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(54) **Title**: METHOD AND APPARATUS FOR MAGNETRON SPUTTERING

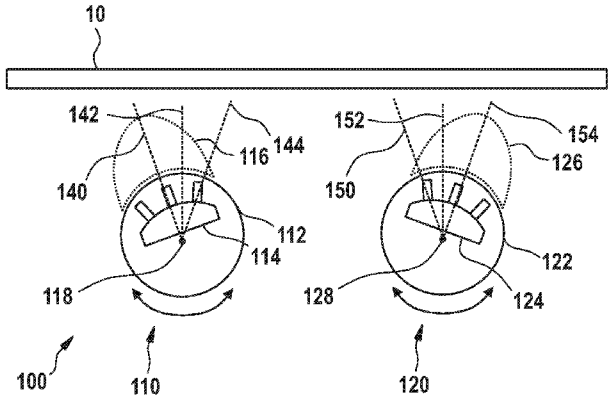


Fig. 1

(57) **Abstract**: The present disclosure relates to a method for material deposition on a substrate, including moving a substrate (10) into a processing zone in a vacuum chamber having an array (100) of at least two rotatable sputter cathodes (110, 120), the at least two rotatable sputter cathodes (110, 120) including a first rotatable sputter cathode (110) and a second rotatable sputter cathode (120), and rotating a first magnet assembly (114) of the first rotatable sputter cathode (110) in a first oscillating rotational motion around a first rotational axis (118) between a first rotational position (140) and a second rotational position (144), and simultaneously rotating a second magnet assembly (124) of the second rotatable sputter cathode (120) in a second oscillating rotational motion around a second rotational axis (128) between a third rotational position (150) and a fourth rotational position (154), wherein the first magnet assembly (114) and the second magnet assembly (124) are rotated in opposite rotational directions during at least 50% of the first oscillating rotational motion and the second oscillating rotational motion.

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METHOD AND APPARATUS FOR MAGNETRON SPUTTERING

FIELD

[0001] Embodiments of the present disclosure relate to a method for material deposition on a substrate, a controller for controlling a material deposition process, and an apparatus for layer deposition on a substrate. Embodiments of the present disclosure particular relate to sputter processes for material deposition on a substrate, a controller for controlling a sputter process, and a sputter apparatus.

BACKGROUND

[0002] Several methods are known for depositing a material on a substrate. For instance, substrates may be coated by a physical vapor deposition (PVD) process, a chemical vapor deposition (CVD) process, or a plasma enhanced chemical vapor deposition (PECVD) process, etc. The process can be performed in a process apparatus or processing chamber in which the substrate to be coated is located. A deposition material is provided in the apparatus. A plurality of materials such as metals, also including oxides, nitrides or carbides thereof, may be used for deposition on a substrate. Coated materials may be used in several applications and in several technical fields. For instance, substrates for displays can be coated by a physical vapor deposition (PVD) process such as a sputtering process, e.g., to form thin film transistors (TFTs) on the substrate.

[0003] With development of new display technologies and a tendency towards larger display sizes, there is an ongoing demand for layers or film used in displays that provide an improved performance, e.g., with respect to electrical characteristics and/or optical characteristics. For example, a uniformity of the deposited layers, such as a uniform thickness and a uniform material component distribution, is beneficial. This particularly applies to thin layers, which can, for example, be used to form thin film transistors (TFTs). In view of the above, it is beneficial to deposit layers with improved uniformity.

[0004] In view of the above, new methods for material deposition on a substrate, controllers for controlling a material deposition process, and apparatuses for layer deposition on a substrate that overcome at least some of the problems in the art are beneficial.

SUMMARY

[0005] In light of the above, a method for material deposition on a substrate, a controller for controlling a material deposition process, and an apparatus for layer deposition on a substrate are provided. Further aspects, benefits, and features of the present disclosure are apparent from the claims, the description, and the accompanying drawings.

[0006] According to an aspect of the present disclosure, a method for material deposition on a substrate is provided. The method includes: moving a substrate into a processing zone in a vacuum chamber having an array of at least two rotatable sputter cathodes, the at least two rotatable sputter cathodes including a first rotatable sputter cathode and a second rotatable sputter cathode; and rotating a first magnet assembly of the first rotatable sputter cathode in a first oscillating rotational motion around a first rotational axis between a first rotational position and a second rotational position, and simultaneously rotating a second magnet assembly of the second rotatable sputter cathode in a second oscillating rotational motion around a second rotational axis between a third rotational position and a fourth rotational position, wherein the first magnet assembly and the second magnet assembly are rotated in opposite rotational directions during at least 50% of the first oscillating rotational motion and the second oscillating rotational motion.

[0007] According to another aspect, a controller for controlling a material deposition process is provided. The controller is configured to perform the method for material deposition on a substrate according to the embodiments described herein.

[0008] According to still another aspect, an apparatus for layer deposition on a substrate is provided. The apparatus includes a vacuum chamber having a processing zone for processing of a substrate, an array of at least two rotatable sputter cathodes, wherein a first rotatable sputter cathode of the at least two rotatable sputter cathodes has a first magnet

assembly and a second rotatable sputter cathode of the at least two rotatable sputter cathodes has a second magnet assembly, and a controller configured for rotating the first magnet assembly in a first oscillating rotational motion around a first rotational axis between a first rotational position and a second rotational position, and for simultaneously rotating the second magnet assembly in a second oscillating rotational motion around a second rotational axis between a third rotational position and a fourth rotational position, wherein the controller is configured for rotating the first magnet assembly and the second magnet assembly in opposite rotational directions during at least 50% of the first oscillating rotational motion and the second oscillating rotational motion.

[0009] Embodiments are also directed at apparatuses for carrying out the disclosed methods and include apparatus parts for performing each described method aspect. These method aspects may be performed by way of hardware components, a computer programmed by appropriate software, by any combination of the two or in any other manner. Furthermore, embodiments according to the disclosure are also directed at methods for operating the described apparatus. It includes method aspects for carrying out every function of the apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] 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:

FIG. 1 shows a schematic view of rotatable sputter cathodes illustrating the method for material deposition on a substrate according to embodiments described herein;

FIG. 2 shows a schematic view of rotatable sputter cathodes illustrating the method for material deposition on a substrate according to further embodiments described herein; and

FIG. 3 shows a schematic top view of an apparatus for layer deposition on a substrate according to embodiments described herein.

