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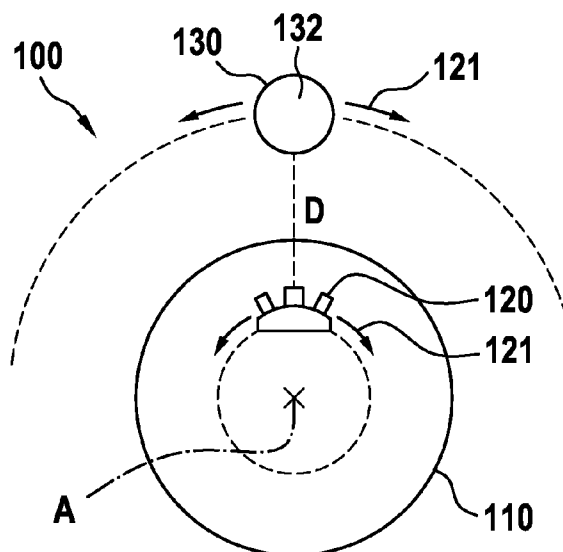
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(54) **Title:** SPUTTER DEPOSITION SOURCE, SPUTTERING APPARATUS AND METHOD OF OPERATING THEREOF

**Fig. 1**



(57) **Abstract:** A deposition source (100, 300, 400, 500) for sputter deposition is provided. The deposition source includes a cathode (110) for providing a target material to be deposited, a movable magnet assembly (120), and an anode assembly (130), which is movable in accordance with the magnet assembly (120).

## **SPUTTER DEPOSITION SOURCE, SPUTTERING APPARATUS AND METHOD OF OPERATING THEREOF**

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### **TECHNICAL FIELD**

[0001] Embodiments of the present invention relate to a deposition source for sputter deposition, a sputtering apparatus, and methods of operating thereof. Embodiments specifically relate to a sputter deposition source for magnetron sputtering utilizing a rotatable cathode, a sputtering apparatus for sputter deposition in a vacuum chamber, and a method of operating a sputter deposition source with a rotatable cathode and a movable magnet assembly.

### **BACKGROUND**

[0002] PVD processes, particularly sputtering processes, gain increasing attention in some technical fields, e.g. display manufacturing. A good deposition rate can be obtained with sufficient layer characteristics by various sputtering techniques. Sputtering, particularly magnetron sputtering, is a technique for coating substrates such as glass or plastic substrates with metallic or non-metallic layers. Accordingly, a stream of coating material is generated by sputtering a target through the use of a plasma. Material is released from the target surface as a result of collisions with high-energy particles from the plasma. Plasma parameters such as pressure, power, gas, magnetic field etc. may be controlled. The material released from the target travels from the target toward one or more substrates to be coated and adheres thereto. A wide variety of materials, including metals, semiconductors and dielectric materials can be sputtered to desired specifications. Magnetron sputtering has found acceptance in a variety of applications including display manufacturing, semiconductor processing, optical coatings, food packaging, magnetic recording, and protective wear coatings.

[0003] Sputtering devices can include a power supply for supplying electric energy, a power delivery assembly for depositing said energy in a gas for igniting and maintaining the plasma, and at least one cathode including a target for providing the coating material through sputtering by the plasma. Typically, sputtering can be conducted as magnetron sputtering, wherein a magnet assembly is utilized to confine the plasma and to control the motion of the plasma ions for improved sputtering conditions. The plasma confinement can also be utilized for adjusting the distribution of the material to be deposited on the substrate. The plasma distribution, the plasma characteristics and other deposition parameters need to be controlled in order to obtain a desired layer deposition on the substrate. A uniform layer with desired layer properties may be desired, particularly for large area deposition, e.g. for manufacturing displays on large area substrates.

[0004] Uniformity and process stability can be particularly difficult to achieve for static deposition processes, wherein the substrate is not moved continuously through a deposition zone. Accordingly, considering the increasing demands for the manufacturing of optoelectronic devices and other devices on a large scale, process uniformity and stability need to be further improved.

## SUMMARY

[0005] In light of the above, according to the independent claims, a deposition source for sputter deposition, an apparatus for sputter deposition in a vacuum chamber and a method of operating a deposition source are provided. Further aspects, advantages, and features of the present invention are apparent from the dependent claims, the description, and the accompanying drawings.

[0006] According to embodiments described herein, a sputter deposition source for sputter deposition is provided. The deposition source includes at least one cathode for providing a target material to be deposited; a movable magnet assembly; and at least one anode assembly, which is movable in accordance with the magnet assembly. In embodiments, the anode assembly is movable synchronously and/or while maintaining a predetermined spatial relationship with respect to the magnet assembly.

[0007] According to a further aspect, a magnetron sputter apparatus for sputter deposition in a vacuum chamber is provided. The apparatus includes a sputter deposition source for sputter deposition in a vacuum chamber; and the vacuum chamber. The sputter deposition source includes at least one cathode for providing a target material to be deposited, a  
5 movable magnet assembly, and at least one anode assembly, which is movable in accordance with the magnet assembly. In some embodiments, the cathode, the magnet assembly, and the anode assembly are positioned inside the vacuum chamber. Further, the apparatus may include a magnet drive unit for moving the magnet assembly and/or an anode assembly drive unit for moving the anode assembly, which are positioned outside  
10 the vacuum chamber.

[0008] Embodiments are also directed to methods for operating a deposition source for sputter deposition. The method includes moving an anode assembly in accordance with a magnet assembly and particularly relative to a cathode or to an axis of a cathode providing a target material to be sputtered. Particularly, a distance between the anode assembly and  
15 the magnet assembly may remain constant during the movement.

[0009] Embodiments are also directed at apparatuses for carrying out the disclosed methods and include apparatus parts for performing the individual method actions. This method 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,  
20 embodiments according to the invention are also directed at methods of operating the described apparatus.

[0010] Further advantages, features, aspects and details that can be combined with embodiments described herein are evident from the dependent claims, the description and the drawings.

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## BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the above recited features of the present invention can be understood in detail, a more particular description of the invention as briefly summarized above may be

had by reference to embodiments. The accompanying drawings relate to embodiments of the invention and are described in the following:

[0012] FIG. 1 shows a schematic sectional view of a deposition source for sputter deposition according to embodiments described herein;

5 [0013] FIG. 2 is a schematic view illustrating a generalized concept of a deposition source for sputter deposition according to embodiments described herein;

[0014] FIG. 3a shows a schematic sectional view of a deposition source for sputter deposition according to embodiments described herein in a first operating position;

10 [0015] FIG. 3b shows a schematic sectional view of the deposition source of FIG. 3a in a second operating position;

[0016] FIG. 4 is a comparative example showing several deposition sources for sputter deposition for illustrating a first plasma distribution;

[0017] FIG. 5 is a schematic sectional view of deposition sources for sputter deposition according to embodiments described herein illustrating a second plasma distribution;

15 [0018] FIG. 6 shows a schematic side view of a deposition source for sputter deposition according to embodiments described herein;

[0019] FIG. 7 shows a schematic sectional view of a deposition source for sputter deposition according to embodiments described herein;

20 [0020] FIG. 8 shows a schematic sectional view of a sputtering apparatus according to embodiments described herein; and

[0021] FIG. 9 shows a flowchart of a method of operating a deposition source for sputter deposition according to embodiments described herein.

## DETAILED DESCRIPTION

[0022] Reference will now be made in detail to the various embodiments of the invention, 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 invention and is not meant as a limitation of the invention. 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.

[0023] In the present disclosure, a “deposition source” may be understood as a deposition source for sputter deposition including a cathode for providing a target material to be deposited on a substrate. The cathode may include a target made of the material to be deposited. For example, the target may be made of or include at least one material selected from the group consisting of: aluminum, silicon, tantalum, molybdenum, niobium, titanium, indium, gallium, zinc, tin, silver and copper. Particularly, the target material can be selected from the group consisting of indium, gallium and zinc. Typically, on the other hand, the anode assembly is not provided with a target material to be deposited.

