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(54) **PLASMA COATING DEVICE AND METHOD FOR PLASMA COATING OF A SUBSTRATE**

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(57) **ABSTRACT**

The invention relates to a plasma coating device (**10**) and a method for homogenous coating of a substrate (**12**). It comprises a particle reservoir (**14**), a dosing device (**16**) for dosing the particles (**15**) contained in the particle reservoir (**14**), a processing chamber (**20**) and a transport line (**18**) to convey particles (**15**) into the processing chamber (**20**). The processing chamber pressure (P**1**) in the processing chamber (**20**) is lower than the particle reservoir pressure (P**2**) in the particle reservoir (**14**).

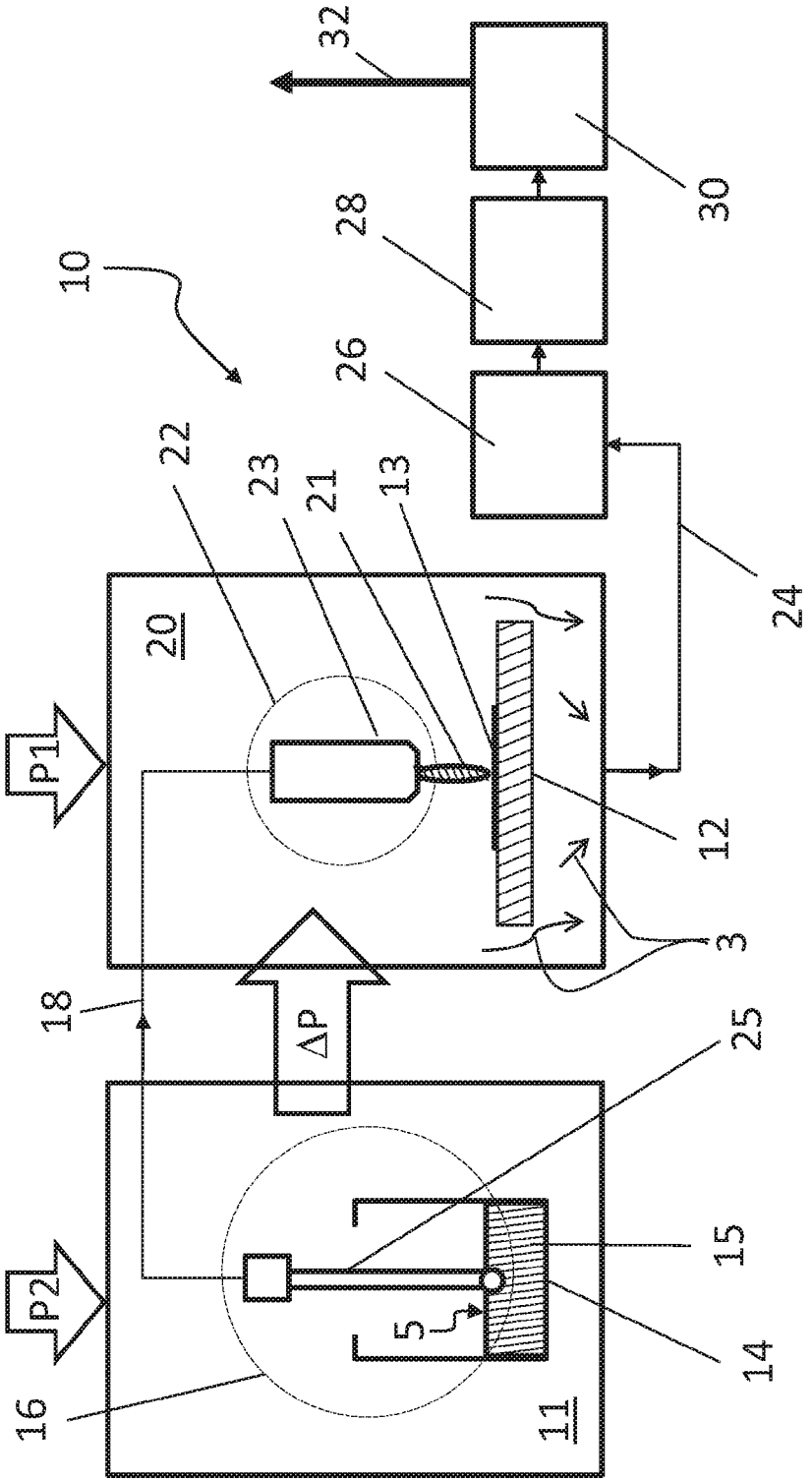

Fig. 1

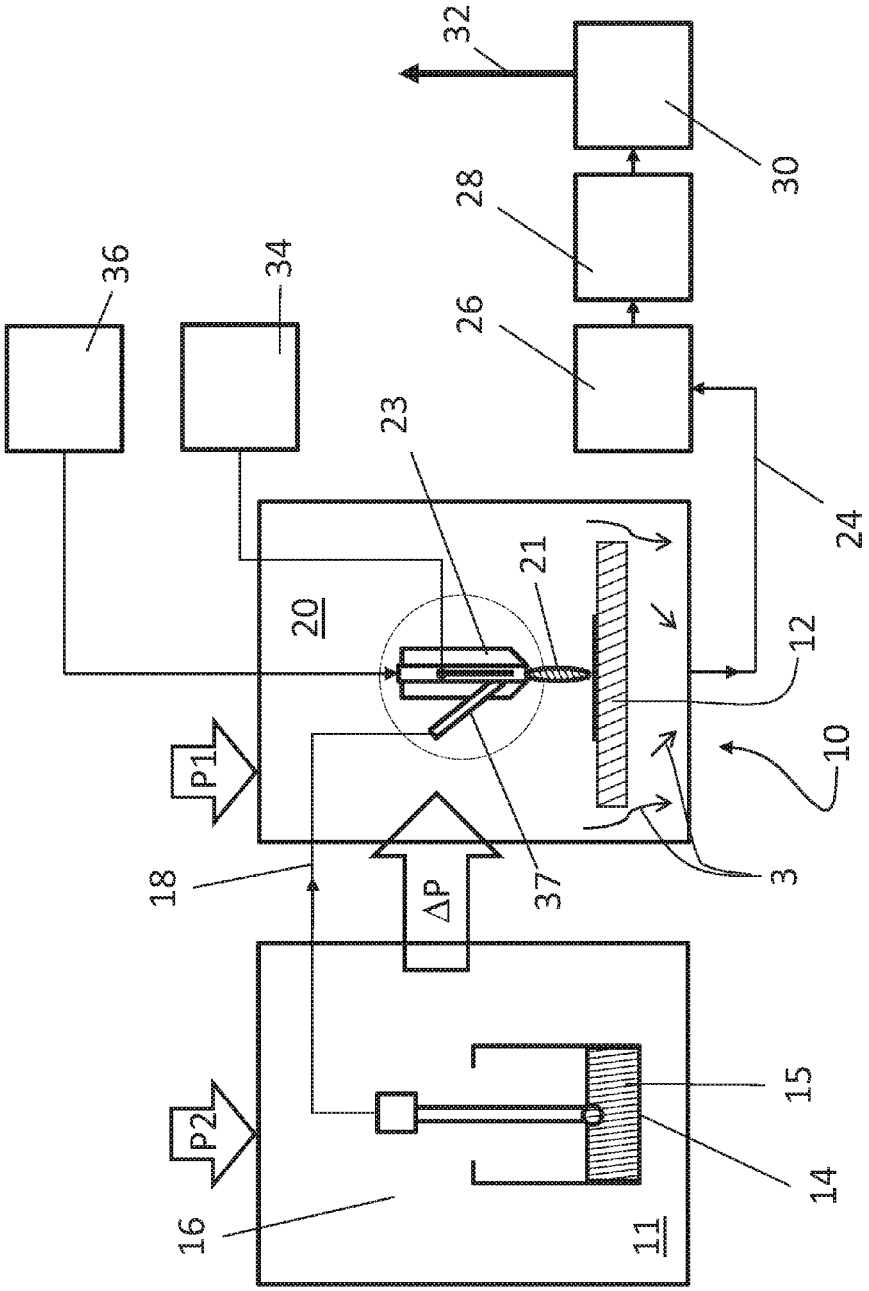

Fig. 2

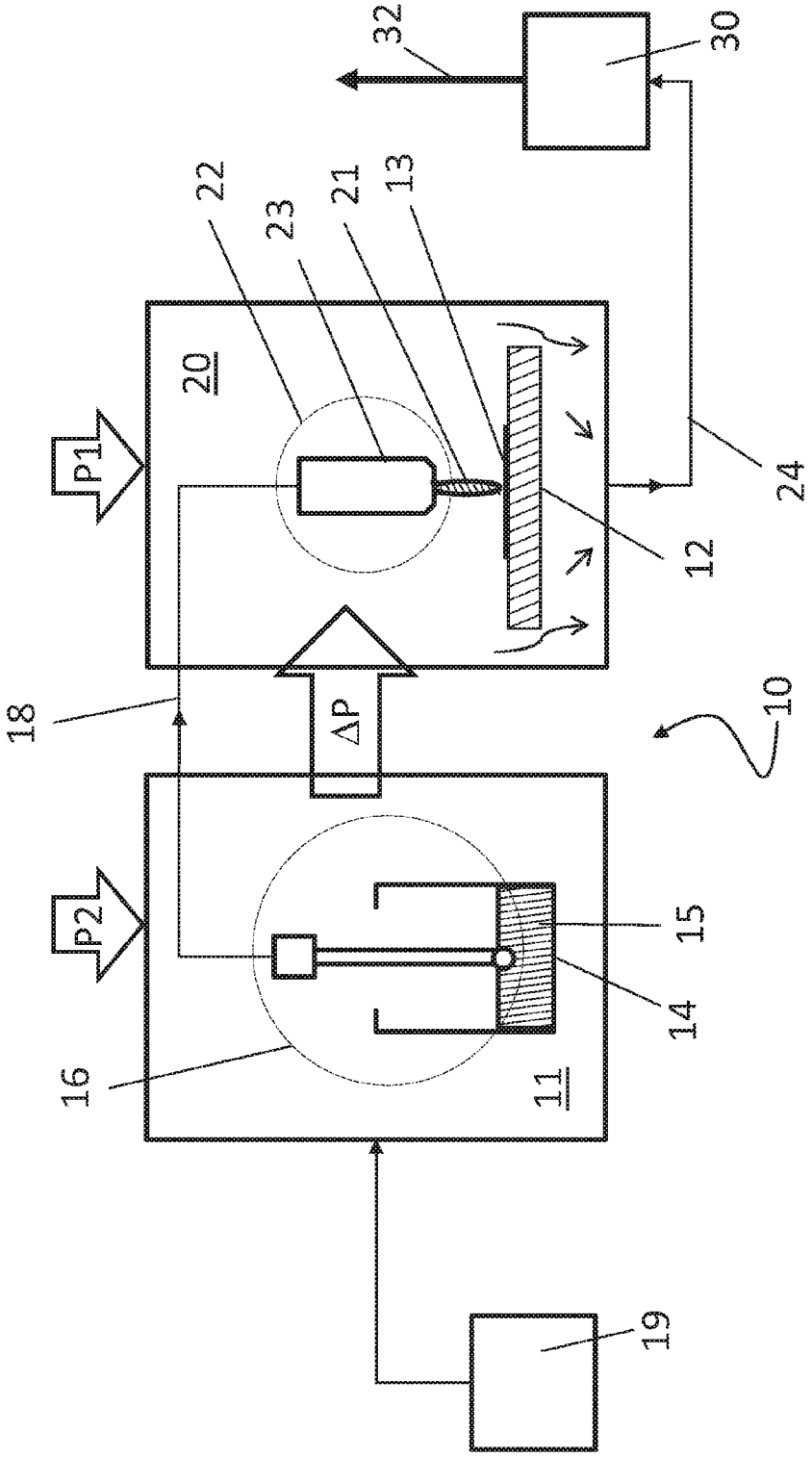

Fig. 3

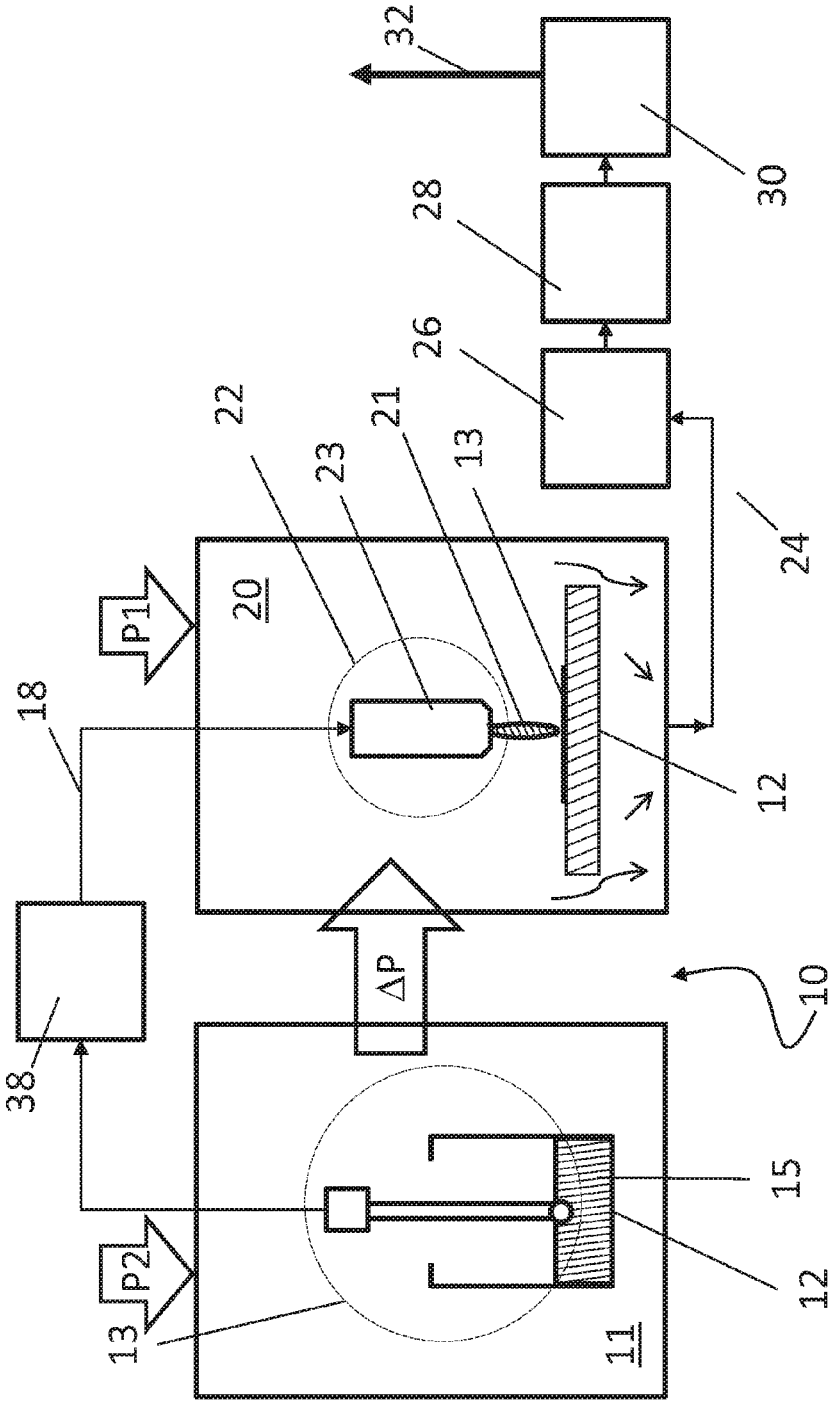

Fig. 4

PLASMA COATING DEVICE AND METHOD FOR PLASMA COATING OF A SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation-in-Part patent application under 35 U.S.C. §120 of U.S. patent application Ser. No. 13/932,581, filed on