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(71) Applicant: **LOUGHBOROUGH UNIVERSITY** [GB/GB]; Loughborough LE 11 3TU (GB).

(72) Inventors: **IZA, Dr Felipe;** Loughborough University, Loughborough LE1 1 3TU (GB). **SHAW, Dr Alexander;** Loughborough University, Loughborough LEI 1 3TU (GB). **WRIGHT, Dr Alexander;** Loughborough University, Loughborough LEI 1 3TU (GB). **BUCKLEY, Dr Benjamin;** Loughborough University, Loughborough LE1 1 3TU (GB).

(74) Agent: **BARKER BRETTELL LLP;** 100 Hagley Road, Edgbaston, Birmingham West Midlands B 16 8QQ (GB).

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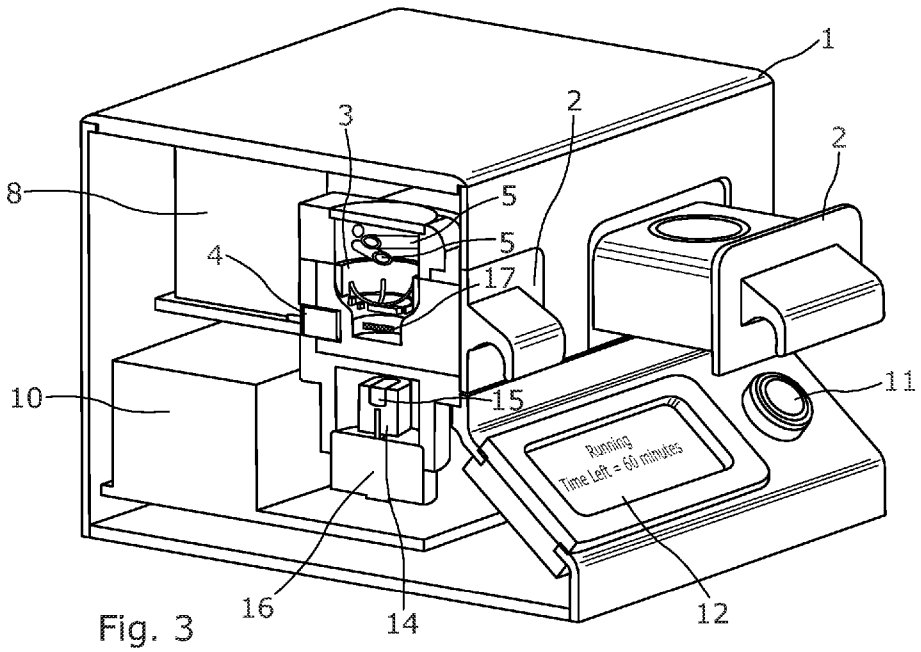

Fig. 3

(57) Abstract: The invention relates to an apparatus for treating a contact lens, and method of use thereof, allowing cleaning and/or disinfecting of contact lenses. The apparatus comprises a reservoir for an aqueous solvent, arranged to receive the contact lens; and a source of ionised gas plasma proximate to the reservoir. The method comprises placing the contact lens into the solvent; producing ionised gas plasma which generates reactive species proximate to the contact lens; and dissolving the reactive species into the solvent so as to form an aqueous solution.

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TREATING A CONTACT LENS

This invention relates to a method of, and apparatus for, treating a contact lens.

Over 125 million people use contact lenses worldwide, including 3.7 million people in the United Kingdom and 40.9 million people in the United States. Any contact lens that is to be used more than once (that is, excluding "disposable" contact lenses) will need to be cleaned to remove protein deposits and dust accumulated on the lens and to disinfect the lens to destroy or inactivate any pathogens, such as bacteria, yeast or viruses. However, many users find this task an unwelcome chore, and may not always give the task the attention it requires.

The greatest risk to a contact lens wearer is eye infections due to organisms such as Acanthamoeba. Almost a third of contact lens wearers experience contact lens related eye problems requiring a doctor's visit and infection is the leading cause of keratitis, an inflammation of the cornea. There are approximately one million healthcare visits per year in the United States for keratitis at an annual cost of US$175 million, typically due to contact lens use. Without daily cleaning, the wearer's eye health is at serious risk.

Current lens cleaning solutions are chemical based and there are two main types: hydrogen peroxide based solutions and so-called multipurpose lens cleaning solutions. Hydrogen peroxide is effective at killing microorganisms but requires several cleaning stages and has the risk of causing eye irritation when not used properly. Multi-purpose solutions vary in their composition and typically contain a mild abrasive (e.g. silica gel particles), detergents or surfactants (e.g. tetronics 1304, poloxamer 407) and preservatives and chelating agents (e.g. ascorbic acid and edetate disodium). Some may include mild disinfectants (e.g. boric acid, poly-hexyl-methyl-biguanide PHMB and polyquaterium-l polyquad). These are more convenient to use but are less effective and in recent years outbreaks of fungal eye infections have triggered international recalls due to lack of sterility.

As such, an alternative approach to the cleaning of contact lenses is desirable.

According to a first aspect of the invention, we provide a method of treating a contact lens, comprising:

- placing the contact lens in an aqueous solvent;
- producing an ionised gas plasma which generates reactive species proximate to the contact lens in the aqueous solvent; and
- dissolving the reactive species into the aqueous solvent so as to form an aqueous solution.

Thus, by generating an ionised gas plasma generating reactive species and allowing those reactive species to dissolve to form a solution, the contact lens in that solution will be treated by the solution. We have found that the reactive species generated by an ionised gas plasma when dissolved to form an aqueous solution have a disinfecting or anti-microbial effect. Likewise, they can also break down protein. By generating the ionised gas plasma proximate to the contact lens in the aqueous solvent, issues of storing and transporting a solution of the species formed are eliminated or at least ameliorated.

Typically, the aqueous solvent is, or comprises, water. This can comprise, consist or consist essentially of deionised water, sterilised water, buffered water (e.g. phosphate buffered saline (PBS), borate buffer), saline solution, peroxide containing solution, surfactant containing solution, buffered saline solution (e.g. PBS), Ringer's solutions, tap or potable water.

Water is very readily available to most contact lens wearers. Given the disinfectant or anti-microbial effect of the ionised gas plasma, microorganisms present in municipal tap water are readily inactivated.

The step of producing the ionised gas plasma may comprise using an ionised gas plasma source. In order to be proximate to the contact lens in the aqueous solvent, the ionised gas plasma may be produced, and the ionised gas plasma source may be within 50cm, 30cm, 20cm, lOcm, 5cm or even in direct contact with the aqueous solvent containing the contact lens.

The method may comprise the step of allowing or causing the reactive species generated by the ionised gas plasma to move from where they are produced to the

aqueous solvent containing the contact lens. The ionised gas plasma may be produced above the aqueous solvent containing the contact lens, in which case the reactive species may travel downwards to the aqueous solvent through the action of diffusion or gravity. The method may comprise applying an electric field or convection in order to promote or cause the movement of the reactive species to the aqueous solvent.

The ionised gas plasma may be formed in atmospheric air. This is plentiful, and is a useful source of both oxygen and nitrogen gas as precursors to form reactive species. Other oxygen and nitrogen containing gas mixtures such as helium/oxygen and argon/oxygen admixtures may also be used. In these cases, the gas mixture would need to be fed into the location where the ionised gas plasma is located, typically from small re-usable or single used gas canisters.

The ionised gas plasma source may comprise at least two electrodes, and the step of producing an ionised gas plasma may comprise applying a voltage between the electrodes. Each electrode may be elongate, having a length. The electrodes may form pairs; with two electrodes there will be a single pair. Each pair of electrodes may be positioned so as to be skew, so that the lengths of the electrodes are non-parallel but the electrodes are spaced apart. Each pair of electrodes will define a crossing zone between and around the points along the length of each electrode where the other electrode of each pair comes closest. On application of a voltage between the electrodes, ionised gas plasma will be produced in the crossing zone. The minimum distance between the electrodes may be between 10 micrometres and 10 millimetres, typically between 0.5mm and l.5mm.

Typically, the ionised gas plasma will be produced from ambient air at room temperature and pressure; that is with the temperature of the aqueous solvent or the temperature of the air from which the ionised gas plasma is formed between 0 and 50 degrees Celsius, and at 1 atmosphere ± 0.2 atm, 0.1 atm, 0.05atm or O.Olatm. The ionised gas plasma may be formed in ambient air surrounding the ionised gas plasma source, without first heating, cooling, pressuring and/or depressurising the ambient air.

The reactive species may comprise ozone. The aqueous solution may achieve a concentration of ozone of at least 0.01 milligrammes per litre (mg/l), 0.1 mg/l, 1 mg/l,

lOmg/l, lOOmg/l or 250mg/l. The reactive species may additionally or alternatively comprise at least one of Nitric Oxide (NO), Hydrogen Peroxide (H_20_2), Hydroxyl radicals (OH), Hydron ions (H^+), Nitrate ions ($N0_3^-$), Nitrite ions ($N0_2^-$) and Oxygen atoms (O).