[0024] Sputtering may be accomplished with a wide variety of devices having differing electrical, magnetic, and mechanical configurations. Some configurations include a power supply connected to the cathode via a power delivery assembly for energizing the cathode with electric current. As a result, an electric field can be provided to a gas located between the cathode and an oppositely charged anode assembly such that the gas is ionized and a plasma is maintained in a region between the cathode and the anode. Typically, the cathode may be adapted to be provided with a negative voltage, and the anode assembly may be adapted to be provided with a positive voltage.

[0025] The power supply may be adapted for providing direct current (DC) or alternating current (AC) for producing the plasma. AC electromagnetic fields that are applied to a gas regularly provide for higher plasma rates than DC electromagnetic fields. In a radio frequency (RF) sputtering apparatus, the plasma is ignited and maintained by applying an RF electric field. Accordingly, also non-conductive materials may be sputtered.

[0026] As used herein, “magnetron sputtering” refers to sputtering performed using a magnet assembly or “magnetron”, that is, a unit capable of generating a magnetic field. The magnet assembly may be provided as a magnet yoke. Typically, a magnet assembly consists of one or more permanent magnets. The permanent magnets may be arranged on a first side of the target of the cathode, the anode assembly and the gas to be ionized being arranged on the other side of the target. Applying both an electric field and a magnetic field to the gas may lead to an increased ionization rate due to the electrons moving along a helical path and may further help in controlling the motion of the plasma ions.

[0027] According to typical implementations, magnetron sputtering can be conducted as DC sputtering, as MF sputtering, as RF sputtering, or as pulse sputtering. As described herein, some deposition processes might beneficially apply DC sputtering, particularly with a negatively charged cathode and a positively charged anode assembly. However, other sputtering methods can also be applied.

[0028] Deposition sources may be provided with static cathodes such as flat plate cathodes, e.g. planar cathodes, or with movable cathodes, e.g. rotatable cathodes such as rotating cylindrical cathodes. For example, the cathode may be a rotatable cathode with a rotatable cylindrical target.

[0029] FIG. 1 shows a sectional view of a deposition source 100 for sputter deposition according to embodiments described herein in a schematic illustration. The deposition source 100 includes: a cathode 110 for providing a target material to be deposited; a movable magnet assembly 120; and an anode assembly 130, which is movable in accordance with the magnet assembly 120. In other words, the anode assembly 130 is configured to be movable to follow a movement of the magnet assembly 120. For example, the anode assembly can be configured to be movable synchronously with the magnet assembly 120 and/or to be movable maintaining a predetermined spatial relationship between the magnet assembly 120 and the anode assembly 130. The predetermined spatial relationship between the magnet assembly 120 and the anode assembly 130 may be maintained throughout the movement of the magnet assembly 120. However, embodiments described herein also include maintaining the predetermined spatial relationship between the magnet assembly 120 and the anode assembly 130 only at specific points of respective movement trajectories, particularly at points where sputtering is carried out.

[0030] Typically, during sputtering, the plasma may be located within a plasma confinement region in front of the magnet assembly, the location of the plasma confinement region depending on the positioning and particularly on a tilting angle of the magnet assembly. Moving the magnet assembly 120 can change the plasma resistance and affects the spatial plasma distribution due to the spatial change of the electromagnetic field associated therewith. For example, a plasma cloud is shifted in space by tilting or pivoting the magnet assembly around a pivot axis. Shifting the plasma by moving the magnet assembly may lead to a better layer thickness uniformity of the substrate to be coated, particularly when the substrate is kept stationary during the coating process. In embodiments described herein, both the magnet assembly 120 and the anode assembly 130 may be movable relative to the substrate to be coated, in particular if the substrate is stationary during the sputtering process.

[0031] When the magnet assembly is moved while the anode assembly maintains stationary, the plasma will follow the plasma confinement region of the magnet assembly and move away from the stationary anode, for example towards a different anode. This effect may result in plasma density fluctuations, poor target utilization and reduced layer thickness uniformity. In contrast thereto, according to embodiments described herein, the anode assembly is configured to be movable in accordance with the magnet assembly such that a desired spatial relationship between the magnet assembly and the anode assembly can be maintained also during the movement or at least at specific movement positions, where sputtering is carried out. Accordingly, according to embodiments described herein, the anode can be moved to have a substantially constant distance to the plasma region.

[0032] In the embodiment shown in FIG. 1, as is indicated by arrows 121, the anode assembly 130 is movable, e.g. synchronously, with the magnet assembly 120, while maintaining an essentially constant distance D between the magnet assembly 120 and the anode assembly 130. "Essentially" as used herein may mean that the distance D between the magnet assembly 120 and the anode assembly 130 varies by less than  $\pm 30\%$ , particularly by less than  $\pm 10\%$ , more particularly by less than  $\pm 5\%$ . Particularly, the distance D between the magnet assembly and the anode assembly is kept constant during sputtering. In other words, a ratio between a smallest distance between the magnet assembly and the anode assembly during the movement and a largest distance between the

magnet assembly and the anode assembly during the movement is more than 0.7, particularly more than 0.95, more particularly 1.

[0033] In embodiments described herein, the magnet assembly is movable along a first trajectory and the anode assembly is movable along a second trajectory, wherein the first trajectory has a first pair of turning points and the second trajectory has a second pair of turning points. A ratio between a minimum distance between corresponding turning points of the first pair of turning points and the second pair of turning points and a maximum distance between corresponding turning points of the first pair of turning points and the second pair of turning points may be more than 0.7, particularly more than 0.95, and more particularly be 1.

[0034] In other words, it may not be practical to provide for a simultaneous or contemporary movement of the magnet assembly and the anode assembly, as long as a distance between the magnet assembly and the anode assembly is kept essentially constant at specific points of the respective trajectories, where sputtering takes place. For example, such specific points may be the turning points of the respective trajectories, at which turning points sputtering is carried out. As an example, initially, the anode assembly may be moved along the second trajectory, and afterwards the magnet assembly may be moved along the first trajectory following the movement of the anode assembly, until a previous distance between the magnet assembly and the anode assembly is restored. Thereafter, sputtering may continue etc. ("split sputtering mode"). "Joint" movement as used herein may also comprise such a successive movement of the magnet assembly and the anode assembly

[0035] Also a distance between the cathode 110 and the anode assembly 130 may be kept constant during the joint movement of the magnet assembly and the anode assembly. Accordingly, a plasma rate and/or a spatial and temporal plasma distribution may be kept more stable due to the constant distances between the anode assembly 130, the magnet assembly 120 and the cathode 110 during the movement of the magnet assembly 130, while at the same time the plasma may be shifted in space with the effect of a more uniform coating layer thickness.

[0036] According to some embodiments, which can be combined with other embodiments described herein, the magnet assembly 120 is moved along a first trajectory and the anode assembly is movable along a second trajectory such that a distance between the plasma confinement region of the magnet assembly 120 and the anode assembly 130 does not vary by more than  $\pm 30\%$ , particularly by more than  $\pm 5\%$  during the movement, and more particularly wherein the distance is kept constant during the movement. In other words, when moving the magnet assembly, the anode assembly is configured to follow the movement of the plasma confinement region of the magnet assembly.

[0037] In embodiments described herein, the anode assembly 130 and the magnet assembly 120 are movable relative to the cathode 110, particularly relative to an axis of the cathode 110. For example, the anode assembly 130 and the magnet assembly 120 may be movable relative to a rotation axis of the cathode 110. For example, the cathode may be stationary, and both the anode assembly 130 and the magnet assembly 120 are movable with respect to the cathode 110. In some embodiments described herein, the cathode 110 may be movable, with the cathode movement being independent of the movement of the anode assembly 130 and the magnet assembly 120. Even though a rotatable cathode according to embodiments described herein, may include a rotation of the target around a rotation axis, wherein the target is rotated in clockwise or counterclockwise direction e.g. by several turns, the cathode position may be stationary relative to a vacuum chamber of a deposition apparatus. That is, a plasma is adjacent to another portion of the target while the target rotates below the plasma, yet, the position of sputtering material from the target by the plasma is essentially constant, such that the cathode can be considered to be essentially stationary.

