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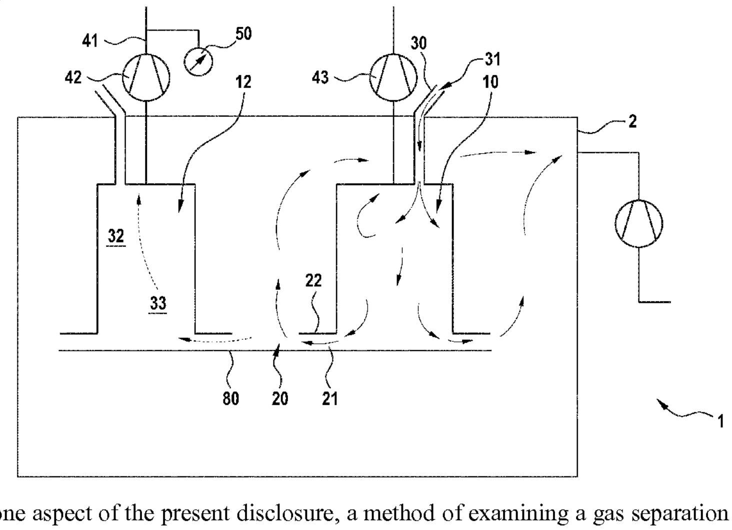
(54) Title: METHOD OF EXAMINING A GAS SEPARATION QUALITY OF A GAS SEPARATION PASSAGE IN A VACUUM CHAMBER, AND VACUUM PROCESSING APPARATUS

Fig. 1



(57) Abstract: According to one aspect of the present disclosure, a method of examining a gas separation quality of a gas separation passage (20) extending between a first vacuum processing region (10) and at least one second vacuum processing region (12) in a vacuum chamber (2) is provided, wherein the gas separation passage (20) is configured as a passageway for a substrate while reducing a gas flow from the first vacuum processing region (10) into the at least one second vacuum processing region (12). The method comprises: introducing a test gas (31) into the first vacuum processing region (10); and measuring a first content (33) of the test gas in a background gas in the at least one second vacuum processing region (12). According to a second aspect, a vacuum processing apparatus (1) and a vacuum deposition apparatus (100, 500) for performing the method are provided.

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METHOD OF EXAMINING A GAS SEPARATION QUALITY OF A GAS SEPARATION PASSAGE IN A VACUUM CHAMBER, AND VACUUM PROCESSING APPARATUS

TECHNICAL FIELD

[0001] Embodiments of the present disclosure relate to thin-film processing apparatuses, particularly to deposition systems, and more particularly to roll-to-roll (R2R) deposition systems and methods for the operation thereof. Embodiments of the present disclosure particularly relate to gas separation in roll-to-roll deposition systems, specifically to methods of examining a gas separation quality between two or more vacuum processing regions in a vacuum processing apparatus, e.g. in a roll-to-roll deposition system. In particular, embodiments disclosed herein relate to methods of examining a gas separation quality of a gas separation passage extending between a first vacuum processing region and a second vacuum processing region in a vacuum chamber, as well as to vacuum processing apparatuses and vacuum deposition apparatuses for processing of a substrate with improved gas separation properties.

BACKGROUND

[0002] Processing of flexible substrates, such as plastic films or foils, is in high demand in the packaging industry, semiconductor industry and other industries. Processing may include coating of a flexible substrate with a desired material such as a metal. Systems performing this task generally include a processing drum, e.g., a cylindrical roller, coupled to a processing system for transporting the substrate, and on which at least a portion of the substrate is processed. Roll-to-roll coating systems can provide a high throughput system.

[0003] Typically, an evaporation process, such as a thermal evaporation process, can be utilized for depositing thin layers of metals which can be metallized onto flexible substrates. However, roll-to-roll deposition systems are also experiencing a strong increase in demand in the display industry and the photovoltaic (PV) industry. For example, touch panel elements, flexible displays, and flexible PV modules result in an increasing demand for depositing suitable layers in roll-to-roll coaters, particularly with low manufacturing costs.

Such devices typically have several layers, which can be manufactured with CVD processes and particularly with PECVD processes.

[0004] The combination of several CVD, PECVD and/or PVD sources working with different gas mixtures and/or different working pressures in a vacuum chamber faces the need of an excellent process gas separation to avoid cross contamination effects in the subsequent processing and to ensure the long term process stability. For example, a first process gas may be utilized in a first vacuum processing region, and a second process gas may be utilized in a second adjacent vacuum processing region. An excellent gas separation factor between the first and the second vacuum processing regions may be beneficial not only for preventing a contamination of a second material layer on the substrate with first material particles, but also for preventing undesired chemical reactions between the first and second materials.

[0005] In some roll-to-roll coating systems, the vacuum processing regions, e.g. sputter compartments, can be separated by a slit which follows the curvature of the coating drum. The gas separation is strongly dependent on the geometrical arrangement of the gas separation passage between the coating drum and the gas separation units. An excellent gas separation factor can be achieved when the gas separation passage includes a slit with a small slit width, which still allows for a transport of the substrate through the slit. The slit width may depend on the adjustment of the gas separation units, the thickness of the substrate and the temperature of the coating drum.

[0006] Therefore, it may be reasonable to regularly check the gas separation passage, in order to make sure that a process gas flow through the gas separation passage is low, but the substrate still passes through the gas separation passage. A conventional geometrical measurement of the gas separation passage may not be sufficient.

[0007] In view of the above, it is desirable to provide a reliable method of examining a gas separation quality of a gas separation passage extending between vacuum processing regions in a vacuum chamber so that the gas separation passage can be adjusted as appropriate.

SUMMARY

[0008] In light of the above, a method of examining a gas separation quality of a gas separation passage in a vacuum chamber is provided. Further, a vacuum processing apparatus, a vacuum deposition apparatus, and methods of operating a vacuum deposition apparatus are provided.

[0009] According to one aspect of the present disclosure, a method of examining a gas separation quality of a gas separation passage extending between a first vacuum processing region and at least one second vacuum processing region in a vacuum chamber is provided, wherein the gas separation passage is configured as a passageway for a substrate while reducing a gas flow between the vacuum processing regions. The method includes introducing a test gas into the first vacuum processing region; and measuring a first content of the test gas in a background gas in the at least one second vacuum processing region.

[0010] According to a further aspect, a vacuum processing apparatus, in particular for performing the method disclosed herein is provided. The vacuum processing apparatus includes: a vacuum chamber; a first vacuum processing region, at least one second vacuum processing region, and a gas separation passage extending between the first vacuum processing region and the at least one second vacuum processing region, wherein the gas separation passage is configured as a passageway for a substrate while reducing a gas flow from the first vacuum processing region into the at least one second vacuum processing region; a first gas inlet for introducing a test gas into the first vacuum processing region; and a test gas sensor configured for measuring a first content of the test gas in a background gas in the at least one second vacuum processing region.

[0011] According to yet another aspect, a vacuum deposition apparatus, in particular for performing the method disclosed herein is provided. The vacuum deposition apparatus includes: a vacuum chamber; and a first vacuum processing region and at least one second vacuum processing region arranged in the vacuum chamber; a first deposition source provided in the first vacuum processing region and configured for depositing a thin layer of a first material on the substrate, and a second deposition source provided in the at least one second vacuum processing region and configured for depositing a thin layer of a second material on the substrate; a substrate support with a substrate support surface for guiding the substrate from the first vacuum processing region along a gas separation passage to the at least one second vacuum processing region, or vice versa; a first gas inlet for introducing a test gas into the first vacuum processing region; and a test gas sensor configured for measuring a first content of the test gas in a background gas in the at least one second vacuum processing region.

[0012] In some embodiments, the vacuum deposition apparatus is a roll-to-roll deposition system, particularly a roll-to-roll deposition system including at least one CVD deposition source.

[0013] According to yet another aspect, a method of operating a vacuum deposition apparatus is provided, including examining a gas separation quality of a gas separation passage arranged between a first vacuum processing region and at least one second vacuum processing region of a vacuum chamber, wherein the gas separation passage is configured as a passageway for a substrate while reducing a gas flow from the first vacuum processing region into the at least one second vacuum processing region, wherein a test gas is introduced into the first vacuum region, and a first content of the test is measured in a background gas present in the at least one second vacuum processing region; the method further comprising: adjusting the gas separation passage in dependence of the measured content; guiding a substrate along the gas separation passage from the first vacuum processing region to the second vacuum processing region; and depositing a first material film on the substrate in the first vacuum processing region, and depositing a second material film on the substrate in the second vacuum processing region.

[0014] Further aspects, advantages, and features of the present disclosure are apparent from the dependent claims, the description, and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] So that the manner in which the above recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments. The accompanying drawings relate to embodiments of the disclosure and are described in the following. Typical embodiments are depicted in the drawings and are detailed in the description which follows.