The method may comprise leaving the contact lens in the aqueous solution for a first period, which may be at least 5 seconds, 30 seconds, 1 minute, 5 minutes, 10 minutes, 30 minutes, 1 hour, 2 hours. 4 hours or 8 hours. The production of ionised gas plasma and/or the dissolution delivery of the reactive species may continue throughout the first period, or may be limited to a second period shorter than the first period but which is at least 5 seconds, 30 seconds, 1 minute, 5 minutes, 10 minutes, 30 minutes, 1 hour, 2 hours, 4 hours or 8 hours.

The method may comprise stirring the aqueous solvent during generation of the ionised gas plasma, typically using a magnetic or mechanical stirrer, convection and advection, Marangoni effect or electro-hydrodynamic effects.

The method may result in the inactivation of pathogens on or in the contact lens, such as viruses, Gram-positive and Gram-negative bacteria, fungi, yeasts and amoebas. It may also result in the removal and/or destruction of protein on or in the contact lens.

The aqueous solvent may be present in a volume of at most 50ml, 25ml, lOml, 5ml, 2ml, lml or 0.2ml. As such, this is sufficient to treat a single contact lens, or possibly two. Alternatively, the aqueous solvent may be present in two volumes, each of at most 50ml, 25ml, lOml, 5ml 2ml, lml or 0.2ml. In such an embodiment, the method may treat two contact lenses, with one lens placed in each volume, as it is recommended practice to keep right and left lenses separately.

In accordance with a second aspect of the invention, there is provided an apparatus for treating a contact lens, comprising:

- a reservoir for an aqueous solvent, arranged to receive the contact lens;
- a source of an ionised gas plasma proximate to reservoir;

in which the reservoir and the source are so relatively arranged within the apparatus that, in use, reactive species are produced from ionised gas plasma generated by the

ionised gas plasma source, and in which the reactive species flow from the source to the reservoir so as to dissolve in aqueous solvent in the reservoir.

Thus, by generating an ionised gas plasma and allowing reactive plasma species thus formed to dissolve to form an aqueous solution, the contact lens in that solution will be treated by the solution. We have found that the reactive species generated by an ionised gas plasma when dissolved to form an aqueous solution have a disinfecting or anti-microbial effect. Likewise, they can also break down protein. By generating the ionised gas plasma proximate to the contact lens in the aqueous solvent, issues of storing and transporting a solution of the species formed are eliminated or at least ameliorated.

Typically, the solvent used for the solution is, or comprises, water. This can comprise, consist or essentially consist of deionised water, sterilised water, buffered water (e.g. phosphate buffer, borate buffer), saline solution, buffered saline solution (e.g. PBS), Ringer's solutions, tap or potable water.

Water is very readily available to most contact lens wearers. Given the disinfectant or anti-microbial effect of the ionised gas plasma, microorganisms present in municipal tap water are readily inactivated.

The ionised gas plasma source may be within 50cm, 30cm, 20cm, lOcm, 5cm or in direct contact with the reservoir. The ionised gas plasma source may be above, in use, the reservoir, in which case reactive species produced in the ionised gas plasma travel downwards to the aqueous solvent. The apparatus may additionally or alternatively comprise means for applying an electric field or convection in order to promote or cause the movement of the reactive species from the source to the reservoir.

The source may be arranged to generate the ionised gas plasma from atmospheric air. This is plentiful, and is a useful source of both oxygen and nitrogen gas as precursors to form reactive species. Other oxygen and nitrogen containing gas mixtures such as helium/oxygen and argon/oxygen admixtures may also be used. In these cases, the apparatus may comprise delivery means for delivering the gas mixture to the ionised gas plasma source, typically from re-usable or single use gas canisters.

The source may comprise at least two electrodes. Each electrode may be elongate, having a length. The electrodes may form pairs; with two electrodes there will be a single pair. Each pair of electrodes may be positioned so as to be skew, so that the lengths of the electrodes are non-parallel but the electrodes are spaced apart. Each pair of electrodes will define a crossing zone between and around the points along the length of each electrode where the other electrode of each pair comes closest. The source may further comprise a voltage source arranged to apply a voltage between the electrodes. When this voltage is applied, ionised gas plasma will be produced in the crossing zone. The minimum distance between the electrodes may be between 10 micrometres and 10 millimetres, typically between 0.5mm and l.5mm.

Each electrode may comprise a metallic member surrounded by an encapsulating dielectric shield, such as a glass tube or ceramic coating. This limits the discharge current although the same could be achieved by quickly pulsing the applied voltage.

Typically, the voltage applied to generate the plasma will be at least 0.5 kilovolts (kV), lkV, 5kV, lOkV, 20kV or 40kV. The voltage may be an alternating current (AC) voltage, having a frequency. The frequency may be between 50Hz and 2.45GHz, and the voltage may be modulated so as to comprise alternating plasma-on periods where the voltage varies at the frequency and plasma-off periods where the voltage does not vary and will typically be zero. This may minimize heating of the solution and reduce power consumption. Alternatively, the voltage can be applied as pulses with a pulse width duration between 0.1 nanosecond and 1000 milliseconds.

Typically, electrical power to generate the plasma will be drawn from mains, a low-voltage DC supply (e.g. USB charger) or batteries.

Typically, the apparatus will be operable to produce ionised gas plasma at room temperature and pressure; but it may be so operable with the temperature of the aqueous solvent or the temperature of the air from which the ionised gas plasma is formed between 0 and 50 degrees Celsius, typically between 10 and 40 degrees Celsius, potentially between 15 and 30 degrees Celsius, and at 1 atmosphere ± 0.2 atm, 0.1 atm, 0.05atm or O.Olatm. The source may provide reactive species formed from ambient air surrounding the ionised gas plasma source, without first heating, cooling, pressuring and/or depressurising the ambient air.

The reactive species may comprise ozone. The aqueous solution may achieve a concentration of ozone of at least 0.01 milligrams per litre (mg/l), 0.1 mg/l or 1 mg/l. The reactive species may additionally or alternatively comprise at least one of Nitric Oxide (NO), Hydrogen Peroxide (H_20_2), Hydroxyl radicals (OH), Hydron ions (H^+), Nitrate ions ($N0_3^-$), Nitrite ions ($N0_2^-$) and Oxygen atoms (O).

The reservoir may have a volume for aqueous solvent of at most 50ml, 25ml, lOml, 5ml, 2ml, lml or 0.2ml. As such, this is sufficient to treat a single contact lens, or possibly two. Alternatively, there may be two reservoirs, each of at most 50ml, 25ml, lOml, 5ml, 2ml, 1 ml or 0.2ml. In such an embodiment, the apparatus may treat two contact lenses, with one lens placed in each reservoir, as it is recommended practice to keep right and left lenses separately.

The apparatus may comprise a body having at least one drawer, with each reservoir being formed in a drawer. Typically, each drawer will have an open state in which each reservoir formed therein can be accessed by a user (so that, for example, the user can fill it with aqueous solvent and a contact lens) and a closed position where the drawer is received within the apparatus to a maximum extent. The apparatus may comprise a sensor for the closure of each drawer; the source of ionised gas plasma may not be allowed to produce ionised gas plasma until each sensor indicates that each drawer is closed. Typically, the sensor would comprise a contact sensor such as a microswitch.

The apparatus may comprise an agitator, such as a magnetic or mechanical stirrer, to mix the solvent or solution in the reservoir. Alternatively, means can be provided for promoting convection, advection, Marangoni effect or the electro-hydrodynamic effect in the reservoir to induce mixing.

Throughout the above aspects, treating will typically comprise cleaning. Additionally or alternatively it may comprise disinfecting, protein degradation or removal, or surface treatment of the contact lens.

There now follows, by way of example only, description of embodiments of the invention, described with reference to the accompanying drawings, in which:

Figure 1 shows a perspective view of an apparatus according to a first embodiment of the invention;

Figure 2 shows a cut-away perspective view of the apparatus of Figure 1, through an open drawer;

Figure 3 shows a cut-away perspective view of the apparatus of Figure 1, through a closed drawer;

Figure 4 shows a plan view of the electrodes of the apparatus of Figure 1;

Figure 5 shows a side-view cross-section of the electrodes of Figure 4;

Figure 6 shows a graph of the dissolution of potassium indigotrisulfonate using the apparatus of Figure 1;

Figure 7 shows a graph showing protein being destroyed by the apparatus of Figure 1; and

Figures 8 to 15 show alternative embodiments of the electrodes of the apparatus of Figure 1.

An apparatus for treating contact lenses is shown in Figures 1 to 5 of the accompanying drawings. It comprises a housing 1 in which are mounted two drawers 2 which can slide into and out of the housing 1. In each drawer there is a well 3 which can hold approximately 2 ml of fluid. A microswitch 4 is provided inside the housing behind each drawer 2 to detect when the drawer 2 is closed (that is, fully received into the housing 1). Typically, a user would fill each well 3 with an aqueous solvent, typically water or a buffered solution, and place a contact lens in each well 3. The drawers 2 can be entirely withdrawn from the housing to tip out any remaining liquid in the wells 3 after use, and then replaced.