DETAILED DESCRIPTION OF EMBODIMENTS

[0011] Reference will now be made in detail to the various embodiments of the disclosure, one or more examples of which are illustrated in the figures. Within the following description of the drawings, the same reference numbers refer to same components. Generally, only the differences with respect to individual embodiments are described. Each example is provided by way of explanation of the disclosure and is not meant as a limitation of the disclosure. Further, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet a further embodiment. It is intended that the description includes such modifications and variations.

[0012] With the development of new display technologies and a tendency towards larger display sizes, there is an ongoing demand for layers or layer systems having improved uniformity, such as uniform thickness of the layers deposited on a substrate. This particularly applies to thin layers or thin films, which can, for example, be used to form thin film transistors (TFTs).

[0013] According to the present disclosure, magnet assemblies of rotatable sputter cathodes perform oscillating rotational motions, wherein the magnet assemblies are rotated in opposite rotational directions during at least 50% of the oscillating rotational motions. As an example, at a time when one magnet assembly is rotated in a clockwise direction, the other magnet assembly is rotated in an anticlockwise direction. Rotating the magnet assemblies in opposite rotational directions during at least 50% of the oscillating rotational motions improves a uniformity of the layer deposited on the substrate. As an example, a thickness uniformity of the deposited layer can be improved.

[0014] FIGs. 1 and 2 show schematic views of a deposition arrangement 100 having rotatable sputter cathodes used in a method for material deposition on a substrate 10

according to embodiments described herein. FIGs. 1 and 2 illustrate oscillating rotational motions of the magnet assemblies with different oscillation angles. FIG. 1 illustrates an oscillating rotational motion with a narrow oscillation angle, and FIG. 2 illustrates an oscillating rotational motion with a wide oscillation angle.

[0015] The method includes moving a substrate 10 into a processing zone in a vacuum chamber having an array of at least two rotatable sputter cathodes. The at least two rotatable sputter cathodes include a first rotatable sputter cathode 110 and a second rotatable sputter cathode 120. The method includes rotating a first magnet assembly 114 of the first rotatable sputter cathode 110 in a first oscillating rotational motion around a first rotational axis 118 between a first rotational position 140 and a second rotational position 140, and simultaneously rotating a second magnet assembly 124 of the second rotatable sputter cathode 120 in a second oscillating rotational motion around a second rotational axis 128 between a third rotational position 150 and a fourth rotational position 154. The first magnet assembly 114 and the second magnet assembly 124 are rotated in opposite rotational directions during at least 50% of the first oscillating rotational motion and the second oscillating rotational motion.

[0016] The deposition arrangement 100 can include a drive or motor for rotating of the magnet assemblies around the respective rotational axes. The drive or motor can be included in the rotatable sputter cathode or an end block associated in the rotatable sputter cathode. According to some implementations, the end block may be considered a portion of the rotatable sputter cathode.

[0017] The deposition arrangement 100 of FIGs. 1 and 2 includes the array of at least two rotatable sputter cathodes each having a magnet assembly. Each rotatable sputter cathode of the array of at least two rotatable sputter cathodes can provide a plasma zone. As an example, the first rotatable sputter cathode 110 provides a first plasma zone 116 and the second rotatable sputter cathode 120 provides a second plasma zone 126.

[0018] The term "oscillating rotational motion" can be understood as a repetitive variation, e.g., in time, of a rotational position of the magnet assemblies between the two rotational positions, such as between the first rotational position 140 and the second rotational position 144 and between the third rotational position 150 and the fourth

rotational position 154. The term "oscillating rotational motion" can also be understood as a repetitive variation, e.g., in time, of a rotational position of the magnet assemblies about a center, such as a line that is perpendicular to a surface of the substrate 10 and that crosses a respective rotational axis (e.g., a first normal 142 and a second normal 152). The term "oscillating rotational motion" as used throughout the present disclosure can also be referred to as "wobbling".

[0019] In some embodiments, the first oscillating rotational motion and the second oscillating rotational motion have a frequency of at least 1/250 Hz, specifically at least 1/10 Hz, and more specifically at least 1 Hz. As an example, the first oscillating rotational motion and the second oscillating rotational motion can have a frequency of equal to, or more than, 1/225 Hz , e.g., for an oscillation angle of about 160 degrees (plus/minus 80 degrees with respect to the normal). As a further example, the first oscillating rotational motion and the second oscillating rotational motion can have a frequency of equal to, or less than, 1/11 Hz, e.g., for an oscillation angle of about 160 degrees (plus/minus 80 degrees with respect to the normal). In some implementations, the first oscillating rotational motion and the second oscillating rotational motion have a frequency of less than 5 Hz, e.g. 1 Hz or less. As an example, the first oscillating rotational motion has a first frequency and the second oscillating rotational motion has a second frequency. The first frequency and the second frequency can be substantially the same or can be different.

[0020] The first magnet assembly 114 and the second magnet assembly 124 are rotated in opposite rotational directions during at least 50%, e.g. 50% of a cycle time, of the first oscillating rotational motion and/or the second oscillating rotational motion. In some embodiments, the first magnet assembly 114 and the second magnet assembly 124 are rotated in opposite rotational directions during at least 60%, 70%, 80%, 90% or 100% of the first oscillating rotational motion and/or the second oscillating rotational motion. Rotating the magnet assemblies in opposite rotational directions during at least 50% of the oscillating rotational motions improves a uniformity of the layer deposited on the substrate. As an example, a thickness uniformity of the deposited layer can be improved.

[0021] According to some implementations, the first magnet assembly 114 and the second magnet assembly 124 are rotated in opposite rotational directions during at least 50% of a first cycle of the first oscillating rotational motion and/or a second cycle of the

second oscillating rotational motion. The term "cycle" can be understood as a time that it takes for the magnet assembly to rotate from an initial rotational position to another rotational position and back to the initial rotational position. As an example, the first cycle can be a time that it takes for the first magnet assembly 114 to rotate from the first rotational position 140 to the second rotational position 144 and back to the first rotational position 140. The second cycle can be a time that it takes for the second magnet assembly 124 to rotate from the third rotational position 150 to the fourth rotational position 154 and back to the third rotational position 150.

