

OZONE GENERATOR

Field of the Invention

[0001] The currently described invention relates to ozone generators and methods for generating ozone.

Background

[0002] Prior art ozone generators are incapable of producing useful quantities of ozone without a dopant (e.g., nitrogen) for extended periods of time. In addition, the ozone generators also are unable to operate at very low temperatures which are necessary to produce high concentrations of ozone.

[0003] A need therefore exists for improved ozone generators and methods for generating ozone.

Summary

[0004] Embodiments of the invention involve ozone generators and methods for producing high concentrations of high purity ozone with systems that have reduced shear stress between the components of the ozone generator cells. These systems are able to operate at very low temperatures and have improved serviceability relative to conventional systems.

[0004a] In one aspect, there is provided an ozone generator comprising: an ozone generator cell comprising: a high voltage electrode layer having a first side and a second side opposing the first side, a first dielectric layer having a first side and a second side opposing the first side, and a second dielectric layer having a first side and a second side opposing the first side, the second side of the first dielectric layer disposed on the first side of the high voltage electrode layer and the first side of the second dielectric layer disposed on the second side of the high voltage electrode layer, a first low voltage electrode layer having a first side and a second side opposing the first side, and a second low voltage electrode layer having a first side and a second side opposing the first side, the second side of the first low voltage electrode layer disposed over the first side of the first dielectric layer and the first side of the second low voltage electrode layer disposed over the second side of the second dielectric layer, two discharge regions, a first discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the first dielectric layer disposed on the first side of the high voltage electrode layer, and the second side of the first low voltage electrode layer disposed on the first side of the first dielectric layer, a second discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the second dielectric layer disposed on the second side of the high voltage electrode layer, and the first side of the second low voltage electrode layer disposed on the second side of the second dielectric layer, and a first thermally conductive plate having a first side and a second side opposing the first side, and a second thermally conductive plate having a first side and a second side opposing the first side, the second side of the first thermally conductive plate disposed over the first side of the first low voltage electrode layer and the first side of the second thermally conductive plate disposed over the second side of the second low voltage electrode layer, wherein the two thermally conductive plates maintain contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located therebetween in the absence of a bonding agent; a base plate over which the ozone generator cell is positioned; and a spring-loaded clamp plate coupled to the base plate such that the ozone generator cell is disposed between the base plate and the spring-loaded clamp plate, such that the coupled base plate and spring-loaded clamp plate apply pressure to the ozone generator cell to hold the layers of the ozone generator cell together, wherein the two dielectric layers, the two low voltage electrode layers, and the high voltage electrode layer are all fabricated using non-aluminum containing materials.

[0004b] In another aspect, there is provided a method for fabricating an ozone generator cell, the method comprising: locating a second side of a first dielectric layer on a first side of a high voltage electrode layer; locating a first side of a second dielectric layer on a second, opposite side of the high voltage electrode layer; locating a second side of a first low voltage electrode layer over a first side of the first dielectric layer to define a first discharge region by combination of the high voltage electrode layer, the first dielectric layer and the first

low voltage electrode layer; locating a first side of a second low voltage electrode layer over a second side of the second dielectric layer to define a second discharge region by combination of the high voltage electrode layer, the second dielectric layer and the second low voltage electrode layer; locating a first thermally conductive plate over a first side of the first low voltage electrode layer; locating a second thermally conductive plate over the second side of the second low voltage electrode layer; locating a base plate over the second thermally conductive plate; locating a spring-loaded clamp plate over the first thermally conductive plate; and coupling the spring-loaded clamp plate to the base plate, the coupled spring-loaded clamp plate and base plate applying pressure to the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located between the first and second thermally conductive plates to maintain contact between the layers located therebetween in the absence of a bonding agent.

[0004c] In another aspect, there is provided an ozone generator comprising: an ozone generator cell comprising: a high voltage electrode layer having a first side and a second side opposing the first side, a first dielectric layer having a first side and a second side opposing the first side, and a second dielectric layer having a first side and a second side opposing the first side, the second side of the first dielectric layer disposed on the first side of the high voltage electrode layer and the first side of the second dielectric layer disposed on the second side of the high voltage electrode layer, a first low voltage electrode layer comprising tungsten and having a first side and a second side opposing the first side, and a second low voltage electrode layer comprising tungsten and having a first side and a second side opposing the first side, the second side of the first low voltage electrode layer disposed over the first side of the first dielectric layer and the first side of the second low voltage electrode layer disposed over the second side of the second dielectric layer, two discharge regions, a first discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the first dielectric layer disposed on the first side of the high voltage electrode layer, and the second side of the first low voltage electrode layer disposed on the first side of the first dielectric layer, a second discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the second dielectric layer disposed on the second side of the high voltage electrode layer, and the first side of the second low voltage electrode layer disposed on the second side of the second dielectric layer, and a first thermally conductive plate having a first side and a second side opposing the first side, and a second thermally conductive plate having a first side and a second side opposing the first side, the second side of the first thermally conductive plate disposed over the first side of the first low voltage electrode layer and the first side of the second thermally conductive plate disposed over the second side of the second low voltage electrode layer, wherein the two thermally conductive plates maintain contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low

voltage electrode layer located therebetween in the absence of a bonding agent; a base plate over which the ozone generator cell is positioned; and a spring-loaded clamp late coupled to the base plate such that the generator cell is disposed between the base plate and the spring-loaded clamp plate, such that the coupled base plate and spring-loaded clamp plate apply pressure to the ozone generator cell to maintain the contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer and the second low voltage electrode layer located therebetween in the absence of a bonding agent.