The apparatus is also provided with a pair of elongate electrodes 5 above each well 3, each pair of electrodes 5 being connected to an output stage of a power supply 8. As shown in Figures 4 and 5 of the accompanying drawings, each electrode 5 comprises a central conducting wire 7, surrounded by a dielectric tube 6. The wire 7 is typically metallic, but could comprise graphite, stainless steel, copper, a conductive liquid or water, or any other suitable conductor; the dielectric is typically borosilicate glass, but could comprise polytetrafluoroethylene (PTFE) or other plastics, ceramics, alumina, Macor (RTM) or other machineable glass-ceramic mixtures, reinforced glass fibre or quartz, or any other suitable dielectric.

The two electrodes 5 are provided so that, with the housing 1 on a flat horizontal surface, the electrodes 5 are both horizontal, with their lengths parallel to the horizontal surface. However, the electrodes 5 are skew to each other, in that they are non-parallel but do not intersect, being spaced apart from each other vertically; in plan view (as shown in Figure 4 of the accompanying drawings) they form an X-shape, with only a small gap (1 mm) where they cross.

The power supply 8 is arranged to provide a voltage between the two electrodes 5; however, it will not do so unless the microswitches 4 indicate that both drawers 2 are closed. Typically, the voltage will be a sinusoidal excitation wave of around 20 kilovolts (kV) peak to peak at a frequency of around 30kHz. The signal can be modulated to comprise pulses having a 5% duty cycle (so each cycle would comprise 5% of the cycle with the voltage comprising a 20kV sinusoidal signal and the other 95% essentially at zero voltage).

When this voltage is applied between the electrodes, an ionised gas plasma 9 is formed in the region where the electrodes 5 cross, from the ambient air at the local temperature and pressure. This ionised gas plasma 9 then generates reactive species from air such as Nitric Oxide (NO), Ozone (0_3), Hydrogen Peroxide (H_20_2), Hydroxyl radicals (OH), Hydron ions (H^+), Nitrate ions ($N0_3^-$), Nitrite ions ($N0_2^-$) and Oxygen atoms (O). The ionised gas plasma can also generate ultraviolet (UV) radiation. These reactive species 9 reach the aqueous solvent by either passive diffusion, convection or mixing caused by moving solvent in the wells 3 and dissolves into the aqueous solvent in the well 3.

Thus, the dissolution of the reactive species 9 into the aqueous solvent in each well 3 forms an active aqueous solution with reactive species. These will act to disinfect the lens in each well 3, and to remove and destroy protein residues that have been deposited on the lens.

A magnetised stirrer 14 is provided to agitate the solution in the well. This comprises a motor 16 driving a magnet 15 for rotation. A magnetic stirrer bar 17 within the well is driven for rotation by rotation of the magnet 15.

A control unit 10 is provided which controls the functions of the apparatus. Control buttons 11 and a display 12 form a user interface controlled by the control unit 10 so that the user can command the apparatus to commence production of ionised gas plasma 9 and the length of time for which it may do so using the buttons 11, and be informed through the display 12 how much time is remaining.

The creation of reactive species and their dissolving in the aqueous solvent can disinfect and remove protein from a contact lens in the aqueous solution. In particular, it can inactivate *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Serratia marcescens*, *Candida albicans* and *Fusarium solani*, as well as bacteria, fungi, yeasts and other pathogens suspended in the liquid and on the lens surface.

In order to demonstrate the efficacy of this apparatus, Figure 6 of the accompanying drawings demonstrates how successful the apparatus is at breaking down potassium indigotrisulfonate. Potassium indigotrisulfonate is commonly used as a chemical probe for reactive species as it breaks down in their presence.

2ml of a 2 ml/l solution of potassium indigotrisulfonate in water was placed in the well 3 of the apparatus of Figure 1 and ionised gas plasma was generated. The concentration of potassium indigotrisulfonate at various times throughout the production of ionised gas plasma is shown in trace 11 of Figure 6 (normalised to a starting value of 1). A commercial hydrogen peroxide contact lens cleaning solution (Oxysept) (trace 18) and a common multi-purpose contact lens cleaning solution (Optifree) (trace 13) were also used with identical potassium indigotrisulfonate solutions combined in 50:50 ratios, and the concentration of potassium

indigotrisulfonate remaining with time of treatment with those solutions is also shown in Figure 6 as a comparison, again normalised to a starting value of 1.

It can therefore be seen that the above apparatus generating the ionised gas plasma is much quicker at destroying potassium indigotrisulfonate than the prior art solutions; this suggests that the apparatus would be useful in disinfecting contact lenses.

Figure 7 of the accompanying drawings demonstrates the apparatus' ability to destroy protein. 2ml of lmg/l bovine serum albumin (BSA) solution was placed in the well 3 and ionised gas plasma generated. The absorbance at 590nm was used to characterise the amount of protein present. This is shown in Figure 7 at various times through the generation of ionised gas plasma, normalised to a starting value of 1. This suggests that in addition to its disinfecting capabilities, the apparatus would be useful in destroying protein deposited on contact lenses.

A device in accordance with the above embodiment was tested using the test procedure set out in "BS EN ISO 14729:2001 +Al:20l0 BS 7208-26:2001 Ophthalmic optics - Contact lens care products - Microbiological requirements and test methods for products and regimens for hygienic management of contact lenses". The solution formed was found to meet the standard, with a recommended cleaning time of 30 minutes.

In this test procedure, each of the following test inocula were placed in well 3 suspended in Dulbecco's phosphate-buffered saline (DPBS) and the device turned on. Neutralisation of the solution was achieved using a neutralizing agent prior to dilutions being spread on agar. In addition, as a fail-safe, D/E Neutralizing Broth was used for dilutions.

Incubation times were as follows:

Pseudomonas aeruginosa	ATCC 9027	TSA	34° C	18h
Staphylococcus aureus	ATCC 6538	TSA	34° C	18h
Serratia marcescens	ATCC 13880	TSA	34° C	18h

Candida albicans	ATCC 10231	SDA	34°C	18h

After incubation on agar, the results were as follows, showing the number of colony forming units (CFU) per millilitre after the time given in the aqueous solution in the well 3 with the device turned on (so for the zero time samples below, this shows the amount of the test substance present before the device is turned on):

Pseudomonas aeruginosa ATCC 9027

Time (m)	**CFU/ml**
0	2.16E+06
7.5	0
15	0
22.5	0
30	0

Staphylococcus aureus ATCC 6538

Time (m)	**CFU/ml**
0	1.14E+06
7.5	0
15	0
22.5	0
30	0

Serratia marcescens ATCC 13880

Time (m)	**CFU/ml**
0	1.91E+06
7.5	0
15	0
22.5	0
30	0

Candida albicans ATCC 10231

Time (m)	**CFU/ml**
0	2.76E+05

7.5	5.89E+01
15	0
22.5	0
30	0
120	0

Fusarium solani ATCC 3603 1

Time (m)	**CFU/ml**
0	3.64E+04
7.5	5.44E+03
15	3.37E+02
22.5	2.83E+02
30	1.13E+02
120	1.14E+02

In all cases, the results show the required reduction in each test subject in order to meet the standard set out above.

Alternative embodiments of the electrodes and well are shown in Figures 8 to 15 of the accompanying drawings. These could generally be used in place of the electrodes 5 and well 3 shown above. The dielectric and electrode material can be as suggested above with respect to the first embodiment.

In the second embodiment of the invention shown in Figure 8, the reference numerals of the first embodiment are used, raised by 20. In this embodiment, the well 23 contains an aqueous solvent 31 such as water or a buffered solution. A contact lens 32 is positioned in the aqueous solvent 31. Rather than using crossed electrodes, a dielectric plate 26 is used mounted above the well 23. On the upper surface of the dielectric plate are mounted two encapsulated parallel electrodes 25; wires 34 lead to a power supply (not shown) for the application of the voltage. The electrodes 25 are backed by resin insulation 33.

In this embodiment, application of the voltage will cause ionised gas plasma to be formed on the bottom surface of the dielectric plate 26, above the well 23. Reactive

species generated in the plasma will then diffuse downwards into the well 23 to dissolve in the aqueous solvent 51.

In the third embodiment of the invention shown in Figure 9 of the accompanying drawings, the reference numerals have been raised by 40 with respect to the first embodiment. In this embodiment, a well 43 contains an aqueous solvent 51 in which has been placed a contact lens 52. There are two electrodes 45 each comprising a central metallic rod 47 (with wires 54 to connect to the unshown power supply) surrounded by dielectric 46. The ends of the electrodes 45 are adjacent; on application of a voltage between the electrodes 45, plasma 49 will form between the ends of the electrodes 45 and reactive species generated in the plasma diffuse downwards into the aqueous solvent.