[0022] According to some embodiments, which can be combined with other embodiments described herein, the first oscillating rotational motion and the second oscillating rotational motion are asynchronous. The term "asynchronous motions" as used throughout the present disclosure can be understood as referring to two motions, such as the first oscillating rotational motion and the second oscillating rotational motion, that are out of phase (not in-phase). As an example, the two motions are, at least temporarily, motions in different directions, such as the rotations of the first magnet assembly 114 and the second magnet assembly 124 in opposite rotational directions during at least 50% of the first oscillating rotational motion and the second oscillating rotational motion.

[0023] The rotational positions between which the oscillating rotational motions are performed, such as the first rotational position 140 and the second rotational position 144, can also be referred to as "reversal positions" or "turning positions" of the respective oscillating rotational motion. At the reversal positions or turning positions a rotational direction of the magnet assembly changes. As an example, a clockwise rotation changes to an anticlockwise rotation and an anticlockwise rotation changes to a clockwise rotation.

[0024] In some implementations, the change of the rotational direction of the magnet assemblies at the rotational positions can be substantially instantly. The term "substantially instantly" shall take into account time used for stopping the rotation of the magnet assembly in one rotational direction and for reversing and starting the rotation in the opposite rotational direction. In other implementations, the change of the rotational direction of the magnet assemblies at the rotational positions can include a stop of the magnet assemblies (a stop of the rotational movement) at at least one of the rotational positions for a predetermined time. As an example, the magnet assemblies can stop at at

least one of the rotational positions for the predetermined time bevor start moving in the opposite rotational direction. The predetermined time can be more than 0.01 s, specifically more than 1 s, and more specifically more than 10 s. In some implementations, the predetermined time can be less than 50 s.

[0025] According to some embodiments, which can be combined with other embodiments described herein, the rotatable sputter cathodes can provide the plasma zones and the deposition material during substantially the full duration of the oscillating rotational motions. In other words, the rotatable sputter cathodes, e.g., the plasmas or the deposition rate, are not switched off or reduced during the oscillating rotational motions. In other embodiments, an operation of the rotatable sputter cathodes can be temporarily switched off or can be reduced. As an example, the supply of the deposition material in the plasma zones can be terminated (this can also be referred to as "zero deposition rate" or "switching off the plasma"), or the supply of the deposition material in the plasma zones can be reduced temporarily (this can also be referred to as "a reduction of the deposition rate").

[0026] In some implementations, the operation of the rotatable sputter cathodes can be switched off temporarily or can be reduced temporarily at the rotational positions between which the oscillating rotational motions are performed, such as the first rotational position 140 and the second rotational position 144. In other embodiments, the operation of the rotatable sputter cathodes can be switched off or can be reduced between the rotational positions between which the oscillating rotational motions are performed, such as the first rotational position 140 and the second rotational position 144. As an example, the operation of the rotatable sputter cathodes can be switched off or a deposition rate can be reduced during the rotation of the magnet assembly between the rotational positions. The rotatable sputter cathodes can be switched on or the deposition rate can be increased when the magnet assembly is at the rotational positions, e.g., when the magnet assembly stops at the rotational position, such as the first rotational position 140 and/or the second rotational position 144, during the predetermined time mentioned above ("split sputter mode").

[0027] According to some embodiments, which can be combined with other embodiments described herein, the rotational axes of the magnet assemblies are vertically oriented. Likewise, the rotational axes of the plasma zones can be vertically oriented.

"Vertically" is understood as "substantially vertically" particularly when referring to the orientation of the rotational axes of the magnet assemblies and/or the plasma zones, to allow for a deviation from the vertical direction of 20° or below, e.g. of 10° or below. This deviation can be provided for example because the rotatable sputter cathode can be positioned with some deviation from the vertical orientation. Yet, the orientation of the respective rotational axis is considered vertical, which is considered different from the horizontal orientation. The term "vertically" can be understood as being parallel to the force of gravity.

[0028] According to some embodiments, which can be combined with other embodiments described herein, the plasma zones can be rotated around a rotational axis. As an example, the first plasma zone 116 of the first rotatable sputter cathode 110 can be rotated around the first rotational axis 118, and the second plasma zone 126 of the second rotatable sputter cathode 120 can be rotated around the second rotational axis 128. In some embodiments, rotating of the plasma zones around the rotational axes includes a rotating of the magnet assemblies around the respective rotational axes. In some implementations, rotating of the first magnet assembly 114 in the first oscillating rotational motion provides a rotation (and a corresponding oscillating rotational motion) of the first plasma zone 116 of the first rotatable sputter cathode 110 around the first rotational axis 118. Rotating of the second magnet assembly 124 in the second oscillating rotational motion provides a rotation (and a corresponding oscillating rotational motion) of the second plasma zone 126 of the second rotatable sputter cathode 120 around the second rotational axis 128. The rotational speed of the plasma zones can be adjusted by adjusting a rotational speed of the respective magnet assemblies of the rotatable sputter cathodes. The rotational axes of the plasma zones and the rotational axes of the magnet assemblies can coincide or can be identical.

[0029] During the oscillating rotational motions, the plasma zones move or sweep in an oscillating motion over the processing zone in which the substrate 10 is located. As an example, a deposition material provided by the first rotatable sputter cathode 110 and the second rotatable sputter cathode 120 is deposited on the substrate 10 during the first oscillating rotational motion and the oscillating second rotational motion.

[0030] The term "processing zone" as used throughout the specification can be understood as an area or zone in which the substrate 10 can be positioned to deposit a

deposition material thereon to form, e.g., a layer for a thin film transistor. The processing zone can be located to face the array of the at least two rotatable sputter cathodes. During a sputter deposition process, the plasma zones, e.g., the first plasma zone 116 and the second plasma zone 126 move or sweep across the processing zone in an oscillating rotational motion to deposit the deposition material on the substrate 10. The processing zone can be an area or region, which is provided and/or arranged for the deposition (the intended deposition) of the deposition material on the substrate 10.

