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(71) Applicant: **Applied Materials Switzerland Sàrl**
1033 Cheseaux-sur-Lausanne (CH)

(72) Inventors:
- **Zominy, Claude**
  74350 Copponex (CH)
- **Valcourt, Floris**
  74570 Evires (CH)

(74) Representative: **Zimmermann & Partner Patentanwälte mbB**
Postfach 330 920
80069 München (DE)

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(54) Wire monitoring system

(57) The present disclosure provides a wire monitoring system (100) for a wire saw device. The wire monitoring system (100) includes a sensor arrangement configured to detect a relative distance (24) between at least two wire portions (22) of a wire of the wire saw device.

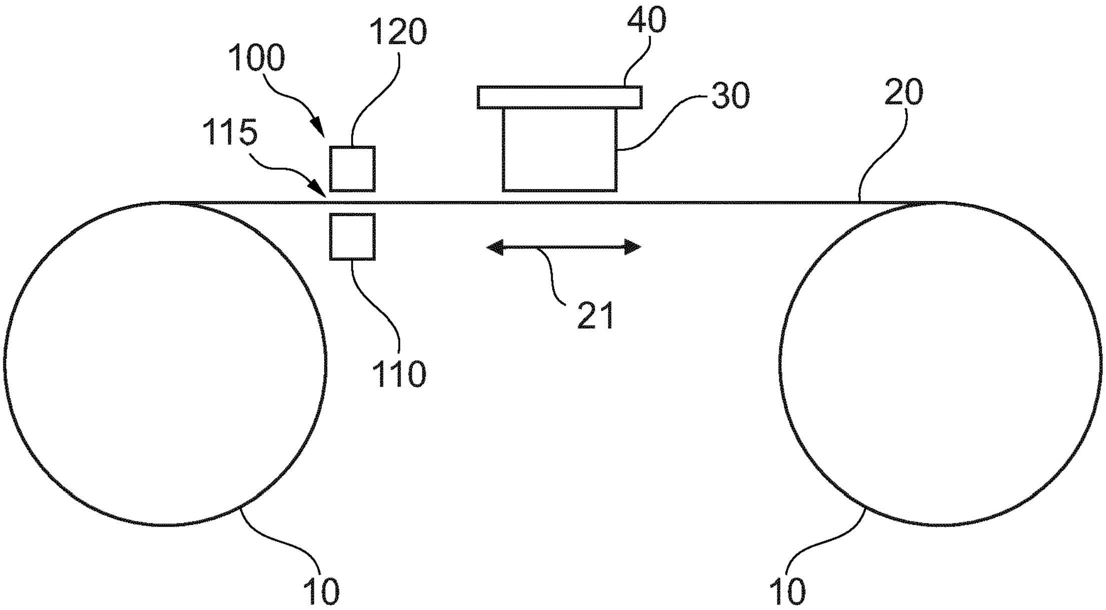

Fig. 3

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Description

TECHNICAL FIELD

[0001] Embodiments described herein relate to a wire monitoring system for a wire saw device, a wire saw device and a method for monitoring a wire in a wire saw device. The wire saw devices of the present embodiments are particularly adapted for cutting or sawing hard materials such as blocks of silicon or quartz, e.g., for cutting silicon wafers, silicon ingots or the like.

BACKGROUND

[0002] Wire saw devices are used to cut workpieces or ingots of hard materials, e.g., silicon. Workpieces or ingots are cut or wafered using wire saw devices for cropping, squaring, or slicing. In such wire saw devices a wire is fed from a spool and is guided and tensioned by wire guides. Different types of wire may be used in wire saw devices. As an example, a diamond wire can be used in combination with a coolant. During cutting, the wire is moved rapidly along its length, and the workpiece or ingot is moved comparatively slowly by a workpiece supply plate or table in a cutting direction substantially perpendicular to the direction of the wire. The wire can be wound around the wire guides, such as rollers, to form a wire web. These wire guides can be grooved, wherein the wire is maintained inside the so-called wire guide grooves by wire tension. The grooves can be equally spaced in order to slice workpieces or ingots to obtain wafers with a regular and equal thickness.

[0003] An issue with wire saw devices is the occurrence of wire jumps and the so-called "thin-thick effect" where some wafers are thin and some others are thick compared to nominal thickness values. Wire jumps can be detected by a visual inspection of the wire web or by touching the web with a finger and sensing the homogeneity of the web. The trend towards using wires with smaller diameters makes this manual detection method difficult.

[0004] In view of the foregoing, there is a need to monitor the wire web in order to achieve higher efficiency of the wire saw device. There is in particular a need to monitor the wire web in order to detect the occurrence of a thin-thick effect and/or wire jumps.

SUMMARY

[0005] In light of the above, a wire monitoring system for a wire saw device, a wire saw device and a method for monitoring a wire in a wire saw device are provided. Further aspects, advantages, and features of the embodiments of the present disclosure are apparent from the dependent claims, the description and the accompanying drawings.

[0006] According to one aspect, a wire monitoring system for a wire saw device is provided. The wire monitoring system includes a sensor arrangement configured to detect a relative distance between at least two wire portions of a wire web of the semiconductor wire saw device.

[0007] According to another aspect, a wire monitoring system for a wire saw device is provided. The wire monitoring system includes a sensor arrangement configured to detect a relative distance between at least two wire portions of a wire web of the wire saw device, the sensor arrangement comprising at least one illumination device and at least one linear sensor array, wherein the at least one illumination device is positioned at a first distance from the at least one linear sensor array to define a wire reception region between the at least one illumination device and the linear sensor array, and wherein the wire reception region is configured for guiding the wire web through the wire reception region.