Jul. 1, 2013, which claims priority from German Patent Application No. 10 2012 106 078.9, filed on Jul. 6, 2012, which applications are incorporated herein by reference in their entireties.

FIELD OF THE INVENTION

[0002] The invention relates generally to a plasma coating device, and more specifically to a plasma coating device for coating of a substrate,

[0003] Furthermore, the invention generally relates to a method for plasma coating of a substrate.

BACKGROUND OF THE INVENTION

[0004] The state of the art comprises a diverse series of sample coating methods and devices. The methods may be selected according to the substrate, the layer to be coated thereon and in particular according to the layer thickness. Amongst suitable coating methods are, according to the initial state of the coating material, gas-phase deposition, dip coating, spraying methods, electroplating or powder coating. Some methods, amongst which in particular thermal spraying methods, plasma spraying, low-temperature plasma coating or laser-assisted powder deposition, are especially suitable for making a homogeneous coating on a substrate. All of these methods require a continuous and well-dosed amount of powder supply to a so-called coating torch.

[0005] To obtain coating layers with specific properties while inducing little thermal and mechanical stress into the substrate to be coated, especially fine-grained powders are used which have particle sizes of 20 μm and below. During the coating of the substrate, the powder is injected into the coating torch. The conveyance of such fine-grained powders is, however, challenging. Furthermore, fine-grained powders tend to form agglomerates that a processing gas stream may not be able to break up. Also, the operation of suitable types of pumps often becomes unstable when handling processing gases with high powder contents. Pumps and conveyance devices are prone to heavy erosion and blockage depending on the powder used. Also, the properties of the powder material itself have a significant impact. Particularly critical are abrasive, low-melting and hygroscopic powders.

[0006] U.S. Pat. No. 5,853,815 discloses a method to homogeneously coat a substrate, wherein a plasma stream covers the entire width of the substrate. For this purpose, a powder reservoir is connected via a feeding line directly with a plasma generation unit. A large pressure difference between the coating torch in the plasma generation unit and the environment of the coating torch generates a shock pattern. Thereby, the coating material is dispersed within the plasma stream and the resulting coating jet is widened.

[0007] German Patent No. DE 198 26 550 C2 proposes that powder may be extracted from a reservoir by mechanical means and converted, together with a carrier gas, into a powder aerosol. The powder aerosol may subsequently be stored in a container and be submitted to ultrasonic treatment in order to break up any particle agglomerates. This process is, however, very complex and not sufficiently reliable for powders prone to agglomeration.

[0008] Other documents of the state of the art, like e.g., DE 102 16 294 A1, DE 10 2005 032 711 A1, US 2007/059436 A1, U.S. Pat. No. 4,109,027 A, DE 43 28 021 A1, EP 0 120 810 A1 or WO 2010/060646 A1, disclose deposition devices or deposition methods that do not involve a plasma and therefore do not inject a deposition material (powder) into a plasma coating torch. Likewise, the problem remains unaddressed of how a constant extraction rate of deposition material is achieved.