[0016] FIG. 1 shows a schematic sectional view of a vacuum processing apparatus for processing of a substrate according to embodiments described herein that can be operated for examining a gas separation quality of a gas separation passage in accordance with methods described herein;

[0017] FIG. 2 shows a schematic sectional view of a vacuum processing apparatus for processing of a substrate according to embodiments described herein that can be operated for examining a gas separation quality of a gas separation passage in accordance with methods described herein;

[0018] FIG. 3 shows a schematic view of a roll-to-roll deposition apparatus according to embodiments described herein that can be operated for examining a gas separation quality of a gas separation passage in accordance with methods described herein;

[0019] FIG. 4 shows a schematic view of a roll-to-roll deposition apparatus according to embodiments described herein that can be operated for examining a gas separation quality of a gas separation passage in accordance with methods described herein;

[0020] FIG. 5 is a schematic view for illustrating the various gas flows in a vacuum processing apparatus while operating according to the methods described herein;

[0021] FIG. 6 is a sectional view of a roll-to-roll hotwire CVD deposition apparatus (HWCVD system) for operating according to the methods described herein;

[0022] FIG. 7 is a flow diagram illustrating a method of examining a gas separation quality of a gas separation passage according to embodiments described herein; and

[0023] FIG. 8 is a flow diagram illustrating a method of operating a vacuum deposition apparatus for depositing a thin film on a substrate according to embodiments described herein.

DETAILED DESCRIPTION

[0024] Reference will now be made in detail to the various embodiments, one or more examples of which are illustrated in each figure. Each example is provided by way of explanation and is not meant as a limitation. For example, features illustrated or described as part of one embodiment can be used on or in conjunction with any other embodiment to yield yet a further embodiment. It is intended that the present disclosure includes such modifications and variations.

[0025] Within the following description of the drawings, the same reference numbers refer to the same or to similar components. Generally, only the differences with respect to the individual embodiments are described. Unless specified otherwise, the description of a part or aspect in one embodiment applies to a corresponding part or aspect in another embodiment as well.

[0026] FIG. 1 shows a vacuum processing apparatus 1 for processing of a substrate, e.g. a flexible substrate such as a web, according to embodiments described herein. The vacuum processing apparatus 1 includes a vacuum chamber 2, a first vacuum processing region 10 in the vacuum chamber 2, and a second vacuum processing region 12 in the vacuum chamber 2. The vacuum chamber 2 is provided such that vacuum, i.e. a pressure below atmospheric pressure, e.g. a pressure below 10 mbar or below 1 mbar, can be generated in the vacuum chamber 2. Various vacuum processing techniques, particularly vacuum deposition techniques, can be used to process a substrate, e.g. to deposit a thin film on the substrate.

[0027] A “passageway for a substrate” as used herein may refer to a passage such as an opening or a slit between two vacuum processing regions with a size suitable for guiding a substrate from the first vacuum processing region to the second vacuum processing region, and/or vice versa. The substrate may be a thin substrate, e.g. a film or a web with a thickness less than 1 mm or less than 0.5 mm. Therefore, the dimension of the passageway may be small, e.g. 2 mm or less, 1 mm or less, or 0.5 mm or less in the thickness direction of the substrate. The passageway can be formed between a substrate support for guiding the substrate and wall portions of the vacuum processing regions. In some embodiments, a lateral dimension of the passageway be essentially correspond to a lateral size of the substrate. For example, a lateral dimension of the passageway may be 30 cm or more, or 1 m or more.

[0028] A “background gas” in one of the vacuum processing regions may be defined as the gas which is present in the respective vacuum processing region. The background gas may for example be composed of a separation gas (e.g. an inert gas), a process gas, a test gas, a purge gas and/or further residual gas components. When performing the method described herein, the background gas may mainly include a separation gas.

[0029] A "vacuum processing region" as used herein may refer to a region inside the main volume of a vacuum chamber, which may be used for processing the substrate, wherein processing may include bringing a surface of the substrate in contact with a process gas. The vacuum processing region may be separated from a main volume of the vacuum chamber by wall sections, but may still be in communication with the main volume via the gas separation passage. A vacuum processing region may be at least partially defined by a source housing of a deposition source arranged in the vacuum chamber.

[0030] Vacuum processing techniques may include introducing a first process gas into the first vacuum processing region 10 so that the first process gas can chemically or physically interact with the substrate. Further, vacuum processing techniques may include introducing a second process gas into the second vacuum processing region 12 so that the second process gas can chemically or physically interact with the substrate. The second process gas can be different from the first process gas. In many cases, gas separation between the first and the second vacuum processing regions should be considered, in order to prevent undesired chemical reactions between different process gases and/or in order to prevent the contamination of first material layers on the substrate with second material components or vice versa.

[0031] A process gas may include at least one or more of a precursor gas, a reactant gas, an inert gas, an etch gas, a gas utilized for depositing a film on the substrate via at least one of CVD, PVD, PECVD, sputtering, HWCVD or a similar deposition technique, a gas for etching of a deposited layer, a gas for doping of a deposited layer.

[0032] FIG. 1 shows that the first vacuum processing region 10 and the second vacuum processing region 12 are separated by one or more separation walls. A gas separation passage 20 is provided between the first vacuum processing region 10 and the second vacuum processing region 12 that is configured as a passageway for a substrate. Accordingly, the substrate may first be processed in the first vacuum processing region 10, be transported along the gas separation passage to the second vacuum processing region 12, and then be processed in the second vacuum processing region 12. However, the gas separation passage 20 may allow for a gas flow between the vacuum processing regions. Therefore, the gas separation passage 20 may be configured such that the gas flow between the vacuum processing regions is reduced, while still allowing the substrate to be transported between the vacuum processing regions. For example, a width of a slit 21 of the gas separation passage 20 shown in FIG. 1 may be 5 mm or less, in particular 2 mm or less.

[0033] Gas separation plays a major role when utilizing processing techniques with a high gas load in the vacuum processing regions, e.g. in CVD roll-to-roll web coating systems. The operation pressure in at least one of the vacuum processing regions may be in the mbar-range, e.g. between 0.1 and 5 mbar, in particular about 1 mbar.

[0034] The gas separation can be improved using a separation gas flow, preventing undesired species of the respective process gases from streaming (diffusing) through the gas separation passage into an adjacent vacuum processing region. However, the separation gas further increases the background pressure in the respective vacuum processing regions.

[0035] In order to guarantee excellent properties of the deposited films, the quality of gas separation between two or more vacuum processing regions may be regularly checked or examined. Checking the respective gas separation factors at a low background pressure, e.g. at a background pressure below 10^{-3} mbar, may be possible by measuring a (total) pressure increase in the second vacuum processing region, when introducing a gas into the first vacuum processing region, or vice versa. However, a total pressure measurement may be difficult when gas separation factors of many orders of magnitude are to be measured, while the background pressure is in the mbar range, e.g. >0.1 mbar.

[0036] According to a method of examining a gas separation quality of the gas separation passage 20 described herein, a test gas 31 is introduced into the first vacuum processing region 10, and a first content 33 of the test gas in a background gas 32 present in the at least one second vacuum processing region 12 is measured. In some embodiments, the measurement is performed inside the vacuum chamber, e.g. via a test gas sensor operable under vacuum conditions. In some embodiments, the measurement is performed outside the vacuum chamber, e.g. in an exhaust line of a vacuum pump configured for pumping the gas out of the respective vacuum processing region, for example via a test gas sensor operable under atmospheric conditions. In other words, the content of the test gas in the background gas 32 is not necessarily measured inside the second vacuum processing region, but the background gas 32 can be guided out of the vacuum chamber, where the measurement of the test gas content can be performed.

[0037] Therein, the first vacuum processing region and the second vacuum processing region are interchangeable. In other words, the described method may alternatively or additionally comprise introducing the test gas 31 into the second vacuum processing region 12, and measuring a content of the test gas present in the first vacuum processing region 10.

[0038] Measuring the first content 33 of the test gas may comprise measuring the first content (e.g., in parts per million, ppm) of the test gas in a background gas 32 taken from the second vacuum processing region 12. For example, the background gas 32 is pumped out of the second vacuum processing region 12, whereupon the first content 33 of the test gas in the background gas is measured. The measured content in the exhaust line of the vacuum pump may correspond to the content (e.g., expressed in ppm) inside the second vacuum processing region 12.

[0039] In some embodiments, measuring the first content 33 of the test gas may comprise measuring at least one of a concentration, a partial pressure, a molecular density (molecules/volume), and a mole fraction of the test gas in the background gas 32 in the second vacuum processing region 12. In some embodiments, also the (absolute) pressure in the second vacuum processing region may be measured. Based on the (absolute) pressure in the second vacuum processing region and on the content 33 of the test gas in the background gas 32, the partial pressure and/or the concentration of the test gas within the second vacuum processing region 12 can be determined.

[0040] If the determined first content 33 (e.g. expressed in ppm with respect to the background gas 32) of the test gas in the second vacuum processing region is higher than a predetermined threshold value, the gas separation quality of the gas separation passage may be defined as insufficient. In this case, the gas separation passage may be adjusted, e.g. by at least one of adjusting a slit width of the gas separation passage, modifying a flow of a separation gas in the gas separation passage, modifying a vacuum pumping rate of one or more vacuum pumps connected to the vacuum chamber or to the vacuum processing regions.