[0031] According to some embodiments, which can be combined with other embodiments described herein, a first angle between the first rotational position 140 and the second rotational position 144 with respect to the first rotational axis 118 is in the range of 1 to 180 degrees, and a second angle between the third rotational position 150 and the fourth rotational position 154 with respect to the second rotational axis 128 is in the range of 1 to 180 degrees. As an example, at least one of the first angle and the second angle is about 10 degrees (FIG. 1: "narrow angle") or about 160 degrees (FIG. 2: "wide angle"). For example, the first and the second angle can be 10 degrees or larger and/or 160 degrees or smaller, particularly, the first angle can be 10 degrees to 60 degrees ("narrow angle") or 90 degrees to 160 degrees ("wide angle"). In some implementations, the first angle and the second angle can be substantially the same or can be different.

[0032] The first angle and the second angle can be absolute angles between the respective rotational positions. The first angle can be an absolute angle between the first rotational position 140 and the second rotational position 144. The second angle can be an absolute angle between the third rotational position 150 and the fourth rotational position 154. However, the angles can also be defined as an angle with respect to a normal, such as the first normal 142 and the second normal 152. The first normal 142 can be normal or perpendicular to a surface of the substrate 10 and can cross the first rotational axis 118. The second normal 152 can be normal or perpendicular to the surface of the substrate 10 and can cross the second rotational axis 128. The first angle between the first rotational position 140 and the second rotational position 144 can then be defined as plus/minus an angle with respect to the first normal 142. The second angle between the third rotational position 150 and the fourth rotational position 154 can be defined as plus/minus an angle with respect to the second normal 152. As an example, at least one of the first angle and

the second angle can be plus/minus 90 degrees (corresponding to an absolute or total angle of 180 degrees). The angles can also be referred to as "oscillation angles".

[0033] In some implementations, the rotational axes of the magnet assemblies and optionally of the plasma zones can be substantially parallel to a surface of the substrate 10 on which the deposition material is to be deposited. The term "substantially parallel" relates to a substantially parallel orientation of the rotational axes and the surface of the substrate 10, wherein a deviation of a few degrees, e.g. up to 10° or even up to 15°, from an exact parallel orientation is still considered as "substantially parallel".

[0034] Although two rotatable sputter cathodes are shown in the example of FIG. 1, the present disclosure is not limited thereto. According to some embodiments, which can be combined with other embodiments described herein, the array of at least two rotatable sputter cathodes includes 3 rotatable sputter cathodes or more, 6 rotatable sputter cathodes or more, or 12 rotatable sputter cathodes or more. Each rotatable sputter cathode of the array can provide a respective plasma zone. According to embodiments described herein, an array of rotatable sputter cathodes is provided, which is configured for large area substrate deposition.

[0035] In some embodiments, two (immediately or directly) adjacent or neighboring rotatable sputter cathodes of an array of rotatable sputter cathodes form a pair of rotatable sputter cathodes. The magnet assemblies of each pair of (immediately or directly) neighboring rotatable sputter cathodes are rotated in opposite rotational directions during at least 50% of their oscillating rotational motions. As an example, the magnet assemblies of each pair of (immediately or directly) adjacent or neighboring rotatable sputter cathodes are rotated asynchronously. The magnet assemblies of a pair formed by a rotatable sputter cathode and a second neighbor, which is not a direct neighbor, can be rotated synchronously. As an example, when the rotatable sputter cathode are sequentially numbered, the magnet assemblies of the first rotatable sputter cathode and the third rotatable sputter cathode are rotated synchronously, the magnet assemblies of the second rotatable sputter cathode and the fourth rotatable sputter cathode are rotated synchronously, the magnet assemblies of the third rotatable sputter cathode and the fifth rotatable sputter cathode are rotated synchronously, etc.

[0036] According to some embodiments, the substrate 10 is static or dynamic during deposition of the deposition material. According to embodiments described herein a static deposition process can be provided, e.g., for TFT processing. It should be noted that "static deposition processes", which differ from dynamic deposition processes do not exclude any movement of the substrate as would be appreciated by a skilled person. A static deposition process can include, for example, at least one of the following: a static substrate position during deposition; an oscillating substrate position during deposition; an average substrate position that is essentially constant during deposition; a dithering substrate position during deposition; a wobbling substrate position during deposition; a deposition process for which the cathodes are provided in one vacuum chamber, i.e. a predetermined set of cathodes are provided in the vacuum chamber; a substrate position wherein the vacuum chamber has a sealed atmosphere with respect to neighboring chambers, e.g. by closing valve units separating the vacuum chamber from an adjacent chamber during deposition of the layer; or a combination thereof. A static deposition process can be understood as a deposition process with a static position, a deposition process with an essentially static position, or a deposition process with a partially static position of the substrate. In view of this, a static deposition process, in which the substrate position can in some cases not be fully without any movement during deposition, can still be distinguished from a dynamic deposition process.

[0037] According to some embodiments, which can be combined with other embodiments described herein, the rotatable sputter cathodes can be connected to a DC power supply such that sputtering can be conducted as DC sputtering. According to some embodiments, which can be combined with other embodiments described herein, the rotatable sputter cathodes can be connected to an AC power supply such that the rotatable sputter cathodes can be biased in an alternating manner, e.g. for MF (middle frequency) sputtering, RF (radio frequency) sputtering or the like.

[0038] According to some embodiments, which can be combined with other embodiments described herein, the rotatable sputter cathodes are tubular cathodes. The tubular cathodes can include a target or target material. The tubular cathodes can be rotatable around a rotational axis, which can coincide with, or be identical to, the rotational axis around which the respective magnet assembly and optionally the plasma zone are

rotated. In some implementations, the first rotatable sputter cathode 110 is a first tubular cathode 112 (or first rotatable target) and the second rotatable sputter cathode 120 is a second tubular cathode 122 (or second rotatable target). The first tubular cathode 112 can be rotatable around the first rotational axis 118 and the second tubular cathode 122 can be rotatable around the second rotational axis 128. The tubular cathodes or rotatable targets can be connected to respective rotating shafts or connecting elements connecting the shaft and the rotatable cathodes or rotatable targets.

[0039] In some implementations, the magnet assembly can be provided in the respective rotatable sputter cathode. The rotatable sputter cathode having the magnet assembly can provide for magnetron sputtering for depositing of the layers. As used herein, "magnetron sputtering" refers to sputtering performed using a magnetron, i.e. a magnet assembly, that is, a unit capable of generating a magnetic field. Such a magnet assembly can consist of one or more permanent magnets. These permanent magnets can be arranged behind the target material of a target, e.g. within the rotatable sputter cathode or rotatable target in a manner such that the free electrons are trapped within the generated magnetic field generated below a surface of the rotatable cathode or rotatable target. The permanent magnets being arranged behind the target material of the target is understood as an arrangement where the target material is provided between the permanent magnets and the processing zone or the substrate 10 when the plasma zones are directed towards the processing zone or substrate 10. In other words, the processing zone or the substrate 10 is not directly exposed to the permanent magnets when the plasma zones are directed towards the processing zone or substrate 10 but the target is interposed therebetween.