[0038] The sputter deposition source 100 may include a rotatable cathode 110 with a target of metallic and/or non-metallic material to be released from the target by sputtering and to be deposited on the substrate to be coated. In the present disclosure, a “rotatable cathode” may be understood as an at least partially cylindrical cathode having a rotation axis. In particular, a “rotatable cathode” may be understood as a cathode which rotates around the rotation axis during sputtering. For example, a “rotatable cathode” may be driven by a drive during sputter deposition of target material on the substrate. In the present disclosure, a “rotatable cathode” may extend along a longitudinal axis from a first end of the rotatable

cathode to a second end of the rotatable cathode, e.g. along a longitudinal rotation axis around which the rotatable cathode may be rotatable. The portion of the rotatable cathode including the target material to be deposited may extend from the first end of the rotatable cathode to the second end of the rotatable cathode.

5 [0039] As compared to a planar cathode, a rotatable cathode may provide the advantage that the target material is reliably utilized around the whole circumference of the target during sputtering, and there are no edge portions of the target in a lateral direction of the target, where less sputtering may occur on the target surface. Thus, by utilizing rotatable cathodes, material costs can be reduced and the target can be used for a longer time period,  
10 before a target exchange becomes necessary.

[0040] For rotatable cathodes 110, the magnet assembly 120 can be provided within a backing tube of the cathode with the target material covering an outer surface of the backing tube. In implementations, the magnet assembly may be arranged within a target material tube of the cathode. The rotatable cathode 110 may be provided at least partially  
15 as a hollow cylinder in order to provide for an inner space for receiving the magnet assembly 120.

[0041] According to some embodiments, the magnet assembly 120 and the anode assembly 130 are pivotable around pivot axes, such as around a common pivot axis A. The magnet assembly 120 may be movable along the first trajectory which follows an arc around the  
20 common pivot axis A at a first radius, and the anode assembly 130 may be movable along the second trajectory which follows an arc around the common pivot axis A at a second radius. The second radius may be larger than the first radius. The magnet assembly may be arranged closer to the common pivot axis A than the anode assembly. At least one of the first and the second trajectories may have the form of an arc, e.g. a circular arc. A  
25 synchronous pivot movement of the magnet assembly 120 and the anode assembly 130 may be provided by a first angular velocity of the magnet assembly 120 circulating the pivot axis A which essentially corresponds to a second angular velocity of the anode assembly 130 circulating the pivot axis A. Corresponding angular velocities may lead to a constant distance D between the magnet assembly 120 and the anode assembly 130 during  
30 the pivot movement. The joint movement of the magnet assembly 120 and the anode assembly 130 may take place simultaneously or successively.

[0042] The first trajectory of the magnet assembly 120 may have the form of a circular arc inside the cathode 110 and/or the second trajectory of the anode assembly 130 may have the form of a circular arc outside the cathode. In some embodiments, the pivot axis A may intersect the magnet assembly 120.

5 [0043] The cylindrical cathode wall may be arranged between the magnet assembly 120 and the anode assembly 130 at a third radius, the third radius being larger than the first radius and smaller than the second radius. Thus, the first trajectory, the second trajectory and the cathode wall may form an essentially coaxial arrangement. The distance between the anode assembly 130 moving along the second trajectory and the wall of the cathode  
10 110 may thus remain constant during the movement of the anode assembly. In some embodiments, the cathode is rotatable around the pivot axis A, but said rotation may be independent of the pivot movement of the magnet assembly and the anode assembly around the cathode center.

[0044] In some implementations, the rotatable cathode 110 could be configured to rotate  
15 with a rotation speed in the range of 1 to 50 rounds per minute, 5 to 30 rounds per minute or 15 to 25 rounds per minute around a rotation axis, which corresponds to the pivot axis A. The rotation can include at least one or more full 360° rotations. Typically, the rotatable cathode 110 could be configured to rotate with a speed of about 20 rounds per minute.

20 [0045] On the other hand, the magnet assembly 120 may be arranged to move on the arc-shaped first trajectory only between a first turning point and a second turning point. In other words, the magnet assembly may not be configured to entirely circulate the pivot axis A, but to oscillate around a central sputtering position, wherein the plasma confinement region of the magnet assembly is directed towards the substrate to be coated. Likewise,  
25 also the anode assembly may not be configured to entirely circulate the pivot axis A, but to oscillate between two turning points in synchrony with the magnet assembly. In particular, the magnet assembly and the anode assembly may reach their respective turning points and change direction simultaneously.

[0046] According to some embodiments, which may be combined with other embodiments  
30 disclosed herein, the anode assembly 130 includes at least one anode rod 132, the at least

one anode rod and the cathode 110 being positioned essentially parallel and next to one another. The shape of the anode rod can be cylindrical. However, other shapes are possible, whereas it is advantageous to avoid sharp edges in order to prevent electric field concentrations or arcing. Typically, the minimum bending radius of the rod should be 2 mm or above.

[0047] An outer dimension of the anode rod 132 may be smaller than an outer diameter of the cylindrical cathode 110. For example, the outer diameter of the anode rod may be less than 50% or less than 25% of the outer diameter of the cathode 110. A distance between an outer surface of the anode rod and an outer surface of the cathode wall may be smaller than the outer dimension of the anode rod.

[0048] The anode assembly 130 may be provided with a heat sink for cooling purposes. In some implementations, at least one anode rod 132 is provided with a cooling element. For example, at least one anode rod 132 may be provided with a cooling channel which runs through the anode rod 132 in an axial direction thereof and which may be used for fluid cooling, e.g. water cooling. Also the cathode may be provided with a heat sink, e.g. a water cooling.

[0049] The anode assembly 130 may contain soft magnetic material or consist of soft magnetic material like iron, mild steel or nickel-iron alloy to guide the magnetic field lines provided by the magnet assembly 120.

[0050] According to an aspect of the present disclosure, a method of operating a deposition source 100 is provided. The anode assembly 130 is moved, particularly during sputtering, in accordance with the magnet assembly 120 and particularly relative to the cathode 110 or to an axis of the cathode 110 providing the target material to be deposited. As is indicated by the arrows 121 in FIG. 1, the anode assembly may be moved synchronously with the magnet assembly and/or keeping a distance D between the anode assembly and the magnet assembly during sputtering essentially constant. Movement of the magnet assembly and of the anode assembly may include a pivot movement about a common pivot axis A at a first radius and at a second radius, respectively, whereas the angular velocity of the magnet assembly may correspond to the angular velocity of the anode assembly. At the same time, the cathode may rotate around its own axis, which may correspond to the pivot axis A,

independently of the pivot movement and at an angular velocity different from the angular velocity of the anode assembly. The method may further include some or all of the above stated activities or features described with reference to the deposition source 100 in an arbitrary combination, and they are not repeated here.

5 [0051] FIG. 2 is meant to illustrate a general concept of embodiments disclosed herein and schematically shows a deposition source for sputter deposition. The deposition source according to FIG. 2 includes a cathode 110, a movable magnet assembly 120 arranged on a first side of the cathode 110, and a movable anode assembly 130 arranged on a second side of the cathode 110. The anode assembly 130 is movable in accordance with the magnet  
10 assembly 120.

