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SYSTEM AND METHOD FOR SURFACE TREATMENT OF MATERIALS

Abstract

A system for surface treatment of materials, including a target material, at least one transfer device and at least one plasma generator device. The plasma generator device includes a fluid (formula B) and generates a column of cold plasma. The target material is able to travel a path between a starting point and an end point, passing through the plasma generator device and the plasma column, along a unit vector of movement. The transfer device includes a fluid (formula A) transferred from the transfer device to the plasma generator device. The plasma column, generated from the fluids (formula A) and (formula B), has an oblong geometric shape of length (formula C), according to a longitudinal axis colinear with the vector of movement, and of width (formula D), according to a transverse axis perpendicular to the vector of movement, such that (formula E).

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Background/Summary

TECHNICAL FIELD
[0001] The present invention relates generally to materials, and in particular to a system and a method for surface treatment of materials using plasma generator devices.
[0002] Systems for surface treatment of materials are typically used in a wide range of fields such as biomedical, cosmetics, material treatment by surface functionalization, lighting, etc.
[0003] Known systems for surface treatment of materials use chemical products, either by passing objects through baths or by spraying/evaporation techniques in order to carry out the surface treatment of materials. However, such solutions require the external supply of chemical components, and are therefore not environmentally friendly.
[0004] To avoid the use and storage of chemicals, other systems for surface treatment of materials use so-called “plasma” techniques to treat materials. These plasma techniques can be implemented using “torches” or even DBD (for “dielectric barrier discharges”) systems.
[0005] However, known plasma techniques are limited in the gas mixtures for plasma generation. In fact, they do not allow materials to be treated with high concentrations of additional gases (such as for example high percentages of nitrogen or oxygen in noble gases), leading to plasma quenching.
[0006] Furthermore, some known techniques (such as torches) consume considerable power. In addition, in the case of torches, the technique is unsuitable for heat-sensitive materials and poorly suited to treating moving objects. In DBD systems, they can lead to inhomogeneous treatments, as plasmas are difficult to produce homogeneously at atmospheric pressure. Thus, these techniques cannot guarantee direct and homogeneous treatment in the case of substantially cylindrically symmetrical objects with very high aspect ratios, such as fibers or wires, ribbons, tubes or capillaries. In addition, these techniques cannot guarantee fast and efficient treatment of these materials and these objects either, due to the small volume of plasma generated at atmospheric pressure.
[0007] There is thus a need for an improved surface treatment method and system capable of treating the surface of materials without degradation, at atmospheric pressure, and in a manner suitable for hollow materials such as tubes or capillaries.
SUMMARY
[0008] The present invention improves the situation by proposing a system for surface treatment of materials comprising a target material, at least one transfer device at least one plasma generator device, the transfer device comprising a fluid custom-character to be transferred to the plasma generator device, the plasma generator device comprising a fluid custom-character and being configured to generate a column of cold plasma, the target material being able to travel a path, between a starting point and an end point, the path passing through at least the plasma generator device and the plasma column, the path being defined in a given reference frame along a unit

vector of movement {right arrow over (t)}, the fluid custom-character being transferred from the transfer device to the plasma generator device, and the plasma column being generated from the fluid custom-character and the fluid custom-character. The plasma column has an oblong geometric shape defined by a length custom-character, a width custom-character and an aspect ratio
[00001] $\frac{\mathcal{L}}{\ell} \geq 1$,
the length custom-character being defined along a longitudinal axis colinear with the vector of movement {right arrow over (t)} and the width custom-character being defined according to a transverse axis perpendicular to the vector of movement {right arrow over (t)}.
[0009] In one embodiment, the target material can further pass through at least part of the transfer device.
[0010] The plasma generator device may comprise a capillary for generating a plasma column comprising an inlet port configured to receive target material at the capillary inlet and an outlet port configured to deliver the target material at the capillary outlet.
[0011] In embodiments, the plasma generator device is a T-shaped device, further comprising a module for controlling and supplying fluid custom-character and a guide for transporting fluid custom-character, the control and supply module being configured to apply a pulsed discharge in the fluid custom-character at a discharge frequency f.sub.2. The guide and capillary of the T-shaped device can each have a shape and dimensions selected based on the target material and on the surface treatment to be applied.
[0012] In some embodiments, the transfer device may be a T-shaped device configured to generate a plasma column, the transfer device and the plasma generator device being spaced apart by a distance ε.sub.1-2 representing the distance between the inlet port of the plasma generator device and the outlet port of the transfer device. The plasma column can be generated based on the distance ε.sub.1-2.
[0013] In particular, the capillary of the plasma generator device may comprise at least one part made of a conductive material and at least one part made of a dielectric material.
[0014] The target material may further have a width ϕ and the capillary may have a width custom-character. The transfer device may be an enclosure attached to the plasma generator device, and connected at the inlet port of the plasma generator device by a connection having a given shape and an opening of diameter δ such that ϕ<δ≤custom-character. The connection may allow the transfer of fluid custom-character into the capillary and the plasma column may be generated based on the connection.
[0015] The target material may be a fiber, a wire or a capillary, wound, at the starting point, into a starting coil, and at the end point into an end coil, each coil being able to be unwound and wound so that the target material travels the path at a given speed defined based on the surface treatment to be applied.
[0016] The invention also provides a method of manufacturing an object from at least one system for surface treatment of materials comprising at least one target material, at least one transfer device and at least one plasma generator device, the target material traveling a path between a starting point and an end point along a unit vector of movement {right arrow over (t)}, the transfer device comprising a fluid custom-character, the plasma generator device comprising a fluid custom-character, the method comprising the steps of: [0017] transferring the fluid custom-character from the transfer device to the plasma generator device, [0018] generating a cold plasma column at surrounding pressure by means of the plasma generator device from fluids custom-character and custom-character, the plasma column having an oblong geometric shape defined by a length custom-character, a width custom-character and an aspect ratio noted
[00002] $\frac{\mathcal{L}}{\ell} \geq 1$,
the length custom-character being defined according to a longitudinal axis colinear with the vector of movement {right arrow over (t)} and the width custom-character is defined according

to a transverse axis perpendicular to the vector of movement {right arrow over (t)}, and [0019] passing the target material along the path, through the plasma generator device, at least when the plasma column is generated.
[0020] The method further comprises a step of passing the target material through the transfer device.
[0021] The method and system for surface treatment of materials according to the embodiments of the invention allow multiple atmospheric plasmas to be generated, involving gas mixtures that are impossible to obtain from prior art plasma reactors. These plasmas can be generated over long lengths and are suitable for inhomogeneous and/or homogeneous treatment of materials with very high aspect ratios. These plasmas can further be generated by interchangeable devices in a system with low energy consumption.

