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

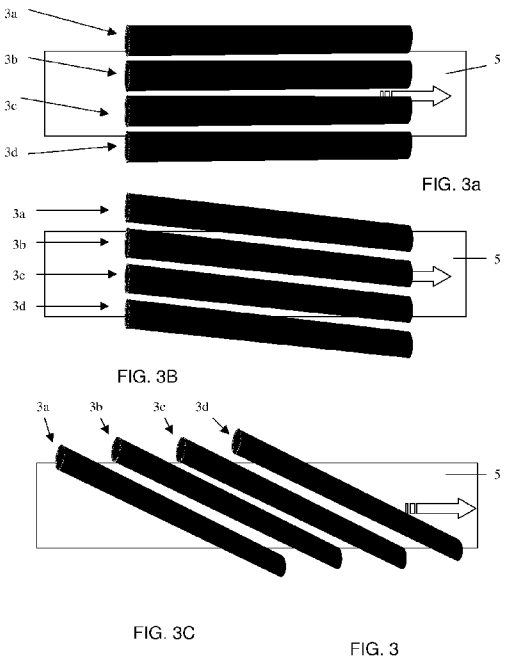


FIG. 3a

FIG. 3B

FIG. 3C

FIG. 3

(57) **Abstract**: A sputtering installation and method are described for coating substrates, the substrate being transportable in said installation in a transport direction, the substrate having a substrate width perpendicular to said transport direction, the installation comprising at least one pair of sputtering targets, each rotatable about a longitudinal axis of the target, the targets having magnet bars arranged lengthwise in pole lines for generating elongated race tracks on the surface of the targets during use. The pole lines are substantially parallel to the substrate transport direction. All targets are arranged side by side with their longitudinal axes parallel. The targets are closer to the substrate than the substrate width, i.e. the distance between the target surfaces and the substrate is lower than the width of the substrate. According to an advantageous embodiment of the invention and especially for coating uniformity the race track angle should be larger than 45°, i.e. the angle between adjacent pole lines is larger than 45° as measured from the target axis.

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SPUTTERING APPARATUS AND METHOD

The present invention relates to a sputtering device and method capable of producing a uniform coating on a substrate at high speed.

Technical Background

DC, AC or RF Sputtering using a magnetron and planar and cylindrical targets is known. On a planar or cylindrical target a plasma "racetrack" is formed and the target erodes to form an erosion region which follows the shape of the racetrack while the eroded material is deposited onto a substrate.

With a cylindrical target, the target material is a tube, which is rotated around its cylindrical axis. On the inside of the tube magnets are arranged that are typically stationary with respect to a substrate to be coated.

Reactive magnetron sputtering is also known e.g. for the deposition of insulating (e.g. oxide or nitride of a metal) and semiconducting coatings. In reactive sputtering, the inert working gas is usually argon and the added reactive gas is often oxygen and/or nitrogen. The coating of dielectric materials can be accomplished by RF sputtering of the dielectric material itself used as the target but the deposition rates are very low. DC or AC reactive magnetron sputtering of insulating films can have higher deposition rates and lower costs, but there is a need to improve the speed of depositing high quality insulating metal oxides and nitrides, e.g. low variation in thickness and/or the chemical variability of the coating at high speeds. Process control for reactively depositing insulating films at high rate traditionally has been difficult. Usually the substrate is moved continuously underneath the magnetron, in a direction perpendicular to the longitudinal axis of the cylindrical target.

FIG. 1 is a schematic diagram of a conventional vacuum sputtering system 1. The magnetron system is for eroding and depositing target material onto a substrate 5. For example, the sputtering may be onto thin film transistors (FPD) for thin film electronics, onto solar absorbers (PV), onto flexible metallic or polymeric substrates, or onto glass substrates. For example, the sputtering may be for deposition of oxide layers by a low pressure plasma process at low temperatures in layers for which providing electronic

functionality raises the problem of plasma damage of the growing film due to unwanted interaction of fast species with the growing film. This is a problem for semiconductor applications such as processing layers in the nanoscale range for Thin Film Transistor applications or in current spreading layers for LED in optoelectronics and for oxide based p-n junctions.

The sputtering chamber 2 has a cathode lid 1 and a plurality of horizontally mounted rotatable cylindrical targets 3a, 3b….., e.g. typically 2 such cylindrical targets 3a, 3b. The tubular target 3a, 3b may be machined from a relatively thick wall tube, or it may consist of target layer fixed onto a carrier tube. Both tubular target layer and the backing tube may rotate when sputtering takes place. Hence means for rotating the targets are provided such as one or more motors. Inside each of the hollow tubular targets 3a, 3b are positioned magnet assemblies 4a, 4b that remain stationary as the cylindrical targets are rotated. Magnet assemblies 4a, 4b create plasma racetracks immediately above the target surface when in operation and the racetracks result in erosion zones on the surfaces of the tubular targets. The magnet assemblies include magnets, e.g. lines of magnets of one polarity parallel to the longitudinal axis of the tubular target. Each magnetic assembly is configured to provide a magnetic field racetrack over the outer surface of each tubular target. In operation, the magnetic field racetrack confines a plasma gas to erode the target material of each target from a pair of substantially parallel erosion zones along the length of the each tubular target, each pair of erosion zones defining a source plane for each target and being separated by a distance there between, and each magnetic assembly configured to fix the distance between the parallel erosion zones in each target to create a combined area of target material flux for each tubular target.

One problem encountered in currently known devices is that the substrates to be coated, for example in strip form, are of variable widths. This means that, if a substrate of a width less than the target is passed before a target of a given length in a cathodic sputtering chamber, material is lost due to sputtering beyond the edges of the substrate resulting in contamination of the chamber. One solution to overcome these problems is to use variable length targets which are changed depending upon the width of the substrate to be processed. This takes up considerable space, entails installation and removal time as well as storage of different targets. According to another solution, a single target is used with

masking elements which can cover at least one of the ends of the target if the substrate to be processed is of width less than the length of the target. However, these masks must be replaced or cleaned regularly.

A process for forming a coating on a substrate by cathodic sputtering is know from US 6,083,359, comprising transfer of the substrate between an inlet and an outlet of a cathodic sputtering chamber, passage of at least one surface to be coated of the substrate parallel to a surface of a target, oriented towards this substrate surface and containing one or more elements to be deposited on the substrate, and during this passage, cathodic sputtering of said one or more elements to be deposited on the entirety of the surface to be coated from said target surface. Depending upon the width of the substrate being coated, the surface of the target is displaced relative to the surface to be coated of the substrate, such that substantially the entirety of the surface of the target is constantly located opposite the surface to be coated during cathodic sputtering.

The longitudinal axis of the target is located in a direction perpendicular to the direction of motion of the strip, when the width of the strip is at its maximum, and at an oblique position relative to this direction of motion, when the width of the strip is less than the maximum width. By means of rotational displacement it is accordingly possible to adjust the target to strips of variable width which are to be processed in succession in the sputtering chamber.

However, the rate of deposition depends upon the angle of the target to the direction of motion of the substrate and this has a negative effect upon costs when the width of the strip is high.

Summary of the Invention

The present invention provides, in embodiments, an alternative vacuum sputtering device and method capable of producing a uniform coating on a substrate at high speed.

The present invention provides in an embodiment a sputtering installation for coating substrates, said substrates being transportable in said installation in a transport direction, said substrate having a substrate width perpendicular to said transport direction, said installation comprising at least one pair of sputtering targets, each rotatable about a

longitudinal axis of the target, said targets having magnet bars arranged lengthwise in pole lines for generating elongated race tracks on the surface of said targets during use, said pole lines being substantially parallel to said substrate transport direction. In arrangements according to the present invention there are at least one pair of targets, all targets being arranged side by side with their longitudinal axes parallel. The targets are preferably closer to said substrate than said substrate width, i.e. the distance between the target surfaces and the substrate is lower than the width of the substrate. According to an advantageous embodiment of the invention and especially for coating uniformity the race track angle should be larger than 45°, i.e. the angle between adjacent pole lines is larger than 45° as measured from the target axis.

According to an advantageous embodiment of the invention, the targets may pivot in the sputtering chamber.

The present invention provides in one embodiment a vacuum sputtering arrangement for coating a substrate, said substrate being transportable through said arrangement in a transport direction, said substrate having a substrate width perpendicular to said transport direction, said arrangement comprising at least one pair of sputtering targets, each rotatable about a longitudinal axis of the target. All targets are arranged side by side with their longitudinal axes parallel, said longitudinal axes being substantially parallel to said substrate transport direction. The distance from the target surface to said substrate is smaller than said substrate width. Preferably, the substrate is transportable through said arrangement, and is positionable in said arrangement, such that the distance from the target surface to said substrate is smaller than said substrate width. Accordingly means are provided for transporting the substrate through said arrangement, and for positioning the substrate in said arrangement, such that the distance from the target surface to said substrate is smaller than the substrate width.

The substrate width may be equal to the maximum substrate width that is transportable through said arrangement.

The substrate may be transported through said arrangement by a transporter, or transport means, that may be part of the arrangement. The transporter is adapted for transporting the substrate through said arrangement, and for positioning the substrate in said arrangement, such that the distance from the target surface to said substrate is smaller than the substrate width. The transporter may determine the maximum transportable substrate width.

The use of targets with their longitudinal axis being parallel, or substantially parallel, to the transport direction, increases the area of target flux that impinges on the substrate and hence increases throughput.