[0004d] In another aspect, there is provided a high concentration ozone generator comprising: an ozone generator cell comprising: a high voltage electrode layer fabricated using non-aluminum containing materials having a first side and a second side opposing the first side, a first dielectric layer having a first side and a second side opposing the first side, and a second dielectric layer having a first side and a second side opposing the first side, the second side of the first dielectric layer disposed on the first side of the high voltage electrode layer and the first side of the second dielectric layer disposed on the second side of the high voltage electrode layer, a first low voltage electrode layer having a first side and a second side opposing the first side, and a second low voltage electrode layer having a first side and a second side opposing the first side, the second side of the first low voltage electrode layer disposed over the first side of the first dielectric layer and the first side of the second low voltage electrode layer disposed over the second side of the second dielectric layer, two discharge regions lacking aluminum containing materials, a first discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the first dielectric layer disposed on the first side of the high voltage electrode layer, and the second side of the first low voltage electrode layer disposed on the first side of the first dielectric layer, a second discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the second dielectric layer disposed on the second side of the high voltage electrode layer, and the first side of the second low voltage electrode layer disposed on the second side of the second dielectric layer, and a first thermally conductive plate having a first side and a second side opposing the first side, and a second thermally conductive plate having a first side and a second side opposing the first side, the second side of the first thermally conductive plate disposed over the first side of the first low voltage electrode layer and the first side of the second thermally conductive plate disposed over the second side of the second low voltage electrode layer, wherein the two thermally conductive plates maintain contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located therebetween in the absence of a bonding agent to

reduce the shear stresses in the ozone generator cell; a base plate over which the ozone generator cell is positioned; and a spring-loaded clamp plate coupled to the base plate such that the ozone generator cell is disposed between the base plate and the spring-loaded clamp plate, such that the coupled base plate and spring-loaded clamp plate apply pressure to the ozone generator cell to maintain the contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located therebetween in the absence of a bonding agent to reduce the shear stresses in the ozone generator cell.

[0005] Herein disclosed is an ozone generator cell that includes a high voltage electrode layer and two dielectric layers. The first dielectric layer is disposed on a first side of the high voltage electrode layer and the second dielectric layer is disposed on the second, opposite side of the high voltage electrode layer. The ozone generator cell also includes two low voltage electrode layers. One low voltage electrode layer is disposed over each of the two dielectric layers. The ozone generator cell also includes two discharge regions, the first discharge region defined, in part, by the high voltage electrode layer, the dielectric layer disposed on the first side of the high voltage electrode layer, and the low voltage electrode layer disposed on the first side of the high voltage electrode layer, the second discharge region defined, in part, by the high voltage electrode layer, the dielectric layer is disposed on the second side of the high voltage electrode layer, and the low voltage electrode layer is disposed on the second side of the high voltage electrode layer. The ozone generator cell also includes two thermally

conductive plates, the first thermally conductive plate in contact with the low voltage electrode layer on the first side of the high voltage electrode layer, and the second thermally conductive plate in contact with the low voltage electrode layer on the second side of the high voltage electrode layer, wherein the two thermally conductive plates maintain contact between the layers located therebetween in the absence of a bonding agent.

[0006] In some embodiments, maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces a reduced thickness of a combination of the dielectric layers and the high voltage electrode layer. In some embodiments, the reduced thickness produces an increased capacitance between the low voltage electrode layers and the high voltage electrode layer. In some embodiments, the dielectric layers, the low voltage electrode layers, and the high voltage electrode layer are fabricated using non-aluminum containing materials.

[0007] In some embodiments, the ozone generator cell includes spacer shims protruding from a surface of each low voltage electrode layer towards a surface of a dielectric layer. In some embodiments, the first dielectric layer is sandwiched between the spacer shims protruding from the surface of one of the low voltage electrode layers and the first side of the high voltage electrode layer, and the second dielectric layer is sandwiched between the spacer shims protruding from the surface of the other of the low voltage electrode layers and the second side of the high voltage electrode layer. In some embodiments, the spacer shims are integral portions of the low voltage electrode layers or separate components sandwiched between the dielectric layers and the low voltage electrode layers.