Description

BRIEF DESCRIPTION OF FIGURES
[0022] Further features, details and advantages of the invention will become apparent upon reading the description made with reference to the appended drawings given by way of example.
[0023] FIG. **1** is a diagram showing a system for surface treatment of materials, according to embodiments of the invention.
[0024] FIG. **2** is a diagram showing a plasma generator device, according to an example of use of the invention.
[0025] FIG. **3** is a diagram showing a plasma generator device, according to another example of use.
[0026] FIG. **4** is a diagram showing a transfer device and a plasma generator device arranged in series, according to embodiments of the invention.
[0027] FIG. **5** is a diagram showing a transfer device and a plasma generator device arranged in series and connected by a connection port, according to other embodiments of the invention.
[0028] FIG. **6** is a diagram showing a transfer device and a plasma generator device arranged in series and connected by a connection nozzle, according to other embodiments of the invention.
[0029] FIG. **7** is a diagram showing a controlled mixing zone between a transfer device and a plasma generator device arranged in series and connected by a connection port, according to other embodiments of the invention.
[0030] FIG. **8** is a diagram showing a transfer device and two plasma generator devices arranged in series, according to embodiments of the invention.
[0031] FIG. **9** is a diagram showing a device for treating materials in the presence of liquid or gel, according to embodiments of the invention.
[0032] FIG. **10** is a diagram showing a system for surface treatment of materials, according to embodiments of the invention.
[0033] FIG. **11** is a flowchart showing a method for manufacturing an object from the system for surface treatment of materials, according to embodiments of the invention.
[0034] Identical references are used in the figures to designate identical or similar elements. For reasons of clarity, the elements shown are not to scale.
DETAILED DESCRIPTION
[0035] FIG. **1** schematically shows a system for surface treatment of materials **10** comprising a target material custom-character, a transfer device **100** and a plasma generator device **200**.
[0036] The surface treatment system, according to the embodiments of the invention can be used in various fields of application, such as, for example and without limitation, the field of biomedicine, sterilization, medicine, cosmetics, material treatment by surface functionalization, ultrafine pattern production, depollution and/or decontamination, germination, lighting, rapid switching, flow

modification, detection, metrology, etc.

[0037] The target material custom-character may be composed of one or more inert dielectric or conductive materials and/or biological tissue. The target material custom-character comprises a surface that can be defined, for example, by its chemical and/or structural composition, and/or its surface finish. The surface of a material is defined in particular by specific surface properties such as for example physical properties, optical properties, and/or electrical properties, etc.

[0038] Some of these surface properties can be modified during and/or after interaction of the target material custom-character with a plasma at ambient temperature or very close to ambient temperature.

[0039] As used herein, the term "plasma" refers to a cold plasma formed at ambient pressure defined by a gaseous plasma (made up of charged species and electrons) out of thermodynamic equilibrium, in which the temperature of the electrons is very high compared to the temperature of the other species contained in the plasma. The temperature of the other species remains close to ambient temperature.

[0040] A plasma formed by the devices of the system for surface treatment of materials **10** generates a controlled and homogeneous production of reactive species. These species are excited chemical elements or elements in their ground state (for example NO, OH, NO_2, H_2O_2, O, O_3, etc.) with given life spans. In particular, some species have so-called 'short' life spans defined such that these reactive species are contained in the formed plasma, while other species have so-called 'long' life spans defined such that these other reactive species can be moved out of the formed plasma.

[0041] For example, and in a non-limiting way, the interaction of the target material custom-character with a plasma can modify the wettability of the surface of the target material custom-character by any type of physical or chemical process notably including but not limited to abrasion (or degreasing), deposition, functionalization, grafting or even cross-linking. In another example, the interaction of the target material custom-character with a plasma containing nanoparticles can modify the optical refraction or fluorescence of the surface of the target material custom-character by depositing thin layers.

[0042] In particular, the interaction of the target material custom-character with a plasma can locally induce a production of reactive species on the surface, used for example to decontaminate the target material custom-character.

[0043] The target material custom-character may be an object with a large aspect ratio or cylindrical symmetry, defined according to a diameter noted Φ. The target material custom-character may be for example a fiber, a wire, a tube or a capillary. The diameter Φ of such a target material custom-character may be characterized by a maximum value Φ_{max}, that is, that the diameter Φ is less than the maximum diameter value Φ_{max}. The maximum value Φ_{max} may be as little as a few millimeters. For example and without limitation, the maximum value Φ_{max} may be 8 mm ($\Phi<8$ mm).

[0044] Advantageously, the target material custom-character treated by the system for surface treatment of materials **10** may be used to manufacture multi-composite woven objects. Such objects are for example used in a biomedical or cosmetic field of application of the invention.

[0045] The system for surface treatment of materials **10** is associated with a given reference frame, noted custom-character. The target material custom-character is able to travel a path T, defined along a unit vector of movement $\vec{t}$ between a starting point A and an end point B, in the reference frame custom-character. The path T passes through at least the plasma generator device **200**.

[0046] In some embodiments, the path T may further pass partially or completely through the transfer device **100**. In other embodiments, the path T does not pass through the transfer device **100**.

[0047] In embodiments where the path T passes at least partly through the transfer device **100**, the transfer device **100** and the plasma generator device **200** are arranged "in series" in the system for surface treatment of materials **10**. In such an embodiment, the path T may therefore extend between a starting point A, located upstream (or inside) of the transfer device **100** and an end point B, located downstream of the plasma generator device **200**, in the reference frame custom-character, as shown in FIG. **1**.

[0048] In some embodiments, all or part of the system for surface treatment of materials **10** may be enclosed in a chamber (also known as an "enclosure") configured to control environmental parameters such as pressure, temperature and humidity, but also the quality of the air in the chamber or even the composition of the surrounding gas. For example, and without limitation, the pressure in the chamber can be set between 0.5 atm and 5 atm (the unit atm corresponds to normal atmospheric pressure), the temperature can be set between 0° C. and 50° C., and the humidity between 0% and 100%.

[0049] The transfer device **100** and the plasma generator device **200** are separated from each other by a distance of ε.sub.1-2. The distance ε.sub.1-2 can be positive, negative or zero. This distance is defined based on the target material custom-character of the surface treatment, and on the embodiment used to implement the devices **100** and **200**.

[0050] The transfer device **100** comprises a fluid custom-character and the plasma generator device **200** comprises a fluid custom-character. These fluids move in their respective devices according to characteristic parameters (such as for example the flow rate or the direction of fluid flow). In some embodiments, the fluids custom-character and custom-character may be identical. Alternatively, the fluids custom-character and custom-character may be different and/or have one or more different characteristic parameters.

[0051] Each fluid custom-character and custom-character may be a gas or a mixture of gases in which and/or from which a plasma can be formed.

[0052] For example, each of the fluids custom-character and/or custom-character may be air, nitrogen, oxygen, etc. Alternatively, each fluid custom-character and/or custom-character may be a mixture of gases. In embodiments where all or part of the system for surface treatment of materials **10** is enclosed in a chamber, fluid custom-character or fluid custom-character can be defined by the composition of the surrounding (or ambient) gas which depends on various chamber control parameters.

[0053] In some embodiments, each fluid custom-character and/or custom-character may be a noble gas, or a mixture of noble gases (typically helium He, argon Ar, neon Ne etc.).