The targets have magnet bars for generating elongated race tracks on the surface of said targets during use. This allows use of standard magnet bars.

In one aspect the targets can be adapted to pivot around an axis perpendicular to the longitudinal axes of the targets and to the substrate. This allows more flexibility in production conditions. However it increases the complexity of the arrangement.

Reference planes, each of which passes through the centre of a tubular target and also through the centre of an erosion zone of the same target preferably subtend an angle at the centre of that tubular target greater than 45°, e.g. between 45 and 90°. This allows an improved target flux at the substrate. For example it allows a wide area on the substrate where the target flux is sensibly constant. In embodiments of the present invention the angle subtended at the target longitudinal axis is between 50° and 80°.

The target flux of each of the targets combines to create an area of substantially uniform flux at the substrate. This combination is controllable by means of adjusting parameters of the sputtering magnetron configuration.

The target to substrate distance can be between 50 and 500mm the spacing of the axes of the at least first and second targets can be between 40 and 500mm, the diameter of the cylindrical targets can be between 30 and 500mm. This allows an arrangement that is

economical in space.

In one aspect at least one or each individual target does not span the complete width of the substrate . This provides a large amount of the target pointing in the direction of substrate movement which improves throughput.

The arrangement is preferably configured such that the target flux at the substrate is substantially constant with a variability of less than 5%, preferably with a variability of less than 2% more preferably with a variability of less than 1% over a distance of at least 75% of the spacing distance between the axes of the outer magnetrons and more preferably over a distance similar (+/- 20%) to the spacing distance between the axes of the outer magnetrons.

The arrangement is preferably adapted for any of the following either individually or in combination:
pivoting the target set through small angles, whereby the pivoting may include rotation of the target set as a whole or rotating each target of the target set so that the tragets remain parallel to each other, and/or
changing the spacing between targets, and/or
reducing or increasing the number of targets in the set which are used for sputtering (e.g. by switching or directing power to relevant ones of the targets, and/or
tilting one or more of the magnet bars, and/or
adjusting the spacing between adjacent targets, and/or
adjusting the spacing between each of the target axes to the substrate surface, and/or
adjusting the power level on any of the targets.

The present invention also provides in an embodiment a method of vacuum sputtering for coating a substrate said using at least one pair of rotatable sputtering targets, each having a longitudinal axis, all targets being arranged side by side with their longitudinal axes parallel, the method comprising:

transporting said substrate through a vacuum chamber in a transport direction, said substrate having a substrate width perpendicular to said transport direction,
said longitudinal axes of the rotatable targets being positioned substantially parallel to said substrate transport direction, wherein the distance from the target surface to said substrate is set to be is smaller than said substrate width.

Preferably at least one or each individual target does not span the complete width of the substrate.

The method may include any of the following or combinations thereof:
pivoting the target set through small angles whereby the pivoting may include rotation of the target set as a whole or rotating each target of the target set so that the tragets remain parallel to each other, and/or
changing the spacing between targets, and/or
reducing or increasing the number of targets in the set which are used for sputtering, and/or
tilting one or more of the magnet bars, and/or
adjusting the spacing between adjacent targets, and/or
adjusting the spacing between each of the target axes to the substrate surface, and/or
adjusting the power level on any of the targets.

The present invention also provides in some embodiments in accordance with another independent aspect, a vacuum sputtering system for eroding and depositing target material on a substrate, comprising:
at least a first and a second cylindrical tubular target,
each having a longitudinal axis and an outside surface and a fixed length,
each of the at least first and second cylindrical tubular targets being rotatable about the longitudinal axis of the cylindrical tubular target,
wherein the second rotatable cylindrical tubular target is positioned relative to the first target such that axes of the at least first and second targets are parallel to each other;
and at least a first and a second magnetic assembly respectively disposed within and along the length of the at least first and the second tubular targets, respectively,

each magnetic assembly being configured to provide a magnetic field racetrack over the outer surface of each tubular target,

the magnetic field racetrack confining a plasma gas to erode the target material of each target from a pair of substantially parallel erosion zones along the length of the each tubular target,

each pair of erosion zones defining a source plane for each target, each pair of erosion zones being separated by a distance,

and each magnetic assembly being configured to fix the distance between the parallel erosion zones in each target to create a combined area of target material flux for each tubular target,

and wherein the magnet assemblies are oriented relative to each other such that an included angle is formed between a pair of reference planes passing through the axis of each target. These reference planes, each of which passes through the centre of a tubular target and also through the centre of an erosion zone of the same target subtend an angle at the centre of that tubular target greater than 45°, e.g. between 45 and 90°.

BRIEF DESCRIPTION OF THE DRAWINGS

Other details and particular features of the invention may be found in the following, non-limiting description given below with reference to the attached drawings.

FIG. 1 is a schematic view of a conventional sputtering chamber.

FIG. 2 is a schematic cross-sectional view of a dual target sputtering chamber in accordance with an embodiment of the present invention.

FIGs. 3a to c are schematic views of different embodiments according to the prsent invention.

FIG. 4 is a graph showing a relationship between parallel dual target length and number of equivalent perpendicular target pairs.

FIGs. 5 to 10 show graphs of target flux for various embodiments of the present invention.

FIG. 11 is a schematic cross-sectional view of a multi-target sputtering chamber in accordance with an embodiment of the present invention.

FIG. 12 is graph showing optimisations of parameters according to the embodiment of a dual target configuration of the present invention.

Identical or analogous elements on the various drawings have identical reference numerals.

DETAILED DESCRIPTION OF EMBODIMENTS

The present invention will be described with respect to particular embodiments and with reference to certain drawings but the invention is not limited thereto but only by the claims. The drawings described are only schematic and are non-limiting. In the drawings, the size of some of the elements may be exaggerated and not drawn on scale for illustrative purposes. Where the term "comprising" is used in the present description and claims, it does not exclude other elements or steps. Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

The present invention relates to coating systems and processes that utilize improved magnetrons as hereafter described. In a dual magnetron configuration, and, likewise, in a triple magnetron configuration, two magnetrons or three magnetrons, are mounted together substantially in parallel. More than three magnetrons can be used with the present invention as well be described below. Minor differences in dimensions or design details would not negate their ability to properly function together.

Certain parts of a sputtering magnetron system will not be described in detail such as vacuum feedthroughs, rotating mechanisms, target support means, plasma and/or argon gas feeds and control systems, power supply and control therefore, and the cooling system (normally using water) and control therefore.

The present invention provides in an embodiment a sputtering installation for coating substrates, said substrates being transportable in said installation in a transport direction, said substrate having a substrate width perpendicular to said transport direction, said installation comprising at least one pair of sputtering targets, each rotatable about a longitudinal axis of the target, said targets having magnet bars arranged lengthwise in pole lines for generating elongated race tracks on the surface of said targets during use, said pole lines being substantially parallel to said substrate transport direction. In arrangements according to the present invention there is preferably at least one pair of targets, all targets being arranged side by side with their longitudinal axes parallel. The targets are preferably closer to said substrate than said substrate width, i.e. the distance between the target surfaces and the substrate is lower than the width of the substrate. Preferably, for certain embodiments of the present invention and especially for coating uniformity the race track angle should be larger than 45°. The magnet bars are arranged in a magnetic assembly that is configured to provide a magnetic field racetrack over the outer surface of each tubular target,

the magnetic field racetrack confining a plasma gas to erode the target material of each target from a pair of substantially parallel erosion zones along the length of the each tubular target. Each pair of erosion zones defines a source plane for each target, each pair of erosion zones being separated by a distance, and each magnetic assembly being configured to fix the distance between the parallel erosion zones in each target to create a combined area of target material flux for each tubular target. The magnet bars are oriented relative to each other such that an included angle is formed between a pair of reference planes passing through the axis of each target. These reference planes, each of which passes through the centre of a tubular target and also through the centre of an erosion zone of the same target subtend an angle at the centre of that tubular target greater than 45°, e.g. between 45 and 90°.

The substrate may be transported through the sputtering arrangement by a transporter, or transport means, that may be part of the sputtering arrangement. The transporter may determine the maximum substrate width that can be transported through the arrangement.

The present invention starts from the principle that, in order to adapt to different substrate widths, the angle of the longitudinal axis of a target to the direction of movement of the substrate should not change too much so that there is little change in the throughput that can be achieved. However if variable width substrates are to be used a mechanism needs to be provided for reducing the width of the sputtered material such as to align the sputter width with the substrate width. To achieve this in accordance with embodiments of the present invention, two or more targets are used whose longitudinal axes are parallel and also are substantially parallel to the direction of motion of the substrate. Substantially parallel to the direction of motion of the substrate means making an angle of less than 45° with this direction. Substrate width variation is provided by a variety of mechanisms which can be used individually or in combination:

a) by pivoting the target set through small angles, whereby the pivoting may include rotation of the target set as a whole or rotating each target of the target set so that the tragets remain parallel to each other or
b) by changing the spacing between targets,
c) by reducing or increasing the number of targets in the set which are used for sputtering or
d) by varying other parameters as indicated below.

In accordance with embodiments of the present invention various parameters of the sputtering arrangement may be adjusted to achieve good deposition of a coating. For example:

a) the angle between the race tracks (defined by the magnet bar) may be set to an angle of greater that 45°.
b) One or more of the magnet bars may be tilted, e.g. preferably outer magnet bars in the set of targets are tilted inwards.
c) The spacing between adjacent target tubes can be adjusted.
d) The spacing between each of the target axes to the substrate surface can be adjusted.

e) The power level on each of the targets may be adjusted, e.g. to achieve an acceptable uniformity over the substrate width, and/or a minimal loss of sputtering besides the substrate for various substrate widths, and/or adequate deposition rates by adjusting the length of the target (for a given maximum power density). For example longer targets allow for higher rates.