[0041] The first content 33 of the test gas may be measured via a test gas sensor 50, i.e. a sensor which is specifically configured for measuring the test gas. This is because simultaneously analyzing various gases which may be present in a background gas 32 in the second vacuum processing region 12, e.g. via a residual gas analyzer RGA, may not be sensitive enough or may deliver no realistic values at high background pressures above 0.1 mbar. In particular, operating residual gas analyzers at high background pressures may be difficult. On the other hand, specific test gas sensors 50 which are specifically configured for measuring the test gas may be highly sensitive and may be operable at high background pressures, e.g. at background pressures of 0.1 mbar or more, or 1 mbar or more.

[0042] If the measured content 33 of the test gas is below a predetermined threshold value, the gas separation quality may be defined as sufficient, and the vacuum processing system may be used for processing a substrate.

[0043] According to the methods described herein, a very small content (e.g. expressed in parts per million) or a very small partial pressure of a specific test gas on a background pressure, which may be up to 5 orders of magnitude higher, can be measured, particularly by using a specific test gas sensor.

[0044] In some embodiments described herein, a sensor with a very high sensitivity for a specific test gas is used. For example, in some embodiments, which may be combined with other embodiments described herein, an optical or a spectroscopic test gas sensor can be used.

[0045] For example, a test gas sensor may include a light source and a light detector, and a spectroscopic property of the test gas, e.g. an absorption at a characteristic wavelength of the test gas, is measured. In particular, the test gas sensor may have an infrared source, a measurement chamber, an interference filter, and an infrared detector. The gas to be examined including the test gas may pass through the measurement chamber, and the absorption of light by the gas may be measured. The filter may be located in front of the light detector and may be configured to prevent wavelengths other than that specific to the test gas from passing to the detector. The light intensity may be detected by the detector and converted into a test gas content value, e.g. a test gas concentration value. For example, a volumetric concentration of the test gas may be measured.

[0046] In some embodiments, the test gas sensor can be an infrared gas sensor. Alternatively or additionally, chemical gas sensors or other gas sensors configured for measuring the first content of the test gas can be used.

[0047] The test gas 31 can be introduced into the first vacuum processing region 10 via a first gas inlet 30, which can be the process gas inlet of the first vacuum processing region 10. Thus, the operation conditions can be imitated when examining the gas separation quality, which may lead to a reliable test result. In particular, the test gas may be introduced into the first vacuum processing region 10 at a predetermined test gas flow rate, which may be a constant flow rate. The test gas may be introduced over a time interval of several seconds, e.g. 10 seconds or more, and more particularly over several minutes, particularly 5 minutes or more, until essentially stationary gas flow rates in the vacuum chamber between the vacuum processing regions and/or in the exhaust lines may be established. In particular, the operation conditions during deposition may substantially deviate from the conditions in the shut-down apparatus, particularly when high gas loads are utilized during operation, e.g. between CVD vacuum processing regions. The method described herein allows for reliable measurements of the separation quality, as the operation conditions can be imitated.

[0048] The operation conditions can be further imitated by using a test gas with properties similar to the properties of the process gas to be used during operation, e.g. during thin film deposition. For example, the molecular weight of the test gas may be similar to the molecular weight of the process gas to be used during operation of the vacuum processing apparatus. Alternatively or additionally, the volatility of the test gas may be similar to the volatility of the process gas to be used. In some embodiments, which may be combined with other embodiments described herein, the test gas has a molecular mass of 5 g/mol or more and 500 g/mol or less, particularly of 20 g/mol or more and 100 g/mol or less. More particularly, the molecular weight of the test gas may be between 40 and 50 g/mol.

[0049] For example, in some cases, helium gas may be too volatile to provide reliable results. In particular, utilizing helium as the test gas may in principle work, but may deliver too conservative values due to the small molecular size and/or weight of helium.

[0050] In some embodiments, which may be combined with other embodiments described herein, the test gas is a CO_2 gas. Further, the first content 33 of the test gas may be measured via a CO_2 sensor, particularly via an optical or spectroscopic CO_2 sensor.

[0051] Utilizing a CO_2 gas as the test gas 31 may provide the following advantages: Sensors for measuring CO_2 with a high sensitivity of 3 ppm or better are commercially available. CO_2 background pressures in typical vacuum processing apparatuses are low so that the measurement results are not negatively affected by previously present CO_2 molecules. CO_2 is not toxic and commonly available. CO_2 works with an optical measuring system, whereas sensors for other gases may operate only under the presence of oxygen. Further, the properties of CO_2 gas may be similar to the properties of typically used process gases. CO_2 test gas leads to very reliable measuring results so that the separation quality of the gas separation passage can be determined in a very exact way.

[0052] In some embodiments, other gases than CO_2 may be utilized as test gases, particularly non-toxic gases that are commercially available and that are typically not present in vacuum processing chambers in a substantial amount.

[0053] The first content 33 of the test gas may be measured in an exhaust line 41 of a vacuum pump 42 connected to the at least one second vacuum processing region. For example, the test gas sensor may be placed in or adjacent to the exhaust line 41 of the vacuum pump 42 that is configured for pumping the inner volume of the second vacuum processing region 12. This is because the composition of the exhaust gas pumped through the exhaust line 41 may exactly or essentially correspond to the composition of the gas present in the second vacuum processing region 12. For example, the second vacuum processing region 12 may include a pumping outlet connected to a vacuum pump 42 so that the second vacuum processing region 12 can be directly pumped.

[0054] During regular processing operation of the vacuum processing apparatus, a purge gas, for example an inert gas, may be provided in the vacuum pumps, in order to avoid undesired chemical reactions of reactive process gases which may potentially stream simultaneously through the vacuum pumps. When the first content 33 of the test gas is measured in an exhaust line 41 of a vacuum pump according to methods described herein, the purge gas supply may be switched off. This is because a purge gas in the vacuum pumps may negatively affect the measuring accuracy.

[0055] Measuring the first content 33 of the test gas in the exhaust line 41 may have the further advantage that the sensitivity of the test gas sensor 50 may depend on the absolute gas pressure. Therefore, arranging the test gas sensor 50 at atmospheric pressure may be beneficial.

[0056] As is shown in FIG. 1, the test gas 31 may be introduced via a first gas inlet 30, e.g. via the process gas inlet, into the first vacuum processing region 10. The first vacuum processing region 10 may be pumped by a first region vacuum pump 43 connected to the inner volume of the first vacuum processing region 10. A major portion of the test gas 31 in the first vacuum processing region 10 may be pumped by the first region vacuum pump 43, and only a small portion of the test gas may diffuse along the gas separation passage 20 into the second vacuum processing region 12.

[0057] As is further illustrated in FIG. 1, the gas separation passage 20 may at least partially be configured as a slit 21 between a gas separation wall 22 and a substrate support 80 which is configured for supporting a substrate. In some embodiments, a width of the slit 21 may be adjustable, e.g. in dependence on a temperature of the substrate support 80 and/or in dependence on a thickness of the substrate to be transported along the gas separation passage 20. In some embodiments, a width of the slit 21 may be in a range of few millimeters, e.g. 5 mm, 2 mm, 1 mm or less.

[0058] The portion of the test gas which enters the second vacuum processing region 12 may be pumped by the vacuum pump 42 which is connected to an inner volume of the second vacuum processing region 12. The first content 33 of the test gas in the background gas 32 of the second vacuum processing region 12 may be measured by the test gas sensor 50 arranged in the exhaust line 41 of the vacuum pump 42.

[0059] FIG. 2 shows a schematic view of a vacuum processing apparatus 5 for processing of a substrate according to embodiments described herein. The vacuum processing apparatus 5 is generally similar to the vacuum processing apparatus 1 shown in FIG. 1 so that reference can be made to the above explanations which are not repeated here.

[0060] The vacuum processing apparatus 5 shown in FIG. 2 includes a vacuum chamber 2, wherein a first vacuum processing region 10 and a second vacuum processing region 12 are arranged in the vacuum chamber 2. A gas separation unit for reducing a gas flow between the vacuum processing regions is provided. A substrate can be transported between the first vacuum processing region 10 and the second vacuum processing region 12 along a gas separation passage 20. The gas separation passage may be at least partially provided as a slit 21 between a substrate support 80 and the gas separation unit which includes a gas separation wall 22. Different layouts of the gas separation unit and of the gas separation passage 20 are possible.

[0061] In some embodiments, the first vacuum processing region 10 is pumped by a first region vacuum pump 43, and the second vacuum processing region 12 is pumped by a second region vacuum pump 42. A test gas sensor 50 is provided for measuring the first content 33 of the test gas in the background gas of the second vacuum processing region 12, and a second test gas sensor 51 is provided for measuring a second content 34 of the test gas in a second background gas 35 of the first vacuum processing region 10. Measuring of the second content 34 of the test gas may comprise measuring the second content of the test gas in the second background gas 35 taken or pumped from the first vacuum processing region 10. Reference is made to the above explanations regarding measurement of the first content 33 of the test gas in the background gas 32 present in the second vacuum processing region 12.