[0054] The gases (and/or noble gases) used may further comprise one or more minority constituents, that is, added in low concentration. These constituents may be molecular gases corresponding, for example, to oxygen O.sub.2, hydrogen H.sub.2, sulfur hexafluoride SF.sub.6, nitrogen N.sub.2 and/or to any type of gas resulting from the vaporization of a liquid, such as water vapor H.sub.2O. In particular, a molecular gas may or may not be loaded with nanoparticles (of a metallic or dielectric nature, etc.), or with any type of precursor such as molecular polymer precursors.

[0055] The plasma generator device **200** may be configured to generate a column **202** of cold plasma formed at ambient pressure from fluid custom-character and fluid custom-character transferred from the transfer device **100** to the plasma generator device **200**. This plasma column **202** has a substantially oblong geometric shape, defined by a length custom-character and a width custom-character. As used herein, the term "width custom-character" refers to the diameter of the plasma column **202** at the center thereof as shown in FIG. **1**. The geometric shape is defined by a ratio custom-character, also known as the "aspect ratio". As the geometric shape is oblong, the value of the length custom-character of the plasma column **202** is greater than the value of the width custom-character. The aspect ratio of the plasma column **202** is therefore defined by equation (1):

[00003] $\frac{\mathcal{L}}{\ell} \geq 1$ (1)

[0056] Advantageously, the length custom-character of the plasma column **202** is defined according to a longitudinal axis colinear with the vector of movement {right arrow over (t)} and the width custom-character is defined according to a transverse axis perpendicular to the vector of movement {right arrow over (t)}.

[0057] In this way, the target material custom-character passes through the plasma column **202**, longitudinally and along path T. One or more surface properties of the target material custom-character are then modified by the interaction between the target material custom-character and the plasma column **202**.

[0058] FIGS. **2** and **3** show a plasma generator device **200**, according to different embodiments and examples of use of the invention. The plasma generator **200** is configured to generate a plasma column **202** from one or more fluids.

[0059] The plasma generator device **200** may comprise a module **204** for controlling and supplying fluid custom-character, a guide **206** for transporting fluid custom-character and a capillary **208** for generating the plasma column **202**.

[0060] The module **204** for controlling and supplying fluid custom-character may comprise a supply enclosure connected to the source of fluid custom-character, and configured to supply fluid custom-character to the capillary **208** through the guide **206**. The supply of fluid custom-character is then controlled, by the module **204**, according to characteristic parameters such as flow parameters associated with: [0061] the flow rate of fluid custom-character in the guide **206** and/or the capillary **208**, noted ρ.sub.2, or even, [0062] the flow modulation m.sub.2 of fluid custom-character, which generates a flow that can be continuous or discontinuous (or intermittent).

[0063] For example, fluid custom-character can flow through guide **206** at a flow rate ρ.sub.2 between 0.001 l/mn and 10 l/mn.

[0064] In embodiments, the control and supply module **204** may be a device for producing a “plasma jet” obtained from a plasma-forming gas, as described for example and without limitation in WO 2009/050240 and WO 2016/083539.

[0065] In one embodiment, a “plasma jet” production device may comprise a supply enclosure connected to a source of fluid custom-character in which are housed one or two electrodes connected to a high-voltage generator (elements not shown in the figures). Reference is made to the notion of a plasma “jet” as the plasma propagates beyond the discharge electrodes through the flow of fluid custom-character. In these embodiments, the control and supply module **204** can control another characteristic parameter corresponding to the discharge parameter (also known as “pulsed discharge”). A pulsed discharge is a discontinuous discharge of plasma jet into fluid custom-character and is defined by a discharge frequency f.sub.2.

[0066] For example, the pulsed discharge in fluid custom-character can be defined so as to obtain a cold plasma in the plasma column **202**, the discharge frequency f.sub.2 being selected according to the target material custom-character and the surface treatment.

[0067] The shapes, dimensions and constituent materials of the guide **206** for transporting fluid custom-character and the capillary **208** for generating the plasma column **202** may advantageously depend on the type of target material custom-character and/or on the surface properties of the target material custom-character to be modified.

[0068] The guide **206** and/or capillary **208** may be made of one or more rigid or flexible materials, from dielectric materials or conductive materials coated with no, one or more dielectric materials. The plasma column **202** forms in the capillary **208** at the level of dielectric materials (or conductive materials whose interior of the capillary is coated with dielectric materials).

[0069] The guide **206** and/or the capillary **208** may be cylindrical in shape. The guide **206** may further extend transversely to the direction of the vector of movement {right arrow over (t)}, at any angle α. In such embodiments, the plasma generator device **200** is referred to as a T-shaped device. For example and without limitation, the angle α may be substantially equal to 90° so that the orientation of the guide **206** may be perpendicular to that of the capillary **208**. In this way, the target material custom-character traveling path T passes longitudinally through the capillary **208** and the plasma column **202** generated.

[0070] The capillary **208** for generating the plasma column **202** may comprise an inlet port **208-01** configured to receive the target material custom-character and an outlet port **208-02** for delivering the target material custom-character out of the capillary **208**, the inlet and outlet ports **208-01** and **208-02** being positioned on path T.

[0071] As shown in FIGS. **2** and **3**, the capillary **208** can be defined by its diameter custom-character and its length custom-character. For example, the diameter custom-character of the capillary **208** can be between 500 μm and 1 cm. In particular, the diameter custom-character of the capillary **208** can be defined in relation to diameter Φ of the target material custom-character, such that d>Φ, taking into account certain stresses such as for example the mechanical stresses of movement of the target material custom-character passing longitudinally through the capillary **208**. Advantageously, diameter custom-character of the capillary **208** may be slightly greater than diameter Φ of the target material custom-character such that custom-character≥Φ, which allows a plasma column **202** to be generated at a lower energy cost.

[0072] In addition, the guide **206** may or may not be positioned in the middle of the capillary **208** of length custom-character. If the guide **206** is positioned in the middle of the capillary, the T-shaped device may be symmetrical. Otherwise, the T-shaped device is asymmetrical. For example, an asymmetrical T-shaped device may comprise a capillary **208** defined by two legs, referred to respectively as a ‘long leg’ of length custom-character.sub.long and ‘short leg’ of length custom-character.sub.court such that custom-character.sub.long>custom-character.sub.court and that custom-character=custom-character.sub.long+custom-character.sub.court. Alternatively, an asymmetrical T-shaped device may comprise a capillary **208** comprising two legs defined with respect to the position of the guide **206**, and having respectively a large diameter custom-character.sub.grand and a small diameter custom-character.sub.petit, such that custom-character.sub.grand>custom-character.sub.petit.

[0073] The guide **206** may also be defined by its diameter custom-character.sub.g and its length custom-character.sub.g. In particular, diameter custom-character.sub.g of the guide **206** may be defined in relation to diameter custom-character of the capillary **208**.

