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WO 2014/119349 A1
JP 2004006152 A
US 20100157503 A1
JP H107405

(58) Field of Search:
INT CL **A61L, F24F, H01T, H05H**
Other: **WPI, EPODOC**

(54) Title of the Invention: **Flexible electrode assembly for plasma generation and air ducting system including the electrode assembly**
Abstract Title: **A flexible plasma discharge electrode for an air treatment device**

(57) A flexible electrode assembly (100) for an air treatment device comprising a flexible dielectric layer forming an insulating sheet, a plurality of conductive tracks and a conductive layer on separate sides of the insulating sheet, wherein plasma is generated from the conductive tracks when a voltage is applied to both the conductive electrodes. The tracks may be formed of several wires separated by gaps and the conductive layer may be formed of a sheet, such electrodes forming a first and second layer respectively. The type of plasma discharge may be that of a dark or townsend discharge. The power source to the electrode may be configured to ensure that the power per unit area is less than 100mW/cm^2 and wherein the dielectric strength of the malleable dielectric layer is at least 100 KV/mm. A further insulting layer may be included between the dielectric layer and at least one of the conductive layers. The flexible electrode assembly may be used with an air treatment assembly having a conduit (504), or be part of an air ducting system, wherein the flexible electrode is provided upon the interior surface of the conduit, and may form a ring.

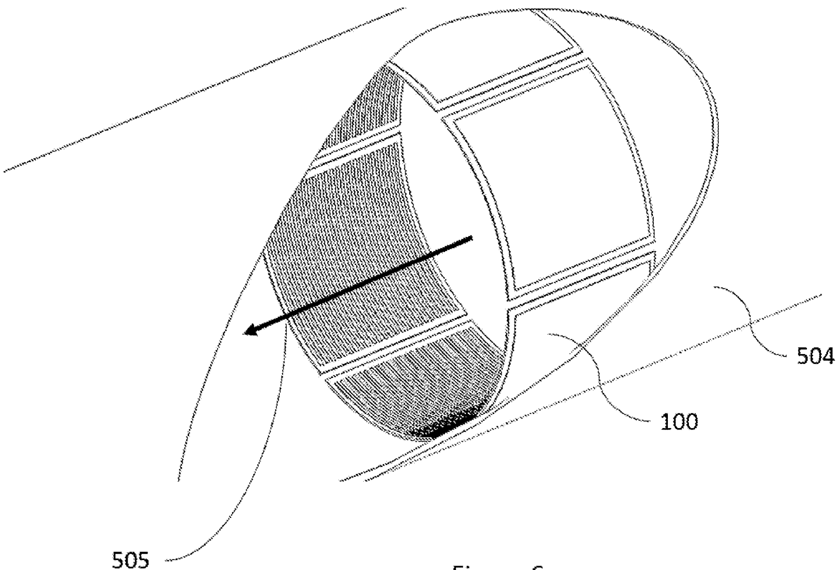

Figure 6

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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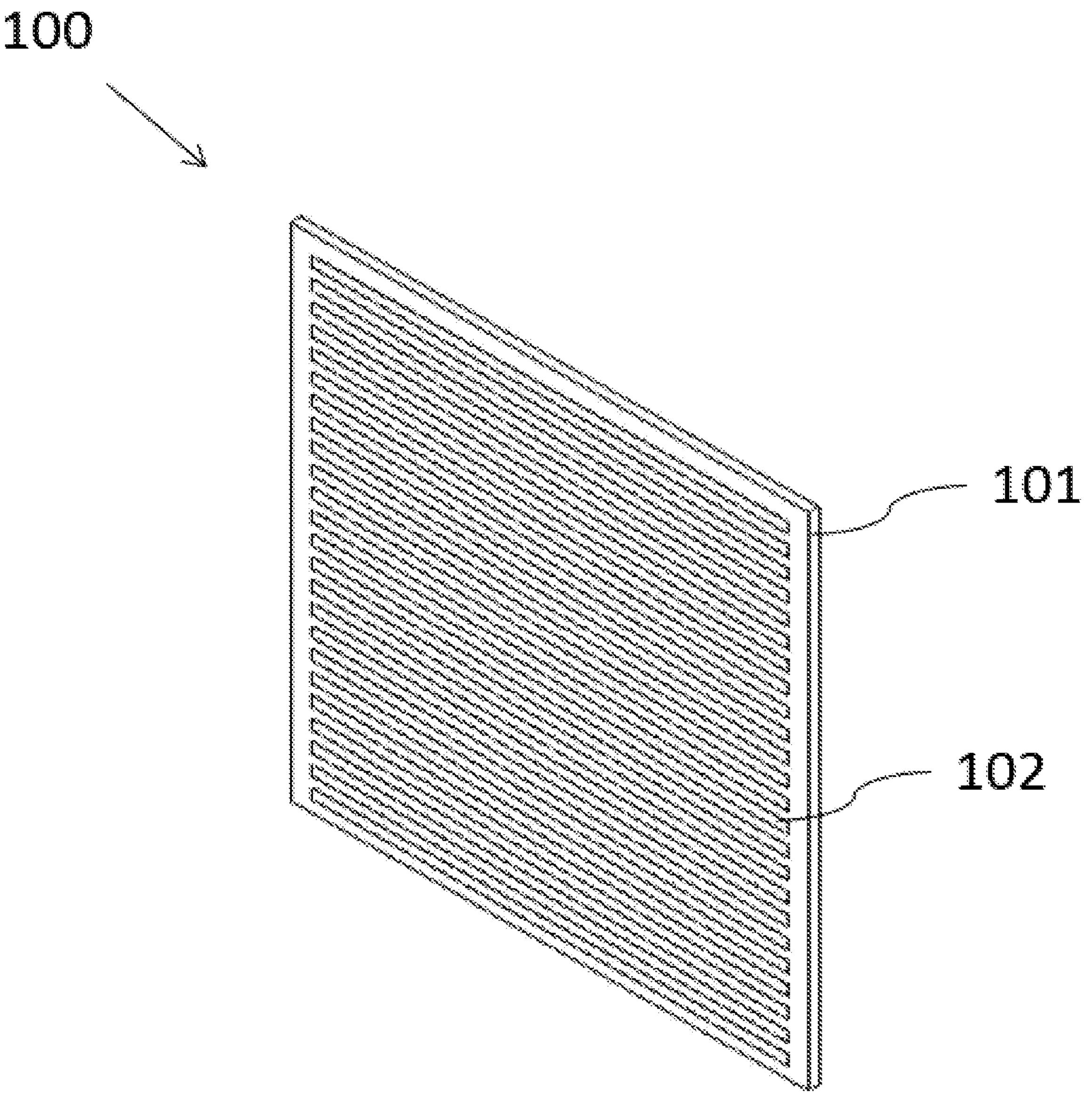