Over the complete life time of the target uniform conditions can be maintained despite change in the target tube diameter and target-substrate spacing caused by target erosion.

A vacuum sputtering system according to embodiments of the present invention is for eroding and depositing target material onto a substrate . For example, the sputtering may be onto thin film transistors (FPD) for thin film electronics, onto solar absorbers (PV), onto flexible metallic or polymeric substrates, or onto glass substrates. For example, the sputtering may be for deposition of oxide layers by a low pressure plasma process at low temperatures in layers for which providing electronic functionality raises the problem of plasma damage of the growing film due to unwanted interaction of fast species with the growing film. This is a problem for semiconductor applications such as processing layers in the nanoscale range for Thin Film Transistor applications or in current spreading layers for LED in optoelectronics and for oxide based p-n junctions.

An embodiment of the present invention is shown in Fig. 2. The sputtering chamber has a cathode lid 1 (see Fig 1) and a plurality of horizontally mounted rotatable cylindrical targets 3a, 3b. The spacing of the targets, centre-to-centre is S. The tubular targets 3a, 3b have a diameter D and may be machined from a relatively thick wall tube, or may consist of a target layer fixed onto a carrier tube. Both tubular target layer and the backing tube may rotate when sputtering takes place. Hence, means for rotating the targets are provided such as one or more motors. Inside each of the hollow tubular targets are positioned magnet assemblies 4a, 4b that remain stationary as the cylindrical targets are rotated. Magnet assemblies 4a, 4b create plasma racetracks 6a, 6b immediately above the target surface when in operation and the racetracks result in erosion zones on the surfaces of the tubular targets. The magnet assemblies 4a, 4b include magnets, e.g. lines of magnets of one polarity parallel to the longitudinal axis of the tubular target. Each magnetic assembly is

configured to provide a magnetic field racetrack 6a, 6b over the outer surface of each tubular target. In operation, the magnetic field racetrack 6a, 6b confines a plasma gas to erode the target material of each target from a pair of substantially parallel erosion zones along the length of the each tubular target, each pair of erosion zones defining a source plane for each target. The erosion zones on a target are separated by a distance, such as defined by an angle distance X subtended at the centre of each target. Each magnetic assembly 4a, 4b is configured to fix this distance between the parallel erosion zones in each target to create a combined area of target material flux for each tubular target. Preferably a greater fraction of the target flux from each target is utilized to deposit target material onto a substrate than from a single zone on each target. One or more of the magnet assemblies 4a, 4b can in some embodiments be rotated or tilted relative to the plane of the substrate, e.g. by an angle Y with respect to a normal through the substrate 5. Accordingly there are means for tilting the magnetic assemblies. This can be done by hand and locked in position by a locking mechanism and optionally a fine adjustment system, or the tilting may be done by a motor such as a stepping motor or a servomotor with angular position feedback control. The magnet assemblies are oriented relative to each other such that, at the substrate, the target flux of each of the targets combines to create an area of substantially uniform flux. In accordance with some embodiments of the present invention the angular distance ("racetrack angle" X) between the parallel erosion zones, subtended at the centre of the cylindrical target is preferably greater than 45°, for example is 45 to 90° or for example 50 to 80°. The placement of the substrate 5 with respect to the targets, e.g. the target surface to substrate distance H and the pointing angles Y of the racetracks toward the substrate 5 and each other are selected to create a uniform target flux over a significant area at the substrate 5. These parameters are optimized to form a relatively wide and efficient constant flux deposition region at the substrate 5. This allows high deposition rates at constant reactive gas partial pressures with substantially uniform film stoichiometry and thickness. For example, the target to substrate distance can be between 50 and 500mm. For example, one magnetic assembly can be oriented with respect to a plane perpendicular to the substrate to subtend an angle of between 5° and 40°. For example, the spacing of the axes of at least first and second targets can be between 40 and 500mm. For example, the diameter of the cylindrical targets can be between 30 and 500mm.

In accordance with embodiments of the present invention the target flux at the substrate is substantially constant with a variability of less than 5%, preferably with a variability of less than 2% more preferably with a variability of less than 1% over a distance of at least 75% of the spacing distance between the axes of the outer magnetrons and more preferably over a distance similar (+/- 20%) to the spacing distance between the axes of the outer magnetrons.

The tubular target includes a target support assembly for holding the target material and for enabling the target material to be rotated with respect to the magnet assembly. Means are provided to rotate the tubular target at a determinable speed. Means are provided for introducing a plasma gas into the sputtering chamber and controlling the gas flow to achieve a determinable density of the plasma gas in the vicinity of the substrate. Means can be provided for introducing a reactive gas into the sputtering chamber and controlling the gas flow to achieve a determinable density of the plasma gas in the vicinity of the substrate. The speed of rotation of the targets and the density of the plasma gas at the erosion zones is preferably set to prevent target material from accumulating on the target at a location away from the erosion zones during a rotation of the tubular target.

The present invention may also include the use of one or more shields to facilitate the removal of target material that did not arrive onto the substrate. In DC operation a separate electrical anode, constructed from a conducting material, usually a metal, may be foreseen.

Each pair of erosion zones on a target defines a source plane and planes normal to the source planes in the direction of the substrate intersect with the substrate in such a way that the intersections of the normals to the source planes lie behind the substrate on the other side from the targets. Hence the substrate is positioned such that a line of intersection that is common to both planes normal to the source planes, is behind the substrate, i.e. on the opposite side of the substrate from the targets. Hence the substrate is positioned at a distance nearer to the targets than this intersecting line. This geometrical arrangement results in a combination of both fluxes from the targets that has a broad area where the flux

is constant (see Fig. 5). If the substrate is placed too close to the targets the peaks of flux from the targets become separated on the substrate. Hence a ripple appears within the uniform flux. This ripple can be defined by a Peak-to-Peak value defined by dividing the maximum local deposition rate minus the minimum local deposition rate by the average deposition rate within the substrate window of substantially constant flux. The variability is defined by dividing the Peak-to-Peak value by 2. If the substrate is too far from the targets the peaks merge but are wider in extent. A target flux from a single erosion zone that is oriented with respect to the substrate typically has a distribution similar to a skewed Gaussian-like curve having a center of distribution and a width. The width of the Gaussian-like curve can be defined as a distance between two one-half points on the curve. The distance between the parallel erosion zones on each target is set so that the target flux at the substrate from the pair of erosion zones is substantially uniform over a field larger than that from a single erosion zone.

In embodiments of the present invention the magnet assembly is fixed with respect to a substrate position. Typically, the substrate 5 is moved continuously below the cylindrical targets 3a, 3b. In a preferred embodiment the movement parallel or substantially parallel to the longitudinal axes of the cylindrical targets. A second rotatable cylindrical tubular target 3b and optionally more (3c, 3d – see Fig. 3a and 3b) is/are positioned relative to the first target 3a such that axes of the first and second targets 3a, 3b and other targets 3c, 3d are parallel to each other and the outside surfaces of the first and second cylindrical tubular targets 3a, 3b are in close proximity.

Referring again to Fig. 2, all of the magnets of the magnet assemblies 4a, 4b point radially away from the geometrical centers of the respective tubular targets 3a, 3b. The centre-to-centre distance S between the targets 3a, 3b, target surface to substrate spacing H, the angle between racetracks X and the rotation or tilting of the magnet assemblies with respect to each other Y are selected so that the target flux of the targets combines to create an area of substantially uniform flux at the substrate 5 and hence of uniform thickness and stoichiometry. This is achieved by spreading the sputtered material flux evenly, and by reducing hot zones on the substrate. As shown in Figs. 5, 6, 7, 8, 9 and 10 this geometrical

arrangement causes the sputtered flux to be uniform across a significant portion of the deposition region at the substrate. The magnetron cross-sections of the targets 3a, 3b, 3c, 3d can be identical except for their orientation. Each magnet assembly 4 can include a support structure constructed from a water resistant magnetic alloy. Each magnet assembly includes center and outer magnets arranged so that erosion zones are produced on the target which subtend an angle (the race track angle X) at the centre of the cylindrical target. The magnets may have magnet pole pieces. Pole pieces aid in smoothing out the magnetic field produced by magnets if they are constructed from an array of smaller individual magnets. The magnets may be arranged in a housing to prevent exposure to the cooling medium. The directions of magnetization of magnets may be selected as desired, however, all the magnet assemblies that are used in a given system usually have like magnetic orientation. The cross section shape of the magnets may be rectangular or may have irregular shape as to accommodate the desired magnetic field distribution. The magnets may be of the rare earth (NeFeB) type, which have very high energy density. They define the erosion zones that are part of the racetrack. The magnet assemblies 4 are intentionally constructed to increase the distance between the center and outer magnets compared to prior art designs, to thereby produce erosion zones spaced at large distances while maintaining high magnetic field strength.

The vacuum sputtering system according to the present invention can be used for high rate reactive deposition of, for example, dielectric thin films at low sputtering gas pressure with both conductive and insulating target materials. This allows the apparatus to produce superior quality dielectric films while maintaining a very constant process over the lifetime of the target tube.