SUMMARY OF THE INVENTION

[0009] The present invention broadly comprises a plasma coating device having a particle reservoir, a dosing device for dosing the particles stored in the particle reservoir, an all-round closed processing chamber, at least one transport line from the particle reservoir to the processing chamber, a suction pump being connected with the processing chamber such that a pressure gradient between the processing chamber and the particle reservoir is settable in such a way that there is a processing chamber pressure in the processing chamber and a particle reservoir pressure in the particle reservoir wherein the processing chamber pressure is lower than the particle reservoir pressure, and a plasma coating torch within the processing chamber that receives at a constant conveying rate the particles from the particle reservoir wherein the constant conveying rate is accurately adjustable by means of the transport line and mechanically or pneumatically generated particle aggregations within the transport line are avoided.

[0010] The present invention also broadly comprises a method for plasma coating of a substrate having the steps of: extracting in a regulated manner particles from a particle reservoir with a dosing device by means of a movable suction lance; supplying the particles via a transport line to a processing chamber, in which a plasma coating torch is provided; and setting a pressure gradient between the processing chamber and the particle reservoir by means of a suction pump connected to the processing chamber such that the pressure gradient determines a delivery rate of particles.

[0011] The object of the present invention is to provide a plasma coating device and a method for plasma coating of a substrate capable of conveying a powder or a mixture of powder and processing gas from a powder reservoir into a processing chamber ensuring a homogeneous, precisely dosed, pulsation-free and time stable powder conveyance between the powder reservoir and the processing chamber.

[0012] Accordingly, a plasma coating device for deposition of a coating onto a substrate is disclosed. The coating is produced from particles contained in a particle reservoir. A dosed quantity of particles is extracted from the particle reservoir by a dosing device and subsequently fed to an all-round closed processing chamber via a transport line. Pressure P**1** within the processing chamber is lower than pressure P**2** within the particle reservoir. The pressure gradient between processing chamber pressure P**1** and particle reservoir pressure P**2** is achievable and adjustable by means of a suction pump connected to the processing chamber. The powder particles in the powder reservoir are fed to a plasma coating torch inside the processing chamber via the transport line. The transport is precisely adjustable so as to avoid aggregation of mechanically or pneumatically-related particles in the transport line.

[0013] In an embodiment of the invention, the particle reservoir of the plasma coating device is arranged within a dosing chamber, and the dosing device is connected with the all-round closed processing chamber via the transport line. Due to their different purposes, the processing chamber and the dosing chamber are functionally separated.

[0014] Processing pressure P**1** may be adjusted and adapted by a suction pump connected to the processing chamber via a suction line. Furthermore, a throttle valve can be provided in order to adapt the suction gas stream acting upon the processing chamber. For this purpose, this throttle valve is arranged between the suction line and the suction pump.

[0015] In another embodiment of the invention, a filter is provided for filtering the suction gas stream siphoned off from the processing chamber by the suction pump. This filter is arranged between the suction line and the suction pump and preferably downstream of the throttle valve. In the context of the present invention, the notion "suction gas stream" is to be understood as the stream composed of the mixture of particles and gas siphoned off from the processing chamber.

[0016] The pressure difference between particle reservoir pressure P**2** and processing pressure P**1** is adjusted between 50 mbar and 1000 mbar, preferably at 200 mbar. For this purpose, the absolute particle reservoir pressure P**2** is adjusted between 900 mbar and 1500 mbar. The absolute processing pressure P**1** in the processing chamber is adjusted to at most 1013 mbar, preferably below 500 mbar and more preferably still at 30 mbar.

[0017] The dosing device has a movable suction lance protruding into the particle reservoir. This setup is particularly advantageous if the deposition device is implemented as plasma coating device with a plasma coating torch inside a processing chamber.

[0018] With respect to the inventive method for coating a substrate, a dosed quantity of particles is extracted from a particle reservoir by means of a dosing device. Subsequently, these particles are conveyed via a transport line from which they are fed into the processing chamber. A pressure gradient is set between the particle reservoir and the processing chamber in order to determine a feed rate of particles into the processing chamber.

[0019] In an embodiment of the inventive method, the pressure gradient is generated by aspiration of the processing chamber. The value of the pressure gradient may be set by adjusting the aspiration power.

[0020] The setup of the proposed plasma coating device has the particular advantage that no pumping unit is required in the powder transport line between the powder reservoir and the processing chamber. Furthermore, one can get around of mechanical or pneumatic units in the transport path.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The nature and mode of operation of the present invention will now be more fully described in the following detailed description of the invention taken with the accompanying figures, in which:

[0022] FIG. **1** is a schematic representation of a first embodiment of the inventive plasma coating device;

[0023] FIG. **2** is a schematic representation of another embodiment of the inventive plasma coating device;

[0024] FIG. **3** is a schematic representation of yet another embodiment of the inventive plasma coating device; and,

[0025] FIG. **4** is a schematic representation of yet another embodiment of the inventive plasma coating device.

