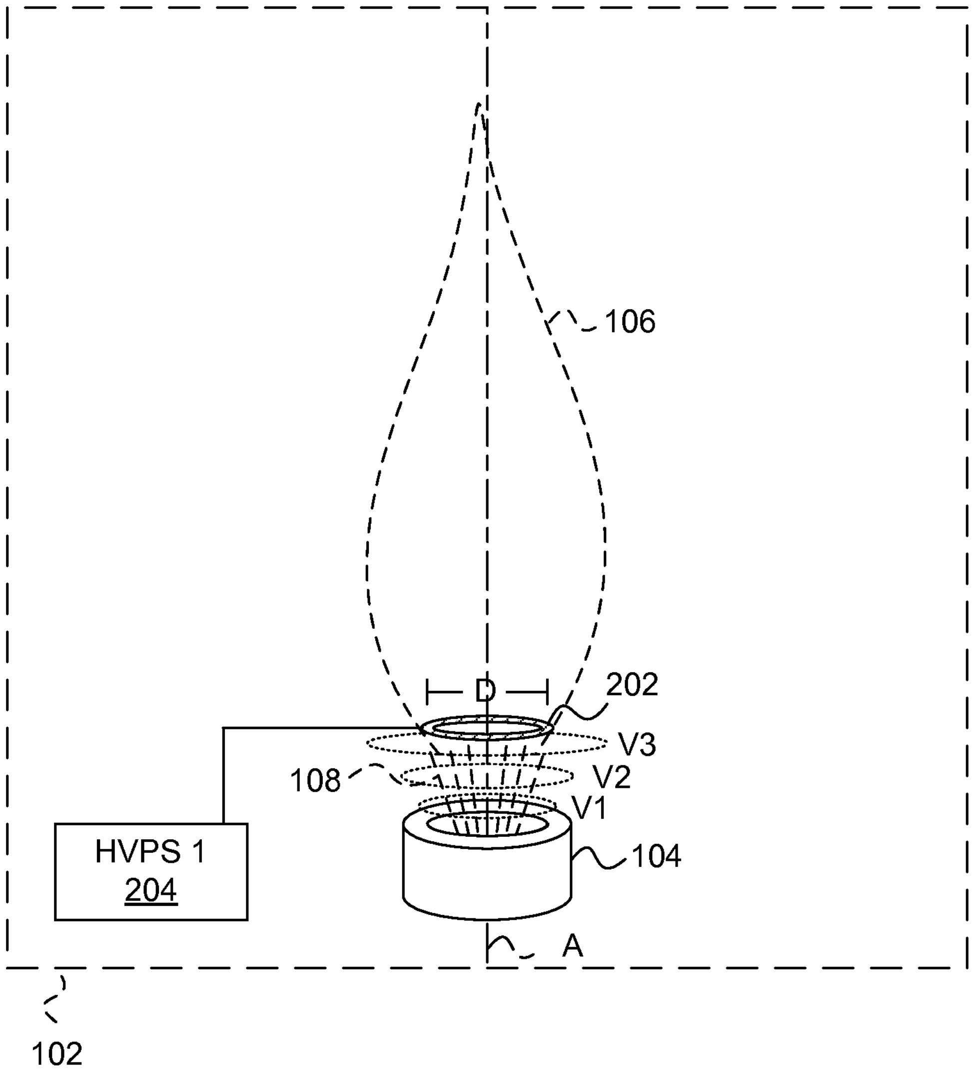


FIG. 3

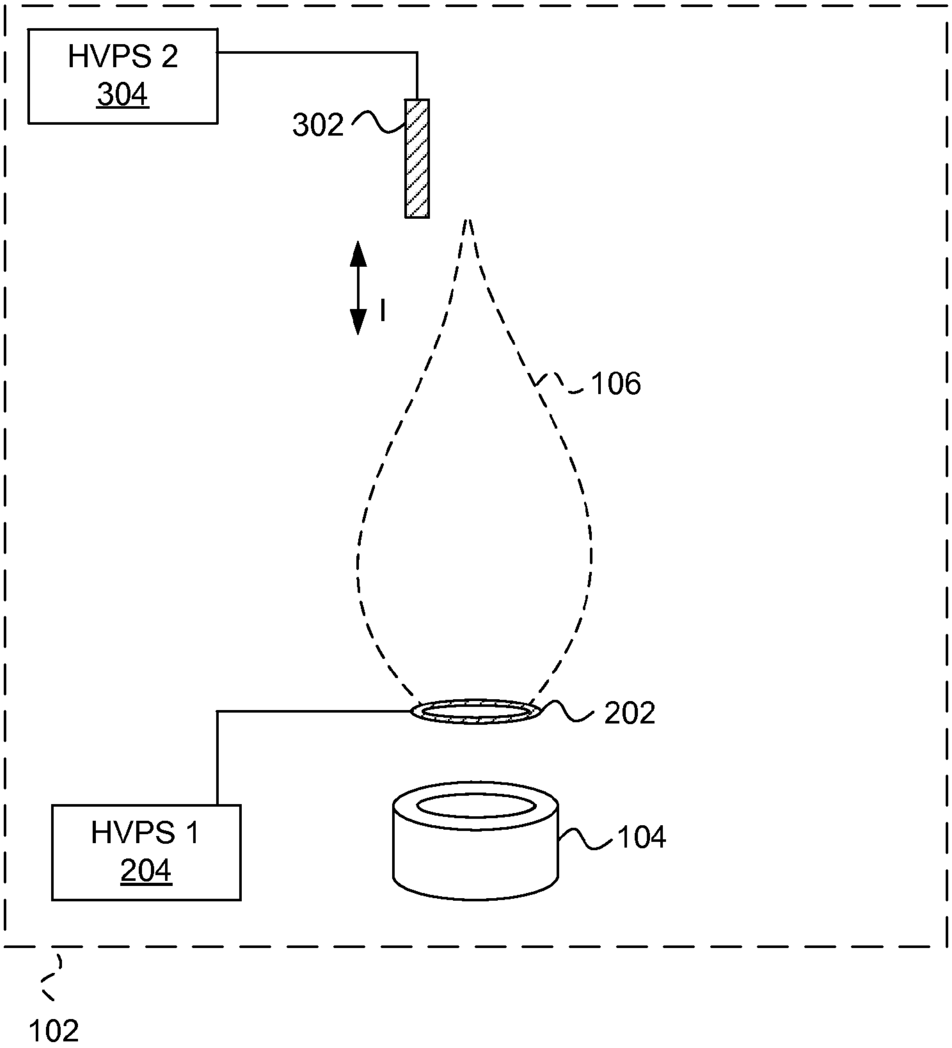