Fig. 3a shows a first arrangement of targets 3a-d in accordance with an embodiment of the present invention. In this arrangement the target longitudinal axis is parallel to the movement direction of the substrate 5. Fig. 3b shows a second arrangement of targets 3a-d in accordance with an embodiment of the present invention. In this arrangement the target longitudinal axis is slightly offset from parallel to the movement direction of the substrate 5 but each target extends in a direction across the substrate that is less than the width of the

substrate. Fig. 3c shows a third arrangement of targets 3a-d in accordance with an embodiment of the present invention. In this arrangement the target longitudinal axis is substantially parallel to the movement direction of the substrate 5 but each target spans the complete width of the substrate 5. The requirements for the control of the target flux which is very important for the embodiments of Fig. 3a and 3b, is not so critical in Fig. 3c as in the latter arrangement the ends of the targets are all outside the envelope of the substrate. Thus the arrangement of Fig. 3c represents an independent aspect of the present invention.

The targets 3a-d may be arranged to pivot from the position shown in Fig. 3a, through the position shown in Fig. 3b to the position shown in Fig. 3c. The angle between the longitudinal axis of the parallel targets to the direction of motion of the substrate is preferably less than 45°. The smaller the angle the lower the effect on throughput of the sputtering apparatus. In the embodiment shown in Fig. 3c, the movement of the targets 3a-d is a combination of a rotation and a translation. In general, the rotation of the targets may be an individual rotation, wherein each target is rotated around an own rotation axis, or, alternatively, the targets may be rotated as a group around a single rotation axis. In the case of rotation as a group, a set of targets forming a rectangle will remain a rectangle, while in the case of individual rotation a rectangular form is changed to the form of a parallelogram, while the distance between the targets is also changed.

Providing a means to pivot the targets increases the complexity of the sputtering chamber and therefore has certain disadvantages compared to other embodiments of the present invention. Hence static targets can be preferred. To alter the width of substrate that is to be coated, more or less targets can be used. Hence the present invention includes N targets being provided in parallel as shown in Fig. 3a and b, wherein the targets are oriented in such a manner with respect to the movement direction of the substrate that an end of at least one target lies above the moving substrate. To avoid variations of the target flux on the substrate when at least one end of a target lies above the substrate, the racetrack angles is preferably 45° or greater and other parameters of the target assembly are set to provide a wider area of uniform target flux on the substrate. To change the width of sputtering the number of contiguous targets that are energised can be changed, e.g. not N but N-m.

The number and length of the parallel targets in accordance with embodiments of the present invention that need to be used to obtain a certain throughput can be related to the number of targets that are used when the targets are placed perpendicular to the direction of movement of the substrate as shown in Fig. 4.

Figs. 5 illustrates schematically the relative distribution of sputtered flux from two targets on the substrate in accordance with embodiments of the present invention. The configuration was as follows: Diameter of target D: 150 mm, Target-substrate spacing H: 75 mm, Spacing of target axis S: 220 mm, Race track angle X: 48°, Tilting of race-track Y: 20°. The results are shown graphically in Fig. 5 and the Peak-to-Peak variation, within length of 220 mm in movement direction, was: <1%, Yield within 400 mm window: 85%. The zone of uniform sputtered flux is taken the same as the axis spacing of the magnetrons. The sputtered flux distribution has the approximate shape of a "pork pie hat". There is a significant area of constant central flux the coating produced is more uniform in content and thickness. With such an arrangement and a constant partial pressure of reactive gas a deposited film on the substrate that has a substantially uniform stoichiometry and thickness. The Gaussian-like flux distribution of the second sputtering erosion zone is added to the first. This alignment of the two distributions yields a relatively broad and uniform flux distribution at the substrate. A further embodiment of the present invention is shown in Fig. 6 with 4 targets, the configuration was: Diameter of target D: 150mm, Target-substrate spacing H: was for two targets 149 mm and for two targets 121mm, Race track angle X: 54°, Spacing of target axis S: 190 mm, Tilting of race-track Y of the outer magnetrons: 6°. The results are shown graphically in Fig. 6 and are: Peak-to-Peak variation: 0.2%, Yield within 400 mm window: about 50% of all sputtered material. Power for all targets was 100%.

Figs. 7 to 9 shows target flux results for the same set of 5 magnetrons in an arrangement as in Fig. 3a whereby not all of the targets are powered up in all of the embodiments. The target flux is a combination of the various target fluxes from the magnetrons. The configuration for Fig. 7 is: substrate width 900mm, racetrack angle for all targets X: 39°,

tilting of the outer magnetrons: 0°, target diameter D: 150 mm, target-target spacing S: 190 mm, number of dual magnetron sets: 3, power level per dual magnetron set: inner (first): 101%, (second) middle 100% and (third) outer 128% , target-substrate spacing H: 150 mm. The results are shown schematically in Fig. 7 and are: Peak-to-Peak variation 3.4%. In this case only three sets of dual magnetrons are driven and hence the sputtered substrate width is small. The configuration for Fig. 8 is: substrate width 1250mm, racetrack angle for all targets X: 39°, tilting of the outer magnetrons: 0°, target diameter D: 150 mm, target-target spacing S: 190 mm, number of dual magnetron sets: 4, power level per dual magnetron set: inner (first): 99%, second 100%, third 100% and outer (fourth) 128%, target-substrate spacing H: 150 mm. The results are shown schematically in Fig. 8 and are: Peak-to-Peak variation 3.7%. In this case four of the magnetron sets are driven to sputter a wider substrate.

The configuration for Fig. 9 is: substrate width 1600mm, racetrack angle for all targets X: 39°, tilting of the outer magnetrons: 0°, target diameter D: 150 mm, target-target spacing S: 190 mm, number of dual magnetron sets: 5, power level per dual magnetron set: inner (first): 99%, second 100%, third 100%, fourth 100%, and (fifth) outer: 128%, target-substrate spacing H: 150 mm. The results are shown schematically in Fig. 9 and are: Peak-to-Peak variation 3.7%. In this case all five of the magnetron sets are driven.

As indicated above the outer magnetrons may be run at a higher power level than the other magnetrons in order to compensate for edge effects. To allow for easy and fast adjustment on changing substrate width, tilting of the outer magnet bars has been excluded in the above embodiments. Magnet bars with a fixed angle between the race track (racetrack angle X) of 39° were used but in accordance with the present invention larger values can be used, e.g. 45-90 or 50-80°. Larger race track angles allow to reduce target substrate spacing without affecting uniformity. Fig. 10 shows an optimisation of parameters according to an embodiment of the present invention for 5 dual magnetron sets (8 targets) and a larger racetrack angle. The configuration for Fig. 10 is: substrate width 1600mm, racetrack angle for all targets X: 54°, tilting of the outer magnetrons: 6°, target diameter D: 150 mm, target-target spacing S: 190 mm, number of dual magnetron sets: 5, power level per magnetron:

all 100%, target-substrate spacing H: 149 mm for all magnetrons except for the outer set at 121 mm. The results are shown schematically in Fig. 10 and are: Peak-to-Peak variation 0.4%. The embodiment described above uses a racetrack angle of above 45° and the example shows that a higher sputter rate can be obtained with better uniformity.

Fig. 12 shows an optimisation of parameters for one dual magnetron set (2 targets) according to embodiments of the present invention. All the points on the graphs relate to a uniform sputter zone perpendicular to target axis depending on the criteria:

- Uniform zone (+/- 1%) from 100 mm to 450 mm with one dual configuration
- Constraints on spacings (between targets and substrate) and angles
- Simulating change in target diameter and target-substrate spacing over target lifetime
- Sensitivity analysis on each variable.

As can be seen from Fig. 12 good results are obtained for uniformity when the racetrack angle X is in the range 45 to 90°, especially 50 to 80°.

In the embodiments described above excess sputtering beyond the substrate width was limited. For narrower substrates; the outer magnetrons are not in use or a smaller amount of magnetron sets need to be installed. For the widest substrates; all magnetrons are in use or a larger amount of magnetron sets need to be installed. One set-up fits all substrate widths. While using narrow substrates, it may be advantages to keep low power sputtering on the outer magnetrons to avoid excessive redeposit and contamination. Turning of the magnet bars is an option for the present invention. Easy and fast adjustment capabilities can be achieved by changing the power levels on change of substrate width. Local uniformity may be tuned by adjusting the power level (besides using the gas distribution; longitudinal or perpendicular).

For embodiments of the present invention when using a large number of magnetrons the configuration of the inner magnetrons (i.e. not the outer magnetron at each side) was:

- Similar power level

- No tilting of the magnet bar
- Similar race track angle
- Similar spacing between the targets
- Similar spacing to the substrate

The configuration of the outer magnetrons (i.e. 1 target at each side) was:

- May have slightly higher power level
- May have inward tilting of the magnet bar
- May have slightly smaller spacing to the substrate

Advantages of embodiments of the present invention include that the reactive gas partial pressure can be reduced to react fully at the location where the largest flux of target particles is arriving. Further, at this working point; the target is less poisoned and may realize a higher sputter rate for the same power level. Also with reference to the homogeneous layer composition, the compound formation is much more homogeneous over the formed layer thickness. Thus higher performing TCO's may be realized with the same target materials. Hence, the compound formation is not different depending on the local flux of target particles arriving at the substrate. Also it is less necessary for TCO's to make a trade-off between conductivity and layer transmittance.

The sputtering process is preferably also stabilized and controlled by fixing parameters such as pumping speed, plasma (i.e. sputtering) gas flow, reactive gas flow, power supply voltage, substrate speed all of which are simply held constant during deposition.