[0008] According to still another aspect, a wire saw device is provided. The wire saw device includes a wire monitoring system as described herein. The wire monitoring system includes a sensor arrangement configured to detect a relative distance between at least two wire portions of a wire web of the wire saw device.

[0009] According to another aspect, a method for monitoring a wire in a wire saw device is provided. The method includes detecting a relative distance between at least two wire portions of a wire web of the wire saw device.

[0010] Embodiments are also directed at apparatuses for carrying out the disclosed methods and include apparatus parts for performing each described method step. These method steps may be performed by way of hardware components, a computer programmed by appropriate software, by any combination of the two or in any other manner. Furthermore, embodiments according to the present disclosure are also directed at methods for operating the described devices and systems. It includes method steps for carrying out every function of the devices and systems.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the manner in which the above recited features of embodiments of the disclosure can be understood in detail, a more particular description of the embodiments, buefly summarized above, may be had by reference to embodiments described herein. The accompanying drawings relate to embodiments of the present disclosure and are described in the following:

FIG. 1 shows a schematic front view of a wire web on a wire guide cylinder and a wire monitoring system according to embodiments described herein;

FIG. 2 shows a schematic front view of a wire web with a wire jump on a wire guide cylinder and a wire monitoring system according to embodiments described herein;

FIG. 3 shows a schematic cross-sectional side view of a wire saw device having a wire monitoring system according to embodiments described herein;

FIG. 4 shows a schematic cross-sectional view of a wire monitoring system according to embodiments described herein;

FIG. 5 shows graphs illustrating the functioning of the wire monitoring system according to embodiments described herein;

FIG. 6 shows a schematic cross-sectional side view of a wire saw device having a wire monitoring system according to further embodiments described herein;

FIG. 7 shows a schematic view of a sensor arrangement of a sensor device of the wire monitoring system according to embodiments described herein; and

FIG. 8 shows a flow chart of a method for monitoring a wire in a wire saw device according to embodiments described herein.

DETAILED DESCRIPTION

[0012] Reference will now be made in detail to the various embodiments of the present disclosure, one or more examples of which are illustrated in the figures. Within the following description of the drawings, the same reference numbers refer to same components. Generally, only the differences with respect to individual embodiments are described. Each example is provided by way of explanation of embodiments of the disclosure and is not meant as a limitation of the embodiments. 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.

[0013] At the beginning of a cut, when the workpiece touches the wire web and the wires enter the workpiece, the wires forming the web can move erratically (e.g., slide) due to the pressure exerted by the workpiece and the contact with the workpiece. Such erratic movements during the entry may result in the wires forming the web being not equally spaced, leading to wafers with various thicknesses. Further, coolant can be poured on the wire web to assist the cutting process, e.g., by carrying abrasive particles or cooling. For example in the case of diamond wire wafering, a capillarity of the coolant may cause wires to stick together, in particular before the entry or during the cut. This leads to wafers with various thicknesses and is also known as "thin-thick effect" where some wafers are thin and some others are thick compared to nominal thickness values.

[0014] An issue with wire saw devices is the occurrence of wire jumps. The term "wire jump" may refer to a situation where a wire that is supposed to be arranged and guided in a first wire guide groove jumps into a second or adjacent wire guide groove, so that two wires are present or overlaying in the second wire guide groove. Wire jumps can occur when a new wire spool is installed and the wire should be positioned correctly in the wire guide grooves. Wire jumps may also happen during operation of the wire saw device, such as during a cutting process, and in particular at the beginning of a cutting process when the workpiece touches the wire web and the wires enter the workpiece. A wire jump can, for example, also happen when a wire guide groove is contaminated by kerf and/or when a wire guiding system is running unstably and/or is vibrating. If a wire jump occurs, the overlaying wires can break wafers, and a production yield is decreased and/or a cut quality or wafer quality is reduced. Wire jumps can be detected by a visual inspection of the wire web or by touching the web with a finger and sensing the homogeneity of the web. The trend towards using wires with smaller diameters makes this manual detection method difficult.

[0015] The wire saw device may be understood as a wire saw device, wherein a wire of considerable length ("wire length"), such as at least 1 km, particularly at least 10 km, or even at least 100 km, is wound around wire guides, such as wire guide cylinders, and forms a web or wire web. The term "wire length" refers to the overall length of the wire and not only to the wire that is, at a given time, used for sawing. The wire is moved along its length. During sawing, the piece to be sawed may be moved through the wire web. The moving speed of the piece to be sawed determines the cutting speed and/or the effective cutting area that can be sawed within a given amount of time. As used herein, the term "cutting" is used synonymously with "slicing", "wafering" or "sawing".

[0016] FIG. 1 shows a schematic front view of a wire web 20 on a wire guide cylinder 10 and a wire monitoring system 100 according to embodiments described herein. FIG. 2 shows a schematic front view of the wire web 20 with a wire jump on the wire guide cylinder 10 and the wire monitoring system 100 according to embodiments described herein.

[0017] A wire can be spirally wound about one or more wire guides, such as wire guide cylinder 10, and may form a layer of parallel wire portions 22, e.g., between two or more wire guide cylinders 10. This layer may be referred to as the wire web 20. The wire can be a diamond wire. The wire guide cylinder 10 can have wire guide grooves (not shown) provided in a circumferential surface of the wire guide cylinder 10. The wire guide grooves can be adapted for guiding a wire portion of the parallel wire portions 22. Two or more wire guide grooves can be arranged in parallel to arrange or guide the wire portions 22 in parallel. The number of parallel wire guide grooves can correspond to the number of parallel wire portions

22. For instance, the wire may be wound up in such a way that the resulting wire web 20 includes 100 parallel wire portions 22. A workpiece or ingot pushed through this web 20 of 100 wire portions 22 is sliced into 101 wafer pieces.

