

Controlled Radical Assisted Polymerization

Field of the invention

- 5 The present invention is directed to a new method of producing polymer coatings or films.

Background of the invention

10 In general it is known to prepare polymers in a liquid solution. However, such methods require in many cases the use of expensive, corrosive or toxic solvents. Further, often undesired or uncontrollable reactions take place in such a solution. Finally, after polymer formation in the liquid solution, a film or coating has still to be formed which requires normally multiple further time-consuming cleaning and deposition steps.

- 15 Another known method allowing a direct deposition of polymer films is the method of chemical vapor deposition (CVD).

One type of CVD is the method of vapor deposition polymerization (VDP). According to VDP a condensation reaction is initiated between two monomers at a surface of a substrate without using any initiator or oxidizing agent. In particular, monomers are volatilized at the surface of a temperature controlled substrate. Such a method allows polymerization of monomers which are not soluble in solvents and offers to some degree a control of generated chain lengths. However, according to the VDP it is difficult to control the monomers' concentration and their flux to the surface of the sample to be coated. In particular, there is a competition between an adsorption on the sample's surface and the formation of long polymer chains, wherein adsorption is preferred at low temperatures and the formation of long polymer chains is preferred at rather high temperatures. This is only one of the reasons for the difficulty in controlling the composition of copolymers according to this method.

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Another known polymerization method is the plasma enhanced chemical vapor deposition (PECVD). This technique has mainly been used for the deposition of inorganic films at relatively low temperatures and with a high deposition rate. Unfortunately, monomers injected into the plasma chamber are ionized or
5 fragmentized by the plasma due to electrons, ions or radicals in the plasma. Further, such plasma polymers are often irregular and have rather short chain lengths. Moreover, they are frequently cross-linked and randomly terminated. Plasma polymerization leads to a random poly-recombination of radicals and fragments of monomers. A known innovation in the field of plasma polymerization is the use of the
10 pulsed-plasma mode. In that case, short plasma pulses (of a few microseconds) can activate molecules, produce radicals and initiate the polymerization reaction. After the pulse, the residual radicals initiate a purely chemical radical chain reaction during the plasma-off period (typically tens of microseconds). In that case, a more chemically-regular product is expected but the chain propagation during chemical
15 polymerization is restricted by the low probability of attaching a new monomer to the radical at the growing chain-end. Moreover, the deactivation of chain propagation is expected under the usual vacuum conditions (e.g. about 10 Pa) due to the recombination of neighboring radicals. This leads to a significant loss of active radical sites during the plasma-off period. Plasma is thus re-ignited to reproduce
20 fresh initiating radicals. The resulting polymer films have a structure and composition closer to their counterparts produced by radical polymerization in liquid phase but show repeatable irregularities induced by the plasma-on period. Such issues should be circumvented.

Another known method for depositing polymer coatings is the initiator chemical vapor
25 deposition (iCVD). This method is based on a thermal decomposition of an initiator into free radicals assisting in initiating the polymerization of co-injected monomers. Typically the iCVD uses a network of heated filaments (e.g. between 200°C and 550°C) such that the initiator molecule is pyrolyzed into radicals capable of initiating a polymerization reaction. Then the radicals diffuse together with the monomers to a
30 carrier substrate. Unfortunately, pyrolysis may also result in the degradation of monomers and is difficult to control. Moreover, pyrolysis of initiator material may result in further undesired ions or agents which may deteriorate the quality of the produced polymer and impede the control of polymer formation. Further, the amount

of radicals and monomers reaching a substrate's surface is difficult to control. In other iCVD methods it is possible that initiators are activated by UV radiation (photo initiator CVD). However, all known iCVD methods do not allow for sufficient control of the polymerization reaction. In particular, free radicals recombine uncontrollably before deposition.