Fig. 11 shows a schematic representation of how a vacuum sputtering apparatus can be implemented in accordance with a further embodiment of the present invention. A moving substrate 5 is arranged to pass through a chamber 2 having one or two hinged lids 11, 12, e.g. hinged at edges 9 and 10. Lids 11, 12 fold together into a cabinet 13 to form a vacuum sputtering chamber. Within each lid 11, 12 a plurality of rotating cylindrical targets 3a-d and/or 3e to h are arranged. Certain parts of the sputtering system will not be described in detail such as vacuum feedthroughs, rotating mechanisms, target support means, plasma and/or argon gas feeds and control systems, power supply and control therefore, and the

cooling system (normally using water) and control therefore.

Although the present invention has been described in considerable detail with reference to certain preferred versions thereof, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions.

Claims

1. A vacuum sputtering arrangement for coating a substrate, said substrate being transportable through said arrangement in a transport direction, said substrate having a substrate width perpendicular to said transport direction, said arrangement comprising at least one pair of sputtering targets, each rotatable about a longitudinal axis of the target, all targets being arranged side by side with their longitudinal axes parallel, said longitudinal axes being substantially parallel to said substrate transport direction, wherein said substrate is transportable through said arrangement and positionable in said arrangement such that the distance from the target surface to said substrate is smaller than said substrate width.

2. The arrangement of claim 1 wherein the substrate width is the maximum substrate width transportable through said arrangement.

3. The arrangement of claim 1 or claim 2 wherein said targets have magnet bars for generating elongated race tracks on the surface of said targets during use.

4. The arrangement of any previous claim, wherein the targets are adapted to pivot around an axis perpendicular to the longitudinal axes of the targets and to the substrate.

5. The arrangement of any previous claim, wherein reference planes, each of which passes through the centre of a tubular target and also through the centre of an erosion zone of the same target subtend an angle at the centre of that tubular target greater than 45°, e.g. between 45 and 90°.

6. The arrangement of claim 5, wherein the angle subtended at the target longitudinal axis is between 50° and 80°.

7. The arrangement of any previous claim, wherein and the target flux of each of the targets combines to create an area of substantially uniform flux at the substrate.

8. The arrangement of any previous claim, wherein the target to substrate distance is between 50 and 500mm.

9. The arrangement of any previous claim wherein the spacing of the axes of the at least first and second targets is between 40 and 500mm.

10. The arrangement of any previous claim wherein the diameter of the cylindrical targets is between 30 and 500mm.

11. The arrangement of any of the previous claim wherein each individual target does not span the complete width of the substrate.

12. The arrangement of any previous claim wherein the target flux at the substrate is substantially constant with a variability of less than 5%, preferably with a variability of less than 2% more preferably with a variability of less than 1% over a distance of at least 75% of the spacing distance between the axes of the outer magnetrons and more preferably over a distance similar (+/- 20%) to the spacing distance between the axes of the outer magnetrons.

13. The arrangement of any previous claim further comprising means for:
pivoting the target set through small angles, and/or
changing the spacing between targets, and/or
reducing or increasing the number of targets in the set which are used for sputtering, and/or
tilting one or more of the magnet bars, and/or
adjusting the spacing between adjacent targets, and/or
adjusting the spacing between each of the target axes to the substrate surface, and/or
adjusting the power level on any of the targets.

14. A method of vacuum sputtering for coating a substrate said method using at least one pair of rotatable sputtering targets, each having a longitudinal axis, all targets being arranged side by side with their longitudinal axes parallel, the method comprising:

transporting said substrate through a vacuum chamber in a transport direction, said substrate having a substrate width perpendicular to said transport direction, said longitudinal axes of the rotatable targets being positioned substantially parallel to said substrate transport direction, wherein the distance from the target surface to said substrate is set smaller than said substrate width.

15. The method of claim 14, wherein at least one individual target does not span the complete width of the substrate.

16. The method of claim 14 or claim 15 wherein the substrate width is the maximum substrate width transportable through the vacuum chamber.

17. The method of any one of claims 14 to 16 further comprising pivoting the target set through small angles.

18. The method of any one of claims 14 to 17 further comprising changing the spacing between targets.

19. The method of any one of claims 14 to 18 further comprising reducing or increasing the number of targets in the set which are used for sputtering.

20. The method of any one of claims 14 to 19 further comprising tilting one or more of the magnet bars.

21. The method of any one of claims 14 to 20 further comprising adjusting the spacing between adjacent targets.

22. The method of any one of claims 14 to 21 further comprising adjusting the spacing between each of the target axes to the substrate surface.

23. The method of any one of claims 14 to 22 further comprising adjusting the power level on any of the targets.

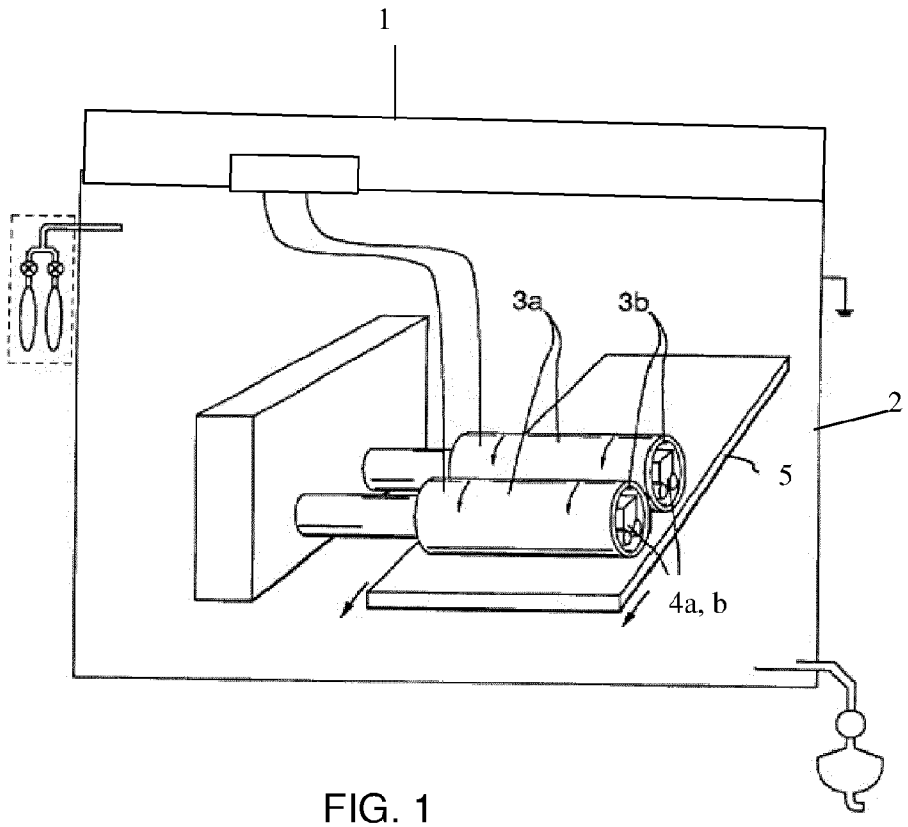
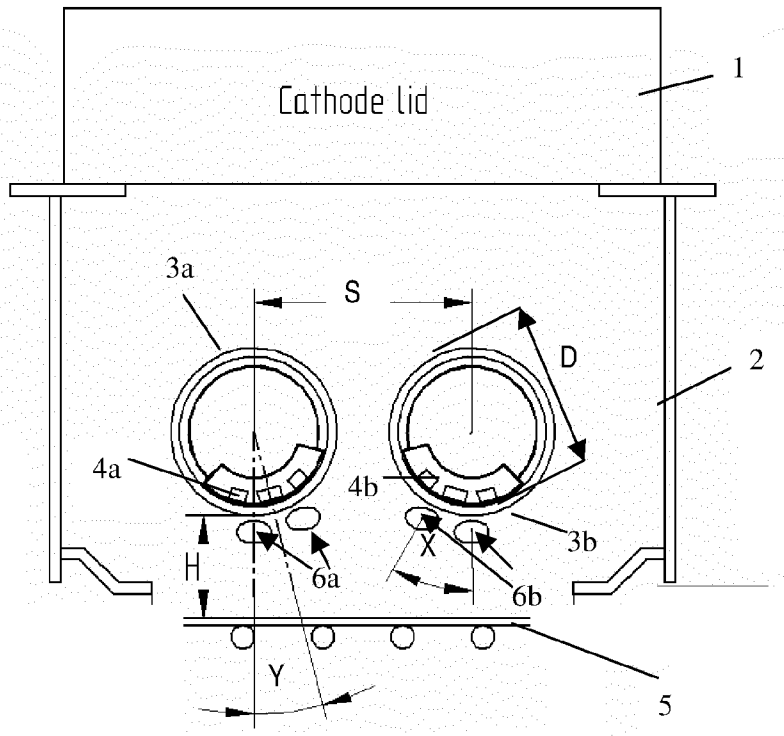