[0018] The wire monitoring system 100 is positioned adjacent to the wire web 20. According to some embodiments, which can be combined with other embodiments described herein, one wire monitoring system 100 is provided per wire guide cylinder 10. According to an aspect of the present disclosure, the wire monitoring system 100 includes a sensor arrangement configured to detect a relative distance between at least two wire portions 22 of the wire of the semiconductor wire saw device. An exemplary relative distance is indicated with reference numeral 24 in FIG. 1.

[0019] The wire monitoring system 100 of the present disclosure is configured to make a detection, and in particular an automatic detection, of wire jumps and/or the thin-thick effect by detecting the relative distance or space between the wire portions 22 forming the web, e.g., close to the wire guide cylinders 10. This detection can for instance be done after having built a new wire web and/or during a cutting process.

[0020] The term "relative distance" as used herein may refer to a distance or space between two wire portions 22, and may particularly refer to the distance or space between two adjacent wire portions 22. The relative distance can be the relative distance at a positon of the wire web 20 corresponding to a position of the wire monitoring system 100. In other words, the relative distance between the two wire portions 22 is measured at a positon of the wire web 20 where the wire monitoring system 100 is positioned. The relative distance can be the relative distance in a direction substantially perpendicular to a moving direction 21 of the wire or wire web 20. In some implementations, the relative distance can be the relative distance in a direction substantially parallel to a cylinder axis 12 of the wire guide cylinder 10.

[0021] The moving direction 21 of the wire (or wire web 20) substantially extends along a wire length. As an example, the moving direction 21 of the wire or wire web 20 can be substantially perpendicular to the cylinder axis 12 of the wire guide cylinder 10. A workpiece or ingot is moved in a cutting direction substantially perpendicular to the moving direction 21 of the wire. A moving speed of the wire or wire web 20 along the moving direction 21 can be at least 5 m/s or even 10 m/s. As an example, the moving speed 21 of the wire or wire web 20 during operation is between 10 m/s and 15 m/s whereas the moving speed may be smaller during start and stop. Also, in the event of a back and forth movement of the wire or wire web 20, the wire or wire web 20 is decelerated from time to time in order to accelerate it in the opposite direction.

[0022] According to some embodiments, the relative distance between two wire portions 22, and in particular between two adjacent wire portions, should correspond to a nominal or preset value (e.g., within given tolerances). This means that the wire portions 22 should be equidistant or evenly distributed over a width of the wire web 20, and in particular over the whole width of the wire web 20, to cut wafers with a regular and equal thickness. In other words, the wire web 20 should be homogenous. The width of the wire web 20 may be the width in a direction substantially perpendicular to the moving direction 21 of the wire or wire web 20. Once the relative distance between at least two wire portions 22 differs from the nominal or preset value, wafers or slices are cut with various thicknesses. Such differing relative distances can result from the thin-thick effect and/or from wire jumps.

[0023] The wire monitoring system 100 according to the present disclosure is configured to detect the relative distances, wherein it can be determined whether the detected relative distances comply with the nominal or preset value (e.g., within a tolerance range). If at least one of the detected relative distances does not comply with the nominal or set value (e.g., the detected relative distance is out of the tolerance range), the wire monitoring system 100 can determine a thin-thick effect and/or a wire jump. The tolerance range may be defined as the nominal or preset value plus/minus 2, 5, 10, 15 or 20 percent of the nominal or preset value, or plus/minus a fixed value. The tolerance range can in particular be defined as the nominal or preset value plus/minus about 50 percent of the nominal or preset value.

[0024] In some implementations, when the wire monitoring system 100 determines that at least one of the detected relative distances does not comply with the nominal or set value, the wire monitoring system 100 can prevent the start of a cutting process because the wire web 20 is not homogeneous from a wire distribution point of view. In another example, the wire monitoring system 100 can generate an alarm and allow the operator to abort a cutting process, e.g., if a wire web distribution is deteriorating. In some implementations, the wire monitoring system 100 according to the present disclosure can be configured to estimate or determine a number of wire jumps and the amount of "thick-thin" and to generate an alarm if a given quality threshold is reached. If the threshold is not reached, the cutting process could continue.

[0025] FIG. 2 shows an example, where two wires are close together, e.g., due to the thin-thick effect and/or a wire jump. In the example illustrated, a first wire portion 25 has moved from its preset position 27, e.g., within a wire guide groove, to a position close to a second wire portion 23. As an example, when the first wire portion 25 has moved into the wire guide groove of the second wire portion 23, a wire jump has occurred. When the first wire portion 25 and the second wire portion 23 stick together, e.g., due to coolant provided to the wire web 20, this is the so-called thin-thick effect.

[0026] According to some embodiments, which can be combined with other embodiments described herein, the wire monitoring system 100 is configured to determine whether at least one of the detected relative distances does not comply with (or correspond to) the nominal or set value, e.g., within given tolerances. In the example of FIG. 2, a first relative distance 26 between the first wire portion 25 and the second wire portion 23 does not comply with the nominal or set value. In particular, the first relative distance 26 between the first wire portion 25 and the second wire portion 23 is smaller than the nominal or set value, e.g., denoted with reference numeral 24. Further, also a second relative distance 28 between the first wire portion 25 and a third wire portion 29 does not comply with the nominal or set value. In particular, the second relative distance 28 between the first wire portion 25 and the third wire portion 29 is bigger than the nominal or set value. By detecting at least one of the first relative distance 26 and second relative distance 28, the wire monitoring system 100 can determine that a wire jump and/or the thin-thick effect has occurred.