[0074] More generally, parameters custom-character, custom-character, custom-character.sub.g and custom-character.sub.g are related to flow parameters of fluid custom-character, the nature of fluid custom-character or even to the pulsed discharge in fluid custom-character. These parameters can influence the characteristic parameters for formation of the plasma column **202**, such as for example its diameter custom-character and its length custom-character.

[0075] For example, the evolution of fluid custom-character in the device can be characterized in particular by the flow parameter and the flow velocity of fluid custom-character in the capillary **208** may depend on a condition relating to diameter custom-character.sub.g of the guide **206** and to diameter custom-character of the capillary **208**. In particular: [0076] if diameter custom-character.sub.g of the guide **206** is greater than or equal to diameter custom-character of the capillary **208** (custom-character.sub.g≥custom-character), fluid custom-character flowing from the guide **206** to the capillary **208** undergoes an increase in flow velocity in the capillary **208**, relative to the guide **206**, and [0077] alternatively, if diameter custom-character.sub.g of the guide **206** is strictly less than diameter custom-character of the capillary **208** (custom-character.sub.g<custom-character), fluid custom-character undergoes a reduction in flow velocity in the capillary **208**, relative to the guide **206**.

[0078] In some embodiments, diameter custom-character of the plasma column **202** may be such that custom-character≥Φ in order to obtain a certain efficiency and homogeneity of surface treatment of the target material custom-character.

[0079] For example, length custom-character of the plasma column **202** may be between 1 cm and 100 cm.

[0080] Length custom-character of the plasma column **202** may further depend on the nature of fluid custom-character. For example, and without limitation, a pure gas may generate a longer length custom-character.sub.pure of the plasma column **202** than a gas mixture generating a length custom-character.sub.mixte of the plasma column **202**, such that custom-character .sub.pure>custom-character.sub.mixte. Fluid custom-character flowing through the capillary **208** to inlet and outlet ports **208-01** and **208-02** mixes with the surrounding air (or ambient air or surrounding gas or even gas in the chamber) outside or inside the capillary **208**. Thus, the flow parameters of fluid custom-character can similarly influence the length custom-character of the plasma column **202**. The high flow velocity (or high flow rate) may limit the mixing of fluid custom-character with the surrounding air and therefore influence certain characteristics of the plasma column **202** generated. For example, a device **200** using a high flow velocity in the capillary **208** may generate a longer length custom-character.sub.forte of the plasma column **202** than a device **200** using a low flow velocity in the capillary **208** generating a length custom-character.sub.faible of the plasma column **202**, such that custom-character.sub.forte> custom-character.sub.faible.

[0081] By way of illustrative example, FIG. **2** shows a device comprising a plasma column **202** held in the capillary **208**, such that custom-character<custom-character. FIG. **3** shows a device alternatively comprising a plasma column **202** extending on either side of the inlet and outlet ports **208-01** and **208-02** of capillary **208**, such that custom-character>custom-character.

[0082] In the operating mode shown in FIG. **2**, fluid custom-character flows from the control and supply module **204**, through the guide **206**, then through the plasma column **202** according to flow parameters defined for example by the velocity of fluid custom-character to the inlet and outlet ports **208-01** and **208-02**. In particular, the plasma column **202** may comprise reactive species with ‘long life spans’ that can be carried away/displaced from the plasma formed depending on the direction of flow of the fluid. The result is a modified fluid custom-character, referred to as fluid custom-character comprising reactive species. The length of this modified fluid custom-character depends in particular on the life span of the species and on the flow rate of fluid custom-character. Advantageously, the smaller the diameters involved, the greater the speeds at which the species can move and the greater the distances fluid custom-character and the reactive species can travel.

[0083] The operating mode shown in FIG. **3** shows a propagation zone of the plasma column **202** outside the capillary **208**, also known as the “plasma plume” **202-02**. The plasma plume **202-02** corresponds to the plasma column **202** interacting outside the capillary **208** with ambient air for example. The so-called plasma properties of the plasma plume **202-02** and the plasma column **202** may therefore be different.

[0084] The external supply of fluid custom-character can be provided by the transfer device **100**. For example and in a non-limiting way, the supply of fluid custom-character can be achieved by means of: [0085] another plasma generator device as described in relation to FIGS. **2** and **3**; or [0086] an enclosure connected to a plasma-forming gas source.

[0087] FIG. **4** shows the transfer device **100** and the plasma generator device **200** arranged in series, according to the embodiment of the invention wherein the external supply of fluid custom-character is provided by another plasma generator device (as described in relation to FIGS. **2** and **3**).

[0088] In such an embodiment, the transfer device **100** may comprise the same characteristics as the plasma generator device **200** described in relation to FIGS. **2** and **3**. Thus, the transfer device **100** may be configured to generate a plasma column **102** from one or more fluids. The transfer device **100** may also comprise a control and supply module **104** for fluid custom-character, a guide **106** for transporting fluid custom-character and a capillary **108** for generating the plasma column **102**, also of oblong geometric shape. The transfer device **100** may be a T-shaped device such that the orientation of the guide **106** may extend substantially perpendicular to the orientation of the capillary **108**.

[0089] As shown in FIG. **4**, in some embodiments, the target material custom-character traveling path T can pass longitudinally and completely through capillary **108** and the generated plasma column **102**.

[0090] Alternatively, in other embodiments (not shown in the figures), the target material custom-character may not pass through the transfer device **100**. In such an embodiment, the capillary **108** and the generated plasma column **102** may for example have a transverse direction or at a given angle to the longitudinal direction of path T.

[0091] The devices **100** and **200** may be identical and induce identical fluids custom-character and custom-character. Alternatively, fluids custom-character and custom-character may be different and/or the devices **100** and **200** may be different or comprise one or more different characteristic parameters associated with the control and supply of fluids. For example, the flow rates of fluids custom-character and custom-characterin the capillaries **108** and **208** may be equal or different and/or defined according to different, identical synchronous or asynchronous flow modulations of fluids m.sub.1 and m.sub.2. Similarly, pulsed discharges from modules **104** and **204** in fluids custom-character and custom-character may be defined by different, identical synchronous or asynchronous discharge frequencies and/or discharge frequency modulations f.sub.1 and f.sub.2.

[0092] In the embodiment s own in FIG. **4**, the capillary **108** comprises an inlet port **108-01** configured to receive the target material custom-character and an outlet port **108-02** configured to deliver the target material custom-character out of the capillary **108**. The inlet and outlet ports may therefore be positioned on path T. In this case, the target material custom-character passes through the transfer device **100** and the plasma generator device **200** arranged in series, and the target material custom-character passes through the plasma column **102** and the plasma column **202**, longitudinally, along path T. Thus, one or more surface properties of the target material custom-character may be modified by the interaction between the target material custom-character and the plasma columns **102** and **202**.

[0093] Distance ε.sub.1-2 between the transfer device **100** and the plasma generator device **200**, shown in FIG. **4**, corresponds to the distance between the outlet port **108-02** of the transfer device **100** and the inlet port **208-01** of the plasma generator device **200**. In other embodiments, the order of the devices may be reversed on path T, so that distance ε.sub.1-2 represents the distance between the outlet port **208-02** of the plasma generator device **200** and the inlet port **108-01** of the transfer device **100**.