[0008] Herein disclosed is a method for fabricating an ozone generator cell. The method includes locating a first dielectric layer on a first side of a high voltage electrode layer and locating a second dielectric layer on a second, opposite side of the high voltage electrode layer. The method also includes locating a first low voltage electrode layer over the first dielectric layer to define a first discharge region by combination of the high voltage electrode layer, the first dielectric layer and the first low voltage electrode layer. The method also includes locating a second low voltage electrode layer over the second dielectric layer to define a second discharge region by combination of the high voltage electrode layer, the second dielectric layer and the second low voltage

electrode layer. The method also includes locating a first thermally conductive plate over the first low voltage electrode layer and locating a second thermally conductive plate over the second low voltage electrode layer. The method also includes applying pressure to all the layers located between the first and second thermally conductive plates to maintain contact between the layers located therebetween in the absence of a bonding agent.

[0009] In some embodiments, maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces an increased electrical capacitance between the low voltage electrode layers and the high voltage electrode layer.

[0010] In some embodiments, maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent reduces thermal variation effects in the ozone generation cell. In some embodiments, the ozone generation cell may be operated over a wider range of temperatures because of the absence of a bonding agent.

[0011] In some embodiments, maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces a reduced thickness of a combination of the dielectric layers and the high voltage electrode layer. In some embodiments, the method includes fabricating the dielectric layers, the low voltage electrode layers, and the high voltage electrode layer using non-aluminum containing materials. In some embodiments, the method includes using an assembly jig to locate the first dielectric layer, the high voltage electrode layer, the second dielectric layer, the first low voltage electrode layer, the second low voltage electrode layer, the first thermally conductive plate, and the second thermally conductive plate relative to each other.

[0012] In some embodiments, spacer shims protrude from a surface of each low voltage electrode layer towards a surface of a dielectric layer. In some embodiments, the first dielectric layer is sandwiched between the spacer shims protruding from the surface of one of the low voltage electrode layers and the first side of the high voltage electrode layer, and the second dielectric layer is sandwiched between the spacer shims protruding from the surface of the other of the low voltage electrode layers and the second side of the high voltage electrode layer.

[0013] Herein disclosed is an ozone generator cell that includes a high voltage electrode layer and two dielectric layers. The first dielectric layer is disposed on a first side of the high voltage electrode layer and the second dielectric layer is disposed on the second, opposite side of the high voltage electrode layer. The ozone generator cell also includes two low voltage electrode layers comprising tungsten, wherein one low voltage electrode layer is disposed over each of the two dielectric layers. The ozone generator cell also includes two discharge regions. The first discharge region is defined, in part, by the high voltage electrode layer, the dielectric layer disposed on the first side of the high voltage electrode layer, and the low voltage electrode layer disposed on the first side of the high voltage electrode layer. The second discharge region is defined, in part, by the high voltage electrode layer, the dielectric layer disposed on the second side of the high voltage electrode layer, and the low voltage electrode layer disposed on the second side of the high voltage electrode layer. The ozone generator cell also includes two thermally conductive plates, the first thermally conductive plate in contact with the low voltage electrode layer on the first side of the high voltage electrode layer, and the second thermally conductive plate in contact with the low voltage electrode layer on the second side of the high voltage electrode layer, wherein the two thermally conductive plates maintain contact between the layers located therebetween in the absence of a bonding agent.

[0014] In some embodiments, maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces a reduced thickness of a combination of the dielectric layers and the high voltage electrode layer. In some embodiments, the ozone generator cell includes spacer shims protruding from a surface of each low voltage electrode layer towards a surface of a dielectric layer. In some embodiments, the first dielectric layer is sandwiched between the spacer shims protruding from the surface of one of the low voltage electrode layers and the first side of the high voltage electrode layer, and the second dielectric layer is sandwiched between the spacer shims protruding from the surface of the other of the low voltage electrode layers and the second side of the high voltage electrode layer. In some embodiments, the spacer shims are integral portions of the low voltage electrode layers or separate components sandwiched between the dielectric layers and the low voltage electrode layers.

[0015] Herein disclosed is a high concentration ozone generator cell that includes a high voltage electrode layer fabricated using non-aluminum containing materials. The cell also includes two dielectric layers, the first dielectric layer disposed on a first side of the high voltage electrode layer and the second dielectric layer disposed on the second, opposite side of the high voltage electrode layer. The cell also includes two low voltage electrode layers, one low voltage electrode layer disposed over each of the two dielectric layers fabricated using non-aluminum containing materials. The cell also includes two discharge regions lacking aluminum containing materials, the first discharge region defined, in part, by the high voltage electrode layer, the dielectric layer disposed on the first side of the high voltage electrode layer, and the low voltage electrode layer disposed on the first side of the high voltage electrode layer, the second discharge region defined, in part, by the high voltage electrode layer, the dielectric layer disposed on the second side of the high voltage electrode layer, and the low voltage electrode layer disposed on the second side of the high voltage electrode layer. The cell also includes two thermally conductive plates, the first thermally conductive plate in contact with the low voltage electrode layer on the first side of the high voltage electrode layer, and the second thermally conductive plate in contact with the low voltage electrode layer on the second side of the high voltage electrode layer, wherein the two thermally conductive plates maintain contact between the layers located therebetween in the absence of a bonding agent to reduce the shear stresses in the ozone generator cell.