[0027] FIG. 3 shows a schematic cross-sectional side view of a wire saw device having a wire monitoring system 100 according to embodiments described herein.

[0028] The wire saw device is exemplarily shown as including the wire or wire web 20, which is guided by two wire guide cylinders 10 (also called "wire guides" or "pulleys") along the wire length. The wire length may extend substantially parallel to the moving direction 21 of the wire or wire web 20. Wire portions (e.g., wire portions 22 in FIGs. 1 and 2) of the wire may be arranged in parallel, forming the wire web 20. The wire provided forms the wire web 20 in particular in the cutting area of the wire saw device. The term "wire web" can relate to the wire web 20 formed by the wire or wire portions between two wire guide cylinders 10. It should be understood that the wire may form more than one wire web 20 which is defined as an area in which a sawing process is performed. According to some embodiments described herein, the wire may form multiple wire webs, for instance two wire webs both adapted for cutting a workpiece or ingot 30. The workpiece or ingot 30 is mounted to a table 40 configured to move against the wire or wire web 20 in order to cut the ingot 30.

[0029] In some embodiments, the wire guide cylinders 10 are adapted to rotate in order to transport the wire or wire web 20. The wire guide cylinders 10 can be configured to rotate at a circumferential speed (i.e., the speed at the outer circumference) of at least 5 m/s or even 10 m/s. As an example, the wire saw device is operated between 10 m/s and 25 m/s during operation whereas the speed may be smaller during start and stop. Also, in the event of a back and forth movement of the wire or wire web 20, the wire or wire web 20 is decelerated from time to time in order to accelerate it in the opposite direction.

[0030] During cutting, the wire or wire web 20 moves substantially along the wire length which can be a longitudinal length of the wire. The term "substantially" shall particularly embrace vibrations or the like. The movement can be relatively rapid in comparison to the perpendicular motion of the workpiece or ingot 30, such as a semiconductor ingot. According to some embodiments, the movement of the wire or wire web 20 is only unidirectional, i.e., always in the forward direction. According to other embodiments, the movement of the wire or wire web 20 may include a movement in the backward direction, in particular, the movement can be a back-and-forth movement of the wire or wire web 20 in which the movement direction of the wire or wire web 20 is amended repeatedly. In operation, the wire or wire web 20 is brought into contact with the ingot 30 to cut the ingot 30, for instance, into a plurality of wafers.

[0031] According to some implementations, the wire or wires forming the wire web 20 can be moved relative to the ingot 30, the ingot 30 can be moved relative to the wire or wire web 20, or the wire or wire web 20 and the ingot 30 can both be moved relative to each other.

[0032] According to some embodiments, which can be combined with other embodiments described herein, the sensor arrangement 100 includes at least one illumination device 110 and at least one sensor device 120. In some implementations, the at least one illumination device 110 is positioned at a first distance from the at least one sensor device 120 to define a wire reception region 115 between the at least one illumination device 110 and the at least one sensor device 120. In other words, the wire web 20 is running through the wire reception region 115, or, the wire web 20 is sandwiched between the at least one illumination device 110 and the at least one sensor device 120. In some implementations, the first distance is at least 2 mm, or the first distance is in the range of 2 to 20 mm, and specifically in the range of 5 to 10 mm.

[0033] According to some embodiments, which can be combined with other embodiments described herein, at least one of the at least one illumination device 110 and at least one sensor device 120 extends substantially perpendicular to the moving direction 21 of the wire or wire web 20. In some embodiments, the at least one illumination device 110 and at least one sensor device 120 can extend substantially parallel to the cylinder axis 12 of the wire guide cylinder 10.

[0034] In some implementations, at least one of the at least one illumination device 110 and the at least one sensor device 120 extends substantially perpendicular to the moving direction 21 of the wire or wire web 20 along at least a part of the width of the wire web 20, or even over the full width of the wire web 20. By the extension over the full width of the wire web 20, the complete wire web 20 can be monitored. The term "width of the wire web" can be understood as the width of the wire web 20 in the direction substantially perpendicular to the moving direction 21 of the wire or wire web 20.

[0035] FIG. 4 shows a schematic cross-sectional view of a wire monitoring system 100 according to embodiments described herein. FIG. 5 shows graphs illustrating the functioning of the wire monitoring system 100 according to embodiments described herein.

[0036] In some implementations, the at least one illumination device 110 is positioned at the first distance from the at least one sensor device 120 to define the wire reception region 115 between the at least one illumination device 110 and the at least one sensor device 120. The wire reception region 115 can be configured for guiding the wire or wire web 29, and in particular the wire portions 22, through the wire reception region 115. In some implementations, the first distance is at least 2 mm, or the first distance is in the range of 2 to 20 mm, and specifically in the range of 5 to 10 mm. As shown in FIG. 4, the first distance can be the sum of a first wire distance 130 and a second wire distance 132. The first wire distance 130 can be a distance between the at least one sensor device 120 and the wire or wire portions 22. The second wire distance 132 can be a distance between the at least one illumination device 110 and the wire or wire portions 22. The first wire distance 130 and the second wire distance 132 can be measured from a center of the wire portions 22. The first wire distance 130 and the second wire distance 132 can be distances in a direction substantially perpendicular to a length direction or the moving direction of the wire or wire web 20. As an example, the first wire distance 130 can be in the range of 1 to 5 mm, and specifically in the range of 2 to 3 mm. The second wire distance 132 can be in the range of 2 to 15 mm, and specifically in the range of 3 to 7 mm.

