separately fused. Plasma produced in each tube is spatially inhomogeneous and ozone production occurs predominately in the vicinity of the streamers. On the other hand, smaller scale applications requiring lower throughput (e.g., <100 g/hr) often employ corona reactors.

A portable ozone generator is described in US 7,157,721 (" '721patent"). In the '721 device, both sides of a glass or ceramic plate are coated with conductive materials to form electrodes having different areas. Such a device produces a corona discharge in the region lying outside the smaller of the two electrodes. An ozone device based upon this corona discharge mixes ozone with water in flow channels that are formed in plastic. No microchannels exist in the ozone-producing reactor. Another manufacturer provides a modular approach to ozone generation that is based upon corona discharge cells. However, because the corona discharge reactors are not flat, nor is the plasma confined to microscopic channels, these reactors are not readily or easily combined and, in particular, are not amenable to being stacked. Furthermore, the voltages required of corona discharge systems are high (multi-kV) and conversion efficiencies (oxygen or air $\rightarrow$ ozone) are low.

SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a modular microplasma microchannel reactor device, comprising: a microchannel array of a plurality of microchannel plasma devices including electrodes arranged with respect to the plurality of microchannels to stimulate plasma generation in the plurality of microchannels upon application of suitable voltage wherein the electrodes are isolated from the microchannels by dielectric; a gas inlet to the microchannels; a gas product outlet from the microchannels; wherein a portion of the microchannels between the gas inlet and gas product outlet are covered by a cover; and seals that seal the gas inlet and gas product outlet to provide fluid (gas) communication between the gas inlet and/or gas

product outlet and another microchannel reactor device, wherein the cover and device are structured to be modular to join with additional reactor devices.

According to another aspect of the invention, there is provided a modular microplasma microchannel reactor device, comprising: a microchannel array formed in a thin plate and being arranged with respect to electrodes for generation of plasma and isolated by dielectric from the electrodes; a cover covering a central portion of the microchannel array, while leaving end portions of the microchannel array exposed; a positioning tab extending from the thin plate for alignment of the reactor device with other reactor devices in a stack of reactor devices; a seal to seal the cover to the thin plate; and a gas inlet and product outlet arranged to permit flow into, through and out of the microchannel array, wherein the cover and device are structured to be modular to join with additional reactor devices.

There is also disclosed a modular microplasma microchannel reactor device which includes a microchannel array of a plurality of microchannel plasma devices. The plasma devices include electrodes arranged with respect to the plurality of microchannels to stimulate plasma generation in the plurality of microchannels upon application of suitable voltage. The electrodes are isolated from the microchannels by dielectric. A gas inlet is provided to the microchannels. A gas product outlet is provided from the microchannels. A portion of the microchannels between the gas inlet and gas product outlet are covered by a cover. The cover and device are structured to be modular so as to join with additional reactor devices.

In addition, there is disclosed a modular microplasma microchannel reactor device which includes a microchannel array arranged with respect to electrodes for generation of plasma and isolated by dielectric from the electrodes. A cover covers a central portion of the microchannel array, while leaving end portions of the microchannel array exposed. A gas inlet and product outlet are arranged to permit flow into, through and out of the microchannel array.

Reactor modules of the invention include pluralities of the modular reactor devices. The reactor devices can be arranged by a housing or a frame to be in fluid (gas) communication with other reactor devices. A system of the invention arranges pluralities of modules. Preferred module housings, frames and reactors include structural features to create alignments and connections. Preferred modules include fans to circulate feedstock and reaction product. Other reactor devices provide plasma actuation for flow.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cut-away perspective view of a preferred embodiment microchannel plasma device reactor that forms a unit of a preferred embodiment reactor module of the invention;

FIGs. 2A and 2B present perspective views of microchannel plasma devices with microchannels on opposing sides (FIG. 2A) and on a only one side (FIG. 2B);

FIGs. 3A-3D are, respectively, perspective, transparent, partial magnified, and partial views of a preferred embodiment reactor module of the invention;

FIG. 4A is a perspective view of a preferred embodiment miniature reactor module with a plurality of individual microchannel plasma reactors held in a housing that also incorporates a fan; FIG. 4B is a perspective view of an individual microchannel plasma reactor from the FIG. 4A preferred embodiment miniature reactor module;

FIGs. 5 and 6 are perspective views of another preferred embodiment miniature reactor module;

CLAIMS

1. A modular microplasma microchannel reactor device, comprising:

a microchannel array of a plurality of microchannel plasma devices including electrodes arranged with respect to the plurality of microchannels to stimulate plasma generation in the plurality of microchannels upon application of suitable voltage wherein the electrodes are isolated from the microchannels by dielectric;

a gas inlet to the microchannels;

a gas product outlet from the microchannels; wherein a portion of the microchannels between the gas inlet and gas product outlet are covered by a cover; and

seals that seal the gas inlet and gas product outlet to provide fluid (gas) communication between the gas inlet and/or gas product outlet and another microchannel reactor device, wherein the cover and device are structured to be modular to join with additional reactor devices.

2. The device of claim 1, wherein one of the electrodes comprises the cover that seals the plurality of microchannels between the gas inlet and gas outlet.