FIG. 4

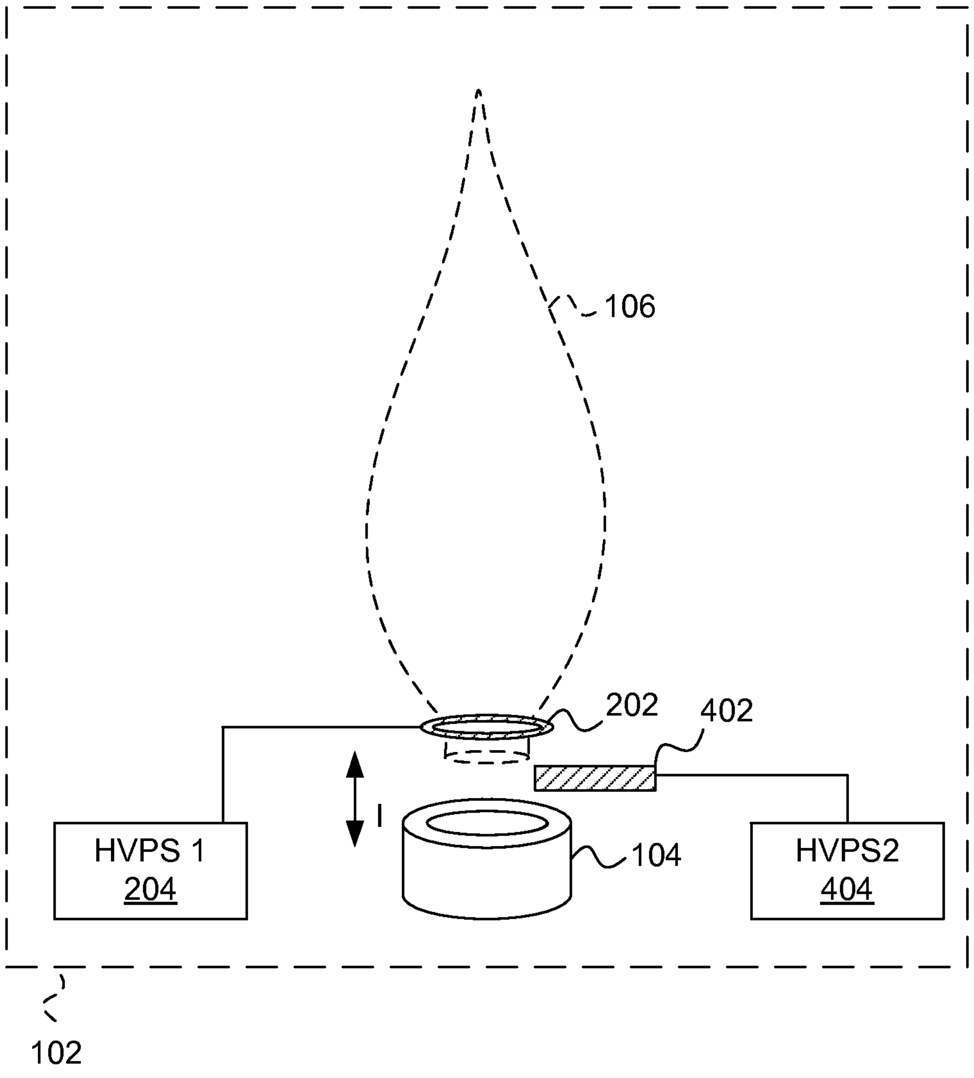


FIG. 5

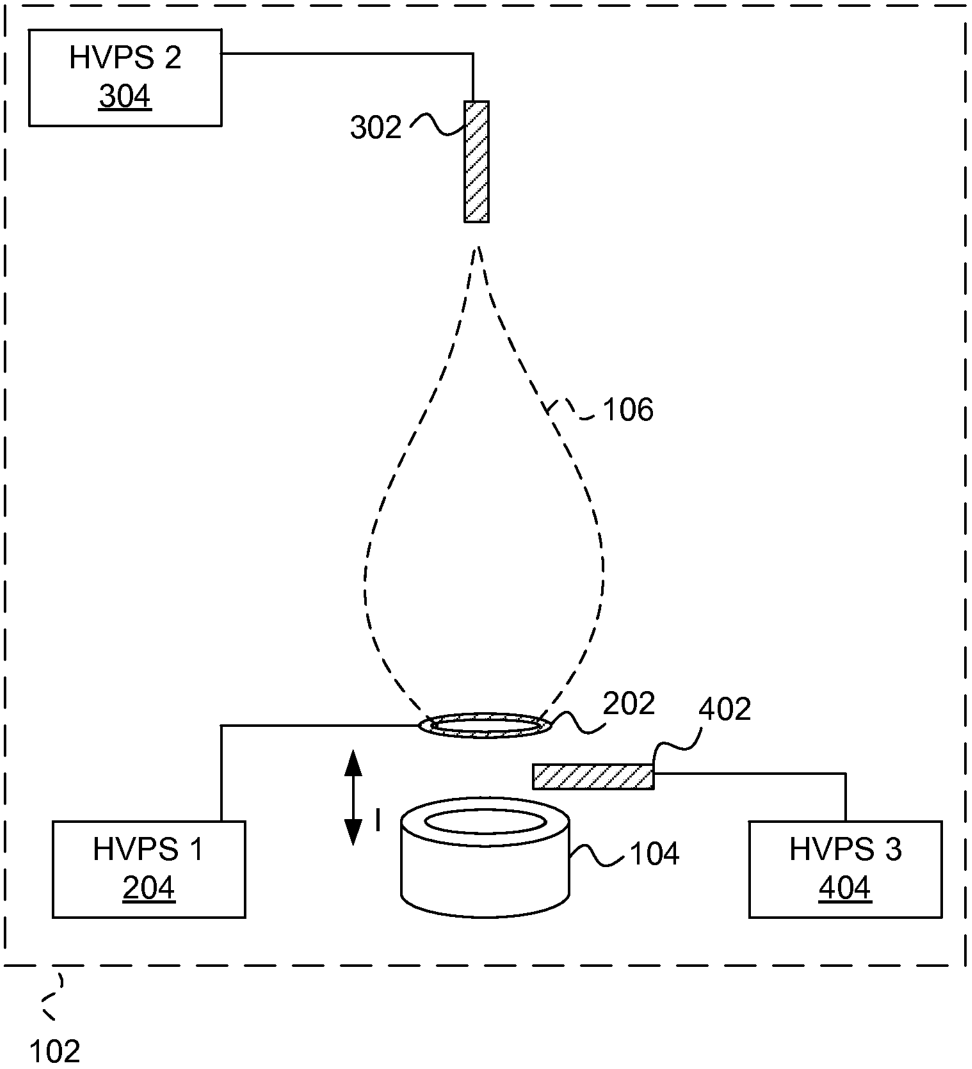