[0037] According to some embodiments, which can be combined with other embodiments described herein, the at least one sensor device 120 is configured to detect light emitted from the at least one illumination device 110. In some implementations, the at least one sensor device 120 is configured to detect or sense a light intensity (or an amount of light) and/or a spatial light distribution of the light emitted from the at least one illumination device 110. As an example, the at least one sensor device 120 includes one or more photosensors. The wire or wire portions 22 disposed between the at least one illumination device 110 and the at least one sensor device 120 affect or influence the light intensity and/or the spatial light distribution received or sensed at the at least one sensor device 120.

[0038] In some embodiments, the at least one sensor device 120 is configured to detect or sense the light intensity and/or the spatial light distribution, e.g., in a direction substantially perpendicular to the moving direction of the wire or wire web. According to some embodiments, which can be combined with other embodiments described herein, the at least one sensor device 120 includes at least one position sensor, such as at least one linear sensor array. As an example, the positon sensor, and in particular the linear sensor array, can be configured to detect or sense the spatial light distribution in the direction substantially perpendicular to the moving direction of the wire or wire web. The at least one sensor device 120, and in particular the linear sensor array, can have a resolution of about 400 to 800 DPI (dots per inch).

[0039] According to some embodiments, which can be combined with other embodiments described herein, the at least one linear sensor array extends substantially perpendicular to the moving direction of the wire or wire web. In some embodiments, the at least one linear sensor array can extend substantially parallel to the cylinder axis of the wire guide cylinder. As an example, the at least one linear sensor array can include two or more sensors, such as photosensors or photodetectors, that are arranged along a line. In other words, the linear sensor array can be one-dimensionally.

[0040] In some implementations, the wire monitoring system 100 is configured to determine the relative distance between the at least two wire portions based on the light intensity and/or light distribution at the at least one sensor device 120. As an example, the light intensity and/or the spatial light distribution at the at least one sensor device 120 can correspond to the positions of the wire portions within the wire reception region 115. In other words, the light intensity and/or the spatial light distribution can correspond to the relative distances between the wire portions or may at least include information about the relative distances between the wire portions. An example is illustrated in FIGs. 4 and 5.

[0041] The at least one illumination device 110 emits light or light beams towards the at least one sensor device 120. In some implementations, the at least one illumination device 110 can include one or more light sources such as LEDs (light emitting diodes). The one or more light sources can be arranged in a line. The line of light sources may extend in a direction substantially perpendicular to the moving direction of the wire or wire web. As shown in the example of FIG. 4, the at least one illumination device 110 is arranged below the wire web. In the example of FIG. 4, the wire portions 22 are sandwiched between the at least one illumination device 110 and the at least one sensor device 120. Due to the presence of the wire portions 22, light shadows 28 are created at the at least one sensor device 120. The light shadows 28 can correspond to positons of respective wire portions 22. The light shadows 28 affect or influence the light intensity and/or the spatial light distribution sensed or detected at the at least one sensor device 120.

[0042] FIGs. 5(a)-(c) illustrate an example of a method to obtain the relative distances between wire portions based on the light intensity and/or the spatial light distribution received or sensed at the at least one sensor device. FIG. 5(a) illustrates a distribution of a plurality of sensors of the at least one sensor device 120, such as the linear sensor array, in terms of a clock distribution (1 clock per dot). The x-direction may indicate the clock (that may correspond to a direction in which the plurality of sensors are arranged, such as the direction perpendicular to the moving direction of the wire or wire web). FIG. 5(b) shows an analog signal corresponding to a light power sensed by the linear sensor array. As can be seen, the light power exhibits a minimum at positions where a wire portion is present (indicated with reference numeral

210), and has a maximum where no wire portion is present (indicated with reference numerals 200 and 220). FIG. 5(c) shows a digital signal obtained by converting the analog signal of FIG. 5(b). The digital signal is "1" where no wire portion is present, and is "0" where a wire portion is present.

[0043] The width of the signal portions having "0" corresponds to a width or diameter of the wire or wire portions (indicated with reference numeral 240). The width may be defined in the x-direction, e.g., in the direction substantially perpendicular to the moving direction of the wire or wire web. The width of the signal portions having "1" corresponds to a width of a gap or space between two wire portions (indicated with reference numeral 230). In particular, the width of the gap or space corresponds to the relative distance between two (adjacent) wire portions.

[0044] As an example, when the width of the wire and the width of the gap always have the same value, e.g., during a cutting process, the cutting process works within normal parameters and everything is ok. When one or more of the widths, such as the widths of the wire portions and/or the widths of the gaps, are smaller or larger than e.g. nominal or preset values, an anomaly can be determined. An anomaly can be a wire jump and/or a thin-thick effect. In some implementations, the wire monitoring system is configured to count or determine a number of widths of the wire portions and/or widths of the gaps that do not comply with the nominal or preset value (e.g., within the tolerance range). In other words, the wire monitoring system is configured to count or determine a number of anomalies. Based on the number counted, the wire monitoring system can determine or estimate a web degradation. As an example, when the web degradation reaches a quality threshold value, the cutting process can be stopped.