FIG. 1

FIG. 2



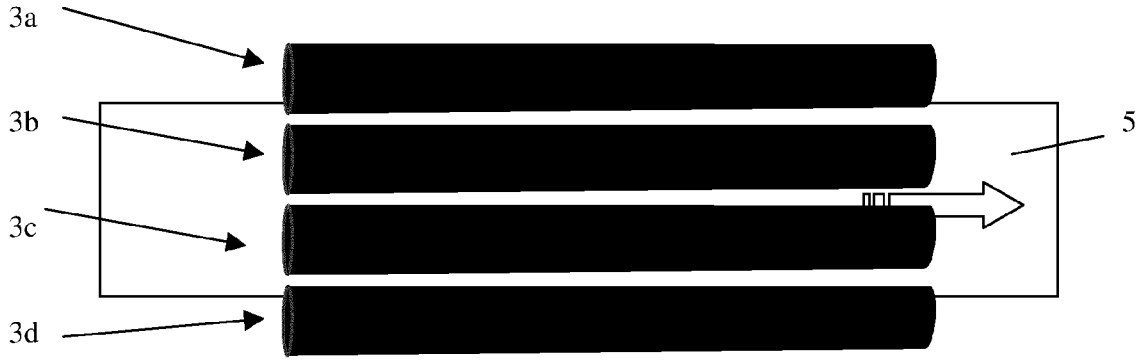


FIG. 3a

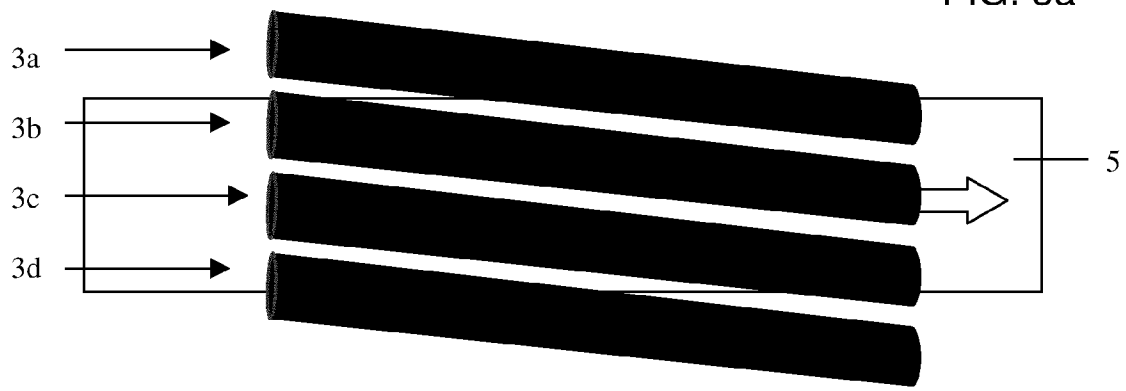


FIG. 3B

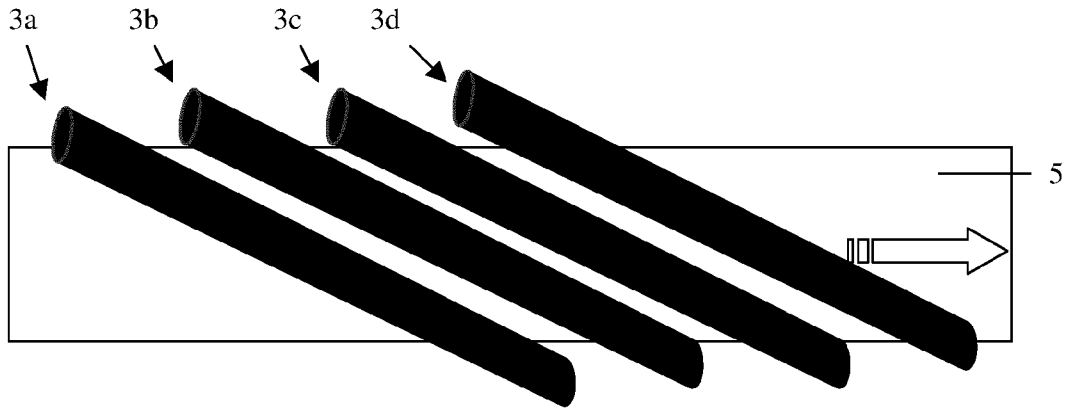


FIG. 3C

FIG. 3

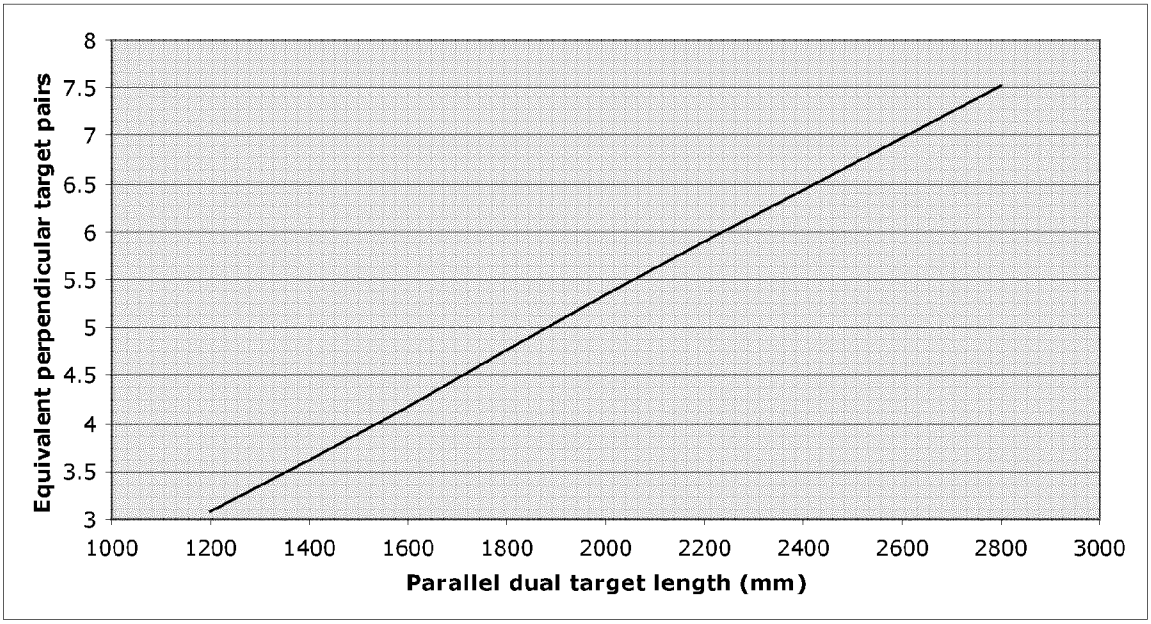

Equivalent perpendicular target pairs
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
Parallel dual target length (mm)

FIG. 4

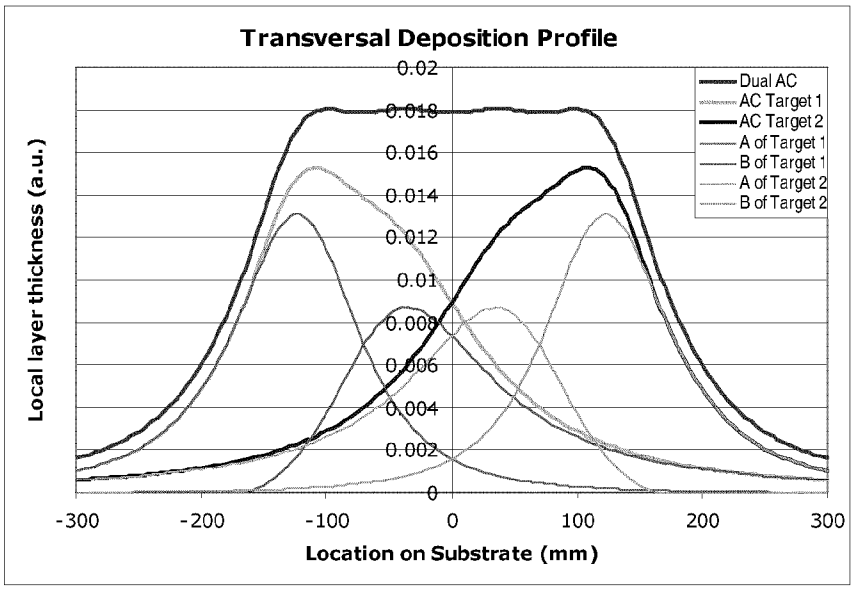

Transversal Deposition Profile
Local layer thickness (a.u.)
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-300
-200
-100
0
100
200
300
Location on Substrate (mm)
Dual AC
AC Target 1
AC Target 2
A of Target 1
B of Target 1
A of Target 2
B of Target 2

FIG. 5

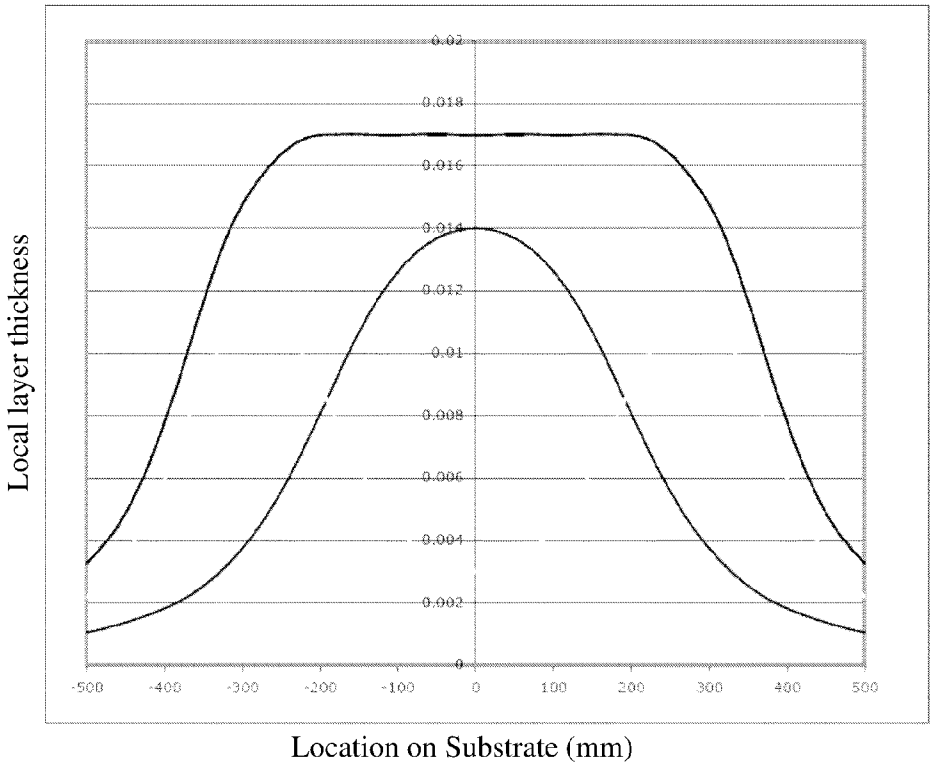

Local layer thickness
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-500
-400
-300
-200
-100
0
100
200
300
400
500
Location on Substrate (mm)