FIG. 6

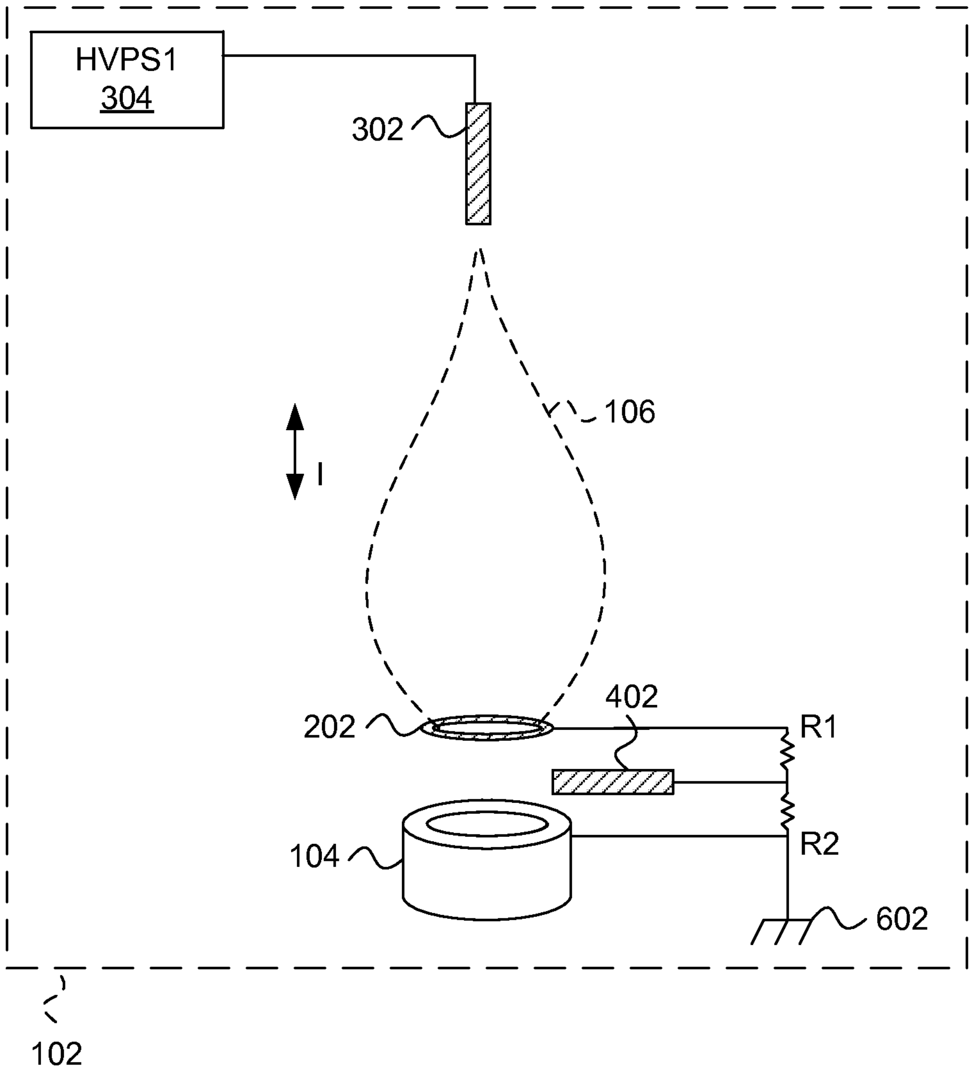
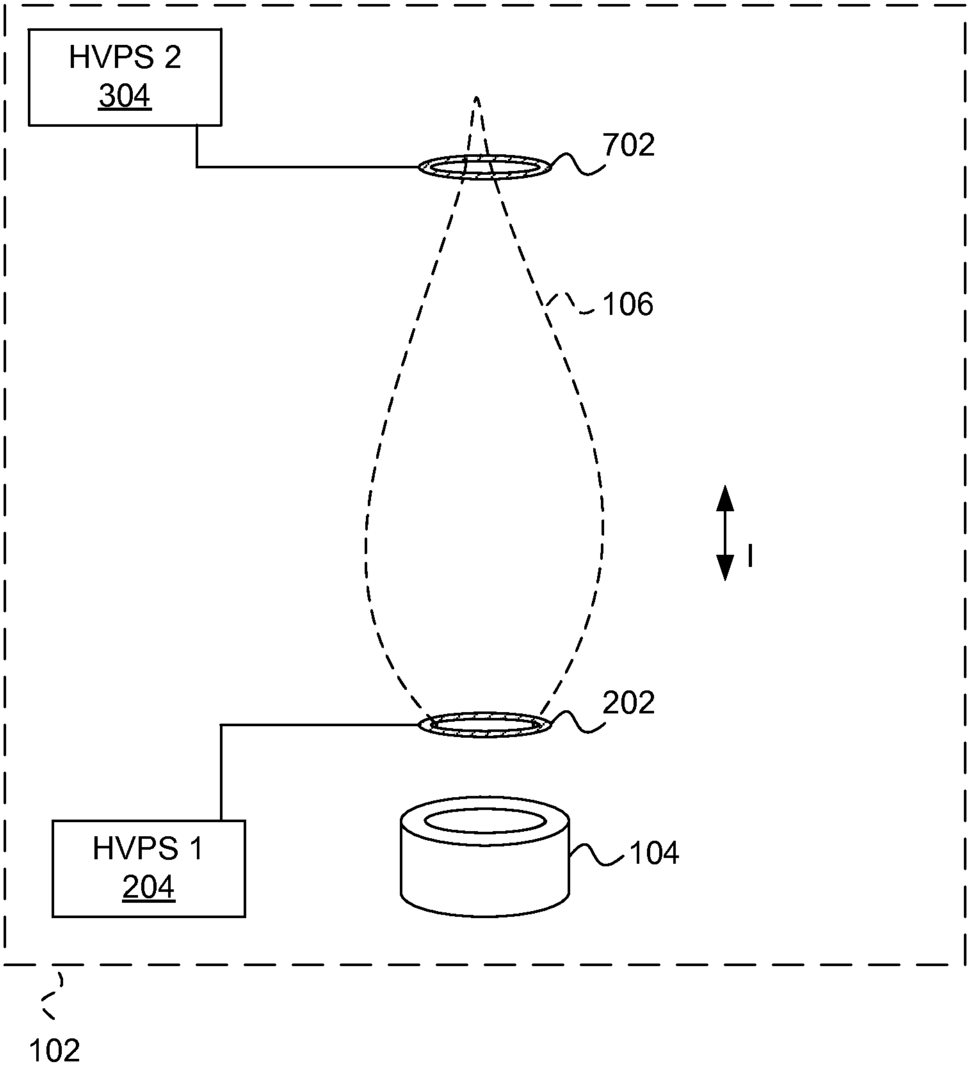