[0016] Other aspects and advantages of the current invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating the principles of the invention by way of example only.

Brief Description of the Drawings

[0017] The foregoing features of various embodiments of the invention will be more readily understood by reference to the following detailed descriptions in the accompanying drawings, in which:

[0018] FIG. 1 is a schematic illustration of an ozone generator, according to an illustrative embodiment of the invention.

[0019] FIG. 2A is a schematic illustration of an exploded view of an ozone generator cell, according to an illustrative embodiment of the invention.

[0020] FIG. 2B is a more detailed view of a portion of the ozone generator cell of FIG. 2A, according to an illustrative embodiment of the invention.

[0021] FIG. 2C is a schematic illustration of a surface of the low voltage electrode layer of FIG. 2A, according to an illustrative embodiment of the invention.

[0022] FIG. 2D is a schematic illustration of an assembled view of the ozone generator cell of FIG. 2A, according to an illustrative embodiment of the invention.

[0023] FIG. 2E is a more detailed view of a portion of the ozone generator cell of FIG. 2D, according to an illustrative embodiment of the invention.

[0024] FIG. 3 is a schematic illustration of an ozone generator, according to an illustrative embodiment of the invention.

Detailed Description of Illustrative Embodiments

[0025] FIG. 1 is a schematic illustration of an ozone generator 100, according to an illustrative embodiment of the invention. The ozone generator 100 is configured to operate with the type of electrical discharge configuration commonly referred to as a dielectric barrier discharge (DBD) configuration. The configuration is typically described as including two current carrying planar or cylindrical, metal electrodes separated by at least one dielectric insulator. Application of high amplitude AC voltage between the metal electrodes results in a series of short-lived discharges (micro-discharges) in the region between the electrodes. If oxygen, or a mixture of oxygen and a dopant (e.g., nitrogen) is fed into the gap and through the discharge region, ozone is produced.

[0026] The ozone generator 100 includes five ozone generator cells 104a, 104b, 104c, 104d, and 104e (generally 104). Each ozone generator cell 104 includes a high voltage electrode layer 108 (e.g., a metal electrode (e.g., tungsten electrode)). Each of the cells 104 also includes two dielectric layers (112a and 112b, generally 112). The first dielectric layer 112a is disposed on a first side of the high voltage electrode layer 108 and the second dielectric layer 112b is disposed on the second, opposite side of the high voltage electrode layer 108.

[0027] The cells 104 also include two low voltage electrode layers (first low voltage electrode layer 116a and second low voltage electrode layer 116b, generally 116). One low voltage electrode layer 116 is disposed over/adjacent each of the two dielectric layers 112 (e.g., low voltage electrode layer 116a is disposed over dielectric layer 112a). In some embodiments, the low voltage electrode layers 116 are electrically grounded

tungsten electrodes. The presence of aluminum in the discharge region (e.g., if the electrode layer were fabricated using aluminum) would reduce the efficiency of ozone generation and reduce the life of the ozone generator cells. Because the components in the discharge region (i.e., dielectric layers, the low voltage electrode layers, and the high voltage electrode layer) are fabricated using non-aluminum containing materials it is possible to create an ozone generator that produces high concentrations of ozone and that prevents long-term degradation of the system. In the absence of aluminum in the discharge region, it is no longer necessary to include a dopant (e.g., nitrogen) in the oxygen supplied to the ozone generator.

[0028] The ozone generator cells 104 also include two thermally conductive plates 120a and 120b (generally 120). The first thermally conductive plate 120a is in contact with the first low voltage electrode layer 116a on the first side of the high voltage electrode layer 108, and the second thermally conductive plate 120b is in contact with the second low voltage electrode layer 116b on the second side of the high voltage electrode layer 108. The two thermally conductive plates 120a and 120b are configured to apply a force to the components (e.g., high voltage electrode layers, dielectric layers, low voltage electrode layers) located between the plates to maintain contact between the layers located therebetween, in the absence of a bonding agent. Because a bonding agent is not used between the components, the shear stress between components is reduced; which reduces the sensitivity and fragility of the system to very low temperatures that are preferable for ozone generation. Further, the reduction in shear stress allows the ozone generators to be operated over a wide range of temperatures.

[0029] In this embodiment, the thermally conductive plates 120 have a fluid input 136a and a fluid output 136b. The fluid inputs 136a are configured to receive fluid from a coolant fluid source (not shown) into a cavity located within the plates 120. The fluid outputs 136b are configured to output fluid from the cavity. Heat applied to the thermally conductive plates 120 generated by the discharge process is transferred to the fluid in the cavity; the heat is then removed as the fluid is output from the fluid outputs 136b.

[0030] Each ozone generator cell 104 is bounded by two thermally conductive plates 120. An ozone generator cell 104 positioned adjacent to another ozone generator cell 104 share a common thermally conductive plate. For example, thermally conductive plate 120b is shared/used by ozone generator cell 104a and by ozone generator cell 104b

to apply force to the components of the respective ozone generator cells and to cool the ozone generator cells.