FIG. 6

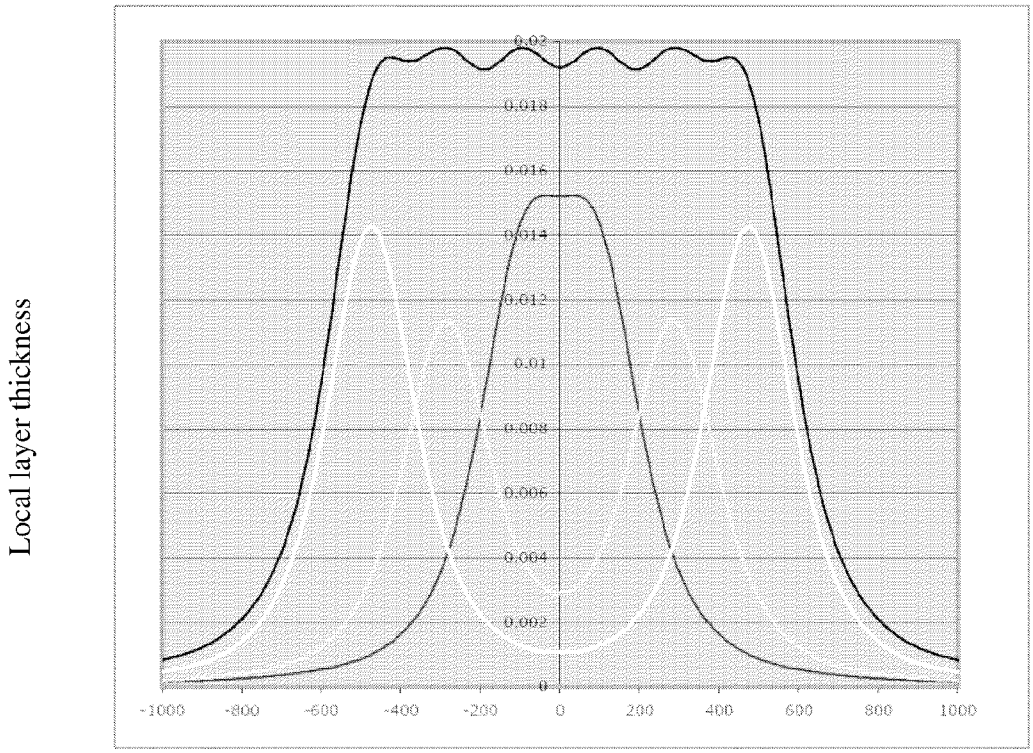

Local layer thickness
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0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
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-800
-600
-400
-200
0
200
400
600
800
1000
Location on Substrate (mm)

FIG. 7

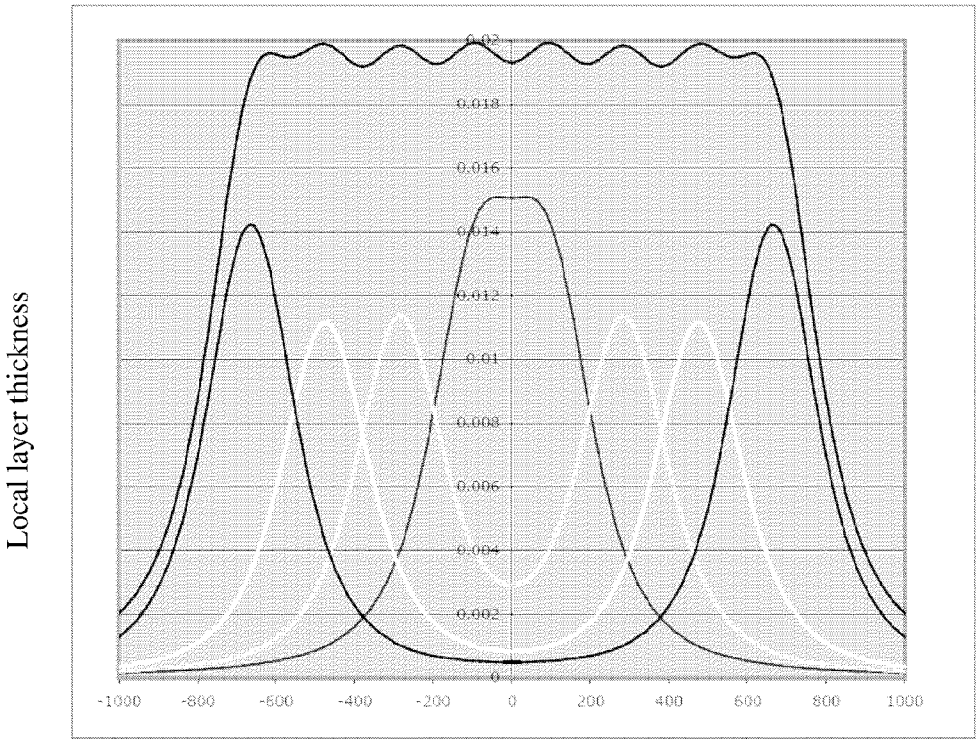

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0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
Location on Substrate (mm)

FIG. 8

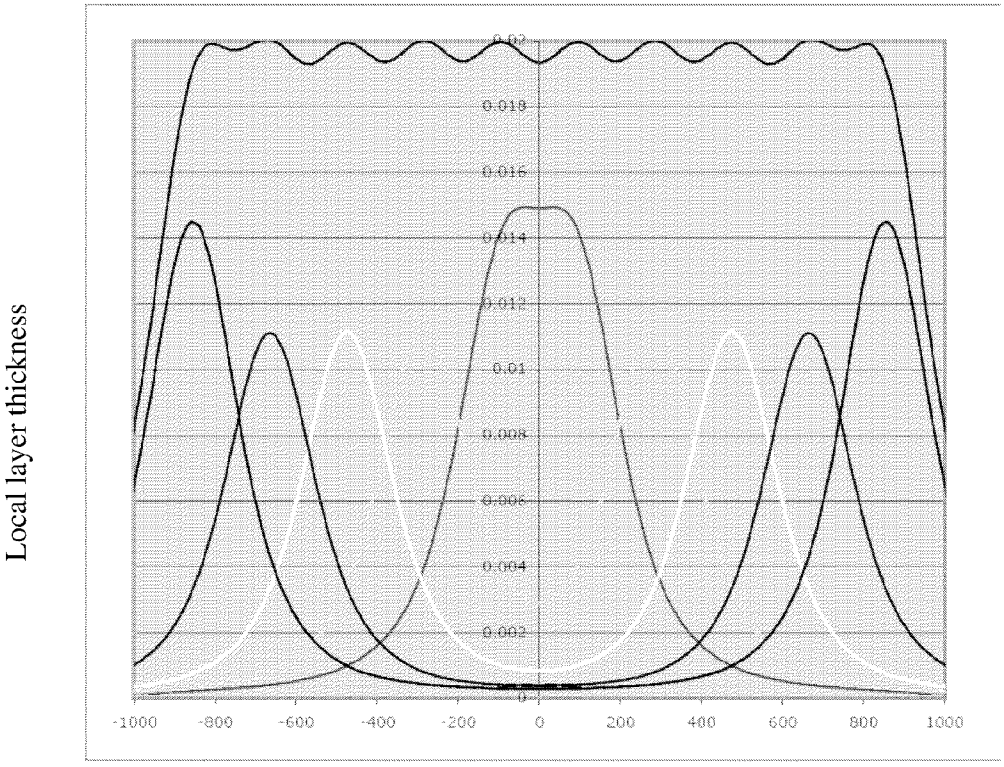

Local layer thickness
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0.012
0.01
0.008
0.006
0.004
0.002
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
Location on Substrate (mm)