DETAILED DESCRIPTION OF THE INVENTION

[0026] At the outset, it should be appreciated that like drawing numbers on different drawing views identify identical, or functionally similar, structural elements of the invention. While the present invention is described with respect to what is presently considered to be the preferred aspects, it is to be understood that the invention as claimed is not limited to the disclosed aspect. The present invention is intended to include various modifications and equivalent arrangements within the spirit and scope of the appended claims.

[0027] Furthermore, it is understood that this invention is not limited to the particular methodology, materials and modifications described and as such may, of course, vary. It is also understood that the terminology used herein is for the purpose of describing particular aspects only, and is not intended to limit the scope of the present invention, which is limited only by the appended claims.

[0028] Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood to one of ordinary skill in the art to which this invention belongs. In the context of the present invention, the notion "suction gas stream" is to he understood as the stream composed of the mixture of particles and gas siphoned off from the processing chamber. Although any methods, devices or materials similar or equivalent to those described herein can be used in the practice or testing of the invention, the preferred methods, devices, and materials are now described.

[0029] FIG. **1** illustrates a first embodiment of inventive plasma coating device **10**. Plasma coating device **10** has dosing chamber **11**. Dosing chamber **11** holds dosing device **16** with particle reservoir **14** containing particles **15** used for coating substrate **12**. Furthermore, a particle separation unit is provided within dosing device **16** by means of which particles **15**, i.e., powder, can be extracted from particle reservoir **14**. This particle separation unit may be embodied as, e.g., suction lance **25**. Suction lance **25** dips into the stock of particles or, alternatively, is positioned closely above surface **5** of the stock of particles. The deposition of particles **15** onto substrate **12** as coating **13** is carried out inside processing chamber **20**. In order to supply particles **15** to be deposited onto substrate **12** from dosing chamber **11** to processing chamber **20**, dosing device **16** is connected to processing chamber **20** via transport line **18**.

[0030] Preferably, suction lance **25** is operatively arranged to be movable during an extraction of particles **15** from particle reservoir **14**, and in particular, suction lance **25** moves parallel to the surface of particles **15** in particle reservoir **14**. This movement provides a plasma coating device and a method for plasma coating of a substrate capable of conveying a powder or a mixture of powder and processing gas from a particle reservoir into a processing chamber ensuring a homogeneous, precisely dosed, pulsation-free and time stable powder conveyance between the powder reservoir and the processing chamber. In one embodiment, a three-axle system is utilized, which allows for relative motion of the suction lance in the X-, Y- and

Z-directions. The X/Y motion drives the horizontal relative motion between suction lance **25** and the surface **5**, while the Z-axis permits the vertical adjustment of suction lance **25** in order to ensure a constant distance from surface **5**, a continuous contact to the powder surface, or a constant immersion depth of the suction lance into the particle reservoir. It should be appreciated that the suction lance may move at any point throughout the extraction process and may also move circularly, omni-directionally, etc., or in any other suitable manner known in the art.

[0031] According to the invention, the conveyance of particles **15** from dosing device **16** to processing chamber **20** is achieved by the generation of a suitable pressure gradient ΔP between dosing chamber **11** and processing chamber **20**. Dosing chamber **11** and processing chamber **20** are functionally independent of each other. For this purpose, processing chamber pressure P**1** is set within processing chamber **20**. Also, dosing chamber pressure P**2** within particle reservoir **14** is set to be higher than processing chamber pressure P**1**. The value of pressure gradient ΔP can be adjusted, thus enabling the powder **15** feed rate generated by pressure gradient ΔP to be accurately set. In this way, it is possible to avoid the formation of particle agglomerates caused by mechanical or pneumatic units or means in the conveyance path of particles **15** towards substrate **12**. Avoiding the formation of such particle agglomerates allows a homogeneous, precisely dosed, pulsation-free and reliable powder conveyance between powder reservoir **14** and processing chamber **20**.

[0032] In order to adjust pressure gradient ΔP between processing chamber **20** and particle reservoir **14**, processing chamber **20** is equipped with suction line **24**. Suction line **24** is connected to suction pump **30** generating processing pressure P**1** within processing chamber **20** which is lower than particle reservoir pressure P**2** within dosing chamber **11**. The suction pump is controlled in order to maintain pressure gradient ΔP between processing chamber **20** and particle reservoir **14** within predetermined deviation limits at a given target value.

[0033] Processing pressure P**1** generated by suction pump **30** takes absolute pressure values of 1013 mbar at most and preferably ranges below 50 mbar. Processing pressures P**1** at 30 mbar are especially preferable, particularly because, in this value range, excess material accumulating in processing chamber **20**, like e.g., loose powder **15** not adhering to coating **13**, and also processing gas can be sucked out with suction stream **3** forming from processing chamber **20** towards suction pump **30**. Particle reservoir pressure P**2** preferably ranges from absolute values between 900 mbar and 1500 mbar.