[0052] As is indicated by arrows 121, the anode assembly 130 may be moved synchronously with and/or keeping an essentially constant distance D to the magnet assembly 120. "Essentially" as used herein may mean that the distance D at least at  
15 positions where sputtering is carried out, does not vary by more than  $\pm 30\%$ , particularly by more than  $\pm 5\%$ , and more particularly by more than  $\pm 1\%$ . At the same time, a constant distance may be maintained between the cathode 110 and the anode assembly 130. The magnet assembly 120 may be movable relative to the cathode 110, whereas the cathode 110 can also be movable or can be static.

[0053] As is indicated in FIG. 2, the cathode 110 could also be provided as a static planar  
20 cathode 110, which may be provided with the target material to be deposited at least on a first side of the cathode which faces the anode assembly 130. In further embodiments, the cathode 110 could also be provided as a movable planar cathode 110, e.g. a rotatable planar cathode or a linearly displaceable planar cathode.

[0054] For planar cathodes, the magnet assembly 120 can be provided on a side of a planar  
25 backing plate of the cathode opposing the target of the material to be deposited. The anode assembly 130 may be provided on the target side of the cathode, so that the plasma ions to be generated between the anode assembly 130 and the cathode 110 may be used for sputtering the target.

[0055] FIG. 3a shows a sectional view of a deposition source 300 for sputter deposition according to embodiments described herein in a schematic illustration, the deposition source being arranged in a first operating position. FIG. 3b shows the same deposition source in a second operating position. The deposition source 300 includes a rotatable cathode 110 for providing a target material to be deposited; a movable magnet assembly 120; and an anode assembly 130, which is movable in accordance with the magnet assembly 120. The anode assembly 130 is configured to be movable synchronously with the magnet assembly 120 and/or configured to be movable while maintaining a predetermined spatial relationship between the magnet assembly 120 and the anode assembly 130.

[0056] In the embodiment shown in FIG. 3a, the anode assembly 130 includes more than one anode. For example, the anode assembly 130 may include a first anode 332 and a second anode 334. Both the first anode 332 and the second anode 334 may be provided as an anode rod, e.g. a circular anode rod. However, the first anode and the second anode may have other shapes and are not necessarily of an identical shape.

[0057] The first anode 332 and the second anode 334 may be electrically connected to each other, so that both anodes can be powered by the same power connector and may be on the same electric potential. In some embodiments, the first anode and the second anode are electrically isolated from each other.

[0058] Similar to the embodiment shown in FIG. 1, the magnet assembly may be movable along a first trajectory with a first radius, the first radius being smaller than a third radius of the cylindrical cathode 110. Further, both the first anode 332 and the second anode 334 may be arranged on a second trajectory which at least partially runs around the rotatable cathode 110. The second trajectory may have a shape of a circular arc with a second radius, so that the distance between the first anode 332 and the cathode 110 corresponds to the distance between the second anode 334 and the cathode 110, said distances remaining constant when the first anode 332 and the second anode 334 are moved along the second trajectory.

[0059] An angle between the first anode 332 and the second anode 334 with respect to a center of the cathode 110 may be more than 30° and less than 200°, and particularly more

than 90° and less than 150°. The angle between the first anode 332 and the second anode 334 may be made adjustable. In embodiments disclosed herein, the magnet assembly 120 is located essentially at a center angular position between the first anode 332 and the second anode 334. Such a symmetric arrangement of the first anode 332 and the second  
5 anode 334 with respect to the magnet assembly 120 leads to a more homogeneous plasma distribution and to a more uniform thickness of the layer to be deposited on the substrate 20.

[0060] In the first operating position which is shown in FIG. 3a, the magnet assembly 110 is located at a central sputtering position on the first trajectory, wherein the plasma  
10 confinement region of the magnet assembly 120 is directed toward the substrate 20 to be coated. The first anode 332 and the second anode 334 are arranged on the second trajectory at two positions which are equidistant from the substrate 20.

[0061] The first anode 332 and the second anode 334 may be pivoted in accordance with the magnet assembly 120 around the pivot axis A to the second operating position which is  
15 shown in FIG. 3b. During the movement, a first distance D1 between the first anode 332 and the magnet assembly 120, particularly the smallest distance between the first anode and the magnet assembly, and a second distance D2 between the second anode 334 and the magnet assembly 120, particularly the smallest distance between the second anode and the magnet assembly, may remain essentially constant. The first distance and the second  
20 distance may be identical. The pivot movements of the first anode 332, the second anode 334, and the magnet assembly 120 may be performed simultaneously and at corresponding angular velocities. In other embodiments, only the first anode 332 and the second anode 334 are moved simultaneously, whereas the magnet assembly is moved before or afterward.

[0062] The second operating position which is shown in FIG. 3b may be a maximum tilt position of the magnet assembly 120. In other words, the magnet assembly 120 and the first and second anodes 332, 334 are arranged at turning points on the first and second trajectories, respectively, from which the magnet assembly and the anodes return to the first operating position shown in FIG. 3a in the further course of sputtering. Thereafter, the  
25 pivot movement may continue counterclockwise to a third operating position, the third operating position being a mirror image of the second operating position. Such an  
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“oscillating movement” may continue in the further course of sputtering, in order to obtain a desired layer characteristic on the substrate. However, in some embodiments, the maximum tilt angle may be different, or, alternatively, both the magnet assembly 120 and the anode assembly 130 may entirely circulate the pivot axis A.

5 [0063] In embodiments, which may be combined with other embodiments described herein, the plasma may be ignited at a forth operating position of the magnet assembly 120 and the anode assembly 130 such that the substrate 20 is not exposed to the plasma. Thereafter, the magnet assembly 120 and the anode assembly 130 may be moved in accordance with each other to a fifth operating position whilst maintaining the plasma,  
10 wherein the fifth operating position results in the deposition of the material on the substrate. The fifth operating position may correspond to one of the first to third operating positions. In the fourth operating position, the plasma confinement region of the magnet assembly 120 may be directed to a shield which can collect material to be sputtered. Accordingly, at the beginning the substrate 20 is not exposed to the plasma. This condition  
15 of non-exposure can be maintained until the plasma is stabilized. The magnet assembly 120 can then be pivoted or tilted together with the anode assembly 130 towards the substrate 20 while the stabilized plasma is maintained.

[0064] During the pivot movement of the magnet assembly 120 and the anode assembly 130, the cathode may rotate at a given angular velocity about its own axis which axis may  
20 correspond to the pivot axis A. The rotating movement of the cathode 110 and the tilting movement of the magnet assembly 120 may be independent of each other.

[0065] FIG. 4 is a comparative example showing several deposition sources for sputter deposition for illustrating a first plasma distribution.

[0066] The deposition sources are arranged next to each other in a linear arrangement and  
25 include a cylinder-shaped rotatable cathode 810 and a magnet assembly 820 arranged within the cathode, respectively. The magnet assemblies 820 are pivotable around the rotation axis of the associated cathode. Stationary rod-shaped anodes 830, 831 are arranged between the cathodes 810, respectively.

[0067] In the arrangement shown in Fig. 4, the magnet assembly 820 has been moved to a position with a large distance to a first stationary anode 831 and a small distance to a second stationary anode 830. A first plasma cloud 850 has followed the movement of the magnet assembly 820 and moved in a direction away from the first stationary anode 831 following the plasma confinement region of the magnet assembly. Similarly, a second plasma cloud 851 has moved towards the second stationary anode 830 following the plasma confinement region of the magnet assembly. This effect may result in plasma density fluctuations. For example, the shape and density of the first plasma cloud 850 allocated to the first stationary anode 831 may differ from the shape and density of the second plasma cloud 851 allocated to the second stationary anode 830, when the second stationary anode 830 is located closer to the magnet assembly 820 than the first stationary anode 831 or vice versa.

[0068] FIG. 5 is a schematic sectional view showing several deposition sources 300 for sputter deposition according to embodiments described herein for illustrating a second plasma distribution.