Figure 1

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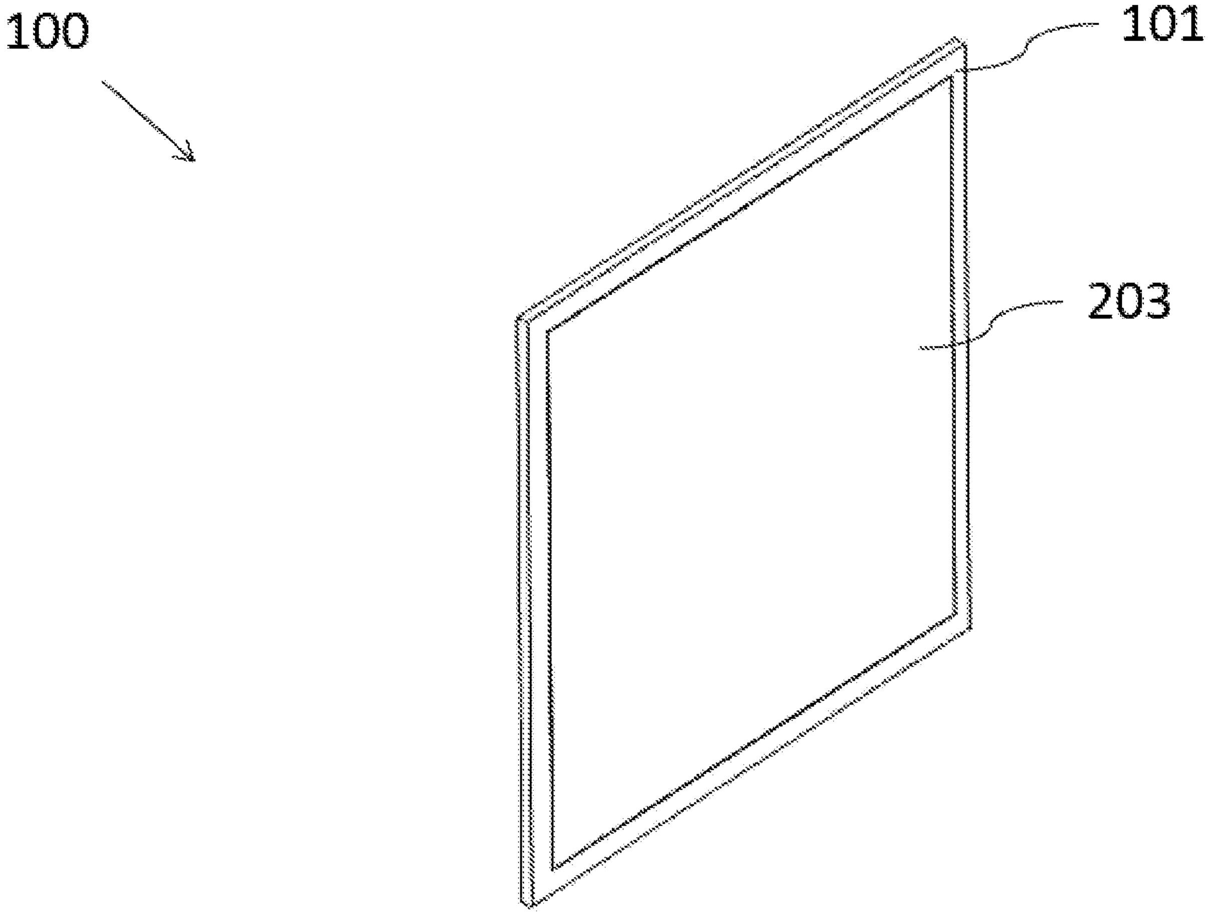

Figure 2

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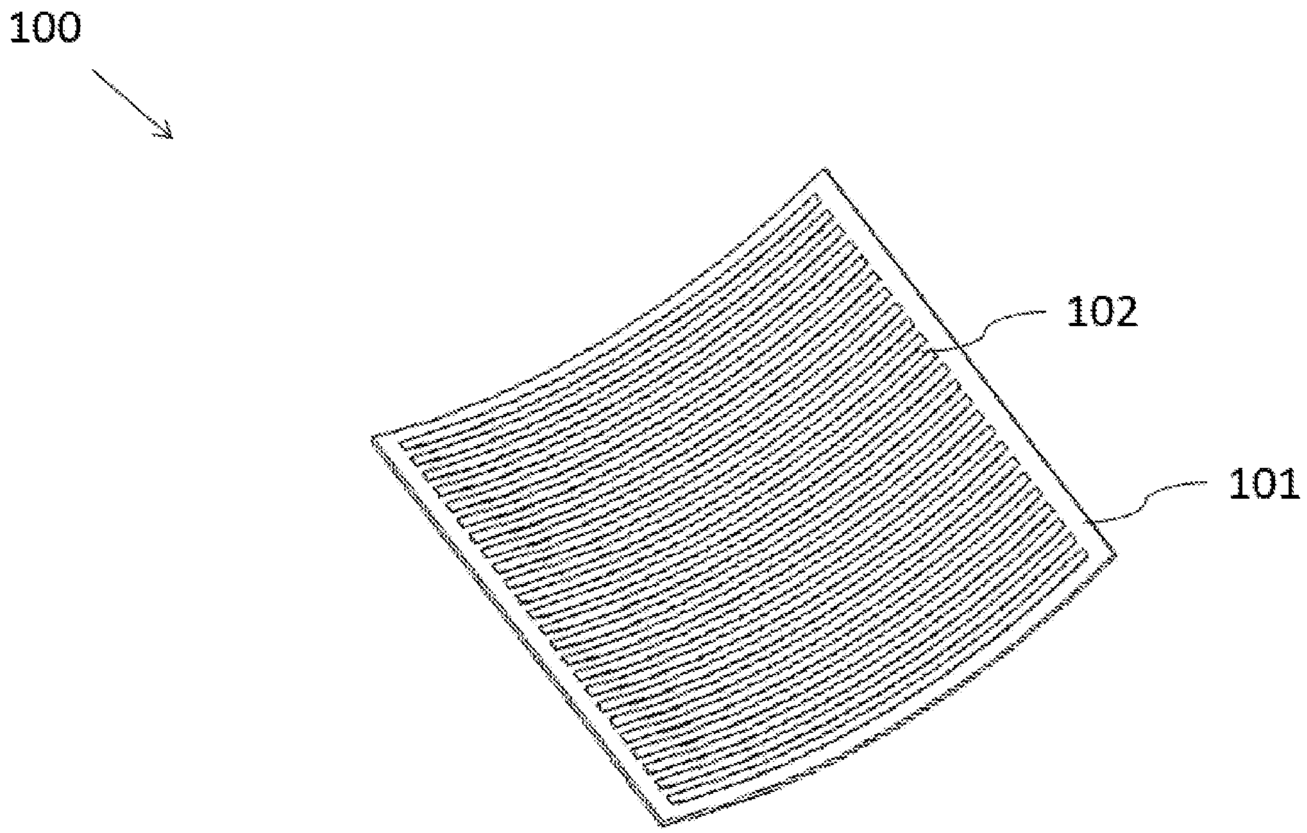