In the fourth embodiment of the invention shown in Figure 10 of the accompanying drawings, the reference numerals have been raised by 60 with respect to the first embodiment. In this embodiment, a well 63 contains an aqueous solvent 71 in which has been placed a contact lens 72. There is a single electrode 63 (with wire 74 to connect to the unshown power supply) terminated by a dielectric plate 26. A further wire 75 is provided terminating in the aqueous solvent 71, which will need to be conductive (typically a salt solution). On application of a voltage between the wires 74, 75, plasma 69 will form underneath the dielectric plate 26 beneath the electrode 63 and reactive species generated in the plasma diffuse downwards into the aqueous solvent.

In the fifth embodiment of the invention shown in Figure 11 of the accompanying drawings, the reference numerals have been raised by 80 with respect to the first embodiment. In this embodiment, the well 82 containing the aqueous solvent 91 and the contact lens 92 is larger, and as its bottom face has a porous membrane 96. Electrodes 85 are placed underneath, with their ends uppermost. Each electrode 85 comprises a central metallic (etc) rod 87 surrounded by a dielectric crucible. Air is passed upwards around the electrodes through the porous membrane to form bubbles 97 in the aqueous solvent.

In order to form a plasma 89 adjacent to the ends of the electrodes 85 and the porous membrane 96, the aqueous solvent can be used as another electrode as in the fifth

embodiment (so that a wire would be placed in the conductive aqueous solvent 91) or the porous membrane could be conductive and used an electrode. Applying a voltage between either the membrane 96 or the aqueous solvent 91 on the one hand and the electrodes 85 on the other will cause a plasma to be formed adjacent to the underside of the porous membrane 96 and swept up with airflow 98 to form the bubbles 97. The content of the bubbles 97, including reactive species generated in the ionised gas plasma, will then dissolve in the aqueous solvent 91.

In the sixth embodiment of the invention shown in Figure 12 of the accompanying drawings, the reference numerals have been raised by 100 with respect to the first embodiment. In this embodiment, a well 103 contains an aqueous solvent 111 in which has been placed a contact lens 112. A dielectric sheet 106 separates two sets of electrodes 105a, 105b; a single planar electrode 105a on the top side of the dielectric sheet and a plurality of patch or elongate electrodes 105b on the bottom side, facing the well 102. On application of a voltage between the electrodes 105a, 105b, plasma 109 will form around the electrodes 105b on the bottom side of the dielectric plate 106, and reactive species generated in the plasma diffuse downwards into the well 102.

In the seventh embodiment of the invention shown in Figure 13 of the accompanying drawings, the reference numerals have been raised by 120 with respect to the first embodiment. In this embodiment, which is similar to the fourth embodiment, a well 123 contains an aqueous solvent 131 in which has been placed a contact lens 132. There is a single needle electrode 123 (with wire 134 to connect to the unshown power supply). A further wire 135 is provided terminating in the aqueous solvent 131, which will need to be conductive (typically a salt solution). On application of a voltage between the wires 134, 135, plasma 129 will form in a jet from the end of needle electrode 123 and reactive species generated in the plasma will spray downwards into the aqueous solvent 131. In this embodiment, the applied voltage can be either DC or AC.

In the eighth embodiment of the invention shown in Figure 14 of the accompanying drawings, the reference numerals have been raised by 140 with respect to the first embodiment. In this embodiment, a well 143 formed of dielectric material contains an aqueous solvent 151 in which has been placed a contact lens 152. There are two plate

electrodes l45a, l45b, one above and one below the well 143 (with wires 154 to connect to the unshown power supply). On application of a voltage between the electrodes 145, plasma 149 will form between the electrodes 145 and reactive species generated in the plasma diffuse into the aqueous solvent, potentially aided by the electric field formed by the electrodes l45a, l45b.

In the ninth embodiment of the invention shown in Figure 15 of the accompanying invention, the reference numerals have been raised by 160 with respect to the first embodiment. In this embodiment, a well 163 formed of dielectric material contains an aqueous solvent 171 in which has been placed a contact lens 172. There are a plate electrode l65a below the well and a needle electrode 165b above the well 163. On application of a voltage between the electrodes l65a, l65b, plasma 169 will form between the electrodes 165a, l65b, with reactive species generated in the plasma spraying from needle electrode 165b into the aqueous solvent 171, potentially aided by the electric field formed by the electrodes l65a, 165b.

CLAIMS

1. A method of treating a contact lens, comprising:
   - placing the contact lens in an aqueous solvent;
   - producing an ionised gas plasma which generates reactive species proximate to the contact lens in the aqueous solvent; and
   - dissolving the reactive species into the aqueous solvent so as to form an aqueous solution.

2. The method of claim 1, in which the aqueous solvent is, or comprises, water.

3. The method of claim 1 or claim 2, in which the aqueous solvent comprises, consists or consists essentially of deionised water, sterilised water, buffered water (e.g. phosphate buffer solution (PBS), borate buffer), saline solution, peroxide containing solution, surfactant containing solution, buffered saline solution (e.g. PBS), Ringer's solutions, tap or potable water.

4. The method of any preceding claim, in which the ionised gas plasma is produced within 50cm, 30cm, 20cm, lOcm, 5cm or even in direct contact with the aqueous solvent containing the contact lens.

5. The method of any preceding claim, comprising the step of allowing or causing the reactive species generated by the ionised gas plasma to move from where they are produced to the aqueous solvent containing the contact lens.

6. The method of claim 5, in which the ionised gas plasma is produced above the aqueous solvent containing the contact lens, such that the reactive species travel downwards to the aqueous solvent through the action of diffusion or gravity.

7. The method of claim 5 or claim 6, comprising applying an electric field or convection in order to promote or cause the movement of the reactive species to the aqueous solvent.

8. The method of any preceding claim, in which the ionised gas plasma is formed in atmospheric air.

9. The method of any preceding claim, in which the ionised gas plasma is formed by an ionised gas plasma source comprising at least two electrodes, and the step of producing an ionised gas plasma comprises applying a voltage between the electrodes.

10. The method of any preceding claim, in which the ionised gas plasma is produced from ambient air at room temperature and pressure.

11. The method of any preceding claim, in which the reactive species comprises ozone, and in which the aqueous solution may typically achieve a concentration of ozone of at least 0.01 milligrammes per litre (mg/l), 0.1 mg/l, 1 mg/l, lOmg/l, lOOmg/l or 250mg/l.

12. The method of any preceding claim, in which the reactive species comprises at least one of Nitric Oxide (NO), Hydrogen Peroxide (H_20_2), Hydroxyl radicals (OH), Hydron ions (H^+), Nitrate ions ($N0_3^-$), Nitrite ions ($N0_2^-$) and Oxygen atoms (O).

13. An apparatus for treating a contact lens, comprising:

- a reservoir for an aqueous solvent, arranged to receive the contact lens;
- a source of an ionised gas plasma proximate to reservoir;

in which the reservoir and the source are so relatively arranged within the apparatus that, in use, reactive species are produced from ionised gas plasma generated by the ionised gas plasma source, and in which the reactive species flow from the source to the reservoir so as to dissolve in aqueous solvent in the reservoir.

14. The apparatus of claim 13, in which the ionised gas plasma source is within 50cm, 30cm, 20cm, lOcm, 5cm or in direct contact with the reservoir.

15. The apparatus of claim 13 or claim 14, in which the ionised gas plasma source is above, in use, the reservoir.

16. The apparatus of any of claims 13 to 15, in which the source comprises at least two electrodes.

17. The apparatus of claim 16, in which each electrode is elongate and has a length, with the electrodes forming pairs and each pair of electrodes being positioned so as to be skew, so that the lengths of the electrodes are non-parallel but the electrodes are spaced apart so that each pair of electrodes will define a crossing zone between and around the points along the length of each electrode where the other electrode of each pair comes closest.