[0062] In some embodiments, which can be combined with other embodiments described herein, the test gas sensor 50 is provided in or adjacent to an exhaust line 41 of the second region vacuum pump 42 for measuring the test gas content in the exhaust gas pumped from the second vacuum processing region. The second test gas sensor 51 may be provided in or adjacent to an exhaust line of the first region vacuum pump 43 for measuring the test gas content in the exhaust gas pumped from the first vacuum processing region. The content of the test gas in the exhaust gas streaming through the respective exhaust lines can be measured.

[0063] In some embodiments, which may be combined with other embodiments described herein, the test gas 31 is introduced into the first vacuum processing region 10, e.g. at a constant flow rate. Then, e.g. after having waited for 5 minutes or longer, the first content 33 is measured via the test gas sensor 50 and the second content 34 is measured via the second test gas sensor 51. The first content 33 can be compared with the second content 34. For example, a ratio between the second content 34 and the first content 33 can be calculated, e.g. by calculating a ratio between the respective partial pressures or contents (expressed in parts per million) of the test gas in the first and second vacuum processing regions.

[0064] A large ratio between the second content 34 and the first content 33, e.g. a ratio larger than 10.000, particularly larger than 100.000 may stand for a good gas separation quality. In other words, a high separation factor of more than 10.000 or more than 100.000 is beneficial. In some embodiments, the gas separation passage may be adjusted, when the ratio is smaller than 100.000 or smaller than 10.000. In some embodiments, for every 100.000 molecules of the test gas present in the first vacuum processing region, not more than 1 molecule of the test gas should be present in the second vacuum region, e.g. when the background gas pressures in the first and second vacuum processing regions are approximately equal. Otherwise, the gas separation passage may be realigned.

[0065] In a similar manner, the gas separation quality can be measured in an inverse direction, i.e. from the second vacuum processing region 12 into the first vacuum processing region 10. In this case, the test gas may be introduced into the second vacuum processing region 12, e.g. via a second gas inlet 36 which may be the process gas inlet of the second vacuum processing region 12. In this case, the second content 34 of the test gas present in the first vacuum processing region may be measured via the second test gas sensor 51.

[0066] In some embodiments, more than two vacuum processing regions may be arranged in the vacuum chamber 2, e.g. three, four or more vacuum processing regions which can be arranged adjacent to each other along a transport direction of the substrate. The vacuum processing regions may be connected via gas separation passages similar to the gas separation passage 20 described with reference to FIG. 1. More than two, particularly all vacuum processing regions may be provided with a test gas sensor for measuring the test gas in the respective vacuum processing region. Then, the gas separation qualities of the respective gas separation passages between adjacent vacuum processing regions can be examined in an analogous way. The overall gas separation quality of the vacuum processing apparatus can be monitored and corrections can be made, if appropriate.

[0067] In some embodiments, which can be combined with other embodiments described herein, a main chamber test gas sensor 52 is provided for measuring a content of the test gas in the background gas of the main volume 3 of the vacuum chamber 2. For example, the main chamber test gas sensor 52 may be arranged in an exhaust line of the main chamber vacuum pump.

[0068] According to some embodiments, which can be combined with other embodiments described herein, a separation gas 60 is introduced into the gas separation passage 20 between the first vacuum processing region 10 and the second vacuum processing region 12. One or more separation gas inlets 61 for introducing the separation gas into the gas separation passage 20 can be arranged such that a first main streaming direction of the separation gas 60 is opposite to a second main streaming direction of the test gas in at least a portion of the gas separation passage 20. The separation quality between the vacuum processing regions can be improved by introducing the separation gas, when operating the vacuum processing apparatus 5.

[0069] As already indicated above, operation conditions may be imitated when performing the method according to embodiments disclosed herein, in order to achieve a reliable indication of the gas separation quality. Therefore, measuring the first content 33 of the test gas may be beneficial, while the separation gas 60 is introduced into the gas separation passage 20. A typical separation gas, particularly an inert gas, e.g. N_2, may be used. In some embodiments, the flow rate of the separation gas in the gas separation passage may correspond to a typical flow rate under operation conditions. The separation gas flow rate may be higher than the test gas flow rate, e.g. by a factor of 10, 100 or more.

[0070] The separation gas 60 may be introduced at more than one separation gas inlets 61. For example, a first separation gas inlet may be provided in a side wall of the first vacuum processing region 10, and a second separation gas inlet may be provided in a side wall of the second vacuum processing region 12.

[0071] As is shown in FIG. 2, in some embodiments, the gas separation passage 20 may be open to a main volume 3 of the vacuum chamber 2 in at least a section between the first vacuum processing region 10 and the second vacuum processing region 12, e.g. in a central section 25 between two slit sections.

[0072] The separation quality can be further improved by pumping from a main pumping outlet 70 connected to the main volume 3 of the vacuum chamber 2. As the gas separation passage 20 is at least partially open to the main volume 3, a major portion of the test gas flowing along the gas separation passage 20 will be pumped by a main chamber vacuum pump 71 connected to the main pumping outlet 70. Only a small portion of the test gas will enter the second vacuum processing region 12.

[0073] While performing the method according to embodiments disclosed herein, a first pressure in the first vacuum processing region 10 and/or the second vacuum processing region 12 may be maintained in a range between 0.1 mbar and 2 mbar, particularly at about 1 mbar. This background pressure may be adjustable by modifying the test gas flow rate, by modifying the separation gas flow rate, and/or by modifying the vacuum pumping rate. Further, the geometrical setup of the gas separation passage, e.g. the width of the slit 21, may be adjusted. A pressure of 0.1 mbar or more may correspond to a pressure within the vacuum processing regions during operation of the vacuum processing apparatus, e.g. during thin film deposition, particular in a CVD system.

[0074] In some embodiments, the separation quality can be further improved by maintaining the first pressure at a higher level than a second pressure in the main volume 3 of the vacuum chamber 2. In this case, the gas which flows through the gas separation passage 20 tends to enter the main volume 3 of the vacuum chamber, where the gas is pumped away by the main chamber vacuum pump 71.

[0075] As is further shown in FIG. 2, the gas separation passage 20 may include a first slit separating the first vacuum processing region 10 from the main volume 3 of the vacuum chamber 2, a central section 25 which is open to the main volume 3 of the vacuum chamber 2, and a second slit separating the main volume 3 from the second vacuum processing region 12. In some embodiments, a main pumping outlet 70 is provided for pumping the main volume 3 of the vacuum chamber 2.

[0076] FIG. 3 shows a schematic sectional view of a roll-to-roll deposition system, in which the above described method may be practiced. The roll-to-roll deposition system is configured as a vacuum deposition apparatus 100 for depositing a thin film on a substrate 106 in at least a first vacuum processing region 10 and a second vacuum processing region 12.

[0077] Similar to the above described embodiments, the vacuum processing regions are separated from each other by at least one gas separation unit, wherein a gas separation passage 20 configured as a passageway for the substrate 106 is provided therebetween. The gas separation passage 20 as well as the setup of the vacuum processing regions may correspond to the setup in the above described embodiments so that reference can be made to the above description which is not repeated here.

[0078] The substrate 106 that is processed in the vacuum deposition apparatus 100 disclosed herein may be a flexible substrate, e.g. a web substrate. A flexible substrate or a web can be characterized as being bendable. For example, the web, as described in embodiments herein, may be a foil or another flexible substrate. However, as described in more detail below, the benefits of embodiments described herein may also be provided for non-flexible substrates or carriers of other inline-deposition systems. Accordingly, a curved or convex substrate support, e.g. a rotatable coating drum 110 as shown in FIG. 3, or a flat substrate support 80, e.g. a flat conveyor as indicated in FIG. 2, may be used. Further, the substrate support is not necessarily movable, and the substrate may be movable via other devices between the vacuum processing regions.

[0075] The vacuum deposition apparatus 100 shown in FIG. 3 includes a vacuum chamber 101. Various vacuum deposition techniques can be used to process the substrate 106 or to deposit the thin film on the substrate. As shown in FIG. 3, and as referred to herein, the vacuum deposition apparatus 100 may be a roll-to-roll deposition apparatus bearing a flexible substrate 106 being guided and processed. However, according to some embodiments, which can be combined with other embodiments described herein, the aspects, details, and features of gas separation, which are described herein, can also be applied for other deposition apparatuses, wherein a glass substrate, a wafer, or another substrate, which can also be non-flexible, or which is provided in a non-flexible carrier, is processed.

[0076] The flexible substrate 106 in FIG. 3 is guided, as indicated by arrow X, into the vacuum chamber 101. For example, the flexible substrate 106 can be guided into the vacuum chamber 101 from an unwinding station. The flexible substrate is directed by rollers 104 to the coating drum 110 configured for supporting the substrate during processing and/or deposition. As shown in FIG. 3, particularly for roll-to-roll deposition apparatuses, the substrate support can be a coating drum, which is rotatable around a drum axis 111. From the coating drum, the substrate 106 is guided to a further roller 104 and out of the vacuum chamber 101, as indicated by the second arrow X.