Figure 3

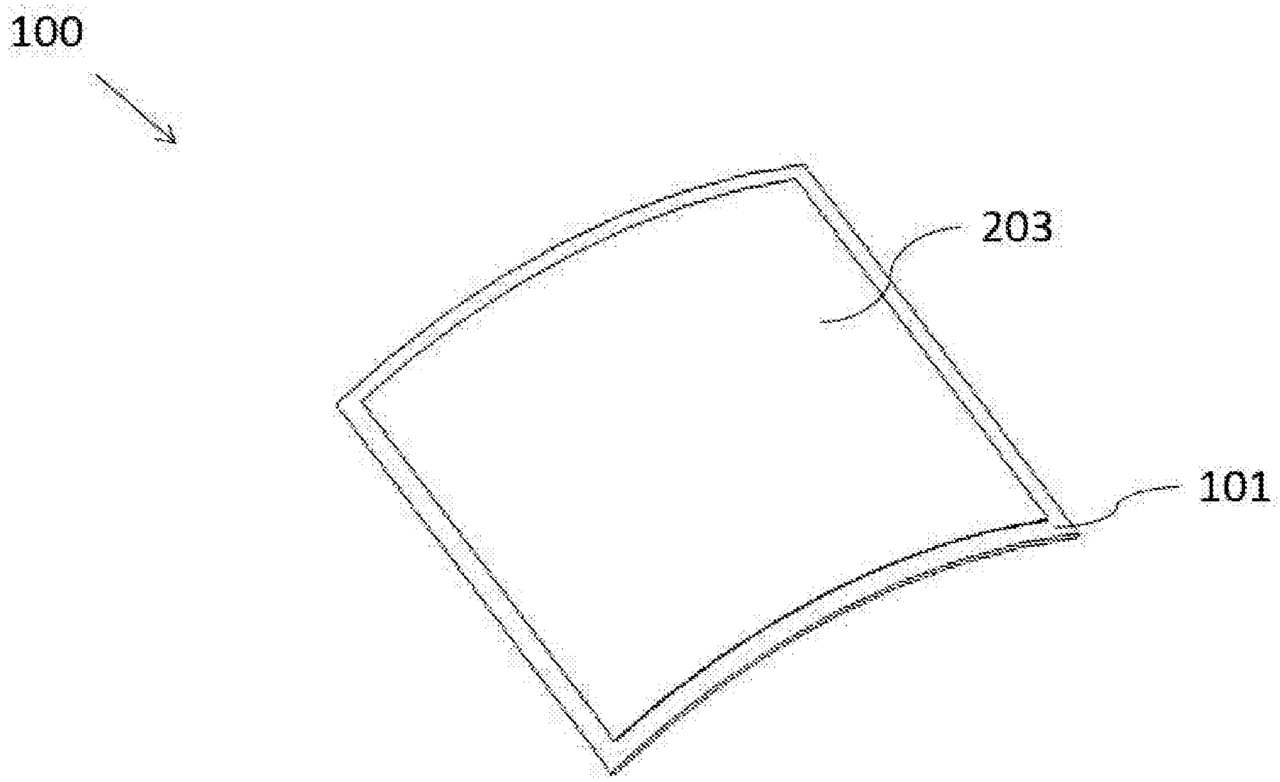

Figure 4

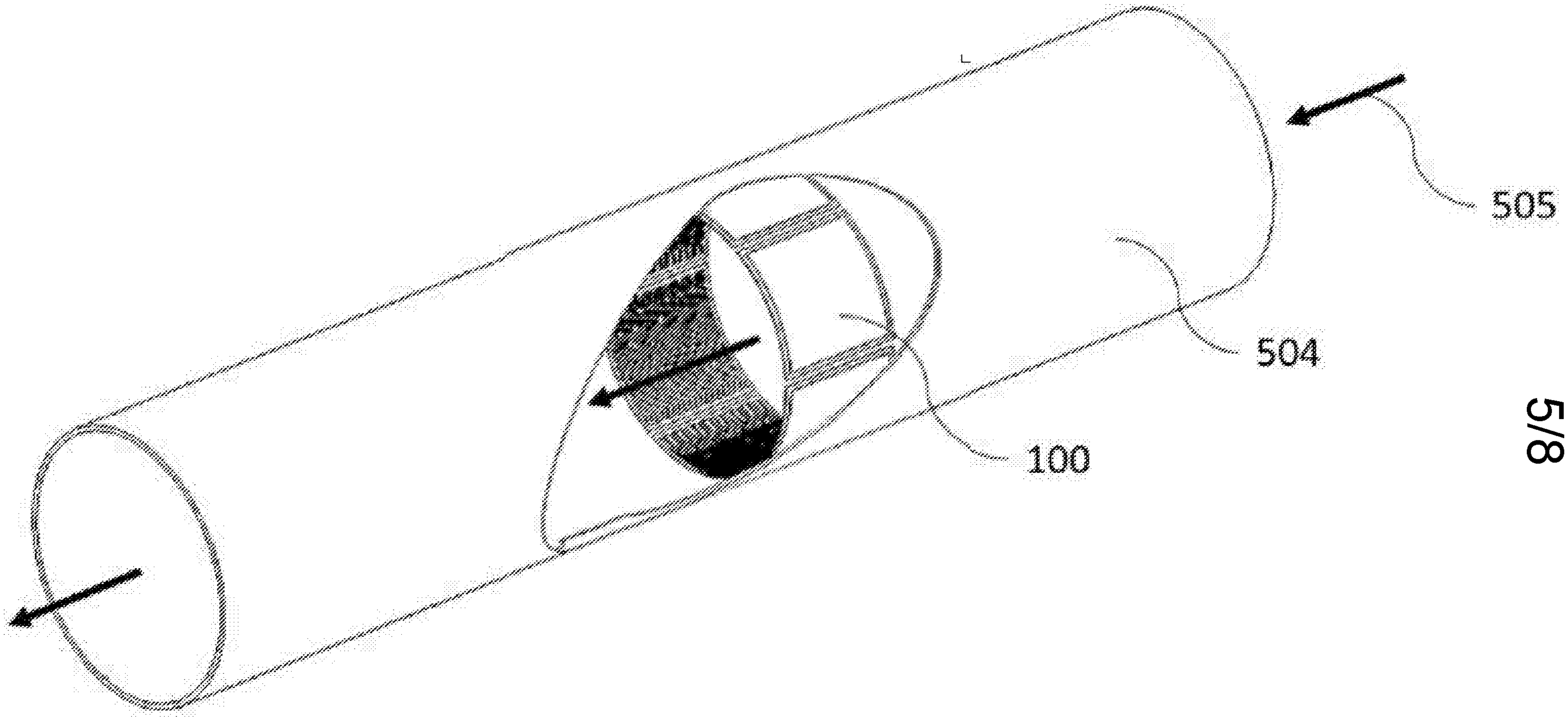

Figure 5

05 11 15

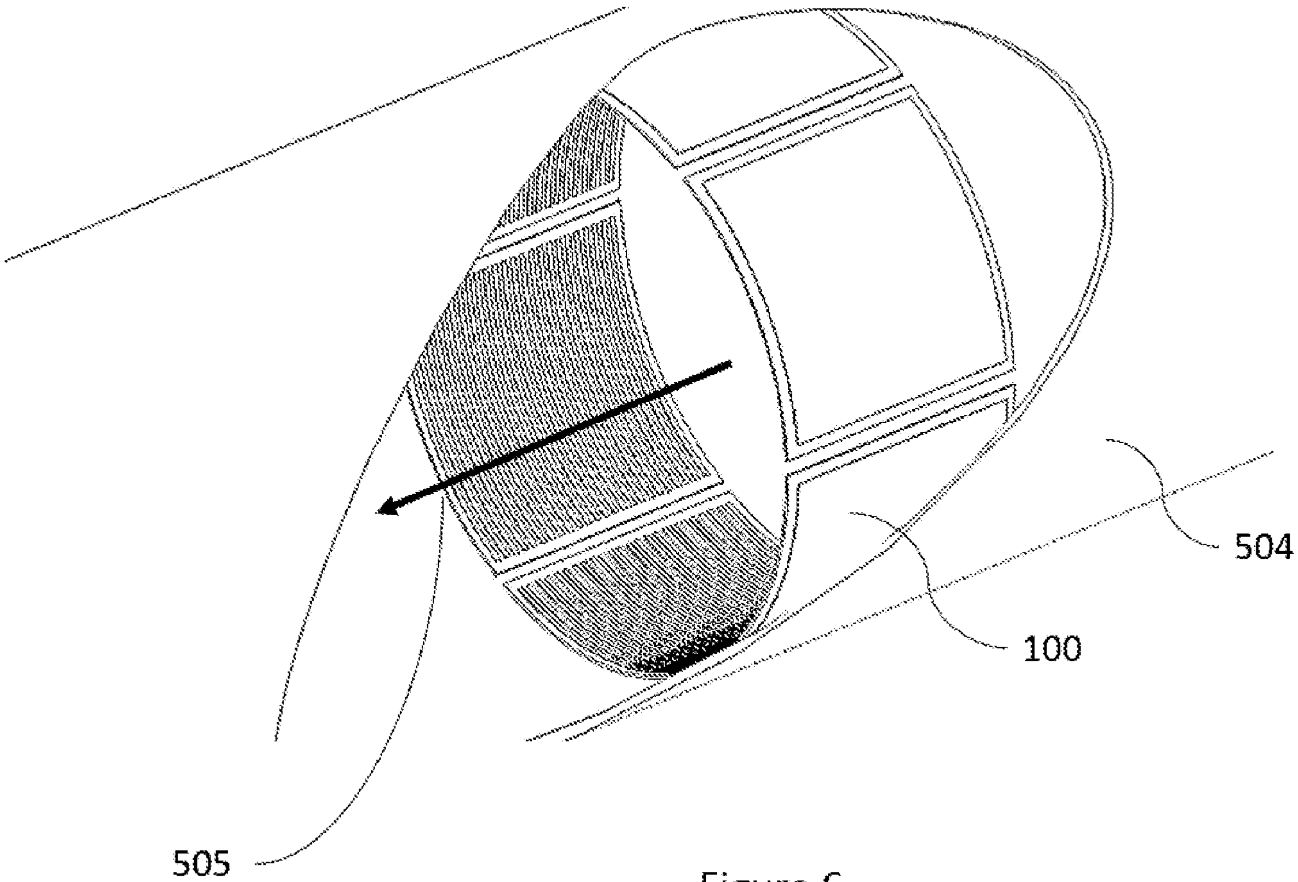

Figure 6

05 11 15

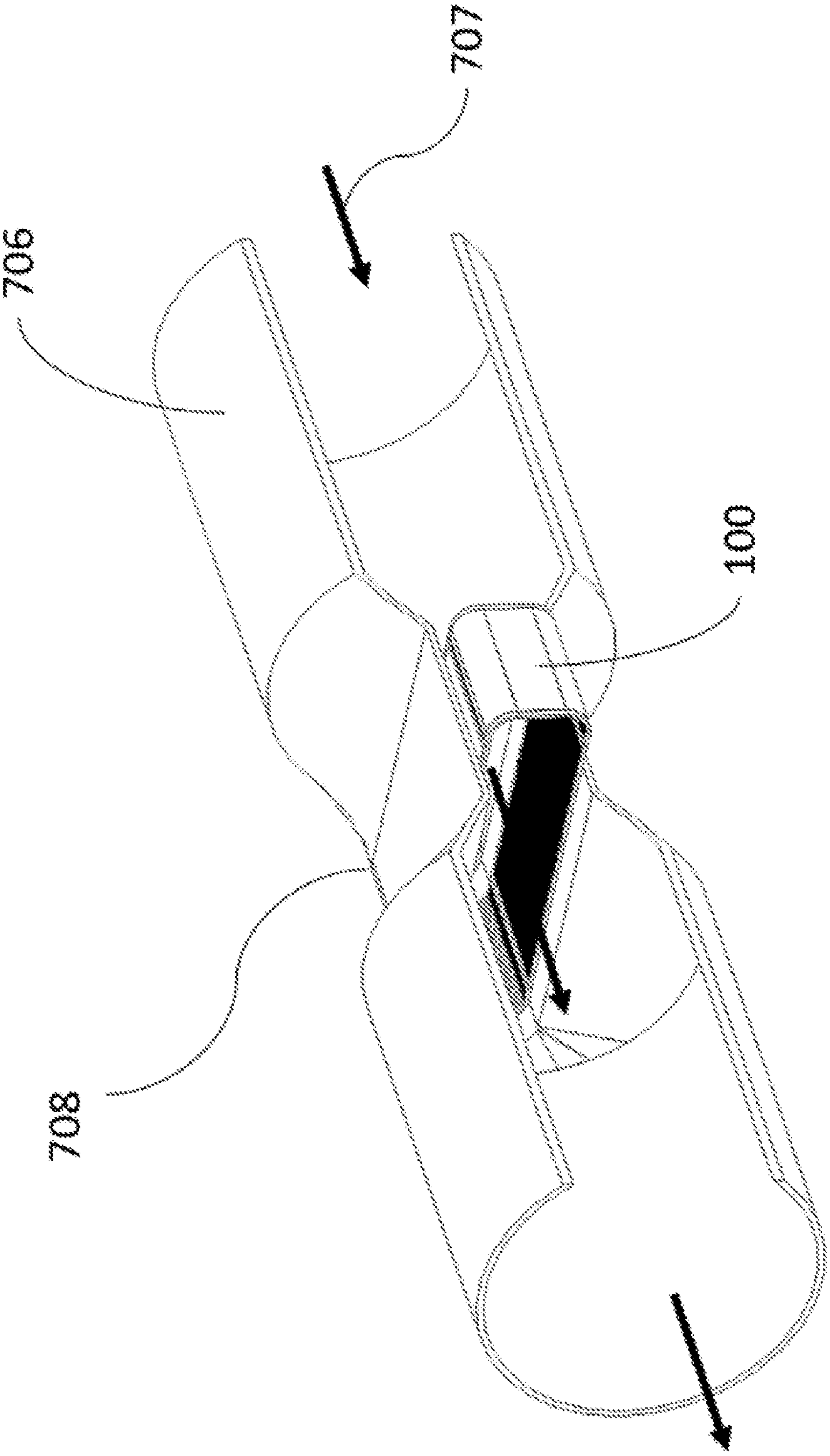

Figure 7

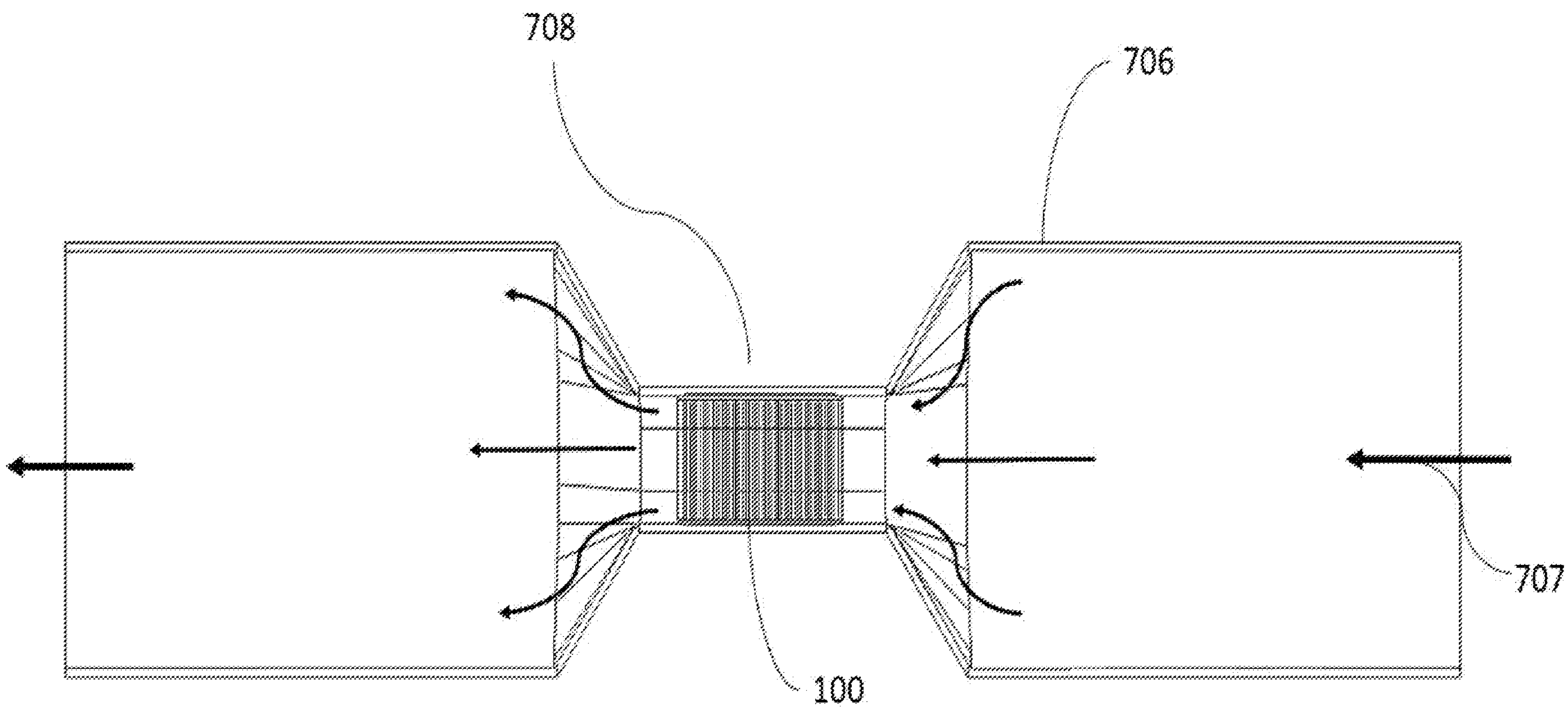

Figure 8

Title

Flexible Electrode Assembly for Plasma Generation and Air Ducting System including the Electrode Assembly

Field

The present invention relates to an air treatment method and apparatus. More specifically, the invention relates to an apparatus comprising an electrode assembly and an air ducting system. The apparatus may further comprise a power source. The electrode assembly is made of flexible materials and used to generate low power electrical discharge plasma for inactivating pathogens present in indoor air and removing pollutants from the same. The present invention also provides a method of using such an apparatus in air treatment applications.

Background

Health threatening airborne pollutants may be subdivided into three groups; (a) airborne pathogens comprising any organism that causes disease that spreads throughout the environment via the air; (b) airborne allergens comprising any substance that, when ingested, inhaled, or touched, causes an allergic reaction and, (c) airborne volatile organic compounds (VOC) comprising any product that is designed to be sprayed at high pressure in the form of tiny particles that remain suspended in the air. The last category includes many cleaning chemicals, hair spray, various types of primer, and fuels such as gasoline and kerosene, as well as other household, beauty, or hobby products. Some fabrics, particularly those recently manufactured, also contribute to indoor airborne VOCs when they outgas, or leak out chemicals in gaseous form, over time.

Airborne pollutants can build up significantly in indoor environments with the result that the air that we breathe may become contaminated. Considering that on average humans spend approximately 90% of their time in an indoor environment, it will be appreciated that the removal of pollutants from indoor air is of importance to reduce allergies and prevent infection transmission, such as sick building syndrome.

Existing state of the art technologies for the control of airborne pathogens can be categorized as: (a) airborne trapping systems or filters, (b) airborne inactivation systems and, (c) some combination of the above.