[0045] In view of the above, at least one sensor device and at least one illumination device (light emitter) are positioned above and below the wire web, respectively, very close but not touching the web. The resolution of the at least one sensor device can be in the range of 200 to 800 DPI. A bit stream can be generated from the at least one sensor device. This bit stream is made of dark points (where the wire portions are, preventing the light from reaching the at least one sensor device) and white points (the space between two wire portions). The number of dark points and the number of white points are directly proportional to the wire diameter and the space between two adjacent sensors, such as photosensors or photodetectors, of the at least one sensor device. This sequence of dark-white points will repeat as per the number of wires forming the wire web and a length of the at least one sensor device. The detection level of light can be adjusted, e.g., by an analogic threshold, to define the amount of light corresponding to a wire (dark points) and the amount of light for space between wires portions (white points).

[0046] FIG. 6 shows a schematic cross-sectional side view of a wire saw device having a wire monitoring system 100 according to further embodiments described herein.

[0047] The wire saw device includes the wire monitoring system 100. The wire monitoring system 100 includes a sensor arrangement configured to detect a relative distance between at least two wire portions of a wire of the wire saw device. The wire monitoring system 100 can be configured according to the embodiments described herein.

[0048] According to some embodiments, which can be combined with other embodiments described herein, the wire saw device includes a debris collection device 50. The debris collection device 50 may also be referred to as a "drawer". As an example, the debris collection device 50 can be located between the wire guide cylinders 10, and can for example be used to collect the debris that may fall during the cutting process.

[0049] In some implementations, the at least one illumination device 110 or the at least one sensor device 120 is mounted on the debris collection device 50, and in particular on a flange of the debris collection device 50. As an example, the at least one illumination device 110 is mounted on the debris collection device 50, in particular on the flange, and the at least one sensor device 120 is installed on a nozzle bar of the wire saw device, or vice versa. The nozzle bar can be configured to provide or spray coolant to the wire web 20. As an example, the nozzle bar can be positioned such that the wire web 20 is arranged between the nozzle bar and the debris collection device 50.

[0050] According to some embodiments described herein, the at least one sensor device 120 can be integrated in the flange of the debris collection device 50 that is located between the wire guides, e.g., wire guide cylinders 10, and is used to collect the debris that may fall during the cutting process, resulting in a "smart" drawer and not only a metallic container.

[0051] When the ingot 30 and the wire (such as the wire web 20) are pressed relatively against each other, the resulting force exerted by the ingot 30 on the wire or wire web 20 causes the wire or wire web 20 to become bowed. The orientation of the wire bow coincides with the cutting direction, and can be substantially perpendicular to the moving direction 21 of the wire or wire web 20. A bow height can be defined as a difference or distance along the cutting direction between a bowed state and an unbowed state of the wire or wire web 20. When the wire bow increases too much, it may lead to a breakage of the wire.

[0052] According to some embodiments, which can be combined with other embodiments described herein, the sensor arrangement further includes a bow detector 140 configured to detect the bow of the wire. As an example, the wire monitoring system 100 can be configured to trigger a reaction in order to avoid a breakage of the wire before the wire bow becomes too large. Such a reaction could be, for instance, the reduction of the speed of the ingot 30 against the wire and/or an increase in the wire speed. Further reactions could encompass an amendment in the amount of provided slurry/coolant or the slurry/coolant composition etc.

[0053] In some implementations, the wire saw device is a semiconductor wire saw device or a sapphire wire saw device. The present disclosure is not limited to semiconductor wire saw devices though. Applications may include slurry wire saws, diamond wire sawing, e.g., in solar cell production using silicon, in Squarers to cut bricks from large ingots, and/or in the semiconductor industry. The wire saw device according to the embodiments described herein can also be used for cutting other materials such as metal.

[0054] FIG. 7 shows a schematic view of a sensor arrangement of a sensor device of the wire monitoring system according to embodiments described herein.

[0055] According to some embodiments, which can be combined with other embodiments described herein, the at least one sensor device includes one or more first sensors 122 and one or more second sensors 124. The one or more first sensor 122 and the one or more second sensors 124 can be offset to one another. As an example, the one or more first sensor 122 can be arranged along a first line 123, and the one or more second sensors 124 can be arranged along a second line 125. The first line 123 and the second line 125 can be offset to one another. In other words, there is a distance between the first line 123 and the second line 125. In some embodiments, the first line 123 and/or the second line 125 can extend substantially parallel to the cylinder axis of the wire guide cylinder. The first line 123 and/or the second line 125 can extend substantially perpendicular to the moving direction 21 of the wires or wire web 20.

[0056] In some implementations, the one or more first sensor 122 and the one or more second sensors 124 can be alternately arranged in a direction substantially perpendicular to the moving direction 21 of the wires or wire web 20. In some embodiments, the one or more first sensor 122 and the one or more second sensors 124 can be alternately offset. As an example, adjacent first sensors and second sensors can be offset to one another, as it is shown in the example of FIG. 7. By arranging the one or more first sensor 122 and the one or more second sensors 124 offset to one another, a distance between the sensors can be decreased, and e.g. the DPI can be increased.

[0057] FIG. 8 shows a flow chart of a method 300 for monitoring a wire in a wire saw device according to embodiments described herein.

[0058] According to an aspect of the present disclosure, the method 300 includes detecting a relative distance between at least two wire portions of a wire of the wire saw device (block 310).