Finally, the method of oxydant chemical vapor deposition (oCVD) is known in the state of the art. In particular, a monomer reacts with an oxidant species. The oCVD uses a spontaneous reaction between the oxidant and the monomer with any energetical initiation (e.g. thermal or optical). However, the oxidants have a very low volatility and their injection into the vapor phase is a difficult problem requiring very specific reactor types.

As indicated above, known methods involve several disadvantages. In summary, they often do not allow for a satisfying control of chain lengths of formed polymers. Another issue is the degradation of polymers and/or polymer forming material which might result in the loss of the desired functional properties of the produced polymer coating. In particular, some of the above methods utilize a plasma within the reaction chamber which results in the degradation of sensitive polymers or precursors, i.e. in particular of organic material.

Moreover, it is not always possible to sufficiently control the concentration of polymer forming material in relation to initiators, thus rendering the control of layer thicknesses and chain lengths difficult.

Other methods involve multiple serial coating steps and are thus time consuming, rendering these methods rather uninteresting for mass production purposes.

The technical problem is to provide an advanced method of forming polymer coatings on substrates.

In particular, the method should allow for an improved control of polymer chain lengths, cross linking and or coating thickness.

Further, the method should be fast, easy to implement or cost-effective.

Another object of the invention is to overcome at least one of the above mentioned disadvantages.

Disclosure of the invention

- 5 The above mentioned technical problem is solved by the method according to claim 1. This method is directed to forming a polymer coating on a substrate, comprising the steps of providing in an evacuated reaction chamber a substrate having a surface to be coated and providing also a first source of polymer forming material and a second source of radicals. In particular, the first source and the second source
- 10 are separated from each other and from the reaction chamber. The polymer forming material and the radicals are (at least temporarily) conducted contemporaneously (at the same time) but spatially separated (distinct) to the substrate's surface, preferably so that a reaction of the polymer forming material with the radicals is avoided before they reach the substrate's surface.
- 15 Since two separate material sources are provided, it is possible to produce a desired amount of radicals and polymer forming material (e.g. monomers) and to provide them to the substrate in the reaction chamber. By keeping polymer forming material and radicals spatially separated (e.g. by fluidly distinct conduit means), it is possible to avoid an early reaction of both source materials. The polymer forming material
- 20 and the radicals react on the substrates surface. An undesired and non-monitorable or uncontrollable prior reaction in the reaction chamber is avoided. The method provides independent controls of polymer forming materials and the radicals that initiate the polymerization reaction. Further, this method leads to a pure chemical polymerization in an appropriate range of pressure and temperature initiated by
- 25 independently (from the reaction chamber) created radicals. The source of radicals can, for example, be a plasma, a pyrolysis system, etc.

Preferably, the formed polymer is an organic polymer. Such organic compounds and corresponding source materials or precursors (e.g. monomers) are particularly

30 sensitive and must not be destroyed or degraded during the deposition process.

Most of the scientists in the field of vapor-phase polymer growth are convinced by the possibility to "polymerize" practically any kind of gaseous or partially volatile organic precursors.

5 In general, it is also possible to remove the deposited coating or film from the substrate for further use.

In accordance with an aspect of the invention, the polymer forming material is conducted or guided via first conduit means to the sample's surface to be coated and the radicals are conducted via second conduit means to the sample's surface to be coated. In other words, the polymer forming material and the radicals are each
10 brought close to the substrate's surface to be coated.

In accordance with another aspect of the invention, the polymer forming material and the radicals are each sprayed essentially perpendicularly onto the sample's surface.

In accordance with another aspect of the invention, the polymer forming material and the radicals are each sprayed in the form of distinct or non-overlapping streams onto
15 the sample's surface.

By spraying radicals and polymer forming material directly onto the surface, a reaction of both materials is avoided.