[0031] The ozone generator 100 also includes a fixture base 124 and a spring loaded clamp plate 128. The spring loaded clamp plate 128 is attached to the base plate 124 with a plurality of screws so the spring loaded clamp plate 128 applies force to the stack of ozone generator cells 104a, 104b, 104c, 104d, and 104e located therebetween. The ozone generator 100 also includes a cover (not shown for clarity of illustration purposes) that mates with the base plate 124 at a grooved surface 140 of the base plate 124. The cover creates a sealed chamber within which the ozone generator cells and plate 128 are located when the cover is mated to the base plate 124.

[0032] FIG. 2A is a schematic illustration of an exploded view of an ozone generator cell 204 (e.g., cells 104 of FIG. 1), according to an illustrative embodiment of the invention. The ozone generator cell 204 includes a high voltage electrode layer 208. The cell 204 also includes two dielectric layers 212a and 212b. The first dielectric layer 212a is disposed on a first side 210a of the high voltage electrode layer 208 and the second dielectric layer 212b is disposed on the second, opposite side 210b of the high voltage electrode layer 208.

[0033] The cell 204 also includes a first low voltage electrode layer 216a and a second low voltage electrode layer 216b. Low voltage electrode layer 216a is disposed over the first dielectric layer 212a. Low voltage electrode layer 216b is disposed over the second dielectric layer 212b. FIG. 2B is a more detailed view of a portion of the ozone generator cell 204 of FIG. 2A. The second low voltage electrode layer 216b includes a plurality of spacer shims 240 located on the surface 250b of the second low voltage electrode layer 216b projecting towards the second dielectric layer 212b and the high voltage electrode layer 208 (with reference to FIG. 2A). FIG. 2C is a schematic illustration of the surface 250b of the low voltage electrode layer 216b of FIGS. 2A and 2B. The spacer shims 240 are distributed across the surface 250b of the low voltage electrode layer 216b.

[0034] The low voltage electrode layers 216, the high voltage electrode layers 208, the dielectric layers 212, the thermally conductive plates 220 have coaxially aligned apertures 280. Gas supplied to the ozone generator cells flows into the outer edges of the ozone generator cells towards the center of the ozone generator cells. As the gas flows towards the center of the ozone generator cells electrical discharges are created within the

ozone generator cells (as described with respect to, for example, FIG. 2E). The electrical discharges create ozone which then flows through central aperture 280 and to a gas output of the ozone generator.

[0035] The spacer shims 240 can be produced using a variety of methods. In some embodiments, the spacer shims 240 are created by etching the surface 250b of the second low voltage electrode around the desired locations of the spacer shims such that the spacer shims protrude from the surface 250b. In some embodiments, material for the spacer shims 240 is screened on to the surface 250b and then fired to create the spacer shims 240. In some embodiments, the spacer shims 240 are formed by creating dimples in the surface 250b of the second low voltage electrode 216b (e.g., by using a punch or other mechanical method to cause the material of the second low voltage electrode layer to dimple). Other methods can be used in alternative embodiments (e.g., plating, vacuum evaporation, sputtering). In some embodiments, the spacer shims 240 are a separate piece of material (or materials) held in place by friction and located between the surface 250b of the low voltage electrode layer 216b and the second dielectric layer 212b.

[0036] While not shown, the first low voltage electrode layer 216a also includes a plurality of spacer shims located on the surface of the first low voltage electrode layer 216a projecting towards the first dielectric layer 212a and the high voltage electrode layer 208 (with reference to FIG. 2A).

[0037] The ozone generator cell 204 also includes two thermally conductive plates 220a and 220b (with reference to FIG. 2A). The first thermally conductive plate 220a is located over the first low voltage electrode layer 216a on the first side 210a of the high voltage electrode layer 208, and the second thermally conductive plate 220b is located over the second low voltage electrode layer 216b on the second side 210b of the high voltage electrode layer 208. The two thermally conductive plates 220a and 220b are configured to apply a force to the components located between the plates to maintain contact between the layers located therebetween in the absence of a bonding agent.

[0038] FIG. 2D is a schematic illustration of an exploded view of the ozone generator cell 204 of FIG. 2A after the components of the ozone generator have been sandwiched together between the first and second thermally conductive plates 220a and 220b. FIG. 2E is a more detailed view of a portion of the ozone generator cell 204 of FIG. 2D. Gaps 260 are defined by the combination of the second dielectric layer 212b, low voltage electrode layer 216b and the spacer shims 240. A high voltage lead wire (not

shown) energizes the high voltage electrode layer 208 relative to the low voltage electrode layer 216b at a voltage level sufficient to cause an electrical discharge in the region of the gaps 260. The electrical discharges produce ozone if oxygen is introduced into the gaps 260 of the ozone generator cell 204.