FIG. 7



FLAME POSITION CONTROL ELECTRODES

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority benefit from U.S. Provisional Patent Application No. 62/010,931, entitled "FLAME POSITION CONTROL ELECTRODES", filed Jun. 11, 2014; which, to the extent not inconsistent with the disclosure herein, is incorporated by reference.

BACKGROUND

Technical Field

[0002] The present disclosure relates generally to combustion systems, and more particularly, to electrical configurations for stabilizing a flame position within a combustion volume.

SUMMARY

[0003] Methods and devices for stabilizing a flame provided by combustion of a fuel and an oxidizer within a combustion volume may include a burner nozzle supporting the flame, and one or more electrodes configured to electrically communicate with one or more voltage power sources. The flame may additionally be charged by different methods for allowing interaction with electrical charges that may be applied within the combustion volume for better flame stabilization.

[0004] According to various embodiments, a halo electrode may include an applied voltage potential configured to charge the halo electrode, and include additional applied voltage potentials configured to charge one or more electrodes disposed above or below the charged halo electrode and may be configured to improve flame stability by attaching or anchoring the flame to the halo electrode and thereby maintaining the flame in a suitable shape and position. Different electrical configurations may be employed for the application of the voltage potentials.

[0005] According to an embodiment, a suitable voltage source, such as a DC or an AC low-voltage power source or a DC or an AC high-voltage power source, may apply a voltage potential to the halo electrode to create an electric field that may interact with the flame to attach or anchor the flame to the halo electrode. Additionally, another voltage source may apply a voltage potential to a top electrode disposed above the halo electrode configured to create a voltage difference between the top electrode and the halo electrode. Such an arrangement may create an electric current that may assist in keeping the flame attached or anchored to the halo electrode. Furthermore, sensors located in various parts of the combustion volume may be configured to detect movements in the flame and may be further configured to send signals to switches and controllers for application of voltage potentials to either or both electrodes, respectively, for keeping the flame in a desired position. Other embodiments may further include combinations of one or more electrodes disposed above and/or below the flame configured to provide for better flame stabilization.

[0006] According to another embodiment, the top electrode again may be positioned above the halo electrode and configured to charge the flame. A first resistor may be operatively coupled between the halo electrode and a bottom electrode positioned below the halo electrode and a second resistor may be operatively coupled between the bottom electrode and the burner nozzle, wherein the burner nozzle is itself operatively coupled to a ground potential. When the flame makes contact with the halo electrode, a current may flow across the first resistor and second resistor producing voltage drops proportional to the current being passed through the respective resistors that may allow the flame to better attach or anchor to the halo electrode. The halo electrode and resistor may also be combined by coating the halo electrode with a ceramic or otherwise electrically resistive coating applied to its surface or otherwise at least partially in series with the electrically conductive path.

BRIEF DESCRIPTION OF DRAWINGS

[0007] Various, non-limiting embodiments are disclosed and described by way of example with reference to the accompanying figures. The figures are schematic and are not intended to be drawn to scale. Unless indicated as representing the background art, the figures represent aspects of the disclosure.

[0008] FIGS. **1**A and **1**B are intended to show a velocity distribution of a fuel stream exiting a burner nozzle and passing through a surrounding ambient atmosphere and the respective shape of a flame within a combustion volume, according to an embodiment.

[0009] FIG. **2** shows an application of a first voltage potential to a halo electrode disposed above a burner nozzle, according to an embodiment.

[0010] FIG. **3** depicts an application of a second voltage potential to a second electrode disposed above the halo electrode of FIG. **2**, according to an embodiment.

[0011] FIG. **4** depicts an application of a voltage third potential to a third electrode disposed below the halo electrode of FIG. **2**, according to an embodiment.