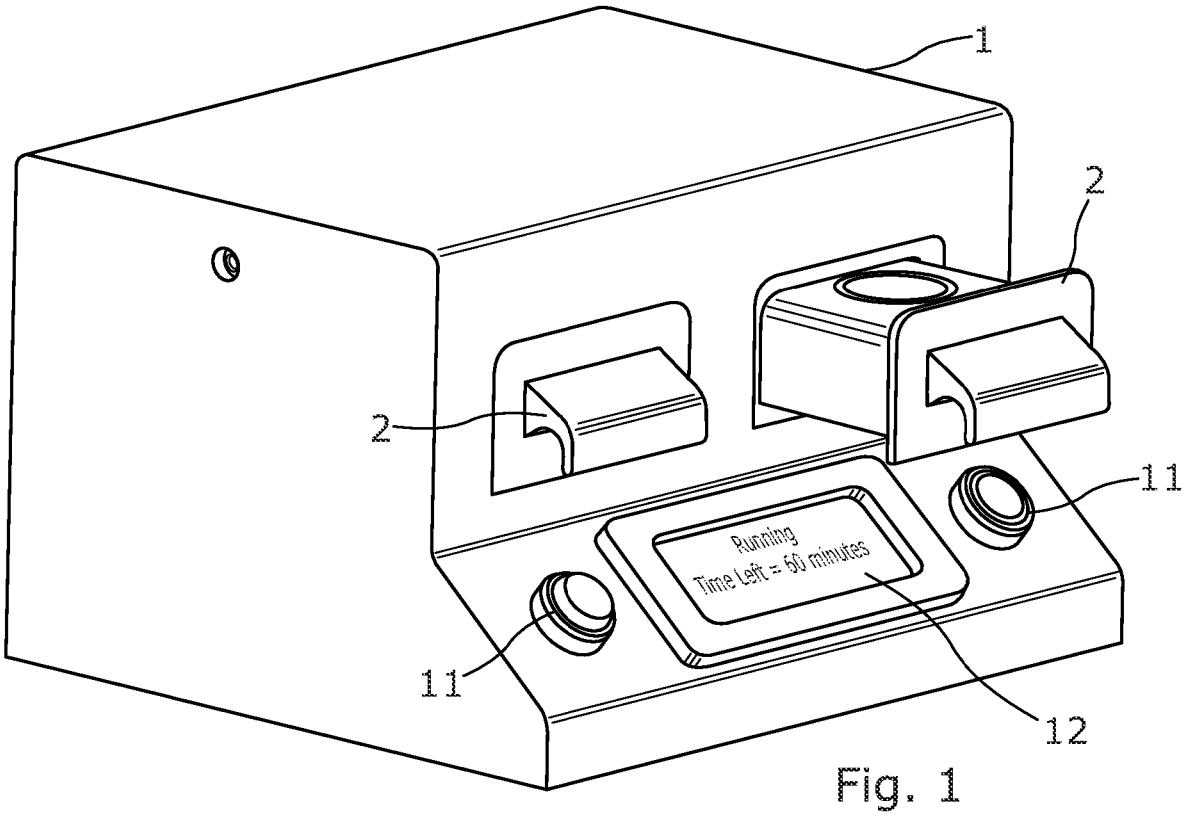
18. The apparatus of claim 16 or claim 17 in which the source further comprises a voltage source arranged to apply a voltage between the electrodes.

19. The apparatus of any of claims 13 to 18, in which the reservoir has a volume for aqueous solvent of at most 50ml, 25ml, lOml, 5ml, 2ml, lml or 0.2ml.

20. The apparatus of any of claims 13 to 19, comprising a body having a drawer, the each reservoir being formed in the drawer, the drawer having have an open state in which the reservoir can be accessed by a user and a closed position where the drawer is received within the apparatus to a maximum extent.

21. The apparatus of claim 20, comprising a sensor for the closure of the drawer.

22. The apparatus of any of claims 13 to 21, comprising an agitator, to mix the solvent or solution in the reservoir.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Running
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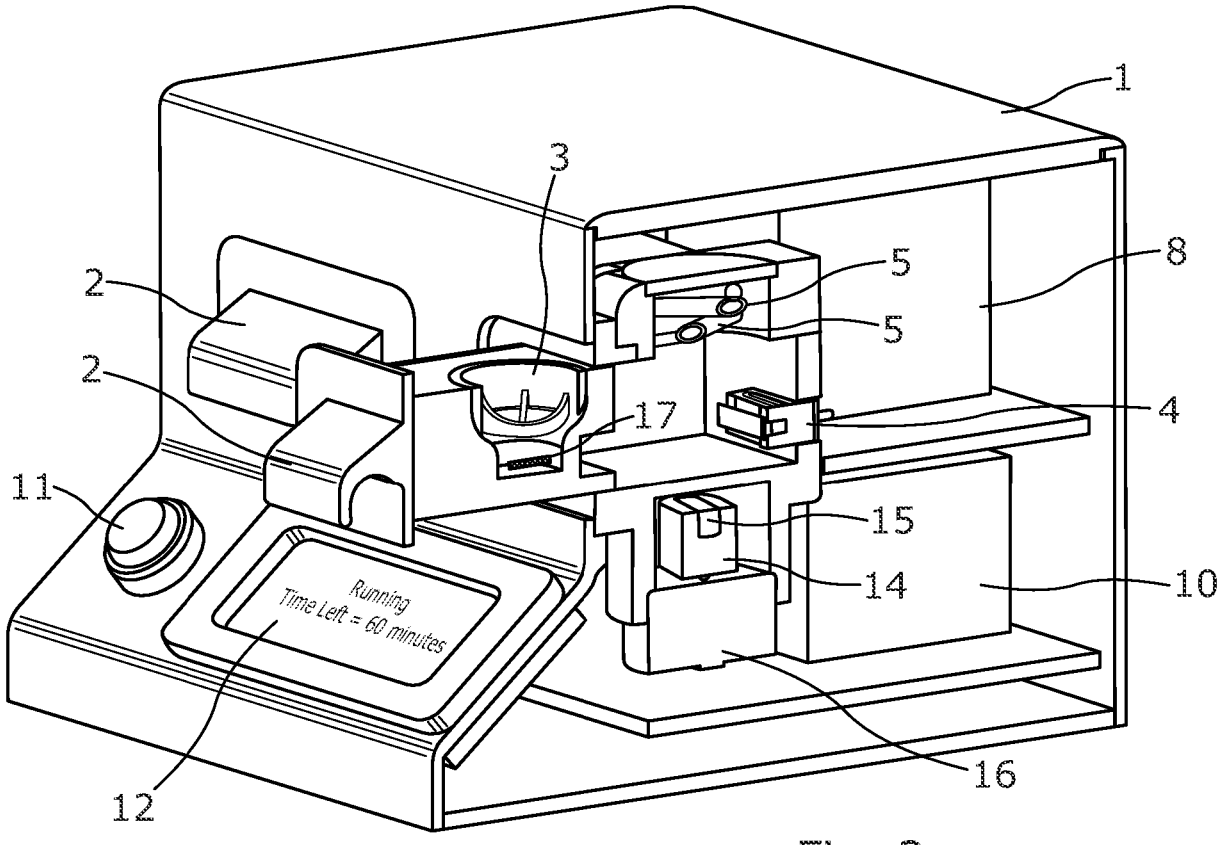
12

Fig. 1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14
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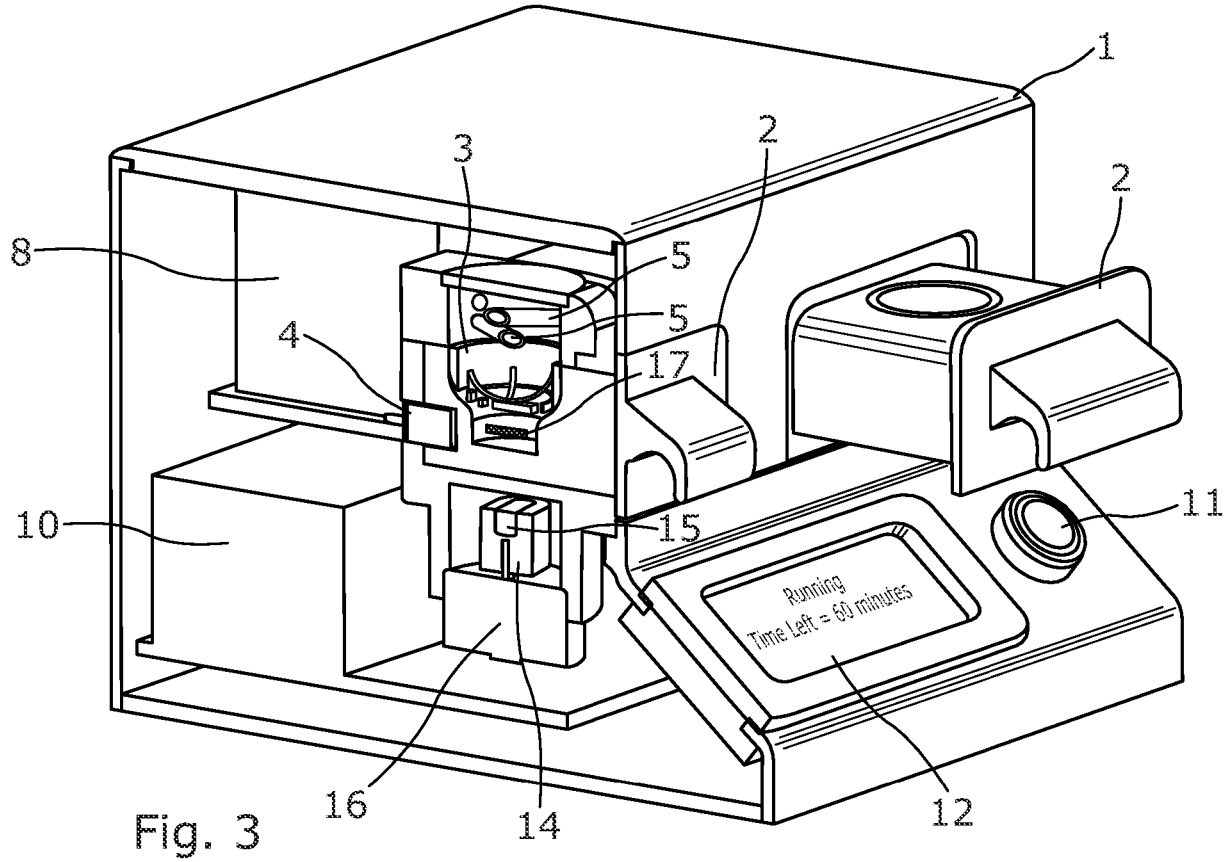
12
16