[0094] In these embodiments, distance ε.sub.1-2 between the capillaries can be selected based on the type of target material custom-character and the surface treatment to be applied. In particular, the variability of the spacing ε.sub.1-2 between capillaries **108** and **208** can influence the interaction between devices **100** and **200**, so that the plasma generator device **200** can generate a plasma column **202** from fluid custom-character and fluid custom-character.

[0095] To this end, in the example shown in FIG. **4**, the transfer device **100** may be configured to generate a plasma column **102** of length custom-character>custom-character, so that a plasma plume **102-02** exits from the outlet port **108-02**. Fluid custom-character then comprises a plasma jet generating a plasma column **102**. The spacing ε.sub.1-2 thus influences the interaction (or mixing) of the plasma plume **102-02** with: [0096] a plasma plume **202-02**, [0097] the plasma column **202**, [0098] fluid custom-character containing reactive species, and/or [0099] fluid custom-character.

[0100] In particular, the plasma plume **102-02** can reach fluid custom-character discharged into

the capillary **208** (at any angle defined by path T) and thus generate a plasma column **202** by plasma transfer, from a new fluid resulting from mixing fluids custom-character and custom-character. In this zone of interaction (or transfer), it should be noted that the spacing ε.sub.1-2 can also influence the treatment of the material custom-character locally.
[0101] The spacing ε.sub.1-2 may notably be negative, zero or positive. Negative spacing ε.sub.1-2 corresponds notably to the case where one of the two capillaries **108** or **208** is inserted into the other capillary, depending on the respective diameters thereof. In addition, positive spacing ε.sub.1-2 may be less than a maximum distance noted ε.sub.1-2.sup.max (with for example and without limitation: ε.sub.1-2.sup.max==10 cm) corresponding to the upper limit of interaction possible between the plasmas and/or fluids of the two devices **100** and **200**.
[0102] In embodiments using an asymmetrical T-shaped device the capillary **208** of the plasma generator device **200** may comprise two legs of different diameters custom-character.sub.grand and custom-character.sub.petit. Advantageously, the leg of capillary **208** having diameter custom-character.sub.grand may comprise the inlet port **208-01** positioned at a distance ε.sub.1-2 from the outlet port **108-02** of the device **100** and the leg of the capillary **208** having diameter custom-character.sub.petit may comprise the outlet port **208-02** of the material custom-character so that diameter custom-character.sub.petit is defined to best match diameter Φ. Such an asymmetrical T-shaped device minimizes flow transfer problems in the interaction zone between devices **100** and **200**, while limiting the energy consumed to generate the plasma **202**.
[0103] FIGS. **5** to **7** show embodiments of the invention in which the external supply of fluid custom-character is provided by an enclosure connected to a source of plasma-forming gas.
[0104] In particular, FIG. **5** shows a series arrangement of the transfer device **100** and the plasma generator device **200**, according to such embodiments of the invention.
[0105] The transfer device **100** may be composed of an enclosure (open or closed) comprising a fluid custom-character (for example a plasma-forming gas, as described above) and/or a source of fluid custom-character. The enclosure further comprises an outlet port **102-02** of the target material custom-character positioned on path T. The source of fluid custom-character can be configured to control the supply of fluid custom-characteraccording to characteristic parameters such as the flow rate of fluid custom-character in the enclosure or through the outlet port **102-02**.
[0106] The starting point A of path T of the target material custom-character may be located inside the enclosure of the transfer device **100**. Alternatively, the starting point A may be located outside the enclosure of the transfer device **100** so that path T of the target material custom-character passes through the transfer device **100**. The transfer device **100** may then also comprise an inlet port **102-01** of the target material custom-character positioned on path T.
[0107] Distance ε.sub.1-2 between the transfer device **100** and the plasma generator device **200** is positive, negative or zero. In some embodiments, as shown in FIG. **5**, **6** or **7** for example, the transfer device **100** may thus be joined to the plasma generator device **200** via a connection coinciding with the outlet port **102-02** of the transfer device **100** and the inlet port **208-01** of the plasma generator device **200**. The connection positioned on path T coinciding with the joining of devices **100** and **200** will be noted below custom-character.
[0108] Connection custom-character has a specific shape and an opening of diameter δ.sub.1-2 through which fluid custom-character is fed into the capillary **208** generating the plasma column **202**. The minimum value δ.sub.1-2.sup.min of diameter δ.sub.1-2 can be defined in relation to diameter Φ of the target material custom-character, such that δ.sub.1-2>ϕ. Similarly, the maximum value δ.sub.1-2.sup.max of diameter δ.sub.1-2 can be defined in relation to diameter custom-character of the capillary **208** generating the plasma column **202**, such that δ.sub.1-2≤ custom-character.
[0109] As shown in FIG. **5**, the connection custom-character may comprise an injection port. For example, diameter δ.sub.1-2 of the injection port may be between 500 μm and 5 mm. Such an injection port allows a simple supply of fluid custom-character, and the diameter δ.sub.1-2

influences the flow rate ρ.sub.1 of the fluid. In some embodiments, the connection custom-character may comprise a unit for controlling diameter δ.sub.1-2 of the injection port to modify or modulate the flow of fluid custom-character to the device **200**. For example, this control unit may comprise a diaphragm or a slit system.

[0110] The embodiment shown in FIG. **6** is similar to that shown in FIG. **5** but features a connection custom-character having a shape comprising a so-called “moving” surface, which may advantageously be structured, textured or porous. The specific shape of the connection custom-character as shown in FIG. **6** may be, by way of example, a connection nozzle comprising an injection cone of angle α, and an injection port of length noted Δ, according to diameter δ.sub.1-2. For example, angle α of the injection cone may be between 30° and 50°, and length Δ of the injection port may be between 1 mm and 20 mm.

[0111] Advantageously, the moving surface induces entrainment of fluid F.sub.1 towards the capillary **208** of the plasma generator device **200** to induce generation of the plasma column **202**. A connection custom-character in the form of an injection nozzle further allows a more complex supply of fluid custom-character, inducing for example, an acceleration of the velocity of fluid custom-character and thus an increase in flow rate ρ.sub.1 compared with a simple supply.

[0112] The transfer device **100** may further comprise one or more units for supplying one or more additional fluids to fluid custom-character (units not shown in the figures). These additional fluids may be steam, mist of microdroplets and/or microparticles or nanoparticles or powders. For example, and without limitation, these additional fluids can be produced by evaporation, nebulization or smoke; an additional fluid supply unit can then be an evaporator, a nebulizer, etc. An additional fluid supply unit can be configured to inject an additional fluid and/or fluid custom-character in a controlled manner at connection custom-character.

[0113] FIG. **7** shows a mixing zone custom-character between a transfer device **100** and a plasma generator device **200** arranged in series, according to another embodiment of the invention. This mixing zone custom-character is located at the start of capillary **208** generating the plasma column **202** on path T.