Existing airborne inactivation technologies also include those that make use of chemicals, UV radiation and plasma discharge by-products.

Examples of chemical inactivation include the use of antimicrobial vaporizers, typically ozone or hydrogen peroxide. While these systems are effective, they are also disruptive, requiring the evacuation of indoor space to be treated and therefore are not suitable for use under normal living circumstances.

Alternative inventions for the purification of air comprise the use of ultra violet light (UV) emission to kill airborne bacteria. For example, international publication No. WO 2003/092751, describes a device in which a fluid (e.g. air) is passed through an array of UV lamps. It is appreciated that in this solution the one and only inactivation mechanism is via UV radiation.

It is also known to use of plasma radicals for sterilisation of air filter medium; see for example US patent publication No. 2004/0184972 A1. In this prior art document, it is proposed that an upstream plasma discharge can generate active radicals which flow upstream to a medium filter and kill any bacteria or virus trapped by the filter.

In such systems which rely on plasma discharge, the design and configuration of the plasma generator are of particular importance. The teachings disclosed in the present document offers an electrode assembly for plasma generation which can be used for air disinfection and pollution control.

Summary

Accordingly, a first embodiment of the application provides a flexible electrode assembly for an air treatment device as detailed in claim 1. The application also provides an air ducting system as detailed in the independent claim. Advantageous embodiments are provided in the dependent claims.

Brief Description Of The Drawings

The present application will now be described with reference to the accompanying drawings in which:

Figure 1 is a view from a first side of an electrode assembly in accordance with the present teachings;

Figure 2 is a view of the electrode assembly of figure 1 from a second side;

Figure 3 is a view from the first side of the electrode assembly bent in a semi-circular manner in accordance with the present teachings;

Figure 4 is a view from the second side of the electrode assembly bent in a semi-circular manner in accordance with the present teachings;

Figure 5 is a view of the flexible electrode assembly in accordance with the present teachings deployed within a conduit;

Figure 6 is a close up view of the flexible electrode assembly of figure 5 deployed within the conduit;

Figure 7 is a view of an alternative configuration for the deployment of the flexible electrode assembly within a conduit; and

Figure 8 is a cross section view of the alternative deployment configuration of figure 7.

Detailed Description Of The Drawings

The present teachings relate to an air treatment apparatus comprising a flexible electrode assembly which is used with a ducting system to operably generate a plasma for treatment of air passing through the ducting system. The apparatus may further comprise a power source which is coupled to the flexible electrode assembly to provide power which is used in the generation of a plasma. In addition, an impeller may be required to force air through the ducting system. By providing such a combination of elements it is possible when power is applied to the electrode assembly to generate a low power plasma discharge field to effectively sterilise air of micro-organisms or pathogens or oxidise organic airborne contaminants and particles that are passing through the ducting system.

The power source may be a high voltage generator with voltage output in the range 1kV to 10kV amplitude. The high voltage generator may be of continuous (DC) or alternating (AC) current type. An exemplary embodiment is driven by an AC power source. In this embodiment the voltage source frequency is the same as mains frequency, i.e. 50 to 60 Hz depending on the geographical region. In an alternative embodiment the frequency of the power supply may be in the kilo-Hertz range; e.g. 1 kHz to 250 kHz. Further alternative embodiments may be fitted with AC power supplies with modulation frequency in the range above or below those listed above.

The configuration of the flexible electrode assembly is best described with reference to figures 1 and 2, which show an electrode assembly 100 comprising a dielectric layer 101 to which conducting electrodes are attached on front and back sides of the dielectric layer. In this way the electrodes are provided on opposing sides of the dielectric layer.

The electrodes each comprise a conducting layer. A first layer 102 is patterned as a series of thin rows of electrically conducting tracks leaving a narrow gap between the rows. The second layer 203 (shown in figure 2) is a uniform electrically conducting material with no gaps of holes therein. The first 102 and second 203 conducting layers act as a pair of electrodes.

A plasma discharge is generated by applying power to the pair of electrodes i.e., the first layer 102 and the second layer 203. The applied power sustains either a DC or an AC discharge from the first surface 102 of the flexible electrode assembly 100. The plasma generation in the present teachings is of a dielectric barrier discharge (DBD) type with both electrodes insulated from one another by the dielectric layer 101. The configuration and positioning of the first 102 and second 203 conducting layers ensures that the plasma discharge is generated and sustained on the first layer 102 of the electrode assembly 100.

Dielectric-barrier discharge (DBD) is an electrical discharge between two electrodes i.e., the first layer 102 and the second layer 203 separated by an insulating dielectric barrier i.e., the dielectric sheet 101. Known DBD devices are typically planar, using rigid parallel plates separated by a dielectric or cylindrical, using coaxial plates with a dielectric tube between them. However, by using flexible materials for the construction of the electrode assembly 100 in accordance with the present teachings, one can assemble an electrode pair with flexible characteristics allowing the device to be shaped to geometries other than a plane or a cylinder.

The dielectric layer 101 is made of a suitable insulating material with a high dielectric strength, which can be chosen as appropriate by those skilled in the art. In an exemplary arrangement of the present teachings the dielectric insulating layer 101 comprises a polyimide insulating sheet with dielectric strength greater than 100 kV/mm.

In this exemplary arrangement, the electrode assembly 100 consists of a polyimide sheet with a copper sheet on one side (acting as the second conducting layer 203) and copper tracks on the opposite side (acting as the first conductive layer 102).

The use of polyimide with copper attached thereto is well known for manufacturing printed circuit boards. In particular such configuration may generally constitute a flexible printed circuit board. It is appreciated that such flexible circuits are assembled/manufactured in a planar form and become a bendable or flexible sheet/board arising out of the physical characteristics of the materials used. It is also noted that these bendable boards are typically designed to allow flexibility where traditional rigid printed circuit boards are not suitable; e.g. when conforming to non-planar enclosures or surfaces is required. As such these flexible printed circuit boards are used in similar applications as their rigid counterparts including low voltage and low current usage but heretofore have not been used in the context of a plasma generator.

The inventors of the present application have appreciated that these flexible boards can be configured for use as an electrode assembly for generating medium to high power plasma discharges; i.e. discharges where power per unit area is in excess of 1 W/cm^2. However, under these circumstances the lifetime of such flexible printed circuit boards may be reduced due to high voltage and power applied which may cause short circuits on the board and burn out tracks due to high current. Therefore, it is important that the power provided applied to the flexible printed circuit boards in accordance with the present teachings is carefully regulated.