Fig. 2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Running
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Fig. 3

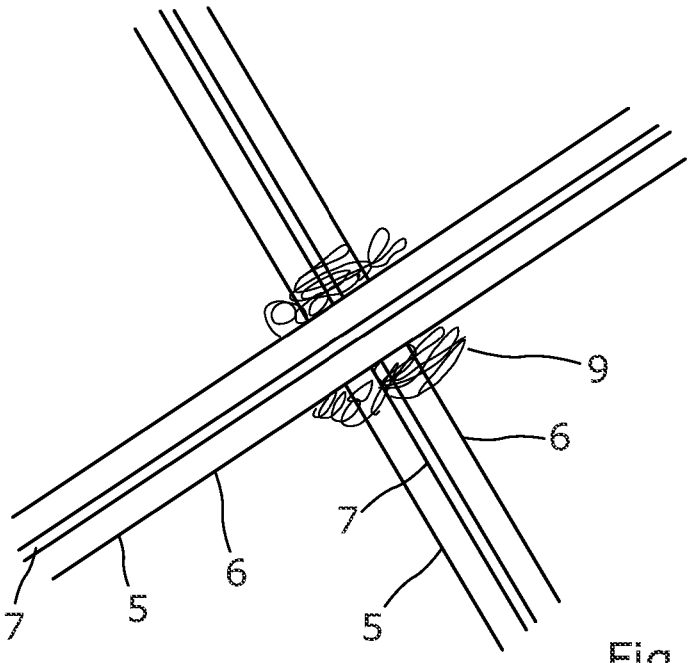
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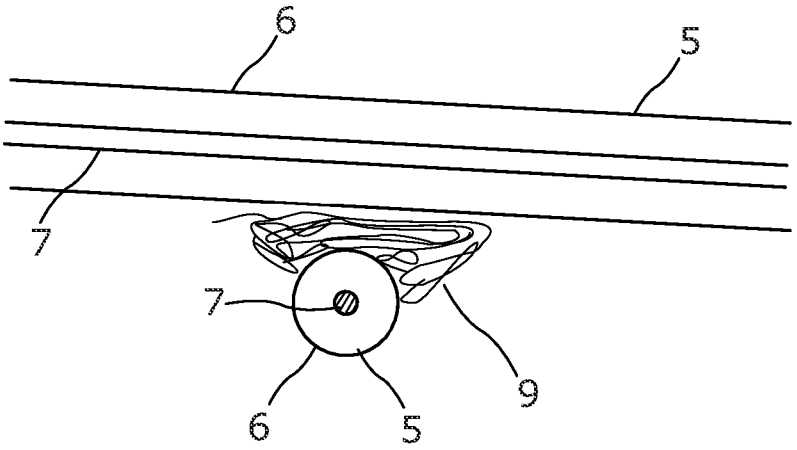
Fig. 4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6
5

Fig. 5

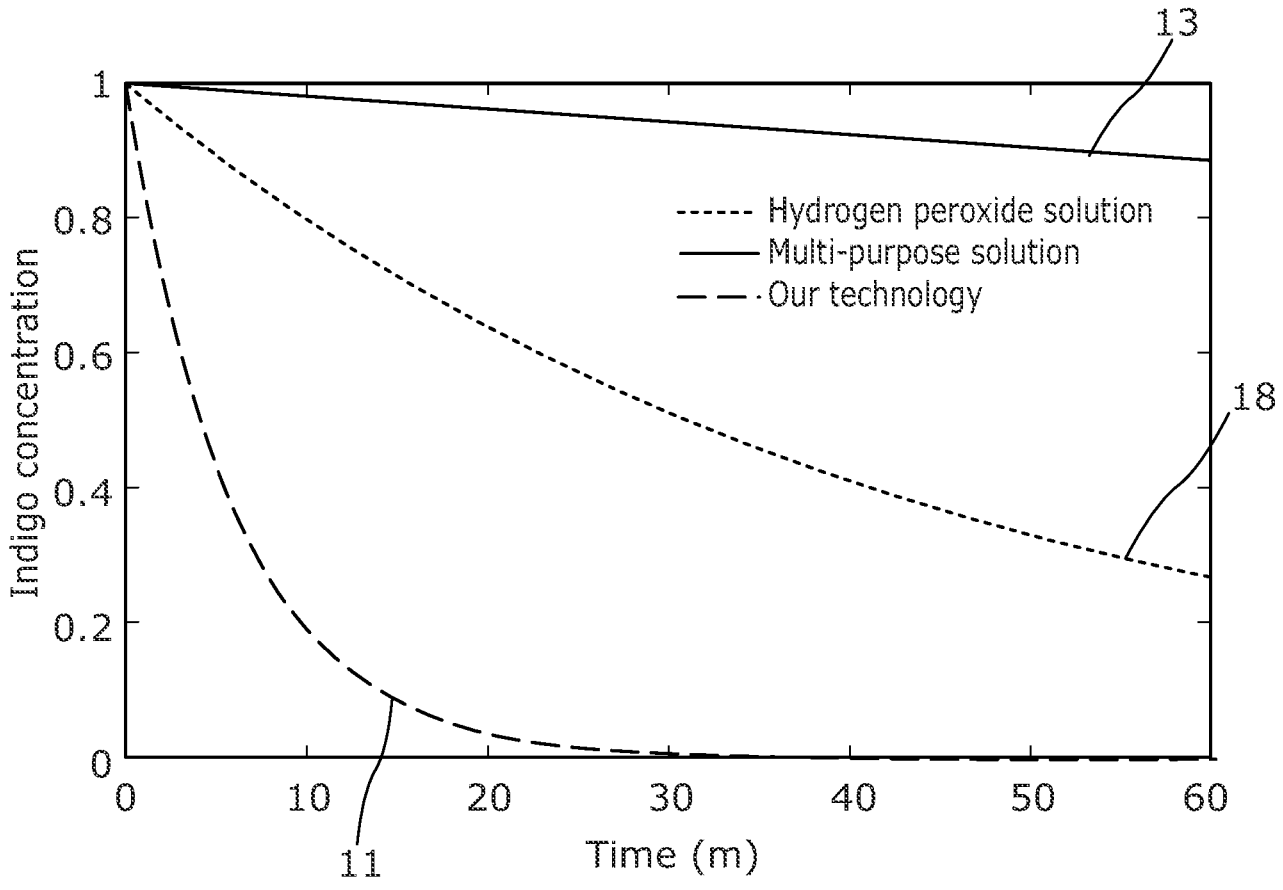
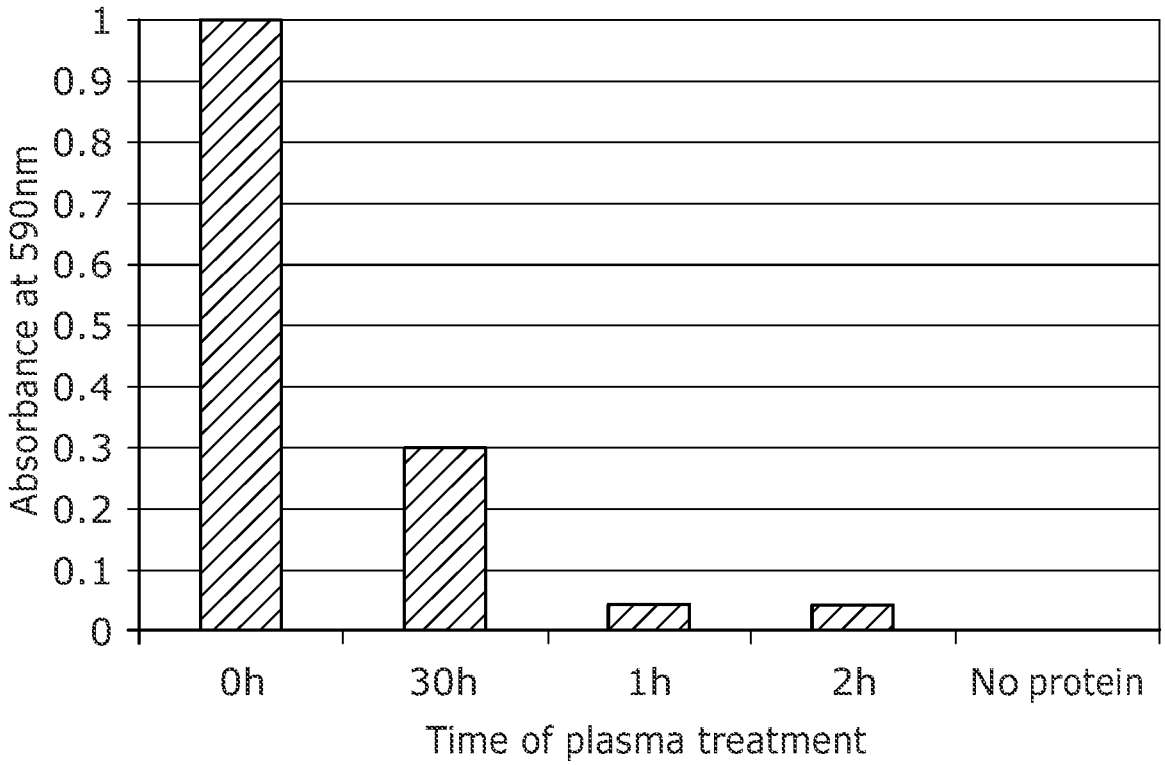