[0114] Advantageously, the control of the mixing of fluids custom-character and custom-character in zone custom-character can be improved by using pulsed discharges from module **204** at a discharge frequency f.sub.2 in fluid custom-character. This discharge frequency f.sub.2 in fluid custom-character is such that it induces entrainment of fluid custom-character according to a fluidodynamic (i.e. related to fluid dynamics) and electrodynamic process, which may depend on the flow rate ρ.sub.2 of fluid custom-character in the capillary **208**. As shown in FIG. **7**, the fluidodynamic and electrodynamic process may induce the flow of fluid custom-character along the walls of capillary **208** in the mixing zone custom-character.

[0115] In the non-limiting example shown in FIG. **7**, the specific shape of connection custom-character is a connection port such that δ.sub.1-2=custom-character.

[0116] In particular, the use of a device **100** and a device **200**, arranged in series, allows pre-treatment of the target material custom-character in device **100** prior to subsequent plasma treatment in device **200**, resulting in more efficient surface treatment of the target material custom-character.

[0117] FIG. **8** shows a transfer device **100** and two plasma generator devices **200-1** and **200-2** arranged in series, according to other embodiments of the invention.

[0118] In such embodiments, the transfer device **100** is a device similar to the plasma generator device described in relation to FIGS. **2** and **3**. The transfer device **100** is thus designed as a device comprising a control and supply module **104**, a guide **106** and a capillary **108**. In particular, module **104** may be a plasma jet production device for generating a plasma column in capillary **108** from a fluid custom-character.

[0119] In the example shown in FIG. **8**, plasma generator devices **200-1** and **200-2** comprise capillaries **208** which are symmetrical relative to the transfer device **100** and positioned respectively at the inlet and outlet of capillary **108**. The target material custom-character traveling path T may pass through one or more of these capillaries **108** and/or **208**.

[0120] The capillaries **208** comprise a fluid custom-character, for example air. The capillaries **208** may consist of at least two parts **208-03** and **208-04** made of different materials. For example, as shown in FIG. **8**, the inner surface of capillary **208** of part **208-03** may be made of a conductive material that does not allow the plasma column **102** to propagate through plasma generator devices **200-1** and **200-2**. Advantageously, the "conductive parts" **208-03** of the capillaries **208** may be completely metallic. The flow of fluid custom-character, comprising reactive species, follows the flow in capillaries **208** connected in series with capillary **108**, based on a spacing δ.sub.1-2 (zero spacing in the example shown in FIG. **8**). In addition, the inner surface of capillary **208** of part **208-04** may be made of a dielectric material, allowing plasma columns **202** to be generated at these "dielectric parts" **208-04** of the capillaries **208**. Note that the plasma in plasma column **102** is conductive and may be able to apply a voltage to the conductive parts **208-03** attached to the capillary **108**. In particular, this applied voltage allows plasma regeneration in plasma columns **202** at the other end of the conductive parts **208-03** (that is, at the dielectric parts **208-04**), as well as the transport of reactive species having "long life spans" through these conductive parts **208-03**.

[0121] In some embodiments, the conductive part **208-03** and the dielectric part **208-04** of a capillary **208** may have equal or different diameters respectively noted custom-character .sub.conducteur and custom-character.sub.dielectrique. A variation in diameters custom-character.sub.conducteur and custom-character.sub.dielectrique, such that for example custom-character.sub.conducteur>custom-character.sub.dielectrique or custom-character .sub.conducteur<custom-character.sub.dielectrique, can induce a slowing or an acceleration of the flow of fluid custom-character, in capillary **208** to respectively slow down or accelerate the residence time of reactive species in a dielectric part **208-04**. Equivalently, the conductive part **208-03** and the dielectric part **208-04** of a capillary **208** may have equal or different lengths.

[0122] In some embodiments, other similar capillaries **208**-*i* may be joined to the capillaries **208** already present. The capillaries **208** already present then act as a transfer device **100** for these other capillaries **208**-*i*. A complex device may be created using a single plasma jet production device, and one or more capillaries **208**. Each capillary then comprises parts formed from one or more dielectric materials and parts formed from one or more conductive materials. Such a complex device may generate a multitude of oblong-shaped plasmas in the dielectric parts of the capillaries. This multitude of plasmas then forms a so-called "intermittent plasma" having an equivalent length custom-character. Advantageously, such a configuration comprising other capillaries **208**-*i* allows the target material custom-character to be treated over a very long length custom-character while reducing energy consumption compared with a device forming a "continuous" plasma having a long length custom-character=custom-character.

[0123] In addition, this multitude of plasmas can have a defined geometry depending on the complexity of the arrangement of the different capillaries. For example, at least two capillaries may be connected to each other at one point, at any connection angle, in particular between 0° and 180°. In addition, the plasma columns generated in such a device may be of the same or different nature based on the geometries applied and the fluids contained and/or supplied in these different parts. Advantageously, such a configuration (not shown in the figures) comprising one or more complex connection geometries of three or more capillaries **208**-*i*, at any connection angle (for example 90°), allows the formation of multiple intermittent plasmas from a single transfer device **100** similar to the plasma generator device described in connection with FIGS. **2** and **3**.

[0124] FIG. **9** shows a device for liquid treatment of materials **700** containing a solution in the liquid state **702**.

[0125] Solution **702** can be any chemical solution already used for the treatment of materials. In particular, solution **702** may contain one or more plasma-treated liquids or gels suitable for the desired treatment. For example, the solution may be a 'Plasma Activated Water' (PAW), 'Plasma