In accordance with yet another aspect of the invention, the polymer forming material and the radicals are sprayed onto the substrate's surface in the form of essentially
20 parallel (preferably separate or non-overlapping) streams or jets, wherein the streams of polymer forming material and the streams of radicals are sprayed onto the substrate's surface in a spatially alternating manner. In other words each stream of polymer material may be adjacent to at least one stream of radicals, or vice versa. A stream or a jet of polymer forming material may comprise a vapor of polymer
25 forming material. A stream or a jet of radicals may comprise also a carrier gas. For example, the carrier gas may be an inert gas or noble gas. The stream of polymer material may also comprise a carrier gas such as inert or noble gases. An alternating supply of streams to the substrate's surface allows for a homogeneous formation of the polymer coating.

In accordance with yet another aspect of the invention, the polymer forming material and the radicals are separately conducted via conduit (conducting) means until a distance of less than 10 cm, preferably less than 5 cm, and even more preferably less than 2 cm, but preferably not less than 0.1 cm from the substrate's surface.

5 Then they are preferably sprayed onto the surface of the substrate.

Moreover, the present invention is directed to a device for forming a polymer coating or film on a substrate's surface, preferably according to a method in accordance with an aspect of the present invention. Such a device may comprise a reaction chamber for accommodating the substrate to be coated; a first source for providing polymer
10 forming material (e.g. monomers or oligomers); a second source for providing radicals (e.g. a plasma source of plasma radicals); and a conduit system for contemporaneously and spatially separately conducting polymer forming material and radicals from each source to the substrate's surface to be coated, preferably such that a reaction of the polymer forming material and the radicals is avoided
15 before they reach the substrate's surface.

In accordance with yet another aspect of the invention, the conduit system comprises fluidly separated first and second conduit means, wherein the first conduit means are in fluid communication with the first source and the second conduit means are in fluid communication with the second source. Further the first conduit
20 means may comprise a plurality of first outlets for spraying polymer forming material onto the substrate's surface and the second conduit means may comprise a plurality of second outlets for spraying the radicals onto the substrate's surface.

In accordance with yet another aspect of the invention, the first outlets and the second outlets are essentially arranged in a plane opposite to the substrate's surface
25 to be coated.

In accordance with yet another aspect of the invention, the first outlets and the second outlets are alternatingly arranged in a plane opposite to the substrate's surface. Such a spatially alternating arrangement of first and second outlets results in a homogeneous provision of polymer forming material and radicals to the
30 substrate's surface.

In accordance with yet another aspect of the invention, the conduit system comprises a first inlet in fluid communication with the first source and a second inlet in fluid communication with the second source, wherein the plurality of first outlets is only in fluid communication with the first inlet and the plurality of second outlets is only in fluid communication with the second inlet. In other words, the first and the second conduit means are not in fluid communication with each other but fluidly separated.

In accordance with yet another aspect of the invention, the outlets are arranged such that an outlet of the plurality of first outlets is encompassed by or adjacent to at least two outlets of the plurality of second outlets, or vice versa.

In accordance with yet another aspect of the invention, the smallest distance or normal distance from an outlet to the sample's surface is smaller than 100 mm and preferably smaller than 50 mm, and even more preferably smaller than 20 mm but preferably larger than 1 mm.

In accordance with yet another aspect of the invention, the first conduit means and the second conduit means are adapted to supply essentially parallel flows to the outlets for spraying essentially parallel streams perpendicularly onto the substrate's surface to be coated.

In accordance with yet another aspect of the invention, the first conduit means comprise a first comb-shaped member having a plurality of first parallel teeth and the second conduit means comprise a second comb-shaped member having a plurality of second parallel teeth, the first and second comb-shaped members' teeth engaging one another, and wherein the teeth of the first comb-shaped member comprise the plurality of first outlets and the teeth of the second comb-shaped member comprise the plurality of second outlets. This specific design of the conduit means or of the conduit system, respectively, simplifies the production of such means. Further, one of the conduit means can be exchanged without the need of changing the second means. This helps also to avoid contamination of the conduit means by different materials.

In accordance with yet another aspect of the invention, the outlets are alternatingly arranged in the form of a honeycomb pattern or checkerboard pattern.