[0040] The rotatable sputter cathodes can, for example, each include a target of the material to be deposited on the substrate. The material of the target can include a material selected from the group consisting of: aluminum, silicon, tantalum, molybdenum, niobium, titanium, copper, silver, zinc, MoW, ITO, IZO, and IGZO. In some implementations, the deposition material is present in a solid phase in the target, e.g. a rotatable target. By bombarding the rotatable cathode or rotatable target with energetic particles, atoms of the target material, i.e. the deposition material, are ejected from the rotatable cathode or rotatable target and are supplied into the plasma zone. According to some embodiments, the deposition material can include a material selected from the group consisting of

aluminum, silicon, tantalum, molybdenum, niobium, titanium, copper, silver, zinc, MoW, ITO, IZO, and IGZO. In a reactive sputtering process, one or more process gases can be supplied to the plasma zone, e.g., at least one of oxygen and nitrogen. Reactive sputtering processes are deposition processes during which a material is sputtered under a process atmosphere. As an example, the process atmosphere can include the one or more process gases such as at least one of oxygen and nitrogen in order to deposit a material or layer containing an oxide or nitride of the deposition material.

[0041] The deposition material is provided in the plasma zone. As an example, the magnet assemblies of the rotatable sputter cathodes can be utilized to confine the plasma for improved sputtering conditions. In some implementation, the plasma zone can be understood as the sputtering plasma or a sputtering plasma region provided by the rotatable sputter cathode. The plasma confinement can also be utilized for adjusting a participle distribution of the material to be deposited on the substrate 10. In some embodiments, the plasma zone corresponds to a zone that includes the atoms of the target material (the deposition material) that are ejected or released from the target. The plasma zone can be confined by the magnet assemblies, i.e. magnetrons, wherein the ions and electrons of processing gases and/or deposition material are confined in the proximity of the magnetrons or magnet assembly. At least some of the atoms ejected or released from the target are deposited on the substrate to form the layer.

[0042] In some implementations, the plasma zone extends in a circumferential direction of a respective rotatable sputter cathode, e.g., the tubular cathode or rotatable target. As an example, the plasma zone does not extend over a full circumference of the rotatable sputter cathode or rotatable target in the circumferential direction. According to some embodiments, the plasma zone extends over less than a third, and specifically less than a fourth of the full circumference of the rotatable sputter cathode or rotatable target. Based on a rotational position of the plasma zone it can either face the processing zone or it faces away from (is not directed to) the processing zone.

[0043] According to some embodiments, which can be combined with other embodiments described herein, the method includes a determining of a rotational speed of the first magnet assembly and the second magnet assembly based upon a predetermined layer thickness that is to be deposited on the substrate. As an example, the rotational speed

of the magnet assemblies can be selected to allow for a formation of a layer with a predetermined layer thickness. The layer thickness can be more than 1 nm, specifically more than 100 nm, and more specifically more than 1000 nm. In some implementations, the layer thickness can be less than 10 nm.

[0044] In some embodiments, the substrate 10 is in a vertical orientation. The term "vertical direction" or "vertical orientation" is understood to distinguish over "horizontal direction" or "horizontal orientation". That is, the "vertical direction" or "vertical orientation" relates to a substantially vertical orientation of, for example, the substrate 10, wherein a deviation of a few degrees, e.g. up to 10° or even up to 15°, from an exact vertical direction or vertical orientation is still considered as a "vertical direction" or a "vertical orientation". The vertical direction can be substantially parallel to the force of gravity.

[0045] The term "substrate" as used herein shall particularly embrace inflexible substrates, e.g., a wafer, slices of transparent crystal such as sapphire or the like, or a glass plate. However, the present disclosure is not limited thereto and the term "substrate" may also embrace flexible substrates such as a web or a foil.

[0046] The embodiments described herein can be utilized for evaporation on large area substrates, e.g. display manufacturing. For instance, a large area substrate or carrier can be GEN 4.5, which corresponds to about 0.67 m^2 substrates (0.73x0.92m), GEN 5, which corresponds to about 1.4 m^2 substrates (1.1 m x 1.3 m), GEN 7.5, which corresponds to about 4.29 m^2 substrates (1.95 m x 2.2 m), GEN 8.5, which corresponds to about 5.7m^2 substrates (2.2 m x 2.5 m), or even GEN 10, which corresponds to about 8.7 m^2 substrates (2.85 m × 3.05 m). Even larger generations such as GEN 11 and GEN 12 and corresponding substrate areas can similarly be implemented.

[0047] FIG. 3 shows a schematic top view of the apparatus 300 with the magnet assemblies and the plasma zones 2 of the at least two rotatable sputter cathodes 324 moving in oscillating rotational motions over the processing zone according to embodiments described herein. The apparatus 300 is configured for sputter deposition, such as, for example, reactive sputter deposition.

[0048] The apparatus includes a vacuum chamber 302 having a processing zone for processing of a substrate 10. The substrate 10 is moved into the processing zone having an array of at least two rotatable sputter cathodes 324, wherein each of the at least two rotatable sputter cathodes 324 provides a plasma zone 2 in which a deposition material is supplied during operation of the at least two rotatable sputter cathodes 324, and a controller configured for rotating the first magnet assembly in a first oscillating rotational motion around a first rotational axis between a first rotational position and a second rotational position, and for simultaneously rotating the second magnet assembly in a second oscillating rotational motion around a second rotational axis between a third rotational position and a fourth rotational position. The controller is configured for rotating the first magnet assembly and the second magnet assembly in opposite rotational directions during at least 50% of the first oscillating rotational motion and the second oscillating rotational motion. The vacuum chamber 302 can also be referred to as "processing chamber".