According to the teachings of the present invention, the power applied to the electrode assembly 100 by the power source is to be low enough to limit the amount of ionization of the air in the vicinity of said electrode assembly and to keep low electrical stress on the PCB to ensure long operating lifetimes. In an exemplary aspect, the power per unit area applied to the electrode is below 100 mW/cm^2. At this power level, the ionization generated by the system is of the type of a *dark* or *Townsend* discharge. As is known to those skilled in the art, this discharge mode is characterized by a combination of low discharge currents (in the range of micro amperes or lower) and no radiative emission, hence the term *dark*. [see for example Plasma Phys. Control. Fusion 47 (2005) B577–B588]. The generation of radicals in this discharge mode is also limited, which is advantageous in order to maintain a low level of anti-pathogenic agents released by the system of the present invention. The ionized plasma is therefore not of a glow discharge mode where the plasma current and radical and other plasma species concentration is significantly higher resulting in a visible glow, electrode heating and damage and significant release of toxic radicals.

In another aspect, the electrode assembly 100 may include an additional insulating layer between the first 102 layer and the dielectric layer 101. Additionally or alternatively, an insulating layer may be placed between the second 203 conducting layer and the dielectric layer. Such an additional layer(s) serves to protect the dielectric layer 101 from external sources of contamination or degradation. The additional protective layer(s) also reduces the possibility of arcing between the layers acting as electrodes and/or nearby conductors.

Figures 3 and 4 show perspective views of the electrode assembly 100 when bent in a semi-circular manner with the first conductive layer 102 on the inner side and the second conductive layer 203 on the outer side. Specifically, figure 3 shows the inner side of the electrode assembly 100 when bent to be arcuate while figure 4 shows the outer side of the electrode assembly 100.

Although a semi-circular shape is shown, a plurality of shapes can be formed using the flexible electrode assembly 100.

It will be understood by those skilled in the art that power is provided from a power supply to the flexible electrode assembly 100. The exact nature of the connection (e.g., wiring) between the flexible electrode assembly 100 and the power supply can be chosen as appropriate and it is not necessary that the power supply and the electrode assembly 100 be co-located. A transformer (not shown) may also be used between the power supply and the flexible electrode assembly 100 to provide high-voltage alternating current.

The first 102 and second 203 conductive layers maintain direct contact around their respective total surface areas with the dielectric layer 101. This ensures that there are no air pockets within the electrode assembly 100 where elevated levels of plasma can build up during generation of plasma.

In the preferred aspect of the present teachings the continuous uniform material of second conducting layer 203 ensures no plasma is sustained on the bottom layer 203 of assembly 100. On the other hand, the rows of wire separated by gaps in the first conducting layer 102 allows high electric fields to build up in the gaps due to the high voltage potential applied between the first 102 and second 203 conductive layers. This electric field ionizes the gas in the vicinity of the first conductive layer 102 initiating and sustaining an atmospheric plasma discharge. Said plasma discharge is limited to the first surface 102. Furthermore, said plasma discharge generates an inactivation zone above the first conductive layer 102 of the electrode assembly 100 where the plasma field, radiation and active species act as anti-pathogenic agents for the air passing the flexible electrode assembly 100.

An inactivation zone is a zone in which plasma is released and is effective to inactivate airborne pollutant material entrained in the air flow. Health threatening airborne pollutants may be subdivided into three groups: (a) airborne pathogens comprising any organism that causes disease that spreads throughout the environment via the air; (b) airborne allergens comprising any substance that, when ingested, inhaled, or touched, causes an allergic reaction and, (c) airborne volatile organic compounds (VOC) comprising any product that is designed to be sprayed at high pressure in the form of tiny particles that remain suspended in the air.

It will be understood by those skilled in the art that replacing the second conductive layer 203 (i.e., a sheet of conductive material) with a layer similar to that of the first conductive layer 102 (having rows of wire separated by gaps) will result in a plasma discharge being generated and sustained on the second side of the flexible electrode assembly 100 as well as on the front side. This may be desirable under some circumstances and/or applications of the present teachings and it is not intended to limit the present teaching to generation of a plasma on one side only of the electrode assembly.

The flexible electrode assembly 100 should preferably be oriented in a manner that air flows in parallel direction to the direction of the assembly so as to maximise the time that the air is exposed to the plasma that is generated by the assembly. By providing a flexible assembly the inactivation zone that is generated by the electrode assembly does not need to be planar as the assembly may adopt various curved geometries. In particular, due to the flexible nature of the electrode assembly 100 of the present teachings, a plurality of configurations are possible.

Figure 5 illustrates once such exemplary configuration. It can be seen that a plurality of the flexible electrode assemblies 100 are deployed within a circular conduit 504. The conduit 504 is shown with a cut away for ease of viewing of the plurality of flexible electrode assemblies 100 within the conduit. As will be understood by those skilled in the art any suitable shaped conduit may be used and the flexible nature of the assembly allows it adopt the shape of the conduit 504. Air enters the conduit 504 in the direction of arrow 505, flows past a plurality of electrode assemblies 100 and exits at the other end of the conduit 504.

Figure 6 is a close up image of the flexible electrode assembly of figure 5. It can be appreciated that a plurality of electrode assemblies 100 are shaped to match or adopt the interior curvature of the conduit 104. Furthermore, the individual electrode assemblies 100 can be positioned relative to one another to form a continuous ring of electrode assemblies within the conduit. It should be understood that in some configurations, fewer electrode assemblies 100 may be used. For example, although four assemblies 100 are shown in figures 5 and 6, two or three assemblies 100 could be used in non-contiguous ring. The determination of the number of assemblies may be chosen as appropriate by the skilled person. In some circumstances a single assembly may be used as long as the inactivation zone is sufficient to inactivate airborne pollutant material entrained in the air flow 505.

A number of means known to those skilled in the art could be chosen to induce air flow through the conduit 504, for example an impeller may be used.

The plasma concentration in the inactivating zone, created by the flexible electrode assembly 100, should be sufficient to effectively inactivate airborne pollutant material entrained in the air flow. Furthermore the concentration of plasma should decay sufficiently outside the inactivating zone so that the concentration of any anti-pathogenic agents created by the plasma discharge in the cleaned air expelled from the conduit 504 regions of the apparatus is at a physiologically acceptable level.

Figure 7 illustrates another configuration for the deployment of at least one flexible electrode assembly 100 within a conduit 706. A cut out section of the conduit 706 is provided in figure 7 to for ease of visualization. A plurality of electrode assemblies 100 are provided within a restricted rectangular section 708 of conduit 706. Specifically, the plurality of electrode assemblies 100 are positioned on the interior surface of the rectangular section 708 to form a continuous ring of electrode assemblies. It will be appreciated that the flexible nature of the electrode assemblies ensures that easily configured to form a continuous ring within the rectangular section 708.

Air enters the conduit 706 in the direction of arrow 707, flows into a rectangular section 708 of the conduit 706 fitted with a plurality of flexible electrode assemblies 100. The shape of said section 708 is such that air flowing past the electrode assemblies 100 shall do so within one centimetre from the first conducting layer 102 of the electrode assemblies present in the section 708. This means that the electrode assemblies at the top and bottom interior surfaces of the rectangular section 708 cannot be more than one centimetre apart. However, the distance between the sides can be much more than one centimetre.