[0059] The method 300 of the present disclosure can make a detection, and in particular an automatic detection, of wire jumps and/or the thin-thick effect by detecting the relative distance or space between the wire portions forming the web, e.g., close to the wire guides. As an example, the method determines whether the detected relative distances comply with the nominal or preset value (e.g., whether the detected relative distances are within the tolerance range). If at least one of the detected relative distances does not comply with the nominal or set value (e.g., the detected relative distance is out of the tolerance range), the method can determine the occurrence of the thin-thick effect and/or a wire jump.

[0060] According to some implementations, the method further includes determining that an anomaly exists if the detected relative distance is below a first threshold value (block 320). The anomaly may be a wire jump and/or a thin-thick effect. This may correspond to the situation shown in the example of FIG. 2 and the first relative distance (reference numeral 26), in which the first relative distance can be smaller than the first threshold value. The first threshold value can substantially correspond to the nominal or preset value including a preset tolerance. As an example, the first threshold value may correspond to the nominal or preset value minus 2, 5, 10, 15 or 20 percent of the nominal or preset value or minus a fixed value. The tolerance range can in particular be defined as the nominal or preset value minus about 50 percent of the nominal or preset value.

[0061] According to some implementations, the method further includes determining that an anomaly exists if the detected relative distance exceeds a second threshold value. The anomaly may be a wire jump and/or a thin-thick effect. This may correspond to the situation shown in the example of FIG. 2 and the second relative distance (reference numeral 28), in which the second relative distance is bigger than the second threshold value. The second threshold value can substantially correspond to the nominal or preset value including a preset tolerance. As an example, the second threshold value may correspond to the nominal or preset value plus 2, 5, 10, 15 or 20 percent of the nominal or preset value or plus a fixed value. The tolerance range can in particular be defined as the nominal or preset value plus about 50 percent of the nominal or preset value.

[0062] According to some embodiments, the method includes, if it is determined that the anomaly exists, at least one of preventing a start of an operation of the wire saw device, in particular a cutting process; stopping the operation of the wire saw device, in particular the cutting process; and generating an alarm.

[0063] As an example, when the method 300 determines that at least one of the detected relative distances does not comply with the nominal or preset value, the method 300 can prevent a start of a cutting process because the wire web is not homogeneous from a wire distribution point of view. In another example, the method 300 can generate an alarm and allow the operator to abort a cutting process, e.g., if the wire web distribution is deteriorating. In some implementations, the method 300 according to the present disclosure can estimate or determine a number of wire jumps and/or an amount of "thin-thick", and generate an alarm if a given quality threshold is reached. If the threshold is not reached, the cutting process could continue.

[0064] The method of the present disclosure may be implemented by the wire monitoring systems and the wire saw devices according to the embodiments described herein.

[0065] The present disclosure provides for detection, and in particular an automatic detection, of wire jumps and the thin-thick effect by detecting the relative distances or spaces between the wire portions forming the web, e.g., close to the wire guides. This detection can, for instance, be done after having built a new wire web or during a cutting process. The detection of wire jumps and the thin-thick effect allows a higher efficiency of the wire saw device.

[0066] While the foregoing is directed to embodiments described herein, other and further embodiments may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. A wire monitoring system for a wire saw device, comprising:

a sensor arrangement configured to detect a relative distance between at least two wire portions of a wire web of the semiconductor wire saw device.

2. The system of claim 1, wherein the sensor arrangement includes at least one illumination device and at least one sensor device.

3. The system of claim 2, wherein the at least one sensor device includes at least one linear sensor array.

4. The system of claim 2 or 3, wherein the at least one sensor device includes one or more photosensors.

5. The system of one of claims 2 to 4, wherein the at least one illumination device includes two or more light sources arranged in a line.

6. The system of one of claims 2 to 5, wherein the at least one illumination device is positioned at a first distance from the at least one sensor device to define a wire reception region between the at least one illumination device and the at least one sensor device.

7. The system of claim 6, wherein the first distance is at least 2 mm, or wherein the first distance is in the range of 2 to 20 mm, and specifically in the range of 5 to 10 mm.

8. The system of one of claims 2 to 7, wherein the wire monitoring system is configured to determine the relative distance based on at least one of a light intensity and a spatial light distribution sensed by the at least one sensor device.

9. A wire monitoring system for a wire saw device, comprising:

a sensor arrangement configured to detect a relative distance between at least two wire portions of a wire web of the wire saw device, the sensor arrangement comprising at least one illumination device and at least one linear sensor array, wherein the at least one illumination device is positioned at a first distance from the linear sensor array to define a wire reception region between the at least one illumination device and the at least one linear sensor array, and wherein the wire reception region is configured for guiding the wire web through the wire reception region.

10. A wire saw device, in particular a semiconductor wire saw device or a sapphire wire saw device, comprising a wire monitoring system according to any of claims 1 to 9.

11. The wire saw device of claim 10, further including a debris collection device, wherein the sensor arrangement includes the at least one illumination device and the at least one sensor device, and wherein the at least one illumination device or the at least one sensor device is mounted on the debris collection device.

12. The wire saw device of claim 11, wherein the at least one illumination device or the at least one sensor device is mounted on a flange of the debris collection device.

13. A method for monitoring a wire in a wire saw device, comprising:

detecting a relative distance between at least two wire portions of a wire web of the wire saw device.

14. The method of claim 13, further including:

determining that an anomaly exists if the detected relative distance is below a first threshold value; and/or
determining that the anomaly exists if the detected relative distance exceeds a second threshold value.

15. The method of claim 14, wherein, if it is determined that the anomaly exists, the method includes at least one of

preventing a start of an operation of the wire saw device, in particular a cutting process;
stopping the operation of the wire saw device, in particular the cutting process; and
generating an alarm.