Activated Liquid' (PAL), 'Plasma Activated Solution' (PAS), 'Plasma Activated Medium' (PAM), or 'Plasma Activated Gel' (PAG).
[0126] This device for treating materials in the presence of liquid or gel **700** may be, for example, a tank for surface treatment, deposition or modification by immersion of the target material custom-character in solution **702**.
[0127] In some embodiments, such a device **700** may be inserted into the system for surface treatment of materials **10** and arranged in series relative to the transfer device **100** and to the plasma generator device **200**. This arrangement can take place in various configurations, at any point in the system **10** treatment line along path T of the target material custom-character.
[0128] A first arrangement configuration of device **700** can be defined by positioning the device **700** upstream of the plasma generator device **200**. This configuration allows liquid and/or gel deposition on the surface of the target material custom-character then subsequent treatment for applications to modify the surface of materials with plasma. For example, in the field of optical fiber functionalization, such a configuration allows a protective sheath to be deposited.
[0129] A second arrangement configuration of device **700** can be defined by positioning the device **700** downstream of the plasma generator device **200**. This configuration allows molecules to be attached to the surface of the target material custom-character following a previous plasma treatment. In fact, it should be noted that surface treatments of materials by plasma interaction may be treatments that evolve over time defined, for example, according to a time interval τ, depending on the target material custom-character and the surface properties treated. In order to attach certain plasma treatments, the target material custom-character may undergo a liquid treatment of materials **700** in this time interval τ. Thus, such a configuration of devices allows an optimum arrangement of plasma treatments using liquid-state solution **702**.
[0130] FIG. **10** shows a system for surface treatment of materials **10** according to various embodiments, comprising a target material custom-character passing through constituent components **10-01**, **10-02**, **10-03**, **10-04** and **10-05**, between starting point A and end point B.
[0131] The target material custom-character may be for example a material able to be wound on the one hand into a starting coil at point A and on the other hand into an end coil at point B, such as for example a fiber, a wire, a tube or a capillary. Each of these two coils is able to be unwound and wound, so as to allow the target material custom-character to travel along path T, at a defined speed custom-character based on the surface treatment to be applied to the target material custom-character by plasma interaction.
[0132] In embodiments, the system for surface treatment of materials **10** (and therefore the two coils starting at point A and ending at point B) is configured so that the target material custom-character passes through the constituent components **10-01**, **10-02**, **10-03**, **10-04** and **10-05** at least once. For example and without limitation, the route of the target material custom-character may be a round trip such that the target material custom-character first passes through constituent components **10-01**, **10-02**, **10-03**, **10-04** and **10-05**, then through constituent components **10-05**, **10-04**, **10-03**, **10-02** and **10-01** a second time.
[0133] When the target material custom-character passes through the plasma generator device **200**, the interaction with the generated cold plasma can take place either statically or on the fly. A static interaction is defined by the generation of the plasma column **200** when the target material custom-character is stationary in capillary **208**: the velocity custom-character of the target material custom-characteris then zero (custom-character=0 m/s). Similarly, an on-the-fly interaction is defined by the generation of the plasma column **200** when the target material custom-character is in motion: the velocity custom-character of the target material custom-character can then lie between a minimum value custom-character.sub.min and a maximum value custom-character.sub.max.
[0134] In other embodiments, the target material custom-character can be an object, with a large aspect ratio comprising a small object length relative to the size of path T. The target material

custom-character can move on a conveyor belt from a starting point A to an end point B, at a velocity custom-character defined based on the surface treatment to be applied.

[0135] The velocity custom-character of the target material custom-characteralong path T can be limited by a maximum value custom-character.sub.max defined by the maximum movement limit of the target material custom-character. In particular, such a maximum velocity custom-character.sub.max can be determined from a minimum residence time. This minimum residence time is defined by the minimum plasma interaction time with the target material custom-character to obtain the surface treatment to be applied.

[0136] Similarly, the velocity custom-character of the target material custom-characteralong path T can be limited by a minimum value custom-character.sub.min defined by the minimum movement limit of the target material custom-character in the case of an on-the-fly interaction. In particular, such a minimum velocity custom-character.sub.min can be determined from a maximum residence time of the target material custom-character in a generated plasma column. This maximum residence time is defined by the maximum plasma interaction time so as not to damage the target material custom-character or produce any other unwanted surface treatment.

[0137] Advantageously, the system may comprise a plurality of devices **200** generating a plurality of plasma columns **202** arranged in series, with or without transfer devices **100**. Such an implementation makes it possible, for example, to perform multiple surface treatments or even to reduce the so-called “local” residence time of the target material custom-character in a specific plasma column, while guaranteeing a so-called “overall” residence time sufficient to induce the surface treatment to be applied. For example, for natural fibers with very low local residence times, such an implementation allows cooling of the target material custom-character between two plasma interactions. Alternatively, such an implementation allows plasma heating of the target material M allowing, for example, expansion of the material followed by subsequent surface treatment, thus avoiding the known problems of treated materials undergoing stretching during application as a result of loss of functionalization.

[0138] In some embodiments, the velocity custom-character of the target material custom-character may vary over time, during the movement of the target material custom-character in system **10**. For example, if the initial properties of the target material custom-character evolve during the unwinding of the starting coil and/or if the properties to be modified need to evolve during treatment.

[0139] Advantageously, the various constituent components **10-01**, **10-02**, **10-03**, **10-04** and **10-05** may be any devices for treating materials or surface of materials. For example, and without limitation, a constituent component may be a device as described above, that is, T-shaped device, an enclosure, or a device for liquid treatment of materials. In particular, the constituent components may be interchangeable to easily adapt the surface treatment of the target material custom-character according to the desired functionality, depending on the application of the invention.

[0140] In the embodiment shown in FIG. **10**, component **10-01** is an enclosure comprising a fluid noted custom-character, similar to the enclosure shown in FIGS. **5**, **6** and **7**. Components **10-02**, **10-03** and **10-05** are also plasma generator devices respectively comprising the fluids, noted custom-character, custom-character and custom-character, similar to the plasma generators shown in FIGS. **2**, **3** and **4**. Component **10-04** custom-characteris a device for treating materials in the presence of liquid or gel **700**, similar to the device for liquid treatment shown in FIG. **9**.

[0141] Component **10-01** is thus a transfer device **100** with respect to component **10-02**, and fluid custom-character is injected into component **10-02** to create the first plasma column **12** through which the target material custom-character passes. Similarly, component **10-02** may be a transfer device **100** relative to component **10-03** (depending on the spacing between components **10-02** and **10-03**), and fluid custom-character (or resulting from the mixture of fluids custom-character and custom-character) is injected into component **10-03** to create the second plasma column **14** through which the target material custom-character passes. Component **10-03** may be a transfer device **100** relative to component **10-05** (depending on the structure of component **10-04** and the spacing between components **10-03** and **10-05**), and fluid custom-character (or resulting from the mixture of fluids custom-character and custom-character is injected into component **10-05** to create the third plasma column **16**, through which the target material custom-character passes.

[0142] The embodiments of the invention thus allow the generation of multiple, homogeneous atmospheric plasmas over long lengths. These cold plasmas are generated using mixtures that are generally impossible to obtain using other plasma treatment techniques known to the skilled person. Such mixtures comprise, for example, high percentages of nitrogen or oxygen in noble gases. These plasmas are particularly suitable for consecutive, homogeneous plasma treatments of materials with very high aspect ratios.

[0143] The various types of device according to the embodiments allow plasmas of different compositions to be generated and combined very easily, one after the other. In addition, the system makes it very easy to inject aerosols, microdroplets, specific vapors or nanomaterials outside plasma generator devices, and to combine these plasma treatments with liquid treatments (or aerosols, or microdroplets). The treatment system according to the embodiments of the invention allows optimum treatment of a material from point A to point B, in a single pass along path T.

[0144] FIG. **11** is a flowchart describing the method of manufacturing an object using a system for surface treatment of materials **10**, according to embodiments of the invention.

[0145] In step **902**, fluid custom-character is transferred from the transfer device **100** to the plasma generator device **200**.

[0146] In step **904**, the column **202** of cold plasma at atmospheric pressure is generated by the plasma generator device **200** from fluid custom-character and fluid custom-character.

[0147] In step **906**, the target material custom-character passes through the plasma generator device **200**, along path T, at least while the plasma column **202** is being generated. In step **904** or step **902**, the target material custom-character may additionally pass through the transfer device **100** based on the defined path T.