In general, the outlets may have any cross-section but preferably a hexagonal, circular, elliptical, rectangular, triangular, star-shaped or polygonal cross-section.

All features of the above described aspects of the invention may be combined or replaced with one another.

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Brief description of the drawings

In the following, the figures according to the embodiments of the present invention are briefly described. Further details are given in the detailed description of the embodiments. The Figures have the purpose of illustrating the invention and should
10 not be understood in a limiting sense.

Figure 1 depicts a schematic view of the deposition principle according to an embodiment of the present invention;

Figure 2 depicts a schematic lateral view of the deposition process and the respective conduit system,

15 Figure 3a depicts an arrangement of alternating circular outlets;

Figure 3b depicts an arrangement of outlets arranged in a checkerboard pattern;

Figure 3c depicts an arrangement of outlets in a honeycomb pattern; and

Figure 3d depicts a comb-like arrangement of conduit means comprising outlets.

20 Detailed description of the embodiments

Figure 1 schematically depicts an embodiment of a device 100 according to the present invention. A substrate 1 to be coated is placed in a reaction chamber 3 of the device 100. Further, the device 100 comprises a first material source 5 for providing a polymer forming material 6. The first material source 5 may comprise an inert gas,
25 as for example nitrogen or noble gases, as well as a monomer, oligomer or precursor material 6 depending on the polymer material to be produced. Moreover, the device 100 comprises a second material source 7, i.e. a source of radicals 8.

Such a source 7 may be for instance a plasma radical source 7. However, other possibilities of providing radicals in a separate source 7 are appreciated, as e.g. the formation of radicals 8 via radiation or heating systems. As already described above with respect to the prior art, radicals may assist or trigger the polymerization of polymer forming materials 6.

Preferably, both sources 5, 7 may provide material 6, 8 to the substrate's surface 2 with pressures of less than 1 bar. As depicted in Figure 1 both sources 5 and 7 are separated from each other and from the reaction chamber 3. However, both sources 5 and 7 could also be installed within the reaction chamber as long as no material from each source 5, 7 may get into the reaction chamber 3 in an uncontrolled manner. In other words, the materials 6, 8 from both sources 5, 7 are guided to the sample's surface 2 via conduit means 9, 10 but especially not via an uncontrollable diffusion through the reaction chamber 3.

Depending on the used radicals 8 and/or radical source 7, the amount of radicals 8 might for example be controlled by the time of flight through the conduit means 10. For example, it is possible to avoid the arrival of ions generated in a plasma radical source 7 by choosing the length of the conduit means from the radical source 7 to the outlet 12 such that ions have already recombined to molecules (being not relevant to the polymerization process), since free ions have a shorter lifetime than radicals. Alternatively, or in addition, control might also be possible by adjusting the pressure in the conduit means and/or the flow velocity through the conduit means.

Likewise, it is possible to control the amount of polymer forming material 6 arriving at the substrate's surface 2 by controlling the pressure and/or flow velocity through the conduit means.

For example, polymer forming materials 6 may comprise one or more of the following substances: EDOT, pyrole, ethyl-glycol, methanol, monoglyme, tetraglyme, nipam and propylamine. These substances could also be used to form radicals 8 in a radical source 7. This is a non-exhaustive list of materials since any kind of organic substances might be polymerized with this method.

Further, radicals 8 may also be one or more of: carbon-tetra-fluoride, di-tert-butyl-peroxide, hydrogen-peroxide and borontrifluoride or may be formed in source 7 from

methane or ammonia. Radicals could also be obtained directly from the polymer forming materials.

Produced polymer coatings or films may be for instance polymers which are obtainable from the above mentioned substances. In particular, poly-EDOT, polypyrrole, polyethyl-glycol, polymethanol, polymonoglyme, polytetraglyme, polynipam and polypropylamine. However, it is emphasized that the above listed materials or substances have merely been mentioned for the sake of illustration but must not be understood in a limiting sense. The principle of the invention can be applied to a vast variety of materials and substances falling under the scope of the independent claims.