[0034] By means of a suitable combination of an aspiration of processing chamber **20** and the dosing and fluidizing of the particles, pressure gradient ΔP between the two functionally separated chambers (processing chamber **20** and dosing chamber **11**) can thus he achieved and the feed rate of particles **15** can be precisely set. The supply of the coating process with the coating material, e.g., the powder, is governed by pressure gradient ΔP and can thus be regulated by setting pressure gradient ΔP. In this way, the dosing and fluidizing process of powder particles **15** in a processing gas can be controlled. Pressure gradient ΔP is set such that the pressure difference between particle reservoir pressure P**2** and processing pressure P**1** ranges between 50 mbar and 1000 mbar, preferably around 200 mbar.

[0035] Throttle valve **26** is arranged downstream of suction line **24** and can provide an additional means of control and regulation of the pressure difference. By means of throttle valve **26**, the suction power generated by suction pump **30** and acting upon processing chamber **20** can be adjusted without the suction power of suction pump **30** having to be changed itself. This fact allows a fast setting of the effective suction power acting upon processing chamber **20** and thus constituting an efficient means of regulation of plasma coating device **10**. The control of additional components, such as suitable sensors (not shown), can optionally be automated by a control unit (not shown). Additionally, filter **28** may be mounted upstream of suction pump **30** to avoid undesired contamination of suction pump **30** with particles **15**. The extracted gases can be exhausted from suction pump **30** via outlet **32**. Suction pump **30** and throttle valve **26** are coordinately controlled in order to maintain pressure gradient ΔP between processing chamber **20** and particle reservoir **14** on the set target level within predetermined limits.

[0036] FIG. **2** shows a schematic embodiment of the invention in which substrate **12** is coated by plasma coating device **10**. For this purpose, particles **15** are conveyed from dosing chamber **11**, where the pressure within processing chamber **20** is lower than within dosing chamber **11**. Particles **15** are guided via transport line **16** directly into plasma coating nozzle **23**, are injected into plasma coating torch **21** and subsequently impinge onto substrate **12** to be coated. Here, plasma coating torch **21** is a plasma jet. As previously described, pressure gradient ΔP for quantity control and dosage of the conveyed particles **15** is to be set via the suction pump **30**. Upstream of suction pump **30**, throttle valve **26** and filter **28** are provided. Additional components of plasma coating device **10** are electrical power supply **34** and processing gas supply **36** to plasma coating nozzle **23** in processing chamber **20**. Preferably, they are connected to plasma coating nozzle **23**. Likewise, particles **15** are fed from particle reservoir **14** to plasma coating nozzle **23** via feeder **37**.

[0037] FIG. **3** shows yet another embodiment of plasma coating device **10**. This embodiment supplements the setups of the embodiments of FIG. **1** or **2** by pressure pump **19** connected to dosing chamber **11**. The action of auxiliary pressure pump **19** helps to achieve a sufficient pressure gradient ΔP between processing chamber **20** and dosing chamber **11**. Besides suction pump **30**, this provides an additional means to regulate the particle stream from dosing chamber **11** to processing chamber **20**. With this setup, pressure values can be obtained within dosing chamber **11** which are higher than the normal pressure of the surrounding atmosphere. This embodiment may also be supplemented by throttle valve **26** and filter **28** according to FIG. **1** or **2**.

[0038] FIG. **4** shows yet another embodiment of plasma coating device **10**. This embodiment supplements the setups of the embodiments shown in FIG. **1**, **2** or **3** by transport line element **38** arranged in transport line **18** and serving to further stabilize pressure gradient ΔP between dosing chamber **11** and processing chamber **20**. Transport line element **38** may he implemented in two ways. According to a first implementation, transport line element **38** is an auxiliary pump generating a supportive pressure in the direction of processing chamber **20** that further stabilizes pressure gradient ΔP between dosing chamber **11** and processing cham-

ber **20**. Thereby, it supports the stabilization of the feed rate of particles **15** fed to processing chamber **20**. According to a second implementation, transport line element **38** is a throttle in transport line **18** serving to counteract an undesirably high pressure gradient ΔP between dosing chamber **11** and processing chamber **20**. Preferably, the throttling action of this throttle is tunable. By means of suitable measurement, sensor and control units, control and regulation of the throttling action of the throttle and the suction power of suction pump **30** may be automated. Suction pump **30**, transport line element **38** and throttle valve **26** can be coordinately controlled such that pressure gradient ΔP between processing chamber **20** and particle reservoir **14** remains at an adjusted target value within predetermined deviation limits, thus ensuring the constancy of the powder delivery rate from particle reservoir **14**.

[0039] The invention has been described with reference to preferred embodiments. On the basis of the disclosure it is obvious to one skilled in the art that changes, modifications of the invention and in particular combinations of features disclosed in the context of different embodiments are contained in the protective scope of the present invention.