[0077] The embodiment depicted in FIG. 3 includes a first deposition source 130 provided in the first vacuum processing region 10, and a second deposition source 131 provided in the second vacuum processing region 12. In the vacuum processing regions, the substrate 106 is supported by the coating drum while being processed. Yet, it is to be understood that according to further embodiments, which can be combined with other embodiments described herein, more than two deposition sources can be provided. For example, four, five, six, or even more deposition sources can be provided. The vacuum processing regions are separated from adjacent vacuum processing regions and from a main volume of the vacuum chamber 101 by gas separation units 120.

[0078] In some embodiments, which can be combined with other embodiments described herein, the first vacuum processing region 10 is arranged radially outside the coating drum 110 at a first angular position, and the second vacuum processing region 12 is arranged radially outside the coating drum 110 at a second angular position.

[0079] According to some embodiments described herein, the gas separation units 120 are configured to have a varying position as indicated by arrow Y. The gas separation units 120 typically include a wall 122, which prevents gas in one vacuum processing region from entering a neighboring region, such as a neighboring vacuum processing region. Further, the gas separation passage 20 may be at least partially configured as a slit 21 between the coating drum 110 and a slit wall 124.

[0080] Similar to the vacuum processing apparatuses described above, at least one of the vacuum processing regions includes a gas inlet for introducing a test gas 31, e.g. CO_2, into the vacuum processing region. A test gas sensor 50 is associated to the other vacuum processing region, wherein the test gas sensor 50 is configured for measuring a first content of the test gas in the other vacuum processing region, i.e. a first content of the test gas in a background gas taken from the respective vacuum processing region.

[0081] The test gas sensor 50 may be connected to an exhaust line of a vacuum pump provided to evacuate the other vacuum processing region.

[0082] Further gas separation passages 121 are arranged on opposing sides of the respective vacuum processing regions. In particular, the flexible substrate 106 may enter the vacuum processing regions along a first gas separation passage and exit the vacuum processing region along a second gas separation passage, respectively.

[0083] Details of the gas flow, in particular the separation gas, the separation gas inlets, details of the gas separation passage and further features are not shown in FIG. 3, in order to provide a transparency in the presentation. In this respect, reference is made to the above described embodiments.

[0084] In some embodiments, each of two or more vacuum processing regions are provided with a gas inlet for introducing a test gas, and each of two or more vacuum processing regions include an associated test gas sensor for measuring a content of the test gas present in the respective vacuum processing region. Therefore, the vacuum separation quality between an arbitrary pair of vacuum processing regions can be examined, and a misaligned separation gas passage can be easily located and corrected.

[0085] FIG. 4 shows a schematic sectional view of a further roll-to-roll deposition system for practicing the method according to embodiments described herein. The roll-to-roll deposition system is configured as a vacuum deposition apparatus 500 for depositing a thin film on a substrate 106 in a first vacuum processing region 10 and a second vacuum processing region 12.

[0086] The vacuum deposition apparatus 500 includes a vacuum chamber 501 with a main volume 503, wherein a first source housing with a first deposition source 510 and a second source housing with a second deposition source 520 are directly or indirectly attached to the vacuum chamber 501 via fastening devices in a gas-tight manner in such a way that the source housings at least partially protrude into the main volume 503 of the vacuum chamber 501 towards the substrate support. The substrate support is a coating drum 110 which is rotatable around a drum axis 111. In some embodiments, a main chamber vacuum pump 71 is connected to a pump outlet provided for directly evacuating the main volume 503.

[0087] The coating drum 110 may be provided with a substrate guiding surface for moving the flexible substrate 106 past open front sides of the source housings containing the deposition sources in succession. The source housing of the first deposition source 510 may include a first gas inlet 30 for introducing a process gas or a test gas 31 into the first vacuum processing region 10, and an evacuation outlet for removing the process gas or test gas from the first vacuum processing region 10. Similarly, the source housing of the second deposition source 520 may include a second gas inlet for introducing a process gas or test gas into the second vacuum processing region 12, and an evacuation outlet with a vacuum pump 42 connected thereto for removing the process gas or test gas from the second vacuum processing region 12.

[0088] A test gas sensor 50 is provided for measuring the first content of the test gas which is present in the second vacuum processing region 12.

[0089] In some embodiments, a pre-treatment plasma source 523, e.g. an RF plasma source, can be provided to treat the substrate 106 with a plasma prior to being moved past the deposition sources. Alternatively or additionally, the vacuum deposition apparatus 500 can include a pre-heating unit 529 to heat the flexible substrate 106. For example, a radiation heater, an e-beam heater or any other element to heat the substrate prior to processing thereof can be provided.

[0090] Gap sluices 524 which are capable of ensuring a vacuum separation between portions of the vacuum chamber 501 may be additionally provided. The substrate 106 may be wound from a first roll 528 and may be transported over a number of interleaf rollers 525 to the coating drum 110 where the substrate 106 is coated. Then, the substrate may be transported over further interleaf rollers 525 to a second roll 526. In addition, interleaf rolls 527 may be provided.

[0091] The deposition source can be provided as CVD deposition source, particularly as hot ware CVD deposition source. The first gas inlet 30 may include a showerhead configured to equally distribute the process gas or the test gas in the first vacuum processing region.

[0092] Separation gas channels (not shown) for introducing a separation gas, e.g. an inert gas such as N_2, into the gas separation passage 20 at one or more separation gas inlet positions may be provided in side walls of the source housings. In particular, two or more separation gas inlets configured for introducing the separation gas into a slit of the gas separation passage 20 may be provided along the gas separation passage. The gas separation passage 20 may further include a central section which is open to the main volume 503 of the vacuum chamber 501. A gas separation quality of the gas separation passage 20 may be improved.

[0093] FIG. 5 illustrates the various gas flows in the gas separation passage 20 extending between the first vacuum processing region 10 and the second vacuum processing region 12 when performing the method described herein.

[0094] A first region vacuum pump 43 is connected to the first vacuum processing region 10, a second region vacuum pump 42 is connected to the second vacuum processing region 12, and a main chamber vacuum pump 71 is connected to the main volume of the vacuum chamber.

[0095] A separation gas 60 may be introduced into a first slit section and into a second slit section of the gas separation passage 20, wherein a central section of the gas separation passage may be open to the main volume 3.

[0096] The test gas 31 may be introduced into the first vacuum processing region 10. A content of the test gas present in the second vacuum processing region 12 may be measured via a test gas sensor 50. In some embodiments, the test gas sensor is arranged in an exhaust line of the second region vacuum pump 42.

[0097] FIG. 6 shows part of a roll-to-roll deposition system which may be configured as a hotwire CVD deposition system. The deposition system includes three, four, or more deposition sources 510, 520, 530, wherein the source housings include a vacuum processing region, e.g. a first vacuum processing region 10 and a second vacuum processing region 12. A coating drum 110 with a substrate support surface for supporting and guiding the flexible substrate 106 is provided.

[0098] The source housings which include the vacuum processing regions are arranged radially outside from the coating drum 110 at respective angular positions such that slits between the front walls of the source housings and the coating drum are provided. The slits are part of the gas separation passages 20 between the vacuum processing regions.

[0099] According the methods described herein, a test gas 31 is introduced into a first vacuum processing region, and a first content of the test gas in a background gas taken from another vacuum processing region is measured. Depending on the measured content, one can decide whether the gas separation passage should be adjusted. According to some embodiments described herein, a second content of the test gas is measured in a background gas taken from the first vacuum processing region, and the first content is compared with the second content.

[00100] The test gas may be a CO_2 gas, and the test gas sensor may be a specific gas sensor, particularly an optical CO_2 sensor.

[00101] FIG. 7 shows a flow diagram illustrating a method of examining a gas separation quality of a gas separation passage according to embodiments described herein.

[00102] In box 710, a test gas is introduced into a first vacuum processing region, and, in box 720, a first content of the test gas in a background gas in the second vacuum processing region is measured. If the measured content is above a predetermined threshold value, the gas separation quality may be insufficient, and the gas separation passage can be adjusted.

[00103] FIG. 8 shows a flow diagram illustrating a method of operating a vacuum deposition apparatus for depositing a thin film on a substrate according to embodiments described herein.

[00104] In box 810, a gas separation quality of a gas separation passage arranged between a first vacuum processing region and a second vacuum processing region of a vacuum chamber is examined. In box 811, a test gas is introduced into a first vacuum processing region, and, in box 812, a first content of the test gas in a background gas in the second vacuum processing region is measured. For example, the first content of the test gas is measured in a background gas pumped from the second vacuum processing region, wherein a gas sensor can be arranged in an exhaust line of a vacuum pump.