[0069] Similar to the arrangement of FIG. 4, the deposition sources 300 are arranged next to each other in a linear arrangement and include a cylinder-shaped rotatable cathode 110 and a magnet assembly 120 arranged within the cathode, respectively. The magnet assemblies 120 are pivotable around the rotation axis of the associated cathode. Two movable rod-shaped anodes which form an anode assembly 130 are allocated to each of the cathodes, respectively. The layout of the deposition sources 300 shown in FIG. 5 may correspond to the layout of the deposition source shown in FIG. 3a and FIG. 3b. Thus, the description given above also applies to the embodiment of FIG. 5.

[0070] In the arrangement shown in Fig. 5, the magnet assemblies 120 have been moved clockwise in accordance with the two allocated anodes while maintaining a constant distance between the magnet assembly and each of the two allocated anodes. A first plasma cloud 350 and a second plasma cloud 351 have followed the joint movement of the magnet assembly 120 and the anode assembly 130 following the plasma confinement region of the magnet assembly. It is apparent that the shapes and densities of the first plasma cloud 850 and of the second plasma cloud 851 have remained stable during the movement, and that the first plasma cloud 850 and the second plasma cloud 851 are

essentially of an identical shape and density. Thus, the uniformity of the layers to be coated on the substrate can be optimized.

[0071] FIG. 6 shows a schematic side view of a deposition source 400 for sputter deposition according to embodiments described herein. This embodiment is similar to the embodiment described above with reference to FIG. 3a and FIG. 3b. Thus, the description given above may also apply to the embodiment of FIG. 6.

[0072] The deposition source 400 includes several rotatable cathodes 110, each rotatable cathode having a cylindrical shape with a first axial end 412 and a second axial end 414 opposing the first axial end. In some implementations, the cathode 110 is connected to a cathode support via a rotating shaft, the cathode support having a rotational drive for rotating the cathode. The rotational drive may include an actuator, a drive belt, a drivetrain, or a motor configured for rotating the rotatable cathode around the rotation axis. A magnet assembly 120 is arranged in each cathode.

[0073] According to some embodiments, which could be combined with other embodiments described herein, the deposition source 400 includes magnet assembly drive units 422 for moving the magnet assemblies 120 along the first trajectories and anode assembly drive units 432 for moving the anode assemblies 130 along the second trajectories. Similar to the rotational drives for the cathodes, the magnet assembly drive units and/or the anode assembly drive units may include an actuator, a drive belt, a drivetrain, or a motor configured for moving the respective magnet assembly and/or the respective anode assembly around the pivot axis on their respective trajectories while maintaining a predetermined spatial relationship between the anode assemblies and the magnet assemblies.

[0074] In some embodiments, the anode assembly drive unit is arranged at a first axial end of the cathode, and a cathode drive unit for rotating the cathode is arranged at a second axial end of the cathode opposite the first end. The magnet assembly drive unit may be arranged at the second axial end of the cathode together with the cathode drive unit. For example, the magnet assembly drive unit and the cathode drive unit are integrated in a common drive unit. Alternatively, the magnet assembly drive unit and the anode assembly drive unit may be arranged at the same axial end of the rotatable cathode. For example, the

magnet assembly drive unit and the anode assembly drive unit are integrated in the cathode drive unit.

[0075] In some embodiments, for example in the embodiment shown in FIG. 6, the anode assembly drive unit 432 is arranged at the first axial end 412 of the cathode and the magnet assembly drive unit 422 is arranged at the second axial end 414 of the cathode. Such an arrangement may lead to a less complex drive unit configuration. The anode assembly drive unit 432 may be adapted for simultaneously moving both a first anode 332 and a second anode 334 of the anode assembly 130. For example, both the first anode 332 and the second anode 334 may be connected to a drive shaft of the anode assembly drive unit 432.

[0076] The deposition source 400 may be used as a part of a sputtering apparatus, the sputtering apparatus including a vacuum chamber 401 for performing sputtering within the vacuum chamber 401. A wall portion 402 of the vacuum chamber 401 is schematically shown in FIG. 6. The cathodes, the movable magnet assemblies as well as the movable anode assemblies may be arranged within the vacuum chamber, whereas the magnet assembly drive units and the anode assembly drive units may be positioned outside the vacuum chamber.

[0077] FIG. 7 shows a schematic sectional view of a deposition source 500 for sputter deposition according to embodiments described herein. The deposition source 500 is similar to the embodiment described above with reference to FIG. 3a and FIG. 3b. Thus, the description given above may also apply to the embodiment of FIG. 7.

[0078] The first anode 332 and the second anode 334 may be connected by a housing 550. The housing may be made of a conductive material, so that both anodes can be electrically powered with a single power connector.

[0079] The housing 550 may cover an outer circumference section of the cathode 110 for shielding the cathode from stray coating. For example, the housing 550 may cover a backside of the cylindrical cathode 110 distant from the substrate to be coated, whereas a front of the cathode 110 which faces the substrate may be open to be sputtered. In particular, a section of the second circular trajectory between the first anode and the second

anode may be open, whereas a remaining circumferential section of the cathode may be covered by the housing which forms a cathode shielding. As the housing 550 may be fixed to the first anode 332 and to the second anode 334, the housing is rotated together with the anode assembly 130 around the pivot axis.

- 5 [0080] Further, the first anode 332 and the second anode 334 may be provided with a water cooling 336 including a cooling channel which runs through the anode rods in an axial direction.

[0081] FIG. 8 shows a schematic view of a sputtering apparatus 600 according to embodiments described herein. The sputtering apparatus 600 includes a vacuum chamber  
10 610 and a deposition source in accordance with any of the embodiments described herein. In the shown embodiment, the deposition source includes four rotatable cathodes 110, each cathode 110 being provided with an anode assembly 130 including two anodes 332, 334, the cathodes 110 and anode assemblies 130 being arranged inside the vacuum chamber 610. The anodes 332, 334 are connected by a housing 550 for shielding a backside of the  
15 cathode from stray coating. More than four rotatable cathodes 110 may be provided.

[0082] A power apparatus 625 for power supply is arranged outside the vacuum chamber 610 and is electrically connected to the cathodes and anode assemblies via respective electric connections and power connectors. FIG. 8 shows the rotatable cathodes 110 with magnet assemblies 120 or magnetrons provided in the rotatable cathodes 110, wherein the  
20 magnet assemblies are provided within backing tubes that are equipped with the target material on an outer surface, respectively.

[0083] As indicated in FIG. 8, further chambers 611 can be provided adjacent to the vacuum chamber 610. The vacuum chamber 610 can be separated from the adjacent chambers 611 by valves having a valve housing 604 and a valve unit 605, respectively.  
25 Accordingly, after a carrier 606 with a substrate 607 to be coated is inserted in the vacuum chamber 610, as indicated by arrow 601, the valve units 605 can be closed. Accordingly, the atmosphere in the vacuum chamber 610 can be individually controlled by generating a technical vacuum, for example, with vacuum pumps connected to the vacuum chambers 610, 611, and/or by inserting process gases in the deposition region of the vacuum chamber  
30 610.

[0084] According to typical embodiments, process gases can include inert gases such as argon and/or reactive gases such as oxygen, nitrogen, hydrogen and ammonia, ozone, activated gases or the like.

[0085] Within the vacuum chamber 610, rollers 608 are provided in order to transport the carrier 606 with the substrate 607 into and out of the vacuum chamber 610. The term “substrate” as used herein shall embrace both inflexible substrates, e.g., a glass substrate, a wafer, slices of transparent crystal such as sapphire or the like, and flexible substrates, such as a web or a foil.

[0086] Further details of the deposition source may be taken from one of the previously described embodiments or by combining any of the previously described embodiments, and they are not repeated here.