[0012] FIG. **5** depicts an application of voltage potentials to a second electrode disposed above and a third electrode disposed below the halo electrode of FIG. **2**, according to an embodiment.

[0013] FIG. **6** shows the application of voltage potentials to the halo electrode and the control of the flame position by connection of resistors below the halo electrode between the halo electrode and a third electrode and between the burner and the third electrode, according to an embodiment.

[0014] FIG. **7** shows application of voltage potentials to the halo electrode and to a second halo electrode disposed in and surrounding the top portion of the flame above the first halo electrode, according to an embodiment.

DETAILED DESCRIPTION

[0015] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise.

[0016] Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the disclosure.

[0017] Problems in combustion systems due to instabilities in flame position and shape may be caused in part by high, subsonic, or even supersonic speeds of fuel being injected into a combustion volume. High fuel injection speeds may result in a non-uniform fuel distribution and an unstable flame within the combustion volume, which may cause problems such as poor combustion, increased emissions of pollutants, flashback, poor heat transfer, reduced component life, and system damage, amongst others.

[0018] Embodiments are disclosed that include methods and devices for the application of voltage potentials proximate to a flame within a combustion volume for improving flame position stabilization. The present disclosure is described in detail with reference to embodiments illustrated in the drawings, which form a part hereof. In the drawings, which are not necessarily to scale or to proportion, similar symbols typically identify similar components, unless context dictates otherwise. Other embodiments may be used and/or other changes may be made without departing from the spirit or scope of the present disclosure. The illustrative embodiments described in the detailed description are not meant to be limiting of the subject matter presented herein.

[0019] As used herein, the following terms may have the following definitions:

[0020] "Halo electrode" refers to a conducting material in a circumferential shape such as a ring, a toroid, or an annulus configured for the application of an electric charge, a voltage potential, and/or an electric field proximate to a flame. The halo electrode may be unbroken (continuously circumferential to the flame with no cut) or may be embodied as one or more sections having an air gap. The halo electrode and a resistance may optionally be combined by means of a ceramic or otherwise electrically resistive coating applied to the halo electrode or otherwise partially or wholly in series with the electrically conductive path.

[0021] "Anchoring" refers to maintaining a flame position relative to a solid surface such as the halo electrode, in such a way that the anchored region of the flame stays proximate to the solid surface.

[0022] FIG. **1**A is a diagram showing a fuel flow velocity V**1**, V**2**, V**3** distribution and flame **106** (shown in FIG. **1**B) within a combustion volume **102**, which may include a burner nozzle **104** configured to support a flame **106** (shown in FIG. **1**B), according to an embodiment. Also shown is the distribution of fuel **108** being injected from the burner nozzle **104** into the combustion volume **102**. Accordingly, the closer the fuel **108** is to the burner nozzle **104**, the higher fuel flow velocity is, thus flow velocity V**1** may be greater than flow velocity V**2** and flow velocity V**2** may be greater than flow velocity V**3** (i.e., V**1**>V**2**>V**3**). The combustion volume **102** may be, for example, part of a boiler, a water tube boiler, a fire tube boiler, a hot water tank, a furnace, an oven, a flue, a cook top, or another system employing the combustion volume **102**. Not shown is a source of an oxidizer supporting combustion of the fuel **108**. The oxidizer may include ambient air into which the fuel stream exits or it may include a separate flow of oxidizer materials, such as oxygen concentrated air, oxygen, ozone, hydrogen peroxide, recycled flue gases, or combinations thereof, injected directly into the fuel flow stream.

[0023] FIG. **1**B shows an idealized behavior of a flame **106** according to the distribution of fuel flow velocities V**1**, V**2**, V**3**. Fuel flow velocities V**1**, V**2**, V**3** may range from subsonic to supersonic, making control of the flame **106** more difficult in the areas closer to the burner nozzle **104**. Accordingly, the flame **106** may be more easily controlled in region V**3** than in region V**2** and more easily controlled in region V**2** than in region V**1**. If no control system is applied in the combustion volume **102**, different factors such as heat requirement variations, weather, and component wear or damage, among others, may affect the shape and stability of flame **106**.

[0024] The flame **106** may include a variety of charged and uncharged particles and molecules. The volume of charged particles may include electrons **110**, positive ions **112**, negative ions, positively and negatively charged particles, such as charged and uncharged fuel vapor, and charged and uncharged combustion products, unburned fuel **108**, and air. The volume of charged particles may be distributed in various locations of combustion volume **102** at different times during the combustion process.

[0025] Because of rapid transient behavior, the flame **106** may need to be controlled at every instant to prevent the flame **106** from contact with objects or components or combustion equipment within the combustion volume **102**, in order to avoid potential damages due to thermal effects. During any of such possible events, power may be removed or applied to electrodes in the combustion volume **102** through one or more switches and/or control circuits attached to the power source, to repel or attract the flame **106**. These electrodes may include different shapes and types and may be arranged in different configurations within the combustion volume **102**.

[0026] A halo electrode along with the application of voltage potentials above or below the halo electrode may improve flame stability by anchoring the flame **106** and keeping the flame **106** in a suitable, stable position.

[0027] FIG. **2** depicts an embodiment configured to provide an application of a voltage potential to a halo electrode **202** within a combustion volume **102**. Accordingly, the halo electrode **202** may be located in different areas above a burner nozzle **104**, such as proximate to V**3**, where fuel flow velocity may be lower and a flame **106** may be more easily controlled, as shown in FIGS. **1**A and **1**B. The halo electrode **202** may exhibit a diameter D ranging from about 1 cm to about 10 cm, depending on intended use, and have a center axis of rotation lying on or about coincident with a longitudinal axis A of the burner nozzle **104**. The halo electrode **202** may be made of different suitable high temperature, corrosion resistant conductive materials, including, for example, silver, copper, gold, tungsten, nickel, iron, platinum, tin, and alloys thereof. The halo electrode **202** may be used for anchoring the flame **106**, improving flame stability. The flame **106** may or may not touch the halo electrode **202**. Additionally, the flame **106** may be charged by different methods, such as connecting a voltage power source to the burner nozzle **104**, or connecting a voltage power source to electrodes in different areas near the flame **106** along the flame length, or to the halo electrode **202**, e.g., a first high-voltage power supply (HVPS**1**) **204**. Charging the flame **106** may allow for a better electrical control of the flame **106**, allowing for modifications of the shape and position of the flame **106**.