A preferred mode of providing the sample's surface 2 with radicals 8 and polymer forming material 6 is depicted in Figure 2. The depicted conduit system 4 allows a determined or defined application of polymer forming material 6 and radicals 8 to the substrate's surface 2. The conduit system 4 may comprise first conduit means 9 for conducting or guiding the polymer forming material 6 from the first source 5 to first outlets 11, and second conduit means 10 for conducting or guiding the radicals 8 from the second source 7 to second outlets 12. Thus, the flows of polymer forming material 6 and radicals 8 are (fluidly) separated from each other in the conduit system 4.

In general, the conduit means 9, 11 may be provided in the form of channels or lines. Such channels may have any cross shape as for example circular, ovoid, or polygonal.

Furthermore, the conduit system 4 and/or conduit means 9, 10 may be heatable, wherein the temperature of the surface 2 to be coated is chosen lower than the temperature of the conduit means 9, 10 and in particular of the outlets 11, 12, so as to promote condensation of polymer forming material 6 on the substrate's surface 2.

Thus, the reaction chamber may have a temperature of between about 0°C and about 150°C. Preferably, the conduit system 4 is heatable. Preferably, such heating may provide temperatures of up to 200°C, for example in order to avoid condensation of polymers on the surface of the conduit system 4. The substrate has preferably a temperature of between about 0°C and about 80°C, and preferably

between about 10°C and about 60°C. However, neither the conduit system 4 nor the reaction chamber 3 shall be heated over temperatures of 170°C in order to avoid degradation of polymers or polymer forming material 6.

5 In particular, a pyrolysis of polymer forming material 6 or polymers within the reaction chamber 3 or the conduit means 9, 10 is to be avoided, since such a reaction results in an uncontrollable degradation of materials, and has thus a negative impact on the formed polymer coating.

10 In general, the chamber 3 may be evacuated with a pressure of less than 10 mbar, preferably in the order of between 0.1 mbar and 10 mbar. The substrate or sample 1 may have a flat shape and may have a thickness of less than 1 cm, preferably of 0.1 µm to 3 mm. The lateral size of the sample may be in the order of 1 cm to 100 cm. However, these sizes must not be understood in a limiting sense but have rather an illustrative purpose.

15 When polymer forming material 6 and radicals 8 are streamed through the outlets 11, 12, of the conduit system 4, they may form parallel jets or streams 13, 14 hitting perpendicularly the substrate's surface 2. The jets 13, 14 may also have a conical shape broadening when approaching the substrate's surface 2. Providing such jets 13, 14 to the surface 2 of the substrate 1 helps to avoid a reaction of polymer forming material 6 with the radicals 8 before both materials reach the substrate's surface 2.

20 Preferably the width of the outlets 11, 12 is between about 0.5 mm to about 30 mm and the smallest distance D between an outlet 11, 12 and the substrate's surface 2 is preferably between 3 mm and 50 mm.

25 The outlets 11, 12 of the conduit system 4 may be arranged essentially in a plane essentially parallel to the substrate's surface 2 to be coated. In other words, the outlets 11, 12 face the surface to be coated.

Figures 3a to 3c depict several possible arrangements of outlets or openings 11, 12. In particular, the outlets 11, 12 may be arranged in an alternating manner in order to achieve a homogeneous supply of radicals and polymer forming material over the substrate's surface 2.

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For example, the outlets might have one or more of the following cross-sections: circular (11, 12, 11'', 12''), ovoid, rectangular (11', 12'), triangular, hexagonal (11'', 12''), polygonal, round, cross, star, slit, etc. Preferably, an outlet for polymer forming material 6 has at least two neighbors of outlets for radicals 8, or vice versa.