[00105] Introducing the test gas into the first vacuum processing region may include providing a continuous test gas flow, in particular at a constant test gas flow rate, into the first vacuum processing region. The test gas flow rate may be similar to or may correspond to a typical process gas flow rate utilized for depositing a film on a substrate.

[00106] In box 820, the gas separation passage is adjusted in dependence of the measured content of test gas. For example, the gas separation passage may be adjusted by adjusting a width of a slit of the gas separation passage, by modifying a separation gas flow rate, by modifying a pumping rate and/or by modifying a cooling or heating temperature of the substrate support and/or of the deposition source.

[00107] In box 830, a substrate is guided along the gas separation passage from the first vacuum processing region to the second vacuum processing region, while depositing a first material film on the substrate in the first vacuum processing region, and depositing a second material film on the substrate in the second vacuum processing region. Depositing a first material film may include introducing a first CVD process gas into the first vacuum processing region, and depositing a second material film may include introducing a second CVD process gas into the second vacuum processing region.

[00106] While the foregoing is directed to embodiments of the disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

CLAIMS

1. A method of examining a gas separation quality of a gas separation passage (20) extending between a first vacuum processing region (10) and at least one second vacuum processing region (12) in a vacuum chamber (2), wherein the gas separation passage (20) is configured as a passageway for a substrate while reducing a gas flow from the first vacuum processing region (10) into the at least one second vacuum processing region (12), the method comprising:

introducing a test gas (31) into the first vacuum processing region (10); and

measuring a first content (33) of the test gas in a background gas (32) in the at least one second vacuum processing region (12).

2. The method of claim 1, wherein the first content (33) of the test gas is measured via a test gas sensor (50), particularly via an optical or spectroscopic gas sensor configured for measuring the test gas.

3. The method of claim 2, wherein the test gas is a CO_2 gas, and the first content (33) of the test gas is measured via a CO_2 sensor, particularly via an optical or spectroscopic CO_2 sensor.

4. The method of any of claims 1 to 3, wherein molecules of the test gas have a molecular mass of 5 g/mol or more and 500 g/mol or less, particularly of 20 g/mol or more and 100 g/mol or less.

5. The method of any of claims 1 to 4, further comprising:

measuring a second content (34) of the test gas in a second background gas (35) in the first vacuum processing region (10); and comparing the first content (33) of the test gas and the second content (34) of the test gas.

6. The method of any of claim 1 to 5, further comprising:

introducing a separation gas (60) into the gas separation passage (20) between the first vacuum processing region (10) and the at least one second vacuum processing region (12), wherein a first main streaming direction of the separation gas (60) is opposite to a second main streaming direction of the test gas in at least a portion of the gas separation passage (20).

7. The method of any of claims 1 to 6, wherein the gas separation passage (20) is open to a main volume (3) of the vacuum chamber (2) in a section between the first vacuum processing region (10) and the at least one second vacuum processing region (12), the method further comprising:

vacuum pumping from a main pumping outlet (70) connected to the main volume (3).

8. The method of any of claims 1 to 7, wherein a first pressure in at least one of the first vacuum processing region (10) and the at least one second vacuum processing region (12) is maintained in a range between 0.1 mbar and 2 mbar, particularly wherein the first pressure is maintained at a higher level than a second pressure in the main volume (3) of the vacuum chamber.

9. A vacuum processing apparatus (1) for processing of a substrate, comprising:

a vacuum chamber (2);

a first vacuum processing region (10), at least one second vacuum processing region (12), and a gas separation passage (20) extending between the first vacuum processing region (10) and the at least one second vacuum processing region (12), wherein the gas separation passage (20) is configured as a passageway for a substrate while reducing a gas flow from the first vacuum processing region (10) into the at least one second vacuum processing region (12);

a first gas inlet (30) for introducing a test gas (31) into the first vacuum processing region (10); and

a test gas sensor (50) configured for measuring a first content (33) of the test gas in a background gas (32) in the at least one second vacuum processing region (12).

10. The vacuum processing apparatus of claim 9, wherein the test gas sensor (50) is arranged in or adjacent to an exhaust line (41) of a vacuum pump (42) connected to the at least one second vacuum processing region (12).

11. The vacuum processing apparatus of claim 9 or 10, wherein the test gas sensor (50) is a spectroscopic gas sensor configured for measuring the test gas, particularly a spectroscopic CO_2 sensor.

12. The vacuum processing apparatus of any of claims 9 to 11, wherein the gas separation passage (20) is at least partially configured as a slit (21) between a gas separation wall (22) and a substrate support (80) for supporting a substrate.

13. The vacuum processing apparatus of claim 12, wherein the substrate support (80) is a rotatable coating drum (110) configured to rotate around a drum axis (111), wherein the first vacuum processing region (10) is arranged radially outside the coating drum (110) at a first angular position, and the second vacuum processing region (12) is arranged radially outside the coating drum at a second angular position.

14. The vacuum processing apparatus of any of claims 10 to 13, further comprising one, two, or more separation gas inlets (61) configured for introducing a separation gas into the gas separation passage (20), particularly for introducing the separation gas into the slit (21).

15. The vacuum processing apparatus of any of claims 10 to 14, wherein the gas separation passage (20) comprises a first slit separating the first vacuum processing region (10) from a main volume (3) of the vacuum chamber (2), a central section (25) which is open to the main volume (3) of the vacuum chamber (2) and a second slit separating the main volume (3) from the at least one second vacuum processing region (12), wherein a main pumping outlet (70) is provided for pumping the main volume (3) of the vacuum chamber (2).

16. A vacuum deposition apparatus (100) for depositing a film on a substrate (106), comprising:

a vacuum chamber (2), a first vacuum processing region (10), and at least one second vacuum processing region (12) arranged in the vacuum chamber (2);

a first deposition source (130, 510) provided in the first vacuum processing region (10) and configured for depositing a thin layer of a first material on the substrate (106), and a second deposition source (131, 520) provided in the at least one second vacuum processing region (12) and configured for depositing a thin layer of a second material on the substrate (106);

a substrate support (80) with a substrate support surface for guiding the substrate from the first vacuum processing region (10) along a gas separation passage (20) to the at least one second vacuum processing region (12), or vice versa;

a first gas inlet (30) for introducing a test gas (31) into the first vacuum processing region (10); and

a test gas sensor (50) configured for measuring a first content (33) of the test gas in a background gas (32) in the second vacuum processing region (12).