[0028] Any suitable voltage source, such as a first DC or an AC low-voltage power source or a first DC or an AC high-voltage power supply such as HVPS**1** **204**, may be configured to apply a voltage potential to the halo electrode **202**, which may create an electric field proximate to the halo electrode **202** that may interact with charged particles included in the flame **106**. For example, if the flame **106** carries a positive charge and the halo electrode **202** carries a negative charge, the electric field may attract positive ions **112** of the flame **106** helping to attach or anchor the flame **106** to the halo electrode **202**.

[0029] The electric field may include one or more DC electric fields, one or more AC electric fields, one or more pulse trains, one or more time-varying waveforms, one or more digitally synthesized waveforms, and/or one or more analog waveforms, or combinations thereof.

[0030] Generally, when describing embodiments employing voltage power sources, sensors may also be included in different parts of the combustion volume **102** and configured for detecting movement in the flame **106** and sending signals to switches and controllers operatively coupled to the high-voltage power sources, which may apply voltages to one or more additional electrodes for attracting or repelling the flame **106** in order to maintain the flame **106** at a suitable, stable shape and position. The different voltage potentials may also charge the flame **106**. For example, sensors may be operatively coupled to the halo electrode **202** and may then send signals to switches and controllers for the first high-voltage power supply HVPS**1** **204** to initiate or change the voltage potentials applied to the halo electrode **202**.

[0031] FIG. **3** shows another embodiment configured to control an application of voltage potentials, through one or more switches and/or control circuits, by first and second high-voltage power supplies HVPS**1** **204** and HVPS**2** **304**, respectively, to a halo electrode **202**, and to a second electrode **302** located above a flame **106**, within a combustion volume **102**.

[0032] According to various embodiments, a first voltage potential may be applied by the first high-voltage power supply HVPS**1** **204** to the halo electrode **202** and a second voltage potential may be applied by the second high-voltage power supply HVPS**2** **304** to the second electrode **302**. For example, this arrangement can be especially advantageous for creating an electrical field along the flame **106** to maintain a suitable flame shape and position. For example, if the halo electrode **202** is at a different (e.g., lower) potential than the second electrode **302** (at a higher potential), then a voltage difference (V_{E2}-V_{E1}) between outputs of the first and second high-voltage power supplies HVPS**1** and HVPS**2** can generate a movement or a flow of charges within the flame **106** between the first and second potentials (e.g. parallel or antiparallel to current, depending on polarity). The arrangement of FIG. **3** may thereby drive an electric current, I, that attracts the flame **106** for more stable anchoring on or near the halo electrode **202**. Other charge combinations, levels, and polarities are possible for attracting or repelling the flame **106**, which may depend on flame position and behavior. In experiments, the inventors found either or both (AC) polarities can cause enhanced flame anchoring. Some experiments implied that supplying a positive polarity on HVPS**2** (relative to HVPS**1**), in an otherwise electrically isolated system, may tend to have a stronger relative anchoring effect than the opposite polarity.

[0033] FIG. **4** depicts an additional embodiment configured to provide an application of voltage potentials below a halo electrode **202** within a combustion volume **102**, in which a second electrode **402** may be charged by a second high-voltage power supply HVPS**2** **404**. Accordingly, different voltage potentials may be applied through one or more switches and/or control circuits by a first high-voltage power supply HVPS**1** **204** to the halo electrode **202**, and by the second high-voltage power supply HVPS**2** **404** to the second electrode **402** to create a voltage difference (V_{E1}-V_{E3}). For example, if the second electrode **402** is at a lower potential than the halo electrode **202**, the voltage difference between the first and second high-voltage power supplies HVPS**1** **204** and HVPS**2** **404**, can, again, generate a charge flow in the flame **106** creating an electric current, I, that may drag down the flame **106** and may assist in keeping the flame **106** anchored at or slightly below the halo electrode **202**. Other charge combinations, levels, and polarities are possible for attracting or repelling the flame **106**, which may depend on flame position and behavior.

[0034] FIG. **5** depicts another embodiment configured to provide an application of respective selected voltage potentials above and below a halo electrode **202** within a combustion volume **102**. The halo electrode **202** may be operatively coupled to a first high-voltage power supply HVPS**1** **204**, a second electrode **302** disposed above the halo electrode **202** may be operatively coupled to a second high-voltage power supply HVPS**2** **304**, and a third electrode **402** disposed below the halo electrode **202** may be operatively coupled to a third high-voltage power supply HVPS**3** **404**. Each power source can be controlled through one or more switches and/or control circuits. Different voltage levels and/or polarities may be applied to the halo electrode **202**, second electrode **302**, and third electrode **402** for suitable flame stabilization, flame modulation, or other desirable effects.

[0035] FIG. **6** depicts another embodiment configured to provide an application of voltage potentials within a combustion volume **102**, in which a second electrode **302**, powered by a first high-voltage power supply HVPS**1** **304** controlled through one or more switches and/or control circuits, may charge a flame **106**. A first resistor (R**1**) may be operatively coupled between the halo electrode **202** and a third electrode **402**, neither of which includes a high-voltage power supply. A second resistor (R**2**) may be operatively coupled between the third electrode **402** and the burner nozzle **104**, wherein the burner nozzle **104** is operatively coupled to a circuit ground **602**. The resistors, R**1** and R**2**, may have different values. When the flame **106** makes contact with the halo electrode **202**, a current, I, may flow across the first and second resistors R**1** and R**2**, producing a voltage drop equal to current times the total resistance (V_A=I(R**1**+R**2**)), establishing a first voltage potential (V_A) at the halo electrode **202**, with respect to the ground potential at the circuit ground **602**. The voltage drop produced across the first and second resistors R**1** and R**2** may allow the flame **106** to be more effectively anchored to the halo electrode **202**.