3. A miniature microplasma reactor module, comprising a plurality of modular microplasma microchannel reactor devices of claim 1 held together by a housing to provide an air tight seal between reactor devices.

4. The module of claim 3, wherein all of the microchannel arrays are in fluid (gas) communication with each other.

5. A microplasma reactor system, comprising a plurality of the modules of claim 3 arranged in fluid communication with other modules in an array of miniature microplasma reactor devices.

6. The reactor system of claim 5, comprising a base plate with flow channels that interconnect columns of the array of miniature microplasma reactor devices.

7. The reactor system of claim 6, wherein the modules include structures to join with other modules and the base plate, and the base plate includes structures to align and join with modules.

8. The reactor system of claim 7, wherein the structures to join comprise complementary tongue and groove structures.

9. The reactor system of claim 7, wherein the structures to join comprise complementary male and female connector gas ports.

10. The reactor system of claim 7, comprising outlet plenums that provide outlets from a plurality of microplasma reactor devices in the array.

11. The reactor module of claim 3, further comprising a fan held within the housing.

12. The reactor module of claim 11, wherein the overall dimensions of the reactor device are 10 x 10 x 20 cm or less.

13. A miniature microplasma reactor module, comprising a plurality of modular microplasma microchannel reactor devices of claim 1 mounted side-by-side upon a planar frame and sealed, the module further comprising feedstock and output channels to respectively supply feedstock to and receive gas product from the gas inlet and gas product outlet of the plurality of reactor devices.

14. A miniature microplasma reactor module, comprising a plurality of modular microplasma microchannel reactor devices of claim 1 held together by a housing to provide an air tight seal between reactor devices, further comprising a sprayer plate accepting output from the miniature reactor device, the sprayer plate including a plurality of microchannels that directs output of the miniature reactor device away from the device in a predetermined pattern.

15. The miniature reactor module of claim 14, held with a plastic mold and dimensioned to fit within an individual food package.

16. The device of claim 1, wherein the one of the electrodes is offset with respect to the plurality of microchannels to create a plasma actuator effect that stimulates flow through the microchannels.

17. The device of claim 1, wherein the microchannel array comprises a ladder structure with one or more cross channels connecting the plurality of microchannels to each other between opposite ends of the microchannels.

18. An ozone injection device comprising:

a miniature reactor device in according with claim 1;

a pump and oxygen concentrator for supplying oxygen to the miniature reactors; and

a water inlet and a mixer mixing ozone output from the miniature reactor device with water from the water inlet prior to outputting treated water out a water outlet.

19. The device of claim 1, wherein the electrodes are encapsulated within a metal oxide layer such that it is isolated from the microchannels.

20. The device of claim 1, wherein the microchannels comprise a flat bottom microchannels.

21. The device of claim 1, wherein the microchannel array is formed in polymer.

22. A modular microplasma microchannel reactor device, comprising:

a microchannel array formed in a thin plate and being arranged with respect to electrodes for generation of plasma and isolated by dielectric from the electrodes;

a cover covering a central portion of the microchannel array, while leaving end portions of the microchannel array exposed;

a positioning tab extending from the thin plate for alignment of the reactor device with other reactor devices in a stack of reactor devices;

a seal to seal the cover to the thin plate;

and

a gas inlet and product outlet arranged to permit flow into, through and out of the microchannel array, wherein the cover and device are structured to be modular to join with additional reactor devices.

23. A plurality of the reactor devices of claim 22, stacked together with O-rings sealing the reactor devices to each other around the gas inlet and product outlet.

24. A plurality of the reactor devices of claim 22, held in a frame or housing to form a miniature reactor, the frame or housing having inlet and outlets in gas communication with the gas inlet and product outlets of the reactor devices.

25. The miniature reactor of claim 24, wherein the frame or housing comprises ports for receiving feedstock gas and directing the feedstock gas into the reactor devices and an exit for outputting reactor product generated by the reactor.

26. The miniature reactor of claim 25, the reactor further comprising O-rings between the reactor devices and a top cover held by the frame or housing that exerts pressure on the plurality or reactors to seal respective outlets and inlets of the reactors.

27. A reactor system comprising a plurality of the miniature reactors of claim 26 interlocked, fluid connected, and electrically connected together upon a base plate, wherein the frame or housing of each miniature reactor is configured with grooves and tongues to interlock with other miniature reactors or the base plate, the ports being configured as male and female connectors on opposite ends of the frame or housing to mate with other miniature reactors or the base plate.

28. The reactor system of claim 27, wherein the frame or housing of each miniature reactor comprises electrical contacts to contact other miniature reactors or the base plate.

29. The reactor system of claim 28, wherein the base plate comprises flow channels and features to interlock miniature reactors to the base plate while maintaining gas flow, physical and electrical connections between the base plate and the miniature reactors.

30. The ozone injection device of claim 18, comprising a plurality of the miniature reactor modules and further comprising a power source and controller, wherein ones of the miniature reactor modules can be individually activated and deactivated.

31. The ozone injection device of claim 30, comprising a plurality of water outlets associated with individual ones of the miniature reactor modules.

32. The miniature microplasma reactor module of claim 14, wherein the sprayer plate comprises a spiral or pinwheel design with curved microchannels.