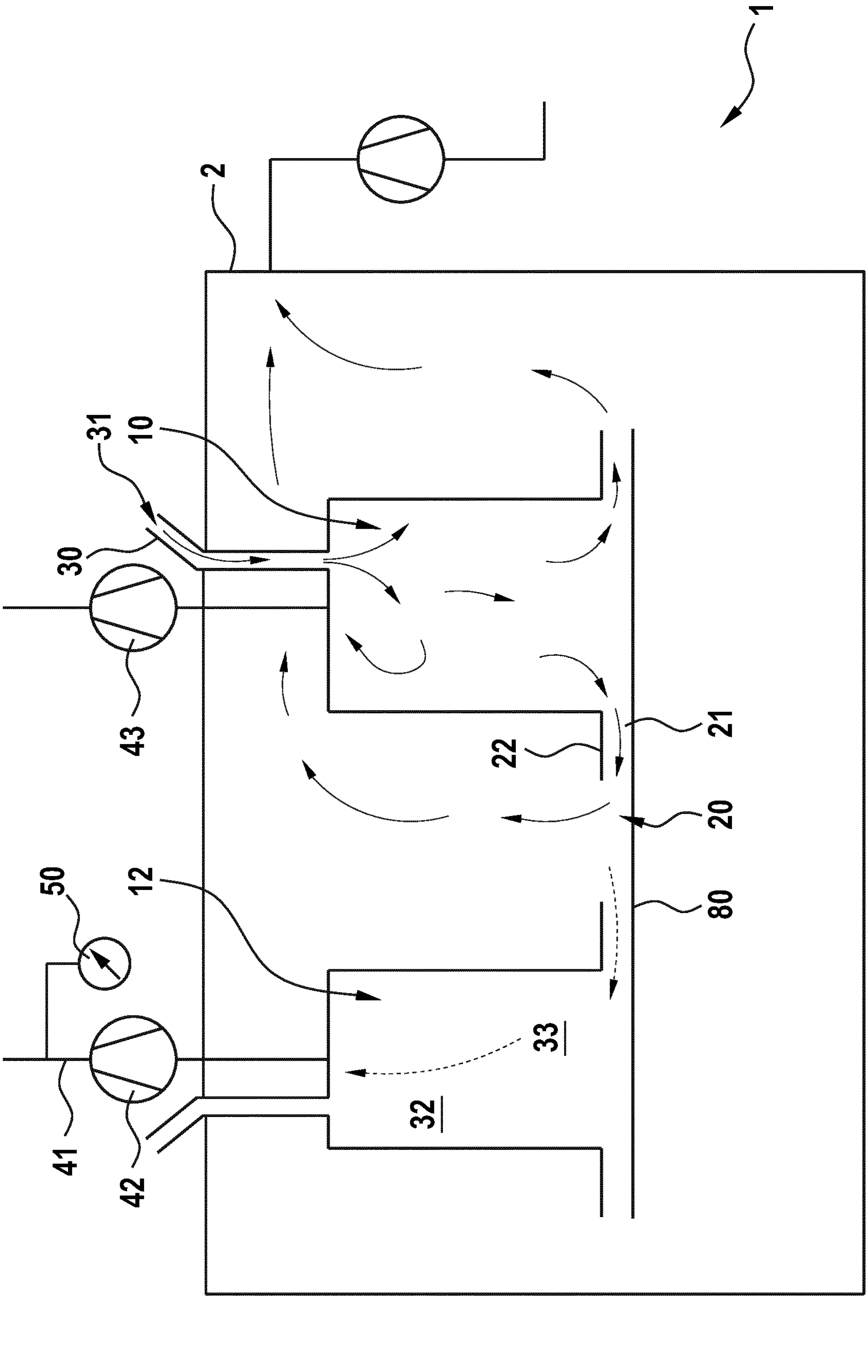

Fig. 1

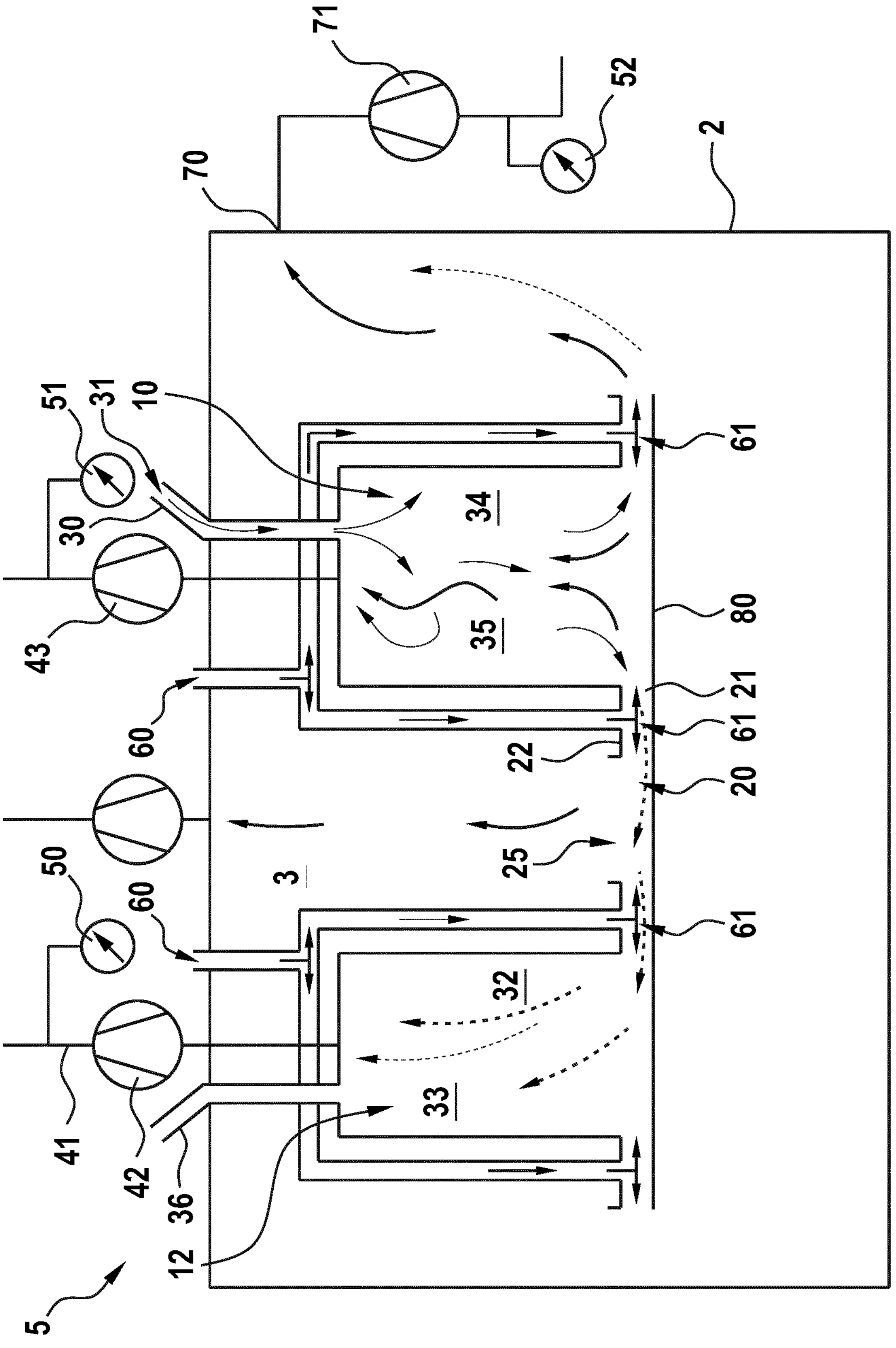
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Fig. 2

Fig. 3

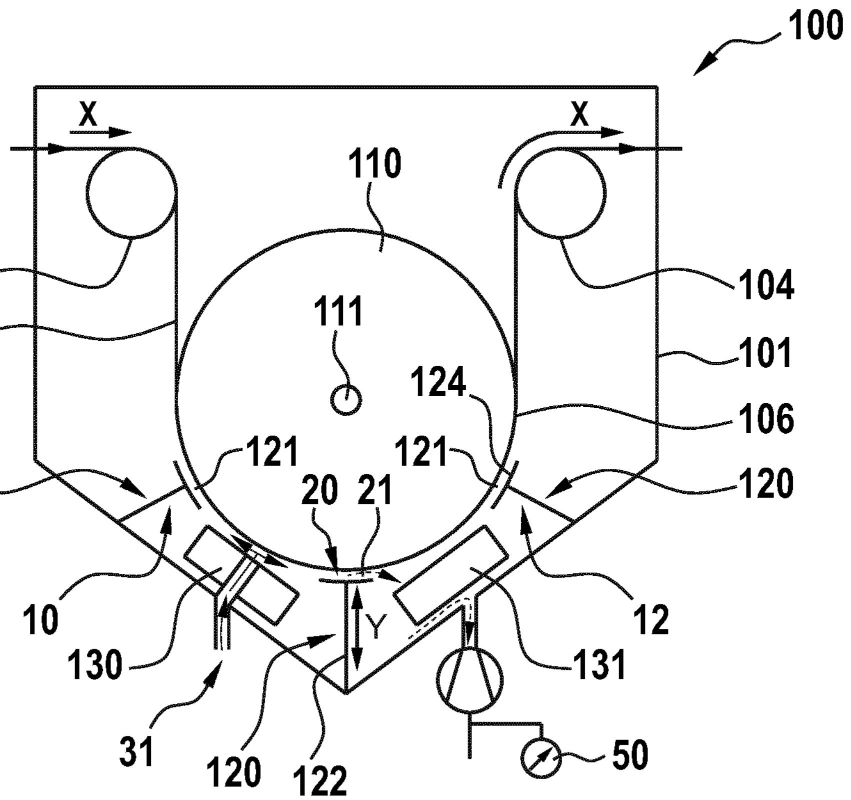
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Fig. 4

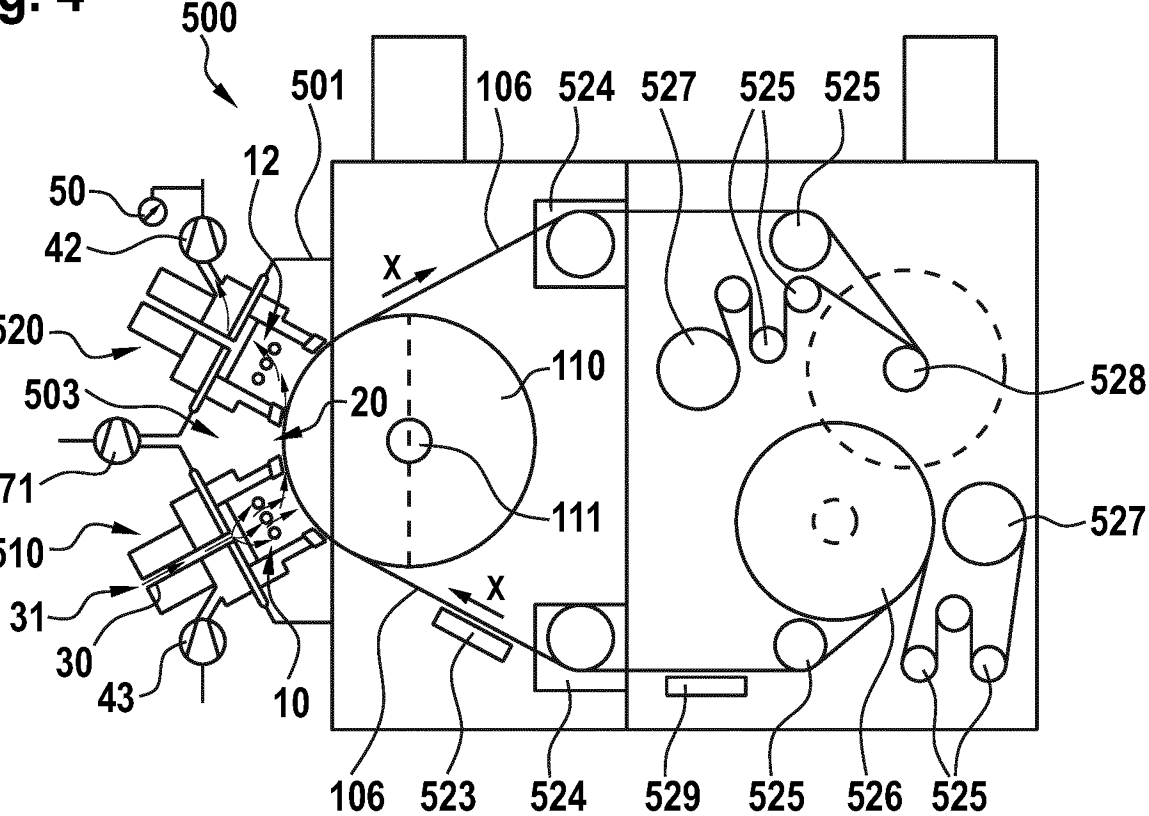
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Fig. 5