[0049] As shown in the example of FIG. 3, in some embodiments, two (immediately or directly) adjacent or neighboring rotatable sputter cathodes of the array of rotatable sputter cathodes form a pair of rotatable sputter cathodes. The magnet assemblies of each pair of (immediately or directly) neighboring rotatable sputter cathodes are rotated in opposite rotational directions during at least 50% of their oscillating rotational motions. As an example, the magnet assemblies of each pair of (immediately or directly) adjacent or neighboring rotatable sputter cathodes are rotated asynchronously. The magnet assemblies of a pair formed by a rotatable sputter cathode and a second neighbor, which is not a direct neighbor, can be rotated synchronously. As an example, when the rotatable sputter cathode are sequentially numbered, the magnet assemblies of the first rotatable sputter cathode and the third rotatable sputter cathode are rotated synchronously, the magnet assemblies of the second rotatable sputter cathode and the fourth rotatable sputter cathode are rotated synchronously, the magnet assemblies of the third rotatable sputter cathode and the fifth rotatable sputter cathode are rotated synchronously, etc.

[0050] Pre-sputtering and/or target conditioning can be utilized in addition to the methods described herein. During pre-sputtering and/or target conditioning, the plasma zones 2 can be facing away from the processing zone. As an example, during pre-

sputtering and/or target conditioning, the plasma zones 2 can be directed away from the processing zone. The plasma zones 2 can, for example, be directed towards a shield (not shown). As shown in FIG. 3, the magnet assemblies of the rotatable sputter cathodes 324 can then be rotated around their rotational axes, and also the plasma zones 2 are rotated. The magnet assemblies and correspondingly the plasma zones 2 can be rotated to face towards the processing zone to perform the oscillating rotational motions to expose the substrate 10 to the plasma zone 2 and the deposition material.

[0051] Exemplarily, one vacuum chamber 302 for deposition of layers therein is shown. Further vacuum chambers 303 can be provided adjacent to the vacuum chamber 302. The vacuum chamber 302 can be separated from adjacent further vacuum chambers 303 by a valve having a valve housing 304 and a valve unit 305. After a carrier 314 with the substrate 10 thereon is, as indicated by arrow 1, inserted in the vacuum chamber 302, the valve unit 305 can be closed. The atmosphere in the vacuum chamber 302, such as a process atmosphere for a reactive sputtering process, can be individually controlled by generating a technical vacuum, for example, with vacuum pumps connected to the vacuum chamber 302, and/or by inserting one or more process gases in the processing zone in the vacuum chamber 302. The one or more process gases can include gases for creating a process atmosphere for a reactive sputtering process. Within the vacuum chamber 302, rollers 310 can be provided in order to transport the carrier 314, having the substrate 10 thereon, into and out of the vacuum chamber 302.

[0052] Within the vacuum chamber 302, the at least two rotatable sputter cathodes 324 are provided. The at least two rotatable sputter cathodes 324 can be configured as described with respect to FIGs. 1 and 2. As an example, the at least two rotatable sputter cathodes 324 can each include one or more tubular cathodes and one or more anodes 326. For example, the one or more tubular cathodes can have the sputter targets of the material to be deposited on the substrate 10. The one or more tubular cathodes can have the magnet assembly therein, and magnetron sputtering can be conducted for depositing of the layers.

[0053] The one or more tubular cathodes and the one or more anodes 326 can be electrically connected to a DC power supply 328. Sputtering for forming the layer on the substrate 10 can be conducted as DC sputtering. The one or more tubular cathodes are connected to the DC power supply 328 together with the one or more anodes 326 for

collecting electrons during sputtering. According to yet further embodiments, which can be combined with other embodiments described herein, at least one of the one or more rotatable cathodes can have its corresponding, individual DC power supply.

[0054] FIG. 3 shows a plurality of rotatable sputter cathodes 324, wherein each rotatable sputter cathode 324 includes one tubular cathode and one anode 326. Particularly for applications for large area deposition, an array of rotatable sputter cathodes can be provided within the vacuum chamber 302. In some examples, six or more rotatable sputter cathodes 324 are provided. As an example, 12 or more rotatable sputter cathodes 324 can be provided.

[0055] According to the present embodiments, a controller for controlling a material deposition process is provided. The controller is configured to perform the method for material deposition on a substrate according to the embodiments described herein. The controller can be included in the apparatus for layer deposition according to the embodiments described herein. According to embodiments described herein, the controller can be configured to perform the method of the present embodiments by means of computer programs, software, computer software products and the interrelated controllers, which can have a CPU, a memory, a user interface, and input and output means being in communication with the corresponding components of the apparatus for processing a large area substrate.

[0056] According to the present disclosure, magnet assemblies of rotatable sputter cathodes perform oscillating rotational motions, wherein the magnet assemblies are rotated in opposite rotational directions during at least 50% of the oscillating rotational motions. As an example, at a time when one magnet assembly is rotated in a clockwise direction, the other magnet assembly is rotated in an anticlockwise direction. The rotating of the magnet assemblies in opposite rotational directions during at least 50% of the oscillating rotational motions improves a uniformity of the layer deposited on the substrate. As an example, a thickness uniformity of the deposited layer can be improved.

[0057] 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. Method for material deposition on a substrate, comprising:

moving a substrate into a processing zone in a vacuum chamber having an array of at least two rotatable sputter cathodes, the at least two rotatable sputter cathodes including a first rotatable sputter cathode and a second rotatable sputter cathode; and

rotating a first magnet assembly of the first rotatable sputter cathode in a first oscillating rotational motion around a first rotational axis between a first rotational position and a second rotational position, and simultaneously rotating a second magnet assembly of the second rotatable sputter cathode in a second oscillating rotational motion around a second rotational axis between a third rotational position and a fourth rotational position, wherein the first magnet assembly and the second magnet assembly are rotated in opposite rotational directions during at least 50% of the first oscillating rotational motion and the second oscillating rotational motion.

2. The method of claim 1, wherein a deposition material provided by the first rotatable sputter cathode and the second rotatable sputter cathode is deposited on the substrate during the first oscillating rotational motion and the oscillating second rotational motion.

3. The method of claim 1 or 2, wherein the first oscillating rotational motion and the second oscillating rotational motion are asynchronous.

4. The method of any one of claims 1 to 3, wherein rotating of the first magnet assembly in the first oscillating rotational motion provides a rotation of a first plasma zone of the first rotatable sputter cathode around the first rotational axis, and wherein rotating of the second magnet assembly in the second oscillating rotational motion provides a rotation

of a second plasma zone of the second rotatable sputter cathode around the second rotational axis.