13
1
0.8
0.6
0.4
0.2
0
Indigo concentration
Hydrogen peroxide solution
Multi-purpose solution
Our technology
18
0
10
20
30
40
50
60
Time (m)
11

Fig. 6


Absorbance at 590nm
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0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
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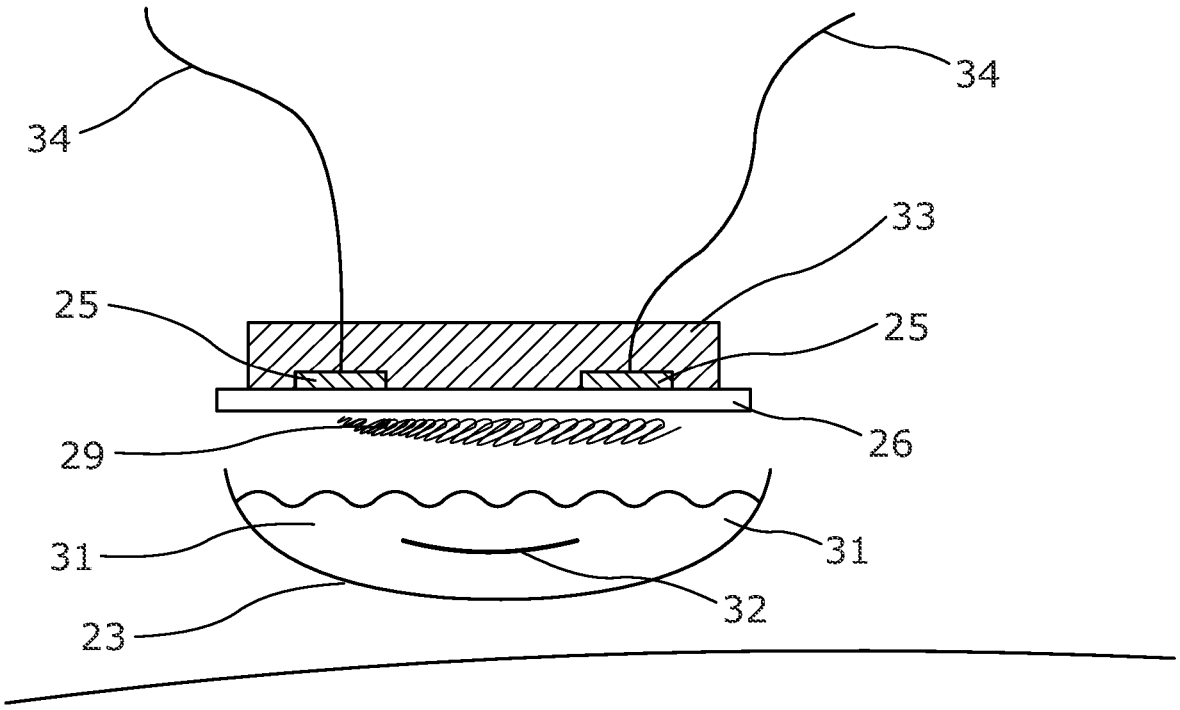
30h
1h
2h
No protein
Time of plasma treatment