[0036] A second voltage potential (V_B) at the third electrode **402**—relative to the ground potential—is equal to the voltage drop across the second resistor R**2**, i.e., current times the second resistance (V_B=I·R**2**). In accordance with very well-known principles, the ratio of the second voltage potential V_B at the third electrode **402** to the first voltage potential V_A at the halo electrode is equal to the ratio of the second resistance R**2** to the total resistance

$$\left(V_B = \frac{R2}{R1 + R2} \cdot V_A\right).$$

Thus, for a given first voltage potential V_A at the halo electrode **202**, the value of the second voltage potential V_B at the third electrode **402** can be varied by varying the relative values of the first and second resistors R**1**, R**2** provided the total resistance R**1**+R**2** remains the same.

[0037] As described above, a first series circuit may be established between the high-voltage power supply HVPS**1** **304** and the circuit ground **602** via the second electrode **302**, the flame **106**, the halo electrode **202**, and the first and second resistors R**1**, R**2**.

[0038] At the same time, however, a second series circuit may be established between the halo electrode **202** and the circuit ground **602** via the fuel stream **108** and the burner nozzle **102**. The second series circuit is electrically parallel to the portion of the first series circuit extending between the halo electrode **202** and the circuit ground **602** via the first and second resistors R**1**, R**2**. Alternatively, where there is little or no electrical current flow in the fuel stream **108**, an electrical field may be established by the voltage difference between first voltage potential V_A, at the halo electrode **202**, and ground potential, at the burner nozzle **104**. Finally, in embodiments that include the third electrode **402**, a voltage distribution within an electric field established across the fuel stream **108** can be controlled by selection of the value of the second voltage potential V_B, at the third electrode **402**. The value of the second voltage potential V_B can, in turn, be determined by selection of the relative values of the first and second resistors R**1**, R**2**, as explained above.

[0039] FIG. **7** depicts another embodiment configured to provide an application of voltage potentials to a first halo electrode **202** and to a second halo electrode **702** configured to further control a flame **106**. Anchoring may result when the first halo electrode **202** is operatively coupled through one or more switches and/or control circuits to a first high-voltage power supply HVPS**1 204** while a second halo electrode **702** is operatively coupled through one or more switches and/or control circuits to a second high-voltage power supply HVPS**2 304** such that, if the first halo electrode **202** is at a lower potential than the second halo electrode **702**, then a voltage difference (V_{E2}-V_{E1}) between the first and second high-voltage power supplies HVPS**1** and HVPS**2** again generates a charge flow (current, I) toward the lower potential that may drag down the flame **106** for more stable anchoring on the first halo electrode **202**. In other embodiments other shapes, positions, and combinations of electrodes may be considered for an efficient anchoring of the flame **106** within the combustion volume **102**.

[0040] Ordinal numbers, e.g., first, second, third, etc., are used in the claims according to conventional claim practice, i.e., for the purpose of clearly distinguishing between claimed elements or features thereof. The use of such numbers does not suggest any other relationship, e.g., order of operation, relative position of such elements, etc. Furthermore, an ordinal number used to refer to an element in the claims does not necessarily correlate to a number used in the specification to refer to an element of a disclosed embodiment on which those claims read, nor to numbers used in unrelated claims to designate similar elements or features.

[0041] Where a claim limitation recites a structure as a grammatical object of the limitation, that structure itself is not an element of the claim, but is a modifier of the subject. For example, in a hypothetical limitation that recites "a burner nozzle configured to emit a flow stream and to support a flame within the flow stream," the flow stream is not an element of the claim (nor is the flame), but instead serves to help define the scope of the term burner nozzle. Additionally, subsequent limitations or claims that recite or characterize additional elements relative to the flow stream do not render the flow stream an element of the claim. Only where the flow stream itself is recited as the grammatical subject of a claim limitation does it become an essential element of the claim.

[0042] The abstract of the present disclosure is provided as a brief outline of some of the principles of the invention according to one embodiment, and is not intended as a complete or definitive description of any embodiment thereof, nor should it be relied upon to define terms used in the specification or claims. The abstract does not limit the scope of the claims.

[0043] Finally, while various aspects and embodiments have been disclosed herein, other aspects and embodiments are contemplated. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

What is claimed is:

1. A combustion system, comprising:

a burner nozzle having a longitudinal axis, positioned within a combustion volume and configured to emit a flow stream, including a mixture of fuel and oxidizer, that expands and slows at distances receding away from the burner nozzle, and to support a flame via the flow stream;

a first high-voltage power supply (HVPS); and

a first electrode operatively coupled to the first HVPS, the first electrode being configured and disposed on a diameter generally concentric with the longitudinal axis of the burner nozzle at a first distance from the burner nozzle, the first distance corresponding to a region in which the flow stream has expanded and marginally slowed, the first HVPS being configured to supply a first voltage potential to the first electrode, sufficient to charge the flame such that the charged flame is stably held on or near a surface of the first electrode.

2. The combustion system of claim **1**, wherein the first electrode has a ring torus shape disposed in a plane and having a center axis of rotation normal to the plane, wherein the center axis of rotation is about coincident with the longitudinal axis of the burner nozzle.

3. The combustion system of claim **2**, comprising an electrically resistive coating on the surface of the first electrode.

4. The combustion system of claim **2**, further including one or more additional electrodes, each operatively coupled to a respective additional HVPS.

5. The combustion system of claim **4**, wherein the one or more additional electrodes include a second electrode disposed a second distance from the burner nozzle, greater than the first distance and corresponding to a top region of the charged flame.

6. The combustion system of claim **5**, wherein the second electrode has a ring torus shape disposed on a diameter generally concentric with the longitudinal axis of the burner nozzle.