FIG. 9

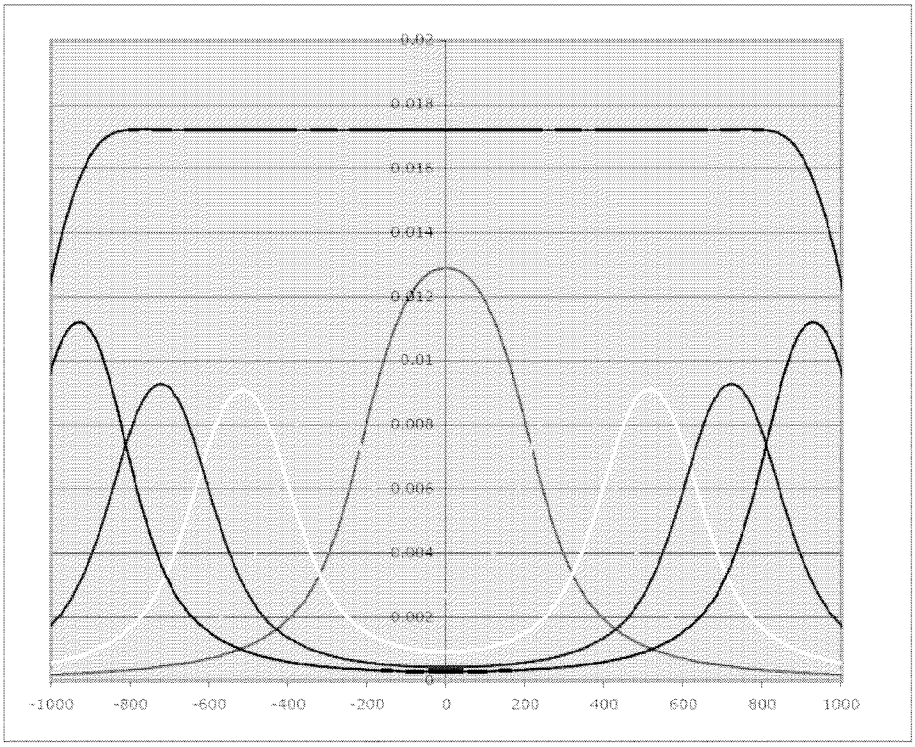

Local layer thickness
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0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
Location on Substrate (mm)

FIG. 10

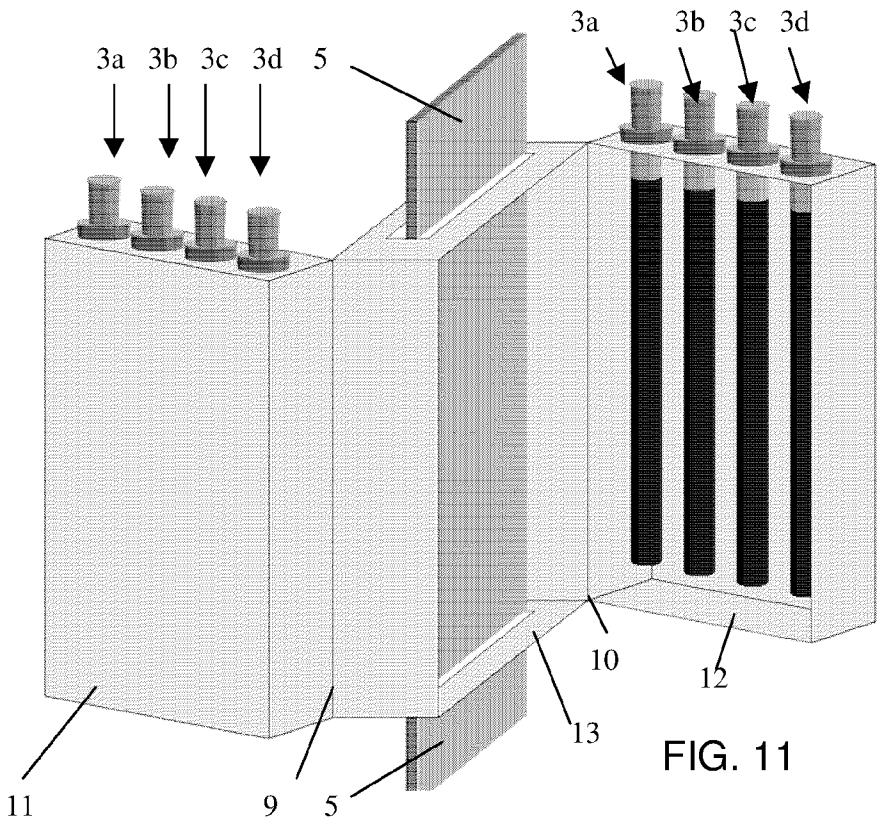

3a
3b
3c
3d
5
3a
3b
3c
3d
10
12
13
11
9
5

FIG. 11

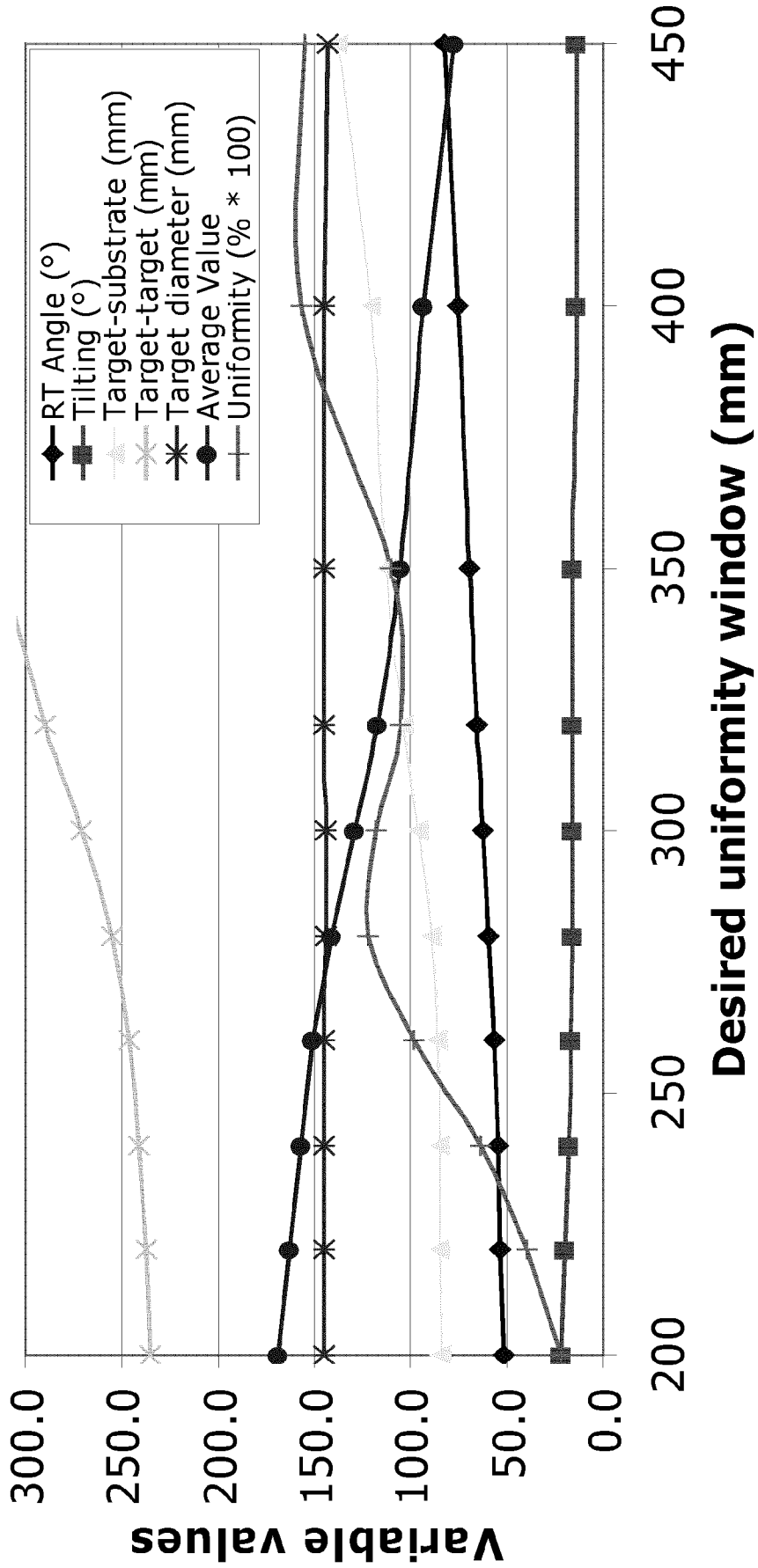

RT Angle (°)
Tilting (°)
Target-substrate (mm)
Target-target (mm)
Target diameter (mm)
Average Value
Uniformity (% * 100)
Variable values
300.0
250.0
200.0
150.0
100.0
50.0
0.0
200
250
300
350
400
450
Desired uniformity window (mm)

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/070359

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 practical, search terms used)
EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 814 195 A (LEHAN JOHN [US] ET AL) 29 September 1998 (1998-09-29) column 3, line 14 - column 5, line 7 figure 3	1-23
A	US 6 083 359 A (COCKERILL RECH & DEV [BE]; VANDEN BRANDE PIERRE [BE]; WEYMEERSCH ALAIN) 4 July 2000 (2000-07-04) cited in the application column 1, line 23 - line 29 figures 2-4 column 3, line 5 - column 5, line 55	1-23
A	US 2001/009221 A1 (ANZAKI TOSHIAKI [JP] ET AL) 26 July 2001 (2001-07-26) paragraph [0054] - paragraph [0061] paragraph [0091] - paragraph [0093] figures 9, 11, 12	1-23

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

"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
12 April 2012	18/04/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Hochstrasser, M

1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/070359

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 6 136537 A (ISHIKAWAJIMA HARIMA HEAVY IND) 17 May 1994 (1994-05-17) abstract figure 2 -----	1-23

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2011/070359

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