Amended claims in accordance with Rule 137(2) EPC.

1. A wire monitoring system (100) for a wire saw device, comprising:

a sensor arrangement configured to detect a relative distance between at least two wire portions (22) of a wire web (20) of the semiconductor wire saw device, wherein the sensor arrangement includes at least one illumination device (110) and at least one sensor device (120), and wherein the wire monitoring system is configured to determine the relative distance (26, 28) based on at least one of a light intensity and a spatial light distribution sensed by the at least one sensor device (120).

2. The system (100) of claim 1, wherein the at least one sensor device (120) includes at least one linear sensor array.

3. The system (100) of claim 1 or 2, wherein the at least one sensor device (120) includes one or more photosensors.

4. The system (100) of one of claims 1 to 3, wherein the at least one illumination device (110) includes two or more light sources arranged in a line.

5. The system (100) of one of claims 1 to 4, wherein the at least one illumination device (110) is positioned at a first distance from the at least one sensor device (120) to define a wire reception region (115) between the at least one illumination device (110) and the at least one sensor device (120).

6. The system of claim 5, wherein the first distance is at least 2 mm, or wherein the first distance is in the range of 2 to 20 mm, and specifically in the range of 5 to 10 mm.

7. A wire monitoring system (100) for a wire saw device, comprising:

a sensor arrangement configured to detect a relative distance (26, 28) between at least two wire portions (22) of a wire web (20) of the wire saw device, the sensor arrangement comprising at least one illumination device (110) and at least one linear sensor array, wherein the wire monitoring system is configured to determine the relative distance (26, 28) based on at least one of a light intensity and a spatial light distribution sensed by the at least one sensor device,
wherein the at least one illumination device (110) is positioned at a first distance from the linear sensor array to define a wire reception region (115) between the at least one illumination device (110) and the at least one linear sensor array (120), and wherein the wire reception region (115) is configured for guiding the wire web (20) through the wire reception region (115).

8. A wire saw device, in particular a semiconductor wire saw device or a sapphire wire saw device, comprising a wire monitoring system (100) according to any of claims 1 to 7.

9. The wire saw device of claim 8, further including a debris collection device, wherein the sensor arrangement includes the at least one illumination device (50) and the at least one sensor device (120), and wherein the at least one illumination device (110) or the at least one sensor device (120) is mounted on the debris collection device (50).

10. The wire saw device of claim 9, wherein the at least one illumination device (110) or the at least one sensor device (120) is mounted on a flange of the debris collection device (50).

11. A method for monitoring a wire in a wire saw device, comprising:

detecting a relative distance between at least two wire portions of a wire web of the wire saw device, wherein detecting a relative distance between at least two wire portions of a wire web comprises determining the relative distance based on at least one of a light intensity and a spatial light distribution sensed by at least one sensor device.

12. The method (300) of claim 11, further including:

determining that an anomaly exists if the detected relative distance is below a first threshold value; and/or
determining that the anomaly exists if the detected relative distance exceeds a second threshold value.

13. The method (300) of claim 12, wherein, if it is determined that the anomaly exists, the method includes

at least one of
preventing a start of an operation of the wire saw device, in particular a cutting process;
stopping the operation of the wire saw device, in particular the cutting process; and
generating an alarm.

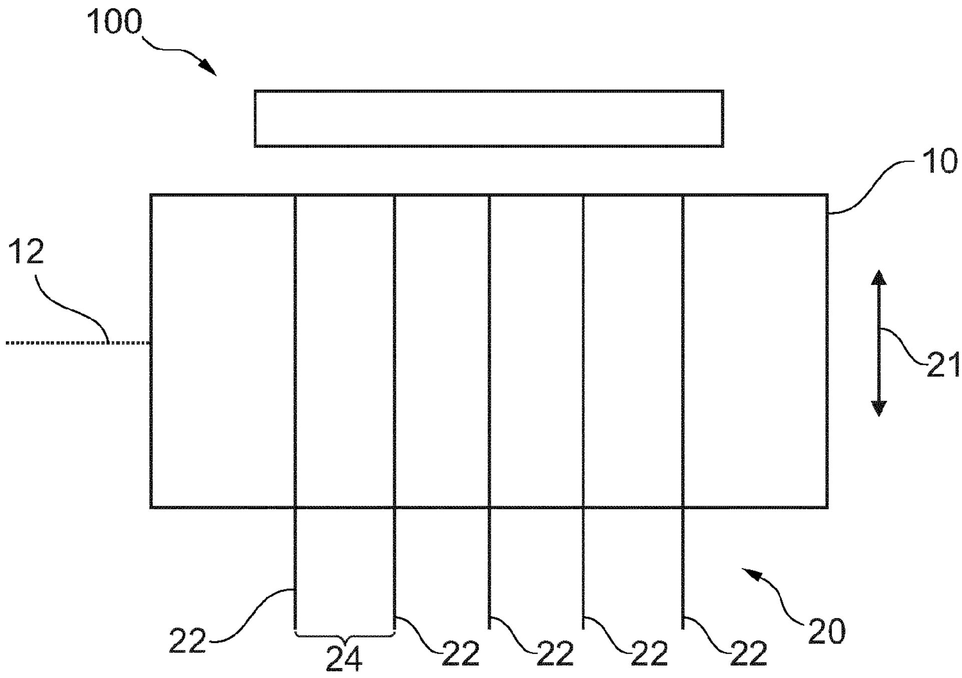
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Fig. 1