[0148] The method may further comprise a step **908** consisting in applying pulsed discharges by the module **204** (and/or the module **104** according to the embodiments) in fluid custom-character (and/or in fluid custom-character), discontinuously at a discharge frequency f.sub.2 (and/or discharge frequency f.sub.1) comprised for example between 10 Hz and 50 kHz.

[0149] The skilled person will understand that steps **902**, **904**, **906** and **908** can be carried out simultaneously and/or in a defined order based on the target material custom-character and surface properties to be applied.

[0150] In some embodiments, several systems for surface treatment of materials **10** can be arranged, in parallel, to form a complete object manufacturing system (not shown in the figures). This complete system may for example comprise n systems configured to treat the surface of n target materials custom-character. The complete system may further comprise a unit for combining n target materials custom-character exiting the n surface treatment systems.

[0151] The n target materials custom-character may notably be different or identical materials, and/or require different or identical surface treatments. The n surface treatment systems may comprise the same or different constituent components. The constituent components may be arranged identically or interchanged, depending on the treatments to be applied in the systems.

[0152] The object manufacturing method may thus comprise an additional step of combining the n target materials custom-character after their surface treatment by the n systems.

[0153] The combination of n target materials custom-character may be, for example, a weave of a set of fibers or wires, tubes or capillaries. The combination unit is then a weaving unit.

[0154] Such a complete system is ideally suited to multi-fiber weaving or to the manufacture of materials with splices. In particular, this complete system has the advantage of not presenting any shading problems encountered in the surface treatment of assemblies of parts, fibers or wires already combined or woven prior to treatment.

[0155] In embodiments, a surface treatment system **10** may comprise k target materials custom-character able to travel q different paths T within the system **10**. The number k of target materials custom-character may be less than, greater than or equal to the number q of different paths T within the system **10**. In this case, the system **10** may further comprise a unit for combining k target materials custom-character n exiting the surface treatment system, as described above. These embodiments, with k target materials custom-character able to travel q different paths T, can be combined with the embodiments relating to the complete object manufacturing system comprising several systems for surface treatment of materials **10** for manufacturing woven or combined objects.

[0156] The invention is not limited to the embodiments described above by way of non-limiting example. It encompasses all the alternatives that may be envisaged by the skilled person. In particular, the skilled person will understand that the invention is not limited to the transfer devices **100** and to the plasma generator devices **200** described by way of non-limiting example.

Claims

1-10. (canceled)

11. A system for surface treatment of materials, comprising a target material (custom-character), at least one transfer device, at least one plasma generator device, characterized in that said transfer device comprises a fluid custom-character to be transferred to said plasma generator device, said plasma generator device comprising a fluid custom-character and being configured to generate a column of cold plasma, said target material (custom-character) being able to travel a path (T) at ambient pressure between a starting point (A) and an end point (B), said path passing through at least said plasma generator device and said plasma column, said path (T) being defined in a given reference frame along a unit vector of movement {right arrow over (t)}, said fluid custom-character being transferred from said transfer device to said plasma generator device, and in that said plasma generator device comprises a device for producing a plasma jet obtained from said fluid custom-character, said plasma column being generated from said fluid custom-character, and from said plasma jet, and the plasma generator device further comprising a capillary (**208**) for generating said plasma column arranged so that said plasma column has an oblong geometric shape defined by a length custom-character, a width custom-character and an aspect ratio $\frac{\mathcal{L}}{\ell} \geq 1,$ said length custom-character being defined according to a longitudinal axis colinear with the vector of movement {right arrow over (t)} and said width custom-character being defined according to a transverse axis perpendicular to the vector of movement {right arrow over (t)}.

12. The system for surface treatment of materials, according to claim 11, wherein the target material (custom-character) additionally passes through at least part of the transfer device.

13. The system for surface treatment of materials, according to claim 11, wherein said capillary comprises an inlet port configured to receive the target material (custom-character) at the inlet of the capillary and an outlet port configured to deliver the target material (custom-character) out of the capillary.

14. The system for surface treatment of materials, according to claim 13, wherein the plasma generator device is a T-shaped device, further comprising a control and supply module for fluid custom-character and a guide for transporting fluid custom-character, said control and supply module being configured to apply a pulsed discharge in fluid custom-character, at a discharge frequency f.sub.2, wherein said guide and said capillary each have a shape and dimensions selected based on the target material (custom-character) and the surface treatment to be applied.

15. The system for surface treatment of materials, according to claim 11, wherein the transfer device is a T-shaped device comprising a capillary and is configured to generate a plasma column, said capillary comprising at least one outlet port, said transfer device and said plasma generator device being spaced apart from each other by a distance ε.sub.1-2 representing the distance between the inlet port of the plasma generator device and the outlet port of the transfer device, and wherein said plasma column is generated based on said distance ε.sub.1-2.

16. The system for surface treatment of materials, according to claim 14, wherein the capillary of the plasma generator device comprises at least one part made of a conductive material and at least one part made of a dielectric material.

17. The system for surface treatment of materials according to claim 14, wherein the target material (custom-character) has a width ϕ and the capillary has a width custom-character, the transfer device being an enclosure connected to the plasma generator device by a connection (custom-character) at the inlet port of the plasma generator device, said connection (custom-character) having a given shape and an opening of diameter δ such that ϕ<δ≤ custom-character, and being adapted to the transfer of fluid custom-character in the capillary, and wherein said plasma column is generated based on the connection (custom-character).

18. The system for surface treatment of materials according to claim 11, wherein the target material (custom-character) is a fiber, a wire or a capillary, wound on the one hand at the starting point (A), in a starting coil, and on the other hand at the end point (B), in an end coil, each coil being able to be unwound and wound so that the target material (custom-character) travels the path (T) at a given speed custom-character defined based on said surface treatment to be applied.

19. A method for manufacturing an object using at least one system for surface treatment of materials, said treatment system comprising at least one target material (custom-character), at least one transfer device and at least one plasma generator device, said target material (custom-character) traveling a path (T) between a starting point (A) and an end point (B), said path (T) being defined in a given reference frame according to a unit vector of movement {right arrow over (t)}, said transfer device comprising a fluid custom-character, said plasma generator device comprising a fluid custom-character, the method comprising the steps of: transferring fluid custom-character from the transfer device to the plasma generator device, generating a cold plasma column at surrounding pressure by means of said plasma generator device from said fluid custom-character and said fluid custom-character, said plasma column having an oblong geometric shape defined by a length custom-character, a width custom-character and an aspect ratio noted $\frac{\mathcal{L}}{\ell} \geq 1$, said length custom-character being defined according to a longitudinal axis colinear with the vector of movement {right arrow over (t)} and said width custom-character being defined according to a transverse axis perpendicular to the vector of movement {right arrow over (t)}, and passing said target material (custom-character), along the path (T), through said plasma generator device, at least when said plasma column (**202**) is generated.

20. The method of manufacturing an object, according to claim 19, wherein step further comprises a step of passing the target material (custom-character) through at least part of the transfer device.