[0039] Experiments conducted by the inventors demonstrate the primary source of ozone in a no-dopant ozone generator with the proper metal electrode is of photocatalytic origin. In some embodiments, tungsten oxide is used because of the material's photocatalytic properties. Tungsten oxide becomes slightly oxygen deficient in use and the resulting oxide is an n-type semiconductor. Molecular oxygen is electro-negative and, when it attracts an electron, forms O_2^- . This produces a layer of O_2^- on the surface of the n-type tungsten oxide. An electron-hole pair is formed when the tungsten oxide absorbs a photon (γ). The hole, which is O^+ , migrates to the surface and combines with the O_2^- to form ozone. The lattice oxygen from the tungsten oxide consumed in this reaction is replenished by contact of the oxide with the discharges and the diffusion of oxygen through the tungsten oxide. Electrons in the discharge create photons by free-free and free-bound collisions with the oxygen species in the discharge. The electrons also destroy ozone, and excite and de-excite molecular oxygen. The photons create ozone on the photocatalyst surface (e.g., tungsten oxide surface of the low voltage electrode layer 216b) and destroy ozone in the gas phase. The gas phase reactions combine the oxygen species present in the gas and produce ozone and molecular oxygen.

[0040] One of the insights gained was the realization that the gas phase reactions create ozone from the atomic oxygen resulting from the destruction of the source ozone generated on the photocatalyst. The gas phase reactions are temperature dependent with the reaction rates decreasing as gas temperature increases. The decrease in ozone generation with increasing gas temperature observed in typical generators of this type is due to the decreased gas phase reaction rates and not due to thermal destruction of the ozone. Photons emitted by the discharge are absorbed by the ozone in the discharge space in the gaps 260. The absorption has two effects: it destroys ozone and reduces the flux of ozone-creating photons to the photocatalytic surface. These effects can be minimized by making the path length of the photons through the ozone containing gas as short as possible by making the gap 270 (distance between second low voltage electrode layer 216b and the second dielectric layer 212b) smaller. The added benefit of making the gap 270 smaller is the capacitance of the combination of the high voltage electrode layer 208

and the dielectric layers 212 increases. The increased capacitance reduces the magnitude of the voltage to be supplied to the high voltage electrode layer to produce ozone.

[0041] FIG. 3 is a schematic illustration of an ozone generator 300, according to an illustrative embodiment of the invention. The ozone generator 300 includes a plurality of stacked ozone generator cells 304 (e.g., cells 104 of FIG. 1). The ozone generator cells 304 are located in a sealed chamber 318 defined by a cover 316 that is attached (e.g., welded) to a base plate 320 (base plate 124 of FIG. 1). The ozone generator 300 includes a high voltage supply 308 that provides a high voltage signal to the high voltage electrode layers 312 of the ozone generator cells 304 (e.g., high voltage layers 108 of the ozone generator cells 104 of FIG. 1).

[0042] The ozone generator 300 also includes a coolant fluid source 324 and a coolant exhaust 328. The coolant supply 324 provides coolant to fluid inputs 332 of thermally conductive plates 334 of the ozone generator cells 304. The coolant flows through cavities within the conductive plates 334 and outputs the coolant via fluid outputs 336 of the ozone generator cells 304 to the coolant exhaust 328.

[0043] The ozone generator cell 300 also includes a gas supply 340 (e.g., oxygen supply) that supplies a flow of gas to sealed chamber 318. The gas flows into the edges 350 of the ozone generator cells 304 towards the center 354 of the ozone generator cells. As the gas flows towards the center 354 of the ozone generator cells 304 electrical discharges are created within the ozone generator cells 304 (as described above with respect to, for example, FIG. 2E). The electrical discharges create ozone which then flows through an aperture (e.g., central aperture 280 of FIG. 2C) in the ozone generator cells 304 to a gas output 344.

[0044] Comprise, include, and/or plural forms of each are open ended and include the listed parts and can include additional parts that are not listed. And/or is open ended and includes one or more of the listed parts and combinations of the listed parts.

[0045] One skilled in the art will realize the invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments are therefore to be considered in all respects illustrative rather than limiting of the invention described herein. Scope of the invention is thus indicated by the appended claims, rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

CLAIMS

1. An ozone generator comprising:

an ozone generator cell comprising:

a high voltage electrode layer having a first side and a second side opposing the first side,

a first dielectric layer having a first side and a second side opposing the first side, and a second dielectric layer having a first side and a second side opposing the first side, the second side of the first dielectric layer disposed on the first side of the high voltage electrode layer and the first side of the second dielectric layer disposed on the second side of the high voltage electrode layer,

a first low voltage electrode layer having a first side and a second side opposing the first side, and a second low voltage electrode layer having a first side and a second side opposing the first side, the second side of the first low voltage electrode layer disposed over the first side of the first dielectric layer and the first side of the second low voltage electrode layer disposed over the second side of the second dielectric layer,

two discharge regions, a first discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the first dielectric layer disposed on the first side of the high voltage electrode layer, and the second side of the first low voltage electrode layer disposed on the first side of the first dielectric layer, a second discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the second dielectric layer disposed on the second side of the high voltage electrode layer, and the first side of the second low voltage electrode layer disposed on the second side of the second dielectric layer, and