5. The method of any one of claims 1 to 4, wherein a first angle between the first rotational position and the second rotational position with respect to the first rotational axis is in the range of 1 to 180 degrees, and wherein a second angle between the third rotational position and the fourth rotational position with respect to the second rotational axis is in the range of 1 to 180 degrees.

6. The method of claim 5, wherein at least one of the first angle and the second angle is about 10 degrees or about 160 degrees, or about 10 degrees to about 160 degrees.

7. The method of any one of claims 1 to 6, wherein the first oscillating rotational motion and the second oscillating rotational motion have a frequency of at least 1/250 Hz.

8. The method of any one of claims 1 to 7, wherein a deposition material to be deposited on the substrate includes a material selected from the group consisting of: aluminum, silicon, tantalum, molybdenum, niobium, titanium copper, silver, zinc, MoW, ITO, IZO, and IGZO.

9. The method of any one of claims 1 to 8, wherein the array of at least two rotatable sputter cathodes includes 3 or more rotatable sputter cathodes, 6 or more rotatable sputter cathodes, or 12 or more rotatable sputter cathodes.

10. The method of any one of claims 1 to 9, wherein the rotatable sputter cathodes are tubular cathodes.

11. The method of any one of claims 1 to 10, wherein the first rotational axis and the second rotational axis are vertically oriented.

12. The method of any one of claims 1 to 11, wherein the substrate is in a vertical orientation.

13. The method of any of claims 1 to 12, further comprising:

determining a rotational speed of the first magnet assembly and the second magnet assembly based upon a predetermined layer thickness that is to be deposited on the substrate.

14. Controller for controlling a material deposition process, wherein the controller is configured to perform the method of any one of claims 1 to 13.

15. Apparatus for layer deposition on a substrate, including:

a vacuum chamber having a processing zone for processing of a substrate;

an array of at least two rotatable sputter cathodes, wherein a first rotatable sputter cathode of the at least two rotatable sputter cathodes has a first magnet assembly and a second rotatable sputter cathode of the at least two rotatable sputter cathodes has a second magnet assembly; and

a controller configured for rotating the first magnet assembly in a first oscillating rotational motion around a first rotational axis between a first rotational position and a second rotational position, and for simultaneously rotating the second magnet assembly in a second oscillating rotational motion around a second rotational axis between a third rotational position and a fourth rotational position, wherein the controller is configured for rotating the first magnet assembly and the second magnet assembly in opposite rotational directions during at least 50% of the first oscillating rotational motion and the second oscillating rotational motion.