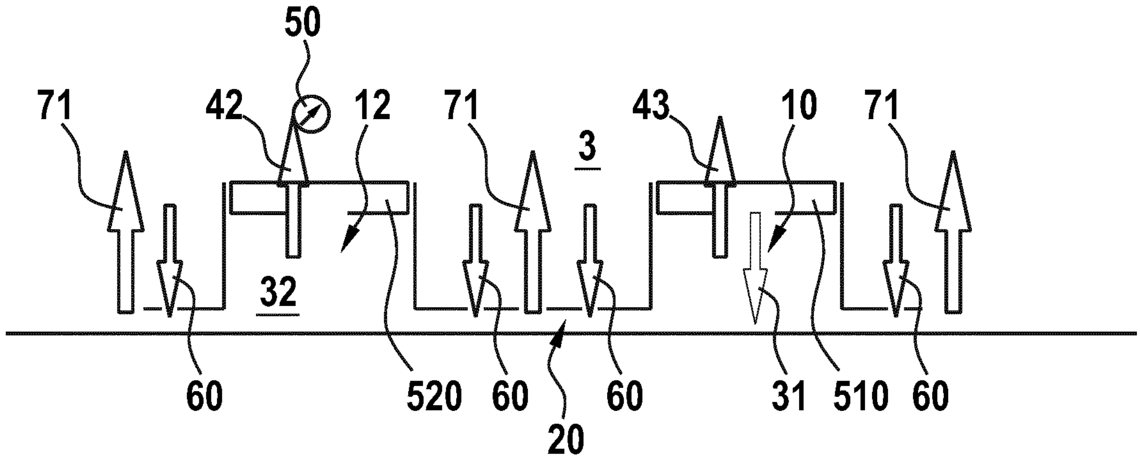
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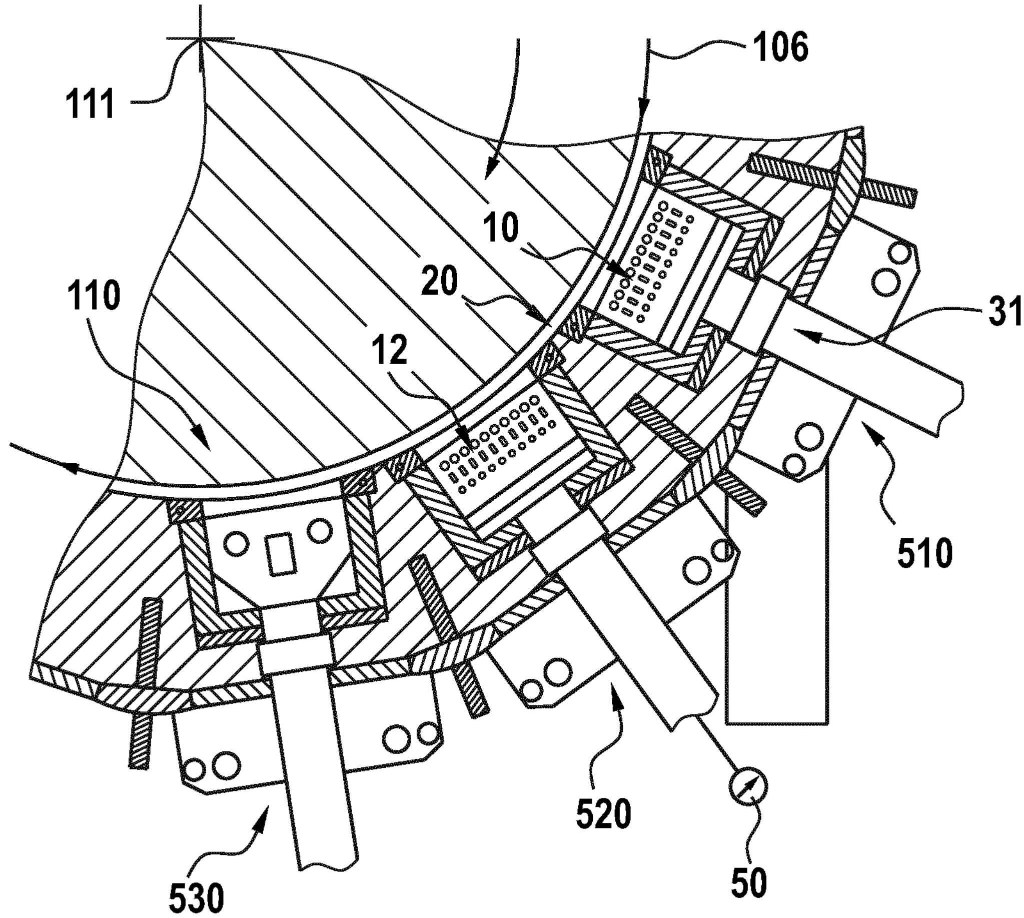
Fig. 6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530
50

Fig. 7

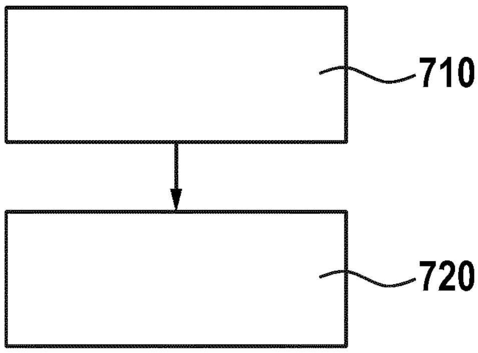
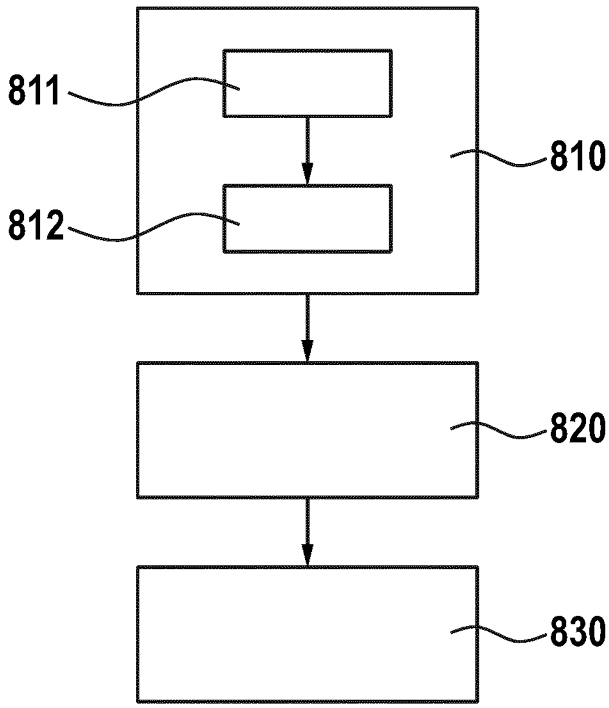


Fig. 8



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/053606

A. CLASSIFICATION OF SUBJECT MATTER
INV. C23C14/56 C23C16/44 C23C16/54
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C23C

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

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

EPO-Internal, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	US 2013/337193 A1 (LECOMTE BENOIT [BE] ET AL) 19 December 2013 (2013-12-19) paragraphs [0009], [0039] - [0058] -----	1,4,6-9, 12,14-16 2,5,10, 11,13 3
Y	US 4 857 136 A (ZAJAC JOHN [US]) 15 August 1989 (1989-08-15) column 2, line 18 - column 3, line 33 -----	2,5,10, 11
Y	US 2014/318452 A1 (STOWELL JR MICHAEL WAYNE [US] ET AL) 30 October 2014 (2014-10-30) paragraph [0124] -----	13

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 August 2016	29/08/2016

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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