The arrangement of figure 7 ensures that any volume of air flowing through the conduit 706 does so within the inactivation zone resulting from the atmospheric plasma discharge. A cross section of the configuration of figure 7 is shown in figure 8.

The words comprises/comprising when used in this specification are to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more other features, integers , steps, components or groups thereof.

Claims

1. A flexible electrode assembly for an air treatment device comprising:
a flexible dielectric layer forming an insulating sheet;
a plurality of conductive tracks on a first side of the insulating sheet;
a conductive layer on a second side of the insulating sheet;
wherein supply of voltage to the conducting tracks and the conductive layer generates plasma which is discharged from the conducting tracks.

2. The electrode assembly of claim 1 wherein the plurality of conductive tracks form a first layer of the assembly and the conductive layer forms a second layer of the assembly, the supply of voltage to the first layer and the second layer generates plasma which is discharged from the first layer.

3. The electrode assembly of claim 2 wherein the first layer comprises rows of wire separated by gaps.

4. The electrode assembly of claim 2 or 3 wherein the second layer comprises a sheet of conducting material.

5. The electrode assembly of any one of claims 1 to 4 further comprising a power source configured to provide power to the electrode assembly such that ionization generated by the system is of the type of a *dark* or *Townsend* discharge.

6. The electrode assembly of any one of claims 5 wherein the power source is further configured to operably ensure that power per unit area applied to the electrode assembly is less than 100 mW/cm^2.

7. The electrode assembly of any one of claims 1 to 6 wherein the dielectric strength of the flexible dielectric layer is at least 100 kV/mm.

8. The electrode assembly of any one of claims 2 to 7 further comprising an insulating layer between the dielectric and at least one of the first and second layers.

9. An air treatment assembly comprising an air conduit and at least one electrode assembly of any one of claims 1 to 8.

10. The assembly of claim 9 wherein the conduit is tubular shaped and the at least one electrode assembly is provided on an interior surface thereof.

11. The assembly of claim 10 comprising a plurality of electrode assemblies configured to form a ring within the conduit.

12. The assembly of 9 wherein the conduit comprises a restricted rectangular section.

13. The assembly of claim 12 wherein the restricted rectangular section holds a plurality of electrode assemblies.

14. An air ducting system comprising:

a power source;

a flexible electrode assembly; and

a ducting section;

wherein the electrode assembly is shaped to match the interior shape of the ducting section and supply of voltage from the power source to the electrode assembly generates plasma which is discharged within the ducting section.

15. The air ducting system of claim 14 wherein the flexible electrode assembly comprises a flexible dielectric layer forming an insulating sheet, a plurality of conductive tracks on a first side of the insulating sheet, and a conductive layer on a second side of the insulating sheet.

16. The air ducting system of claim 14 or 15 wherein the power source is configured to provide power to the electrode assembly such that ionization generated by the system is of the type of a *dark* or *Townsend* discharge.

17. The air ducting system of any one of claims 14 to 16 wherein the power source is configured to operably ensure that power per unit area applied to the electrode assembly is less than 100 mW/cm^2.

AMENDMENTS TO THE CLAIMS HAVE BEEN FILED AS FOLLOWS:

Claims

1. A flexible electrode assembly for an air treatment device comprising:

a flexible dielectric layer forming an insulating sheet;

a plurality of conductive tracks on a first side of the insulating sheet;

a uniform electrically conducting material with no gaps of holes forming a conductive layer on a second side of the insulating sheet; and

an AC power source having a voltage source frequency equivalent to mains frequency and configured to provide power to the electrode assembly such that ionization generated by the assembly is a dark or Townsend type discharge, the power source being further configured to operably ensure that power per unit area applied to the electrode assembly is less than 100 mW/cm^2;

and wherein supply of voltage to the conducting tracks and the conductive layer generates plasma which is discharged from the conducting tracks and further wherein the plurality of conductive tracks form a first layer of the assembly and the conductive layer forms a second layer of the assembly, the supply of voltage to the first layer and the second layer generates a dielectric barrier discharge type plasma which is discharged and sustained only from the first layer.

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2. The electrode assembly of claim 1 wherein the first layer comprises rows of wire separated by gaps.

3. The electrode assembly of claim 1 wherein the second layer comprises a sheet of conducting material.

4. The electrode assembly of any one of claims 1 to 3 wherein the dielectric strength of the flexible dielectric layer is at least 100 kV/mm.

5. The electrode assembly of any one of claims 1 to 4 further comprising an insulating layer between the dielectric and at least one of the first and second layers.

6. An air treatment assembly comprising an air conduit and at least one electrode assembly of any one of claims 1 to 5.

7. The assembly of claim 6 wherein the conduit is tubular shaped and the at least one electrode assembly is provided on an interior surface thereof.

8. The assembly of claim 7 comprising a plurality of electrode assemblies configured to form a ring within the conduit.

9. The assembly of 8 wherein the conduit comprises a restricted rectangular section.

10. The assembly of claim 9 wherein the restricted rectangular section holds a plurality of electrode assemblies.

11. An air ducting system comprising:

a flexible electrode assembly as claimed in any preceding claim; and

a ducting section;

wherein the electrode assembly is shaped to match the interior shape of the ducting section and supply of voltage from the power source to the electrode assembly generates plasma which is discharged within the ducting section.

Intellectual Property Office

Application No:	GB1414244.2	**Examiner:**	Mr Aaron Butt
Claims searched:	1-13	**Date of search:**	23 January 2015

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-13	JP 2004006152 A (SHARP KK) See whole document and Figs
X	1-13	JP H107405 A (KANEGAFUCHI CHEMICAL) See WPI Abst. No. 1998-125958 and Figs.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

A61L; H01T; H05H

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
A61L	0009/22	01/01/2006
H05H	0001/24	01/01/2006

Intellectual Property Office

Application No:	GB1414244.2	**Examiner:**	Mr Aaron Butt
Claims searched:	14-17	**Date of search:**	25 March 2015

Patents Act 1977
Further Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	14-17	JP 2004006152 A (SHARP KK) See whole document and Figs.
X	14-17	WO 2014/119349 A1 (CREATIVE TECH CORP) See WPI Abst. No. 2014-P45568 and Figs
X	14-17	JP H107405 A (KANEGAFUCHI CHEMICAL) See WPI ABst. No 1998-125958 and Figs.
X	14-17	US 2010/157503 A1 (Saito) See whole document, esp. Paras. [0103], [0121] and Figs.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

A61L; F24F; H01T; H05H

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International Classification:

Subclass	Subgroup	Valid From
A61L	0009/22	01/01/2006
H05H	0001/24	01/01/2006