a first thermally conductive plate having a first side and a second side opposing the first side, and a second thermally conductive plate having a first side and a second side opposing the first side, the second side of the first thermally conductive plate disposed over the first side of the first low voltage electrode layer and the first side of the second thermally conductive plate disposed over the second side of the second low voltage electrode layer, wherein the two thermally conductive plates maintain contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located therebetween in the absence of a bonding agent;

a base plate over which the ozone generator cell is positioned; and

a spring-loaded clamp plate coupled to the base plate such that the ozone generator cell is disposed between the base plate and the spring-loaded clamp plate, such that

the coupled base plate and spring-loaded clamp plate apply pressure to the ozone generator cell to hold the layers of the ozone generator cell together,

wherein the two dielectric layers, the two low voltage electrode layers, and the high voltage electrode layer are all fabricated using non-aluminum containing materials.

2. The ozone generator cell of claim 1, wherein maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces a reduced thickness of a combination of the dielectric layers and the high voltage electrode layer.
3. The ozone generator cell of claim 2, wherein the reduced thickness produces an increased capacitance between the low voltage electrode layers and the high voltage electrode layer.
4. The ozone generator cell of claim 1, comprising spacer shims protruding from a surface of each low voltage electrode layer towards a surface of each of the two dielectric layers.
5. The ozone generator cell of claim 4, wherein the first dielectric layer is sandwiched between the spacer shims protruding from the surface of one of the low voltage electrode layers and the first side of the high voltage electrode layer, and the second dielectric layer is sandwiched between the spacer shims protruding from the surface of the other of the low voltage electrode layers and the second side of the high voltage electrode layer.
6. The ozone generator cell claim 4, wherein the spacer shims are integral portions of the low voltage electrode layers or separate components sandwiched between the dielectric layers and the low voltage electrode layers.
7. A method for fabricating an ozone generator cell, the method comprising:
 - locating a second side of a first dielectric layer on a first side of a high voltage electrode layer;
 - locating a first side of a second dielectric layer on a second, opposite side of the high voltage electrode layer;
 - locating a second side of a first low voltage electrode layer over a first side of the first dielectric layer to define a first discharge region by combination of the high voltage electrode layer, the first dielectric layer and the first low voltage electrode layer;
 - locating a first side of a second low voltage electrode layer over a second side of the second dielectric layer to define a second discharge region by combination of the high voltage electrode layer, the second dielectric layer and the second low voltage electrode layer;

locating a first thermally conductive plate over a first side of the first low voltage electrode layer;

locating a second thermally conductive plate over the second side of the second low voltage electrode layer;

locating a base plate over the second thermally conductive plate;

locating a spring-loaded clamp plate over the first thermally conductive plate; and

coupling the spring-loaded clamp plate to the base plate, the coupled spring-loaded clamp plate and base plate applying pressure to the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located between the first and second thermally conductive plates to maintain contact between the layers located therebetween in the absence of a bonding agent.

8. The method of claim 7, wherein maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces an increased electrical capacitance between the low voltage electrode layers and the high voltage electrode layer.
9. The method of claim 7, wherein maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent reduces thermal variation effects in the ozone generator cell.
10. The method of claim 9, wherein the ozone generator cell may be operated over a wider range of temperatures because of the absence of a bonding agent.
11. The method of claim 7, wherein maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces a reduced thickness of a combination of the dielectric layers and the high voltage electrode layer.
12. The method of claim 7, comprising fabricating all of the dielectric layers, the low voltage electrode layers, and the high voltage electrode layer using non-aluminum containing materials.
13. The method of claim 7, comprising using an assembly jig to locate the first dielectric layer, the high voltage electrode layer, the second dielectric layer, the first low voltage electrode layer, the second low voltage electrode layer, the first thermally conductive plate, and the second thermally conductive plate relative to each other.
14. The method of claim 7, wherein spacer shims protrude from a surface of each low voltage electrode layer towards a surface of a dielectric layer.

15. The method of claim 14, wherein the first dielectric layer is sandwiched between the spacer shims protruding from the surface of one of the low voltage electrode layers and the first side of the high voltage electrode layer, and the second dielectric layer is sandwiched between the spacer shims protruding from the surface of the other of the low voltage electrode layers and the second side of the high voltage electrode layer.
16. An ozone generator comprising:
- an ozone generator cell comprising:
 - a high voltage electrode layer having a first side and a second side opposing the first side,
 - a first dielectric layer having a first side and a second side opposing the first side, and a second dielectric layer having a first side and a second side opposing the first side, the second side of the first dielectric layer disposed on the first side of the high voltage electrode layer and the first side of the second dielectric layer disposed on the second side of the high voltage electrode layer,
 - a first low voltage electrode layer comprising tungsten and having a first side and a second side opposing the first side, and a second low voltage electrode layer comprising tungsten and having a first side and a second side opposing the first side, the second side of the first low voltage electrode layer disposed over the first side of the first dielectric layer and the first side of the second low voltage electrode layer disposed over the second side of the second dielectric layer,
 - two discharge regions, a first discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the first dielectric layer disposed on the first side of the high voltage electrode layer, and the second side of the first low voltage electrode layer disposed on the first side of the first dielectric layer, a second discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the second dielectric layer disposed on the second side of the high voltage electrode layer, and the first side of the second low voltage electrode layer disposed on the second side of the second dielectric layer, and
 - a first thermally conductive plate having a first side and a second side opposing the first side, and a second thermally conductive plate having a first side and a second side opposing the first side, the second side of the first thermally conductive plate disposed over the first side of the first low voltage electrode layer and the first side of the second thermally conductive plate disposed over the second side of the second low voltage electrode layer, wherein the two thermally conductive plates maintain contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located therebetween in the absence of a bonding agent;