- 5 As depicted in Figure 3a, the outlets may have a circular shape and might be arranged in lines. In general, the outlets might be arranged at equal distances. The arrangement of outlets might have essentially the form of a honeycomb pattern (see Figure 3c) or a checkerboard pattern (see Figure 3b), or the like.

As depicted in Figure 3d the conduit system 4 might comprise two comb-shaped
10 (hollow) members 15, 16. Each comb-shaped member 15, 16 is preferably in fluid communication with only one of the sources 5, 7. Preferably, each comb-shaped member 15, 16 comprises a plurality of (hollow) teeth 17, 18 being in fluid communication with one another. Each tooth 17, 18 may comprise a plurality of outlets or openings. In any case one comb-shaped member is adapted to apply only
15 material of one of both sources 5 or 7 to the substrate's surface 2. Preferably the teeth 17, 18 are arranged in parallel to the substrate's surface 2 and comprise openings 11'', 12'' facing the substrate's surface 2. Preferably, both members 15, 16 mesh or engage each other. In particular, the teeth 17, 18 of both members 15, 16 mesh or engage each other. This arrangement may substantially simplify the
20 production of the conduit system. Moreover, this arrangement allows for replacing comb-shaped members 15, 16 with one another so that e.g. the position, form, and/or size of outlets might be changed. In particular, a plurality of comb-shaped members may be provided having each outlets with different cross-sections or different positions of the outlets on the teeth.

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The invention has been described with reference to best modes of carrying out the invention. Obviously, modifications and alterations will occur to others upon a reading and understanding of this specification. It is intended to include all such modifications and alterations in so far as they come within the scope of the
30 appended claims or the equivalents thereof.

In any case the above described embodiments shall not be understood in a limiting sense. In particular, the features of the above embodiments may also be replaced or combined with one another.

List of reference signs

- | | |
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| 1 | substrate / sample |
| 2 | substrate's surface to be coated |
| 5 3 | reaction chamber |
| 4 | conduit system |
| 5 | first source / monomer source / polymer forming material source |
| 6 | polymer forming material / monomer material |
| 7 | second source / source of radicals |
| 10 8 | radicals |
| 9 | first conduit means |
| 10 | second conduit means |
| 11 | outlet supplied by first source |
| 11' | alternative outlet supplied by the first source |
| 15 11" | alternative outlet supplied by the first source |
| 11''' | alternative outlet supplied by the first source |
| 12 | outlet supplied by second source |
| 12' | alternative outlet supplied by the second source |
| 12" | alternative outlet supplied by the second source |
| 20 12''' | alternative outlet supplied by the second source |
| 13 | spray cone / stream of polymer forming material |
| 14 | spray cone /stream of radicals |
| 15 | comb-like conduit means supplied by the first source |

16 comb-like conduit means supplied by the second source

100 device

D distance between outlets and the sample's surface to be coated

Claims

1. A method of forming a polymer coating on a substrate (1), the method comprising the steps of:

5 providing in an evacuated reaction chamber (3) a substrate (1) having a surface (2) to be coated;

providing a first source (5) of polymer forming material (6) and a second source (7) of radicals (8);

characterized in that

10 the first source (5) and the second source (7) are separated from each other and from the reaction chamber (3), and in that

the polymer forming material (6) and the radicals (8) are at least temporarily conducted contemporaneously but spatially separated to the substrate's surface (2), so that a reaction of the polymer forming material (6) with the radicals (8) is avoided
15 before they reach the substrate's surface (2).

2. The method according to claim 1, wherein the polymer forming material (6) is conducted via first conduit means (9) to the substrate's surface (2) to be coated and the radicals (8) are conducted via second conduit means (10) to the substrate's
20 surface (2) to be coated.

3. The method according to claim 1 or 2, wherein the polymer forming material (6) and the radicals (8) are each sprayed essentially perpendicularly onto the substrate's surface (2).
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4. The method according to one of the preceding claims, wherein the polymer forming material (6) and the radicals (8) are at least partially sprayed onto the

substrate's surface (2) in the form of essentially parallel streams (13, 14), and wherein the streams (13) of polymer forming material (6) and the streams (14) of radicals (8) are sprayed onto the substrate's surface (2) in a spatially alternating manner.