Fig. 7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23

Fig. 8

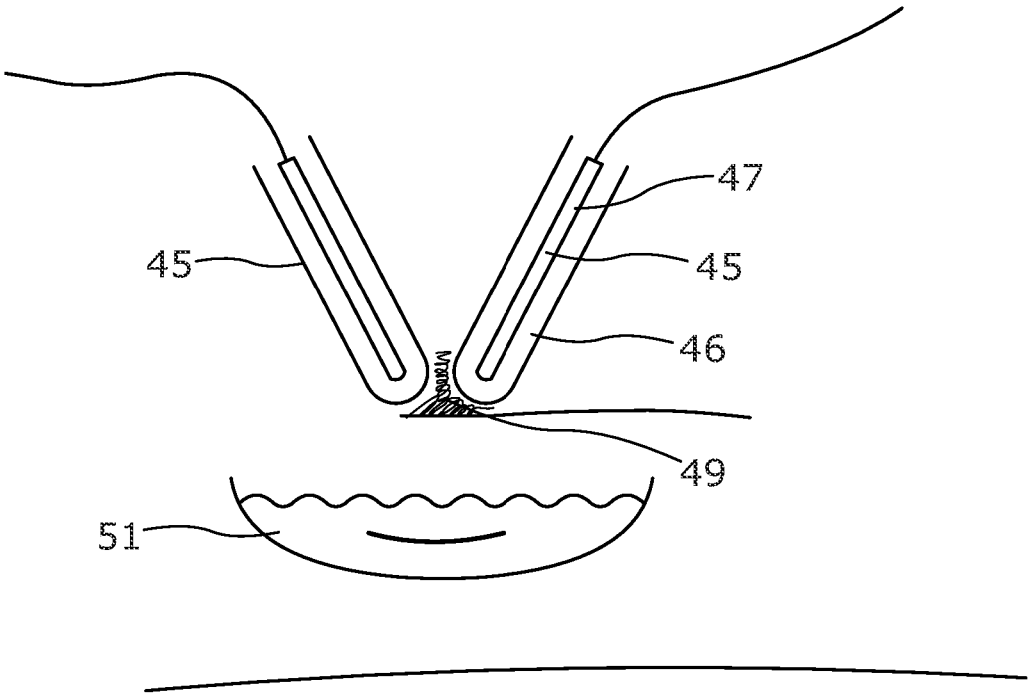

Fig. 9

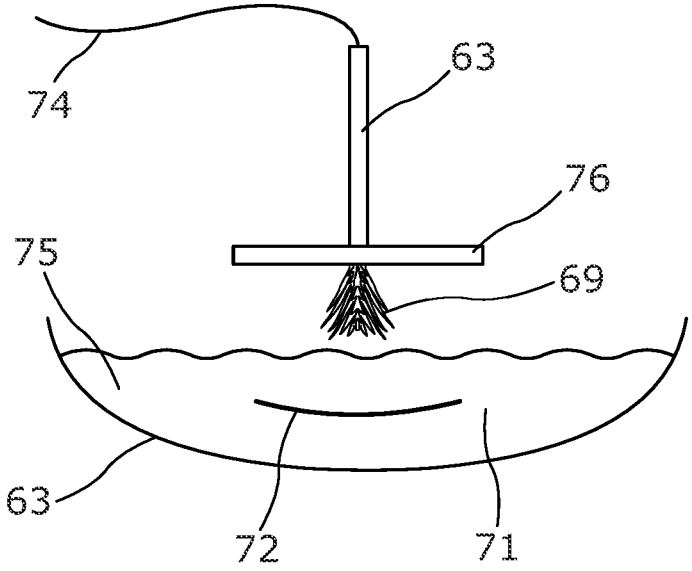

Fig. 10

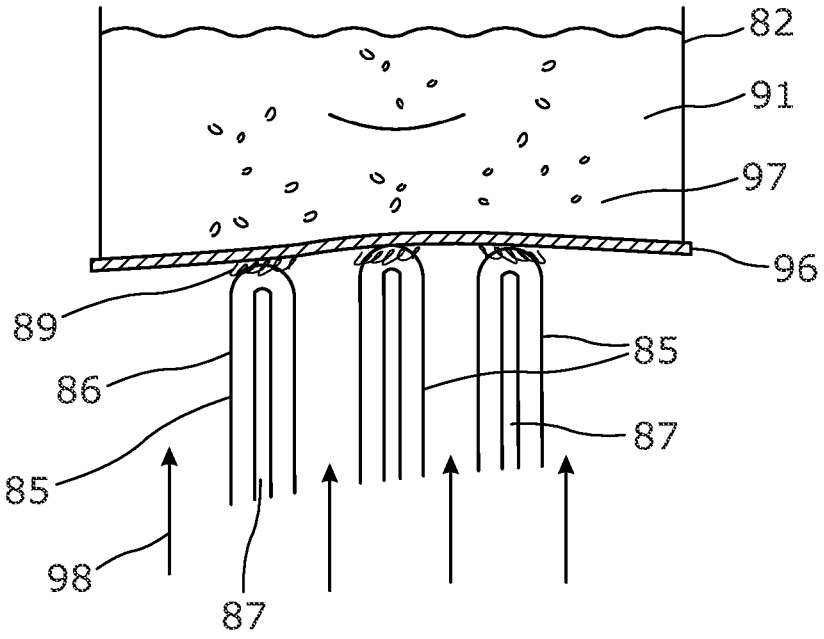

Fig. 11

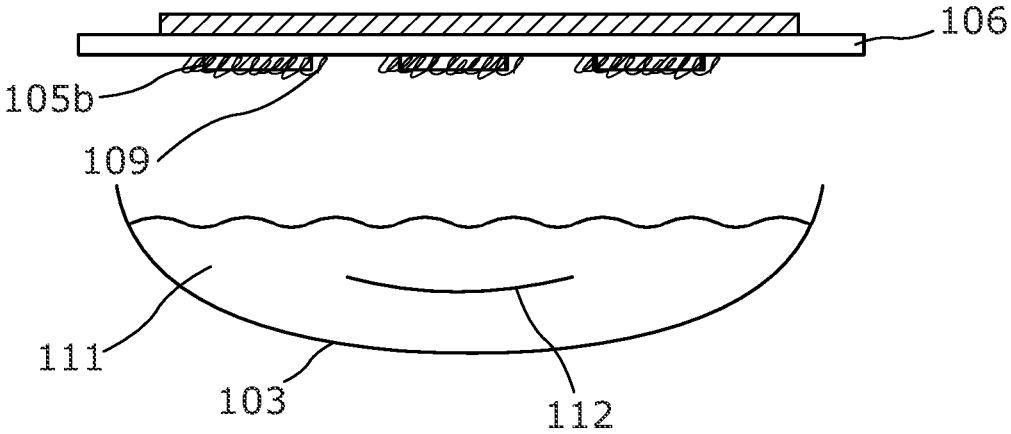

Fig. 12

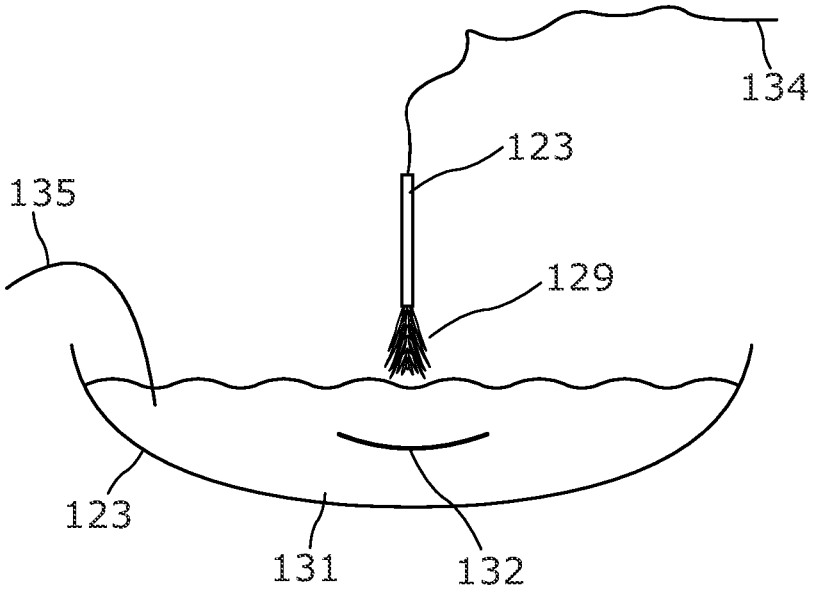

Fig. 13

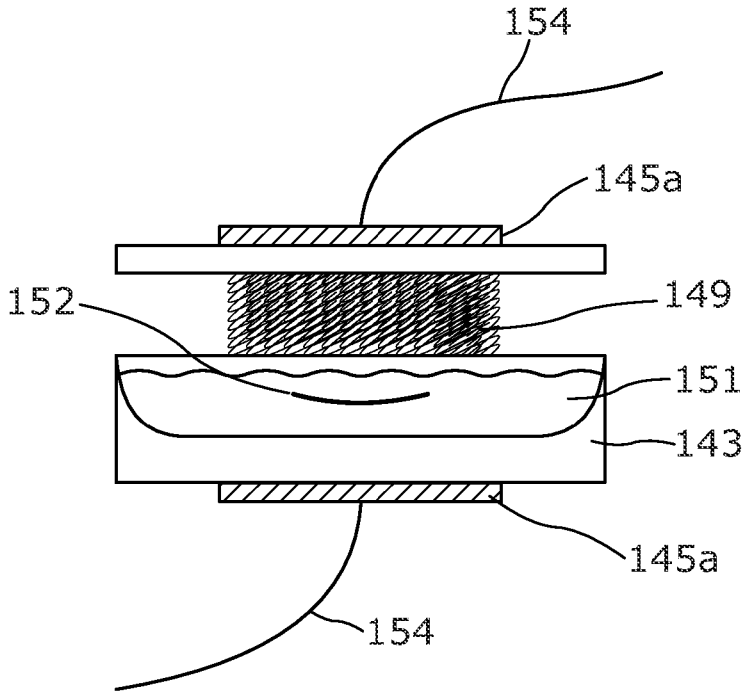

Fig. 14

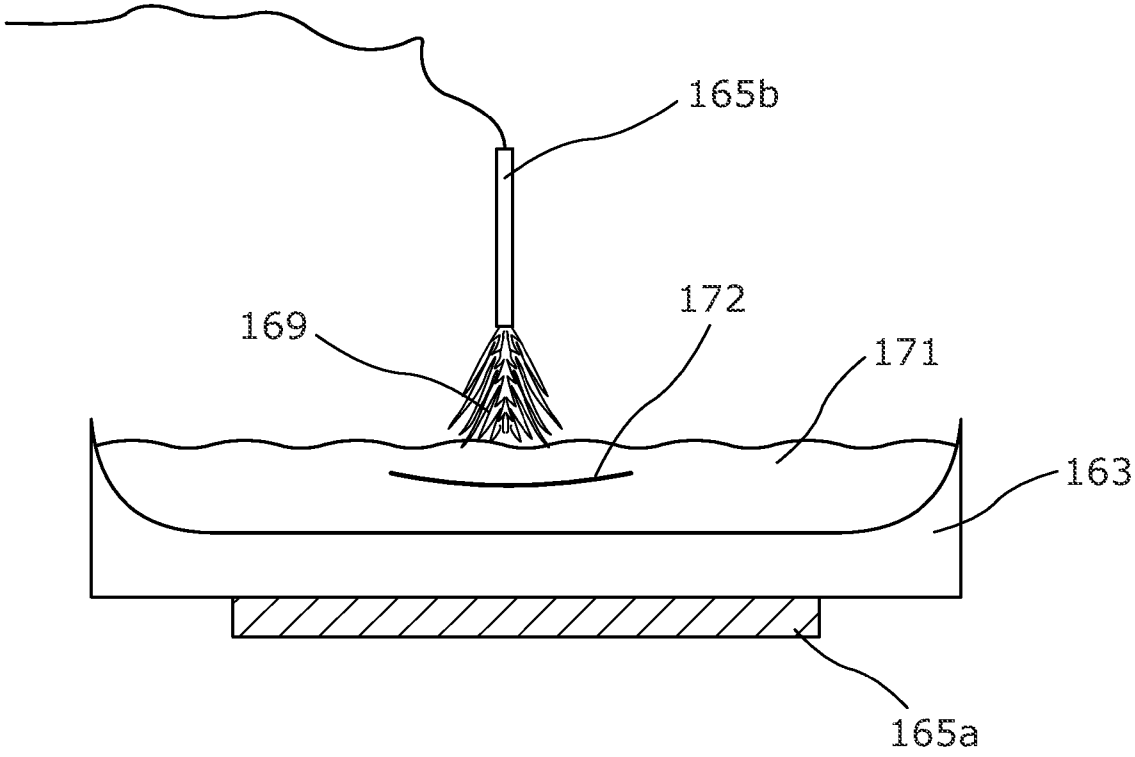

Fig. 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/052367

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61L12/08 A61L12/12 A61L2/18
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	CN 201 101 742 Y (WEIDONG LIU [CN]) 20 August 2008 (2008-08-20) the whole document	1-22 1,9,13, 16,18
Y	JP 2016 203082 A (OKINO AKITOSHI; MIYAHARA SHUICHI) 8 December 2016 (2016-12-08) paragraphs [0003], [0008], [0012], [0023] - [0073]; claims; figures	1,9,13, 16,18
A	WO 2012/083089 A2 (ELECTROLYTIC OZONE INC [US]; ROSTER BILL [US] ET AL.) 21 June 2012 (2012-06-21) paragraphs [0007] - [0011], [0030] - [0031], [0034] - [0055], [0061]; figures	1-22

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 November 2019	20/11/2019

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Varga, Viktoria

1

Form PCT/ISA/210 (second sheet) (April 2005)

International application No
PCT/GB2019/052367

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2016/096751 A1 (UNIV EINDHOVEN TECH [NL]) 23 June 2016 (2016-06-23) page 3, line 5 - page 4, line 11; figures page 5 pages 7-14 -----	13-22

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2019/052367

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