a base plate over which the ozone generator cell is positioned; and

a spring-loaded clamp late coupled to the base plate such that the generator cell is disposed between the base plate and the spring-loaded clamp plate, such that the coupled base plate and spring-loaded clamp plate apply pressure to the ozone generator cell to maintain the contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer and the second low voltage electrode layer located therebetween in the absence of a bonding agent.

17. The ozone generator cell of claim 16, wherein maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces a reduced thickness of a combination of the dielectric layers and the high voltage electrode layer.
18. The ozone generator cell of claim 16, comprising spacer shims protruding from a surface of each low voltage electrode layer towards a surface of a dielectric layer.
19. The ozone generator cell of claim 18, wherein the first dielectric layer is sandwiched between the spacer shims protruding from the surface of one of the low voltage electrode layers and the first side of the high voltage electrode layer, and the second dielectric layer is sandwiched between the spacer shims protruding from the surface of the other of the low voltage electrode layers and the second side of the high voltage electrode layer.
20. The ozone generator cell claim 18, wherein the spacer shims are integral portions of the low voltage electrode layers or separate components sandwiched between the dielectric layers and the low voltage electrode layers.
21. A high concentration ozone generator comprising:
 - an ozone generator cell comprising:
 - a high voltage electrode layer fabricated using non-aluminum containing materials having a first side and a second side opposing the first side,
 - a first dielectric layer having a first side and a second side opposing the first side, and
 - a second dielectric layer having a first side and a second side opposing the first side, the second side of the first dielectric layer disposed on the first side of the high voltage electrode layer and the first side of the second dielectric layer disposed on the second side of the high voltage electrode layer,
 - a first low voltage electrode layer having a first side and a second side opposing the first side, and a second low voltage electrode layer having a first side and a second side opposing the first side, the second side of the first low voltage electrode layer disposed over the first side of the first dielectric layer and the first side of the second

low voltage electrode layer disposed over the second side of the second dielectric layer,

two discharge regions lacking aluminum containing materials, a first discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the first dielectric layer disposed on the first side of the high voltage electrode layer, and the second side of the first low voltage electrode layer disposed on the first side of the first dielectric layer, a second discharge region, of the two discharge regions, defined, in part, by the high voltage electrode layer, the second dielectric layer disposed on the second side of the high voltage electrode layer, and the first side of the second low voltage electrode layer disposed on the second side of the second dielectric layer, and

a first thermally conductive plate having a first side and a second side opposing the first side, and a second thermally conductive plate having a first side and a second side opposing the first side, the second side of the first thermally conductive plate disposed over the first side of the first low voltage electrode layer and the first side of the second thermally conductive plate disposed over the second side of the second low voltage electrode layer, wherein the two thermally conductive plates maintain contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located therebetween in the absence of a bonding agent to reduce the shear stresses in the ozone generator cell;

a base plate over which the ozone generator cell is positioned; and

a spring-loaded clamp plate coupled to the base plate such that the ozone generator cell is disposed between the base plate and the spring-loaded clamp plate, such that the coupled base plate and spring-loaded clamp plate apply pressure to the ozone generator cell to maintain the contact between the first low voltage electrode layer, the first dielectric layer, the high voltage electrode layer, the second dielectric layer, and the second low voltage electrode layer located therebetween in the absence of a bonding agent to reduce the shear stresses in the ozone generator cell.

22. The high concentration ozone generator cell of claim 21, wherein maintaining contact between the layers located between the first and second thermally conductive plates in the absence of a bonding agent produces a reduced thickness of a combination of the dielectric layers and the high voltage electrode layer.
23. The high concentration ozone generator cell of claim 21, comprising spacer shims protruding from a surface of each low voltage electrode layer towards a surface of a dielectric layer.
24. The high concentration ozone generator cell of claim 23, wherein the first dielectric layer is sandwiched between the spacer shims protruding from the surface of one of the low voltage electrode layers and the first side of the high voltage electrode layer,

and the second dielectric layer is sandwiched between the spacer shims protruding from the surface of the other of the low voltage electrode layers and the second side of the high voltage electrode layer.

25. The high concentration ozone generator cell of claim 23, wherein the spacer shims are integral portions of the low voltage electrode layers or separate components sandwiched between the dielectric layers and the low voltage electrode layers.