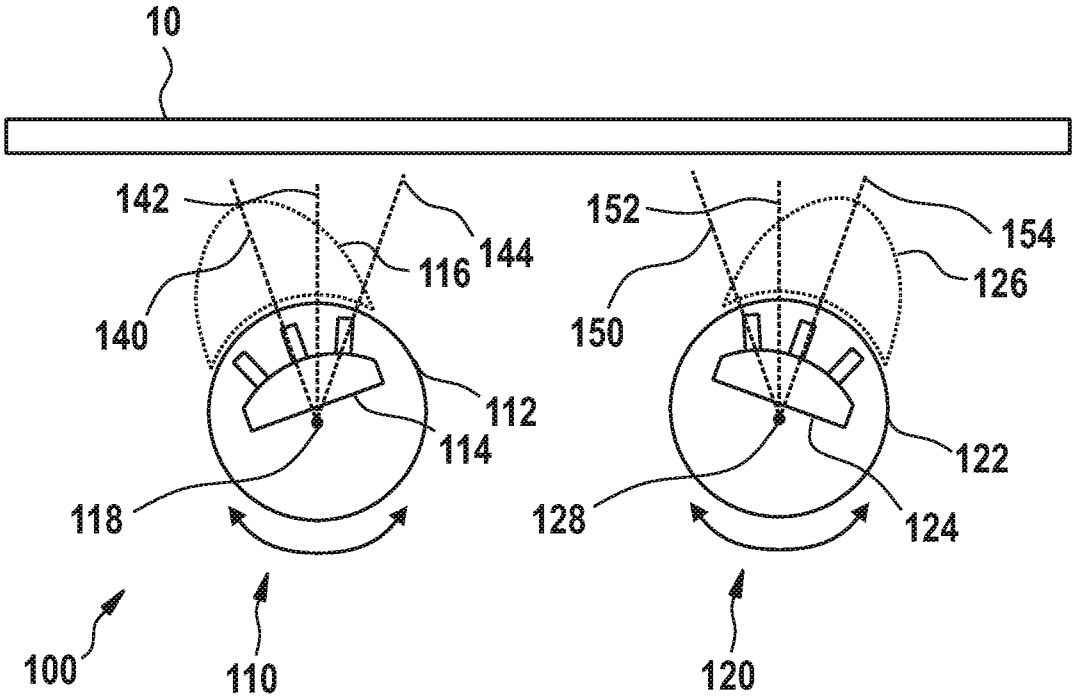

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Fig. 1

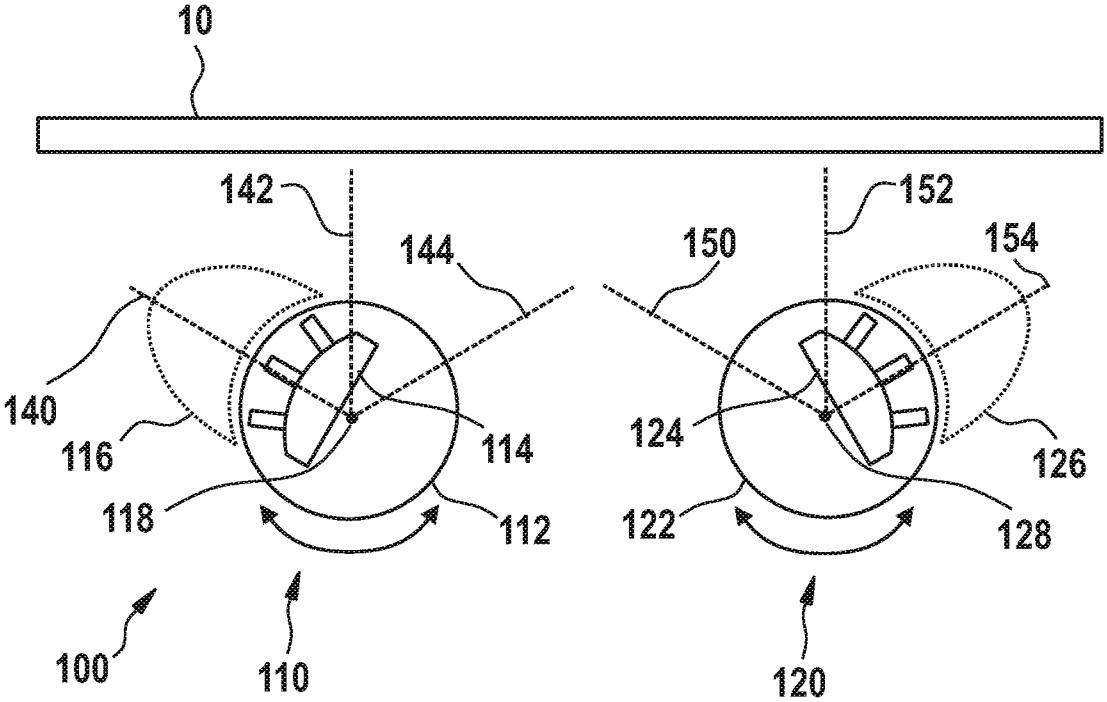

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Fig. 2

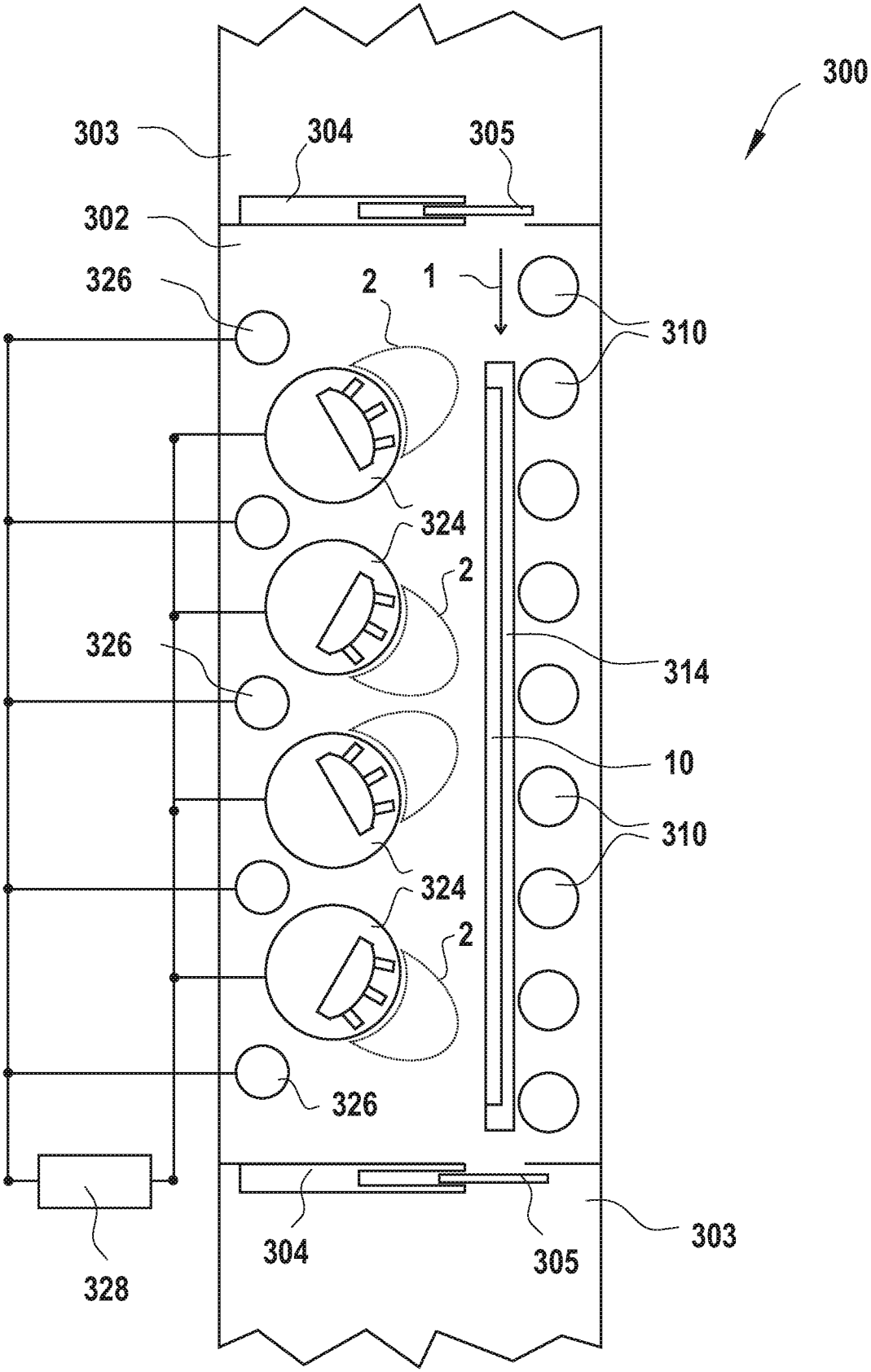

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Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/025681

A. CLASSIFICATION OF SUBJECT MATTER
INV. C23C14/35 H01J37/34
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 H01J

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, COMPENDEX, INSPEC, 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	US 2014/116878 A1 (KIM MYOUNG-HO [KR] ET AL) 1 May 2014 (2014-05-01) paragraphs [0044] - [0050]; figure 4	1-8,10, 14,15 9,11-13
Y	FABIO PIERALISI ET AL: "Split sputter mode: a novel sputtering method for flat-panel display manufacturing", JOURNAL OF INFORMATION DISPLAY, vol. 12, no. 2, 20 May 2011 (2011-05-20), pages 89-92, XP055196114, ISSN: 1598-0316, DOI: 10.1080/15980316.2011.569168 the whole document	9,11-13
Y	US 2010/187104 A1 (TAMAGAKI HIROSHI [JP]) 29 July 2010 (2010-07-29) paragraph [0032]; figures 1, 2	9,11-13

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 June 2016	05/07/2016

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2016/025681

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