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5. The method according to one of the preceding claims, wherein the polymer forming material (6) and the radicals (8) are separately guided by conduit means (9, 10) until a distance (D) of less than 2 cm, preferably of less than 1 cm, and more preferably of less than 0.5 cm from the substrate's surface (2) and are then sprayed
10 onto the substrate's surface (2).

6. A device (100) for forming a polymer coating on a substrate's surface (2), preferably according to a method of one of claims 1 to 5, the device comprising:

a reaction chamber (3) for accommodating the substrate (1) to be coated;

15 a first source (5) for providing polymer forming material (6);

a second source (7) for providing radicals (8);

characterized in that the device (100) further comprises:

a conduit system (4) for contemporaneously and spatially separately
conducting the polymer forming material (6) and the radicals (8) from each source (5,
20 7) to the substrate's surface (2) to be coated, such that a reaction of the polymer forming material (6) and the radicals (8) is avoided before they reach the substrate's surface (2).

7. The device according to claim 6, wherein the conduit system (4) comprises
25 fluidly separated first (9) and second (10) conduit means, wherein the first conduit means (9) are in fluid communication with the first source (5) and the second conduit means (10) are in fluid communication with the second source (7), and wherein the first conduit means (9) comprise a plurality of first outlets (11) for spraying polymer

forming material (6) onto the substrate's surface (2) and the second conduit means (10) comprise a plurality of second outlets (12) for spraying the radicals (8) onto the substrate's surface (2).

5 8. The device according to claim 7, wherein the first outlets (11) and the second outlets (12) are arranged essentially in a plane opposite, and preferably essentially parallel, to the substrate's surface (2) to be coated.

9. The device according to claim 8, wherein the first outlets (11) and the second
10 outlets (12) are alternatingly arranged in at least a part of the plane.

10. The device according to one of claims 7 to 9, wherein the conduit system (4) comprises a first inlet in fluid communication with the first source (5) and a second inlet in fluid communication with the second source (7) and wherein the plurality of
15 first outlets (11) is only in fluid communication with the first inlet and the plurality of second outlets (12) is only in fluid communication with the second inlet.

11. The device according to one of claims 7 to 10, wherein the outlets (11, 12) are arranged such that an outlet of the plurality of first outlets (11) is adjacent to at least
20 two outlets of the plurality of second outlets (12), or vice versa.

12. The device according to one of claims 7 to 11, wherein the smallest distance (D) from an outlet (11, 12) to the substrate's surface (2) is smaller than 20 mm and preferably smaller than 10 mm and more preferably smaller than 5 mm.

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13. The device according to one of claims 7 to 12, wherein the first conduit means (9) and the second conduit means (10) are adapted to supply essentially parallel

flows to the outlets (11, 12) for spraying essentially parallel streams (13, 14) perpendicularly onto the substrate's surface (2) to be coated.

14. The device according to one of claims 7 to 13, wherein the first conduit means
5 (9) comprise a first comb-shaped member (15) having a plurality of first parallel, hollow teeth (17) and wherein the second conduit means (10) comprise a second comb-shaped member (16) having a plurality of second parallel, hollow teeth (18), the first and second comb-shaped members' teeth (17, 18) engaging one another, and wherein the teeth (17) of the first comb-shaped member (15) comprise the
10 plurality of first outlets (11') and the teeth (18) of the second comb-shaped member (16) comprise the plurality of second outlets (12').

15. The device according to one of claims 7 to 13, wherein
the outlets (11, 12) are alternatingly arranged in honeycomb pattern or in a
15 checkerboard pattern; and/or wherein
the outlets' (11, 12) cross-sections are one or more of: hexagonal, circular, elliptic, rectangular, triangular, star-shaped and polygonal.