LIST OF REFERENCE NUMBERS

[0040] **3** Suction stream
[0041] **5** Surface
[0042] **10** Plasma coating device
[0043] **11** Dosing chamber
[0044] **12** Substrate
[0045] **13** Coating
[0046] **14** Particle reservoir
[0047] **15** Particles
[0048] **16** Dosing device
[0049] **18** Transport line
[0050] **19** Pressure pump
[0051] **20** Processing chamber
[0052] **21** Coating torch
[0053] **22** Coating head
[0054] **23** Plasma coating nozzle
[0055] **24** Suction line
[0056] **25** Suction lance
[0057] **26** Throttle valve
[0058] **28** Filter
[0059] **30** Suction pump
[0060] **32** Outlet
[0061] **34** Electrical power supply
[0062] **36** Processing gas supply
[0063] **37** Feeder
[0064] **38** Transport line element
[0065] P**1** Processing chamber pressure
[0066] P**2** Particle reservoir pressure
[0067] ΔP Pressure gradient

What is claimed is:

1. A plasma coating device for coating a substrate with particles, the device comprising:

a particle reservoir;

a dosing device for dosing the particles stored in the particle reservoir;

an all-round closed processing chamber;

at least one transport line for guiding particles directly from the particle reservoir to the processing chamber;

a movable suction lance of the dosing device dips into the particle reservoir or is positioned closely above a surface of the particles in the particle reservoir, wherein the movable suction lance is operatively arranged to be movable during an extraction of the particles from the particle reservoir;

a suction pump being connected with the processing chamber such that a pressure gradient between the processing chamber and the particle reservoir is settable in such a way that there is a processing chamber pressure in the processing chamber and a particle reservoir pressure in the particle reservoir, wherein the processing chamber pressure is lower than the particle reservoir pressure; and,

a plasma coating torch within the processing chamber receives at a constant conveying rate the particles from the particle reservoir, wherein the constant conveying rate is adjustable by means of the at least one transport line and mechanically or pneumatically generated particle aggregations within the at least one transport line are avoided.

2. The plasma coating device as recited in claim **1**, wherein a dosing chamber accommodates the dosing device which is connected with the processing chamber via the at least one transport line.

3. The plasma coating device as recited in claim **2**, wherein the processing chamber is functionally separated from the dosing chamber.

4. The plasma coating device as recited in claim **1**, wherein a suction line is connected to the processing chamber and to the suction pump.

5. The plasma coating device as recited in claim **1**, wherein a throttle valve is arranged upstream of the suction pump and at least one filter is arranged between the throttle valve and the suction pump.

6. The plasma coating device as recited in claim **1**, wherein a pressure difference between the particle reservoir pressure and the processing chamber pressure is between 50 mbar and 1000 mbar.

7. The plasma coating device as recited in claim **6**, wherein the pressure difference is set at 200 mbar.

8. The plasma coating device as recited in claim **1**, wherein the particle reservoir pressure is between 900 mbar and 1500 mbar.

9. The plasma coating device as recited in claim **1**, wherein the process chamber pressure is at most 1013 mbar.

10. The plasma coating device as recited in claim **9**, wherein the process chamber pressure is lower than 500 mbar.

11. The plasma coating device as recited in claim **10**, wherein the process chamber pressure is 30 mbar.

12. The plasma coating device as recited in claim **1**, wherein the movable suction lance which protrudes into the particle reservoir is connected with the at least one transport line.

13. The plasma coating device as recited in claim **2**, wherein an additional supporting pump is assigned to and acts on the dosing chamber.

14. The plasma coating device as recited in claim **1**, wherein a transport line element for stabilization of the pressure gradient is provided in the at least one transport line.

15. The plasma coating device as recited in claim **14**, wherein the transport line element is a supporting pump or a throttle.

16. A plasma coating device for coating a substrate with particles, the device comprising:

a particle reservoir;

a dosing device with a movable suction lance which protrudes into the particle reservoir for dosing the particles stored in the particle reservoir;

an all-round closed processing chamber;

at least one transport line for guiding particles directly from the particle reservoir to the processing chamber;

the movable suction lance of the dosing device dips into the particle reservoir or is positioned closely above a surface of the particles in the particle reservoir, wherein the movable suction lance is operatively arranged to be movable during an extraction of the particles from the particle reservoir;

a suction pump being connected with the processing chamber via a suction line such that a pressure gradient between the processing chamber and the particle reservoir is settable in such a way that there is a processing chamber pressure in the processing chamber and a particle reservoir pressure in the particle reservoir, wherein the processing chamber pressure is lower than the particle reservoir pressure; and,

a plasma coating torch within the processing chamber receives at a constant conveying rate the particles from the particle reservoir, wherein the constant conveying rate is adjustable by means of the at least one transport line and mechanically or pneumatically generated particle aggregations within the at least one transport line are avoided, wherein a dosing chamber accommodates the dosing device which is connected with the processing chamber via the at least one transport line and further comprising an additional supporting pump assigned to and acting on the dosing chamber.

17. The plasma coating device as recited in claim **16** further comprising a transport line element for stabilizing the pressure gradient in the at least one transport line.

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