[0087] FIG. 9 shows a flowchart of a method of operating a deposition source for sputter deposition according to embodiments described herein. The method includes moving an anode assembly in accordance with a magnet assembly and particularly relative to a cathode providing a target material to be sputtered in a first box 902. The method may include moving the anode assembly in accordance with a magnet assembly relative to an axis of the cathode, for example the rotation axis of the cathode. A distance between the anode assembly and the magnet assembly may be kept essentially constant at least at respective sputtering positions or throughout the movement. In some embodiments, the magnet assembly and the anode assembly are pivoted around a common pivot axis which may correspond to the rotation axis of the cylindrical cathode.

[0088] While the foregoing is directed to embodiments of the invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

## CLAIMS

1. A deposition source for sputter deposition (100, 300, 400, 500), comprising:  
at least one cathode (110) for providing a target material to be deposited;

5 a movable magnet assembly (120); and

at least one anode assembly (130), which is movable in accordance with the magnet assembly (120).

2. The deposition source of claim 1, wherein the magnet assembly (120) and the  
10 anode assembly (130) are movable relative to the cathode (110), particularly relative to an axis of the cathode (110).

3. The deposition source of claim 1 or 2, wherein the magnet assembly is movable  
along a first trajectory and the anode assembly is movable along a second trajectory,  
15 wherein the first trajectory has a first pair of turning points and the second trajectory has a second pair of turning points wherein a ratio between a minimum distance between corresponding turning points of the first pair of turning points and the second pair of turning points and a maximum distance between corresponding turning points of the first pair of turning points and the second pair of turning points is more than 0.7, particularly  
20 more than 0.95, and more particularly 1.

4. The deposition source of any of claims 1 to 3, wherein the magnet assembly is movable along a first trajectory and the anode assembly is movable along a second trajectory such that a ratio between a smallest distance between the magnet assembly (120)  
25 and the anode assembly (130) during the movement and a largest distance between the magnet assembly (120) and the anode assembly (130) during the movement is more than 0.7, particularly more than 0.95 and more particularly 1.

5. The deposition source of claim 3 or 4, wherein the first trajectory has the shape of a circular arc inside the cathode (110), and/or the second trajectory has the shape of a circular arc outside the cathode (110).

5 6. The deposition source of any of claims 1 to 5, wherein the cathode (110) is at least partially provided as a hollow cylinder, the magnet assembly (120) being arranged within the hollow cylinder.

7. The deposition source of any of claims 1 to 6, wherein the magnet assembly (120)  
10 and the anode assembly (130) are pivotable around pivot axes, particularly around a common pivot axis (A).

8. The deposition source of claim 7, wherein the cathode (110) is rotatable  
15 independently of the pivot movement of the magnet assembly (120) and the anode assembly (130).

9. The deposition source of any of claims 1 to 8, comprising a magnet assembly drive unit (422) for moving the magnet assembly (120) and/or an anode assembly drive unit (432) for moving the anode (130) assembly.

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10. The deposition source of claim 9, wherein the cathode (110) has a first axial end (412) and a second axial end (414) opposing the first axial end, the anode assembly drive unit (432) being arranged at the first axial end (412) and the magnet assembly drive unit (422) being arranged at the second axial end (414).

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11. The deposition source of claim 9 or 10, wherein the anode assembly (130) comprises a first anode (332) and a second anode (334), the anode assembly drive unit (432) being configured to move the first anode and the second anode such that at least one of a first distance (D1) between the first anode (332) and the magnet assembly (120) and a

second distance (D2) between the second anode (334) and the magnet assembly (120) is kept essentially constant during the movement.

12. The deposition source of claim 11, wherein an angle between the first anode (332) and the second anode (334) with respect to a center of the cathode (110) is more than 30° and less than 200°, and particularly more than 90° and less than 150°, the magnet assembly (120) being located essentially at a center angular position between the first anode (332) and the second anode (334).

13. The deposition source of any of claims 10 to 12, wherein the first anode (332) and the second anode (334) are connected by a housing (550).

14. The deposition source of claim 13, wherein the housing (550) covers an outer circumference section of the cathode (110) for shielding the cathode from stray coating.

15. A sputtering apparatus (600), comprising:

a vacuum chamber (610); and

a deposition source for sputter deposition (100, 300, 400, 500), comprising:

at least one cathode (110) for providing a target material to be deposited;

a movable magnet assembly (120); and

at least one anode assembly (130), which is movable in accordance with the magnet assembly (120),

particularly wherein the at least one cathode (110), the magnet assembly (120), and the at least one anode assembly (130) are positioned inside the vacuum chamber (610), and a magnet assembly drive unit (422) for moving the magnet assembly and/or an anode assembly drive unit (432) for moving the anode assembly are positioned outside the vacuum chamber (610).

16. A method of operating a deposition source (100, 300, 400, 500) for sputter deposition, particularly a deposition source of any of claims 1 to 14, wherein an anode assembly (130) is moved in accordance with a magnet assembly (120) and relative to a cathode (110) providing a target material to be deposited.

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Fig. 1

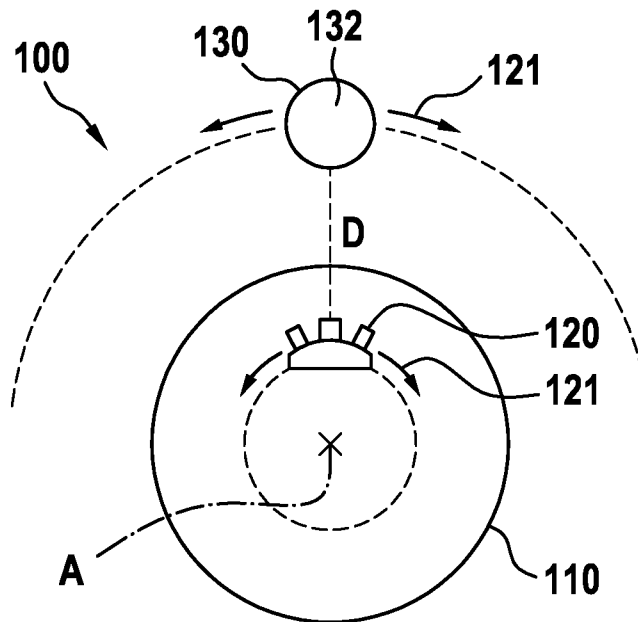
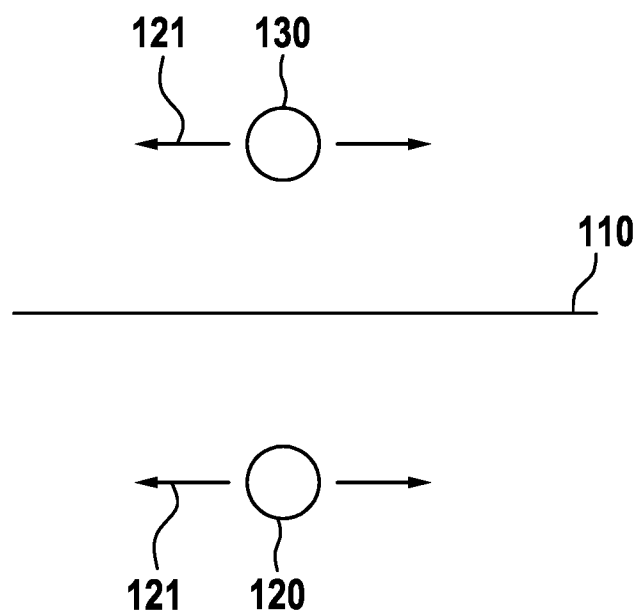