7. The combustion system of claim **5**, wherein the second electrode is configured to receive a second voltage potential, different from the first voltage potential from the respective additional HVPS of the second electrode, and thereby producing an electrical field along a length of the charged flame between the first electrode and the second electrode.

8. The combustion system of claim **5**, wherein the one or more additional electrodes include a third electrode disposed a third distance from the burner nozzle, less than the first distance and corresponding to a base region of the charged flame, the additional respective HVPS of the third electrode being configured to provide a third voltage potential to the third electrode, and to produce thereby a voltage difference between the first electrode and the third electrode.

9. The combustion system of claim **8**, wherein the first, second, and third voltage potentials are selected to produce voltage differences between each of the first, second, and third electrodes.

10. The combustion system of claim **5**, wherein the one or more additional electrodes comprise a second electrode disposed a second distance from the burner nozzle, less than the first distance and corresponding to a base region of the charged flame.

11. The combustion system of claim **6**, wherein each of the first and the one or more additional electrodes further includes a switch for independently opening and closing electrical continuity between the first and the one or more additional electrodes and the respective additional HVPS.

12. The combustion system of claim **1**, wherein the oxidizer is selected from the group consisting of oxygen in ambient air, oxygen concentrated air, oxygen, ozone, hydrogen peroxide, recycled flue gases and combinations thereof.

13. The combustion system of claim **1**, wherein the oxidizer is oxygen from ambient air.

14. A combustion system, comprising:

a burner nozzle having a longitudinal axis and configured to emit a flow stream including a mixture of fuel and oxidizer within a combustion volume, the burner nozzle being electrically coupled to a circuit ground;

a first electrode disposed a first distance from the burner nozzle corresponding to a top region of flame supported by the flow stream emitted by the burner nozzle;

a high-voltage power supply (HVPS) operatively coupled to the first electrode and configured to supply a first voltage potential to the first electrode;

a second electrode having a ring torus shape lying in a plane and having a center axis of rotation normal to the plane and about coincident with the longitudinal axis of the burner nozzle, the second electrode being disposed a second distance, less than the first distance, from the burner nozzle;

an electrical resistance operatively coupled between the second electrode and the burner nozzle, a series circuit being established between the HVPS and the circuit ground, via the first electrode, the flame, the second electrode, the electrical resistance, and the burner nozzle, the series circuit being configured to establish a second voltage potential at the second electrode on the basis of a current flowing in the circuit and the resistive value of the electrical resistance.

15. The combustion system of claim **14**, comprising a third electrode disposed a third distance, less than the second distance, from the burner nozzle, and wherein:

the electrical resistance comprises a first resistor operatively coupled between the second electrode and the third electrode, and a second resistor operatively coupled between the third electrode and the burner nozzle; and

the series circuit is configured to establish the second voltage potential at the second electrode on the basis of the current flowing in the circuit and a sum of the resistive values of the first and second resistors; and

the series circuit is further configured to establish a third voltage potential at the third electrode on the basis of the current flowing in the circuit and the resistive value of the second resistor.

16. A method for stably positioning a flame within a combustion volume, comprising the steps of:

supporting a flame within a combustion volume by emitting into the combustion volume a flow stream, including a mixture of fuel and oxidizer, from a burner nozzle; and

operating a first high-voltage power supply (HVPS) to generate a first voltage potential; and

holding the flame to a first electrode by applying the first voltage potential to the flame and electrically attracting the flame to the first electrode.

17. The method of claim **16**, wherein the applying the first voltage potential to the flame and electrically attracting the flame to the first electrode comprises applying the first voltage potential to the first electrode.

18. The method of claim **16**, wherein the holding the flame to a first electrode comprises holding the flame to a first electrode having a ring torus shape disposed in a plane and having a center axis of rotation normal to the plane and about coincident with an axis of the burner nozzle.

19. The method of claim **16**, wherein the applying the first voltage potential to the flame and electrically attracting the flame to the first electrode comprises:

applying the first voltage potential to a first electrode positioned a first distance from the nozzle; and

applying a second voltage potential, different from the first voltage potential, to a second electrode positioned a second distance, different than the first distance, from the burner nozzle.

20. The method of claim **19**, wherein the applying a second voltage potential to a second electrode comprises applying the second voltage potential to a second electrode having a ring torus shape, disposed on a diameter generally concentric with an axis of the burner nozzle.

21. The method of claim **19**, wherein the applying a second voltage potential to a second electrode positioned a second distance from the burner nozzle comprises applying the second voltage potential to the second electrode positioned a second distance, less than the first distance, from the nozzle.

22. The method of claim **19**, wherein:

the applying the first voltage potential to a first electrode comprises closing a switch operatively coupled between a first voltage source and the first electrode; and

the applying a second voltage potential to a second electrode comprises closing a second switch operatively coupled between a second voltage source and the second electrode.

23. The method of claim **19**, wherein the applying a second voltage potential to a second electrode positioned a second distance from the burner nozzle comprises applying the second voltage potential to the second electrode positioned a second distance, greater than the first distance, from the nozzle.

24. The method of claim **23**, comprising:

applying a third voltage potential to a third electrode positioned a third distance, less than the first distance, from the nozzle.

25. The method of claim **16**, wherein the first electrode is positioned a first distance from the nozzle, and wherein applying the first voltage potential to the flame and electrically attracting the flame to the first electrode comprises:

applying the first voltage potential to a second electrode positioned a second distance, greater than the first distance, from the nozzle;

passing a first electrical current from the second electrode through the flame to the first electrode, and from the first electrode through an electrical resistance to a circuit ground; and

holding the burner at a ground potential.

26. The method of claim **25**, comprising passing a second electrical current from the first electrode through the flow stream to the burner nozzle.

27. The method of claim **25**, comprising establishing an electrical field along the flow stream between the first electrode and the burner nozzle.

28. The method of claim **27**, wherein the electrical resistance comprises first and second series resistors, the method comprising controlling a voltage potential at a third electrode positioned between the first electrode and the burner nozzle and electrically coupled to a node between the first and second series resistors by selecting relative resistance values of the first and second series resistors.

* * * * *