Fig. 2



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Fig. 3a

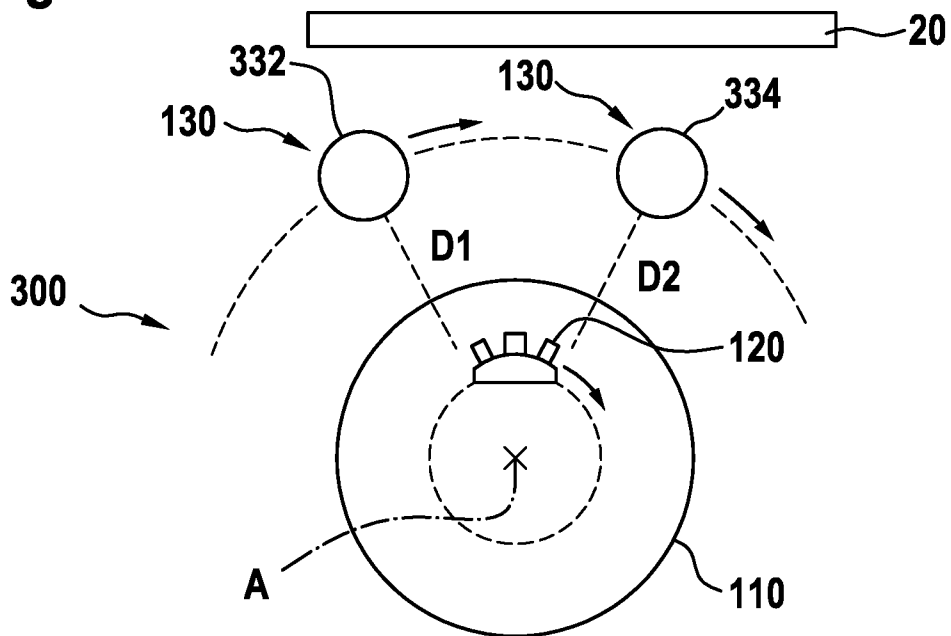


Fig. 3b

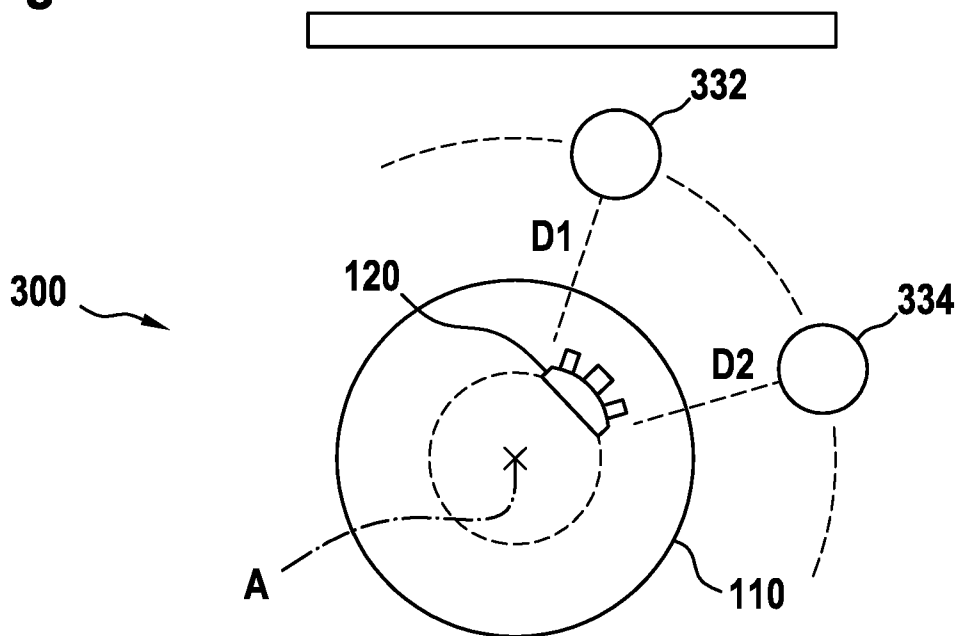


Fig. 4

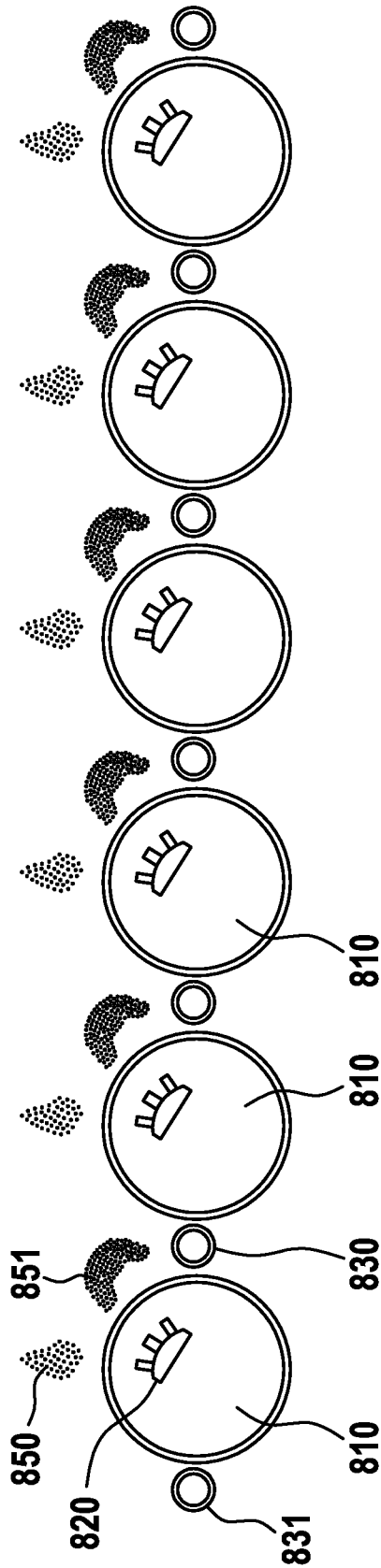
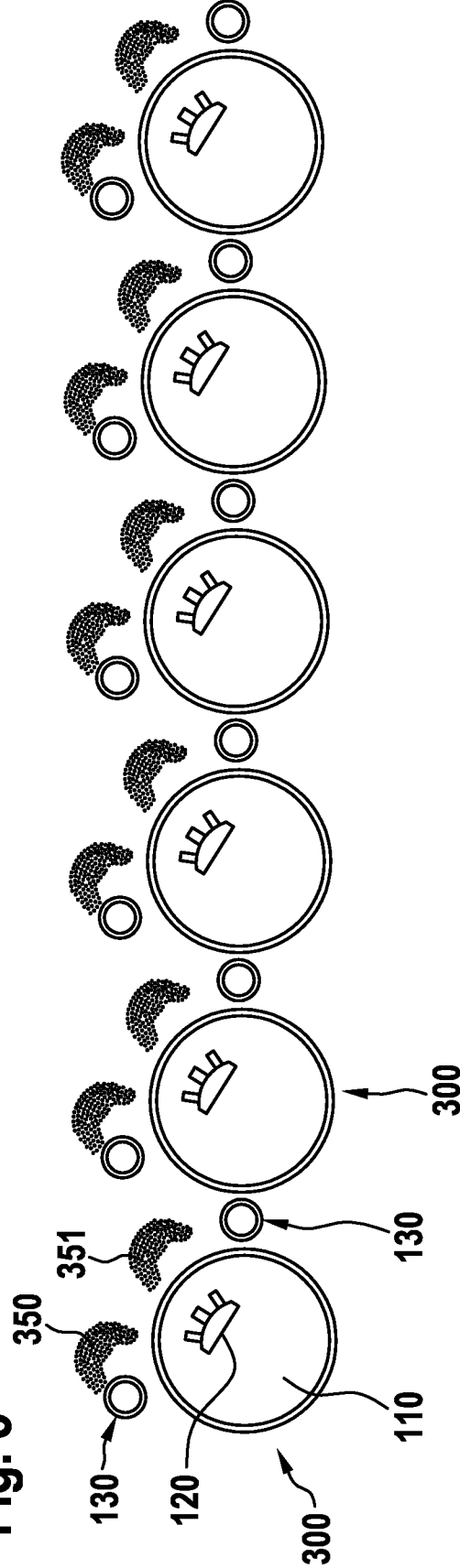


Fig. 5



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Fig. 6

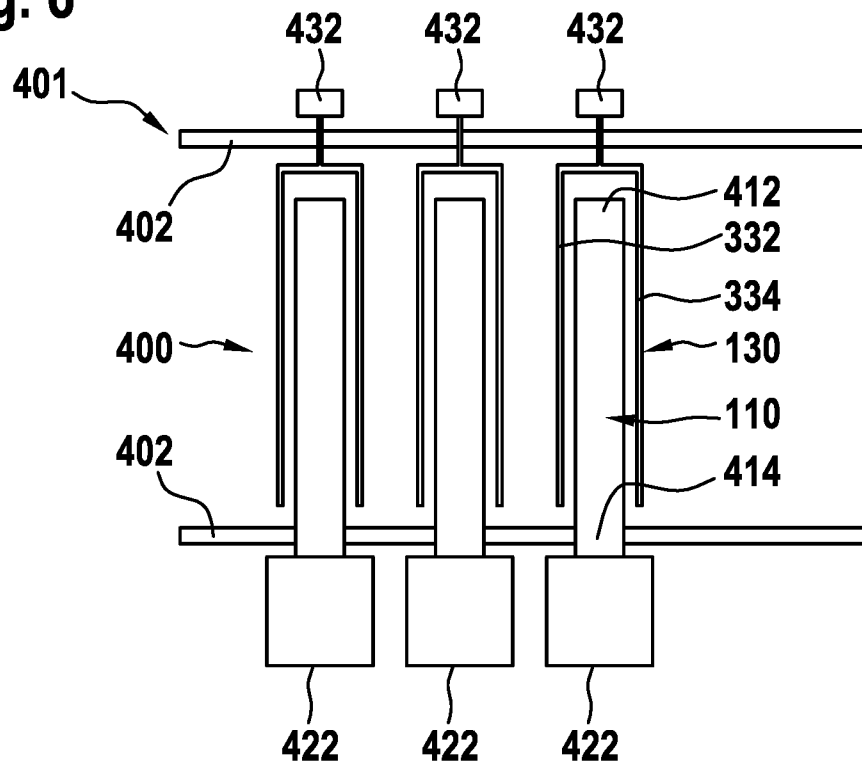
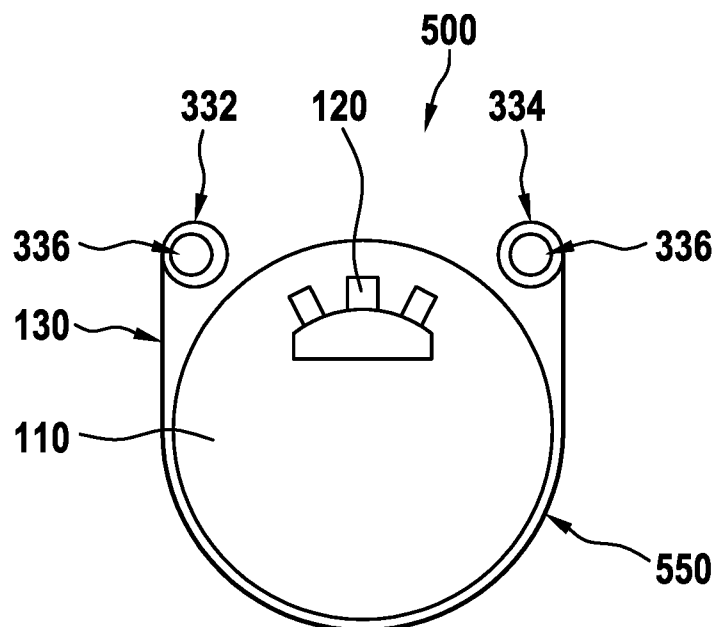
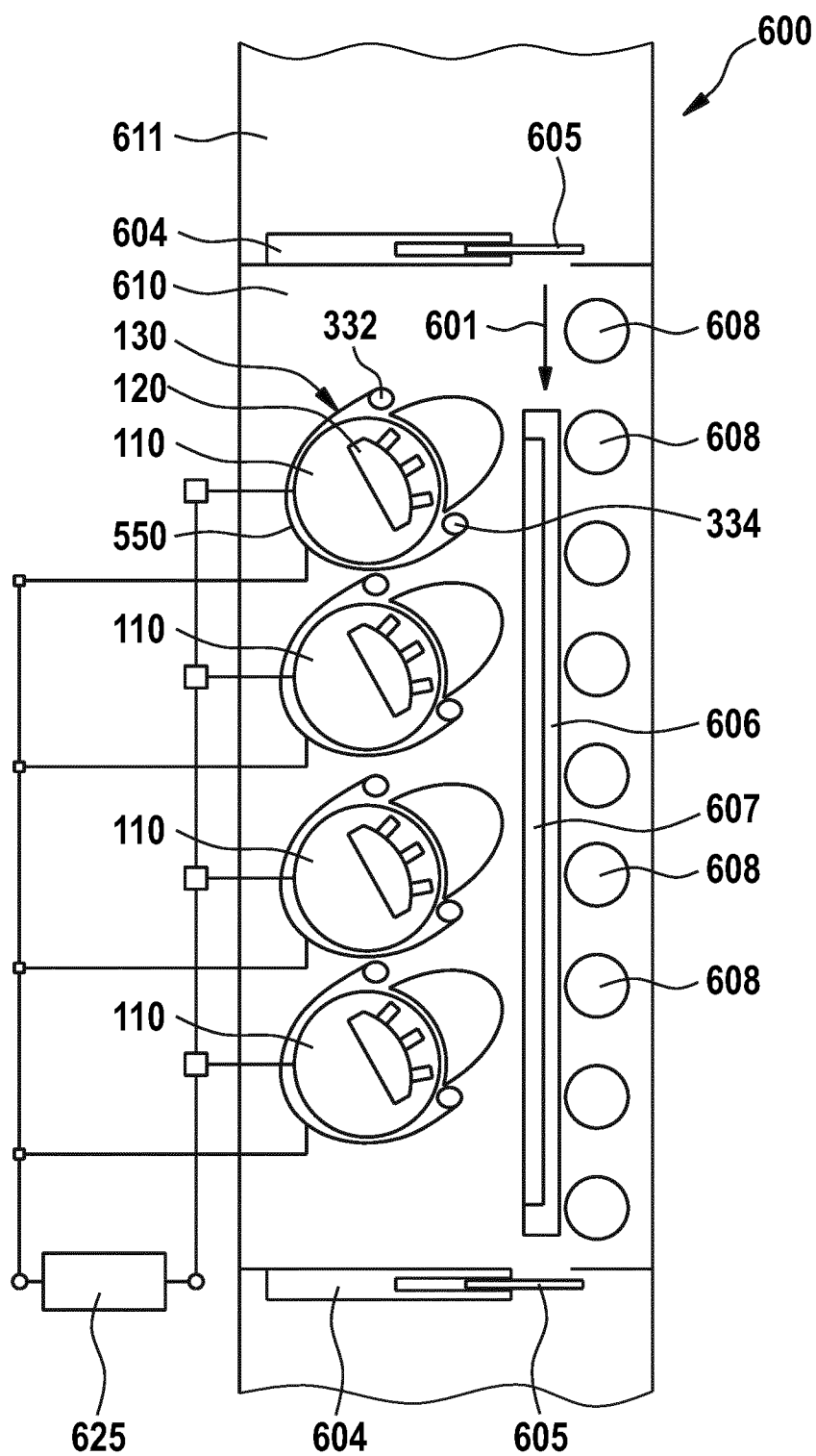


Fig. 7



**Fig. 8**



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Fig. 9

## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/062600

A. CLASSIFICATION OF SUBJECT MATTER  
INV. 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)  
H01J 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, WPI Data

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Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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Date of the actual completion of the international search

17 December 2015

Date of mailing of the international search report

04/01/2016

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## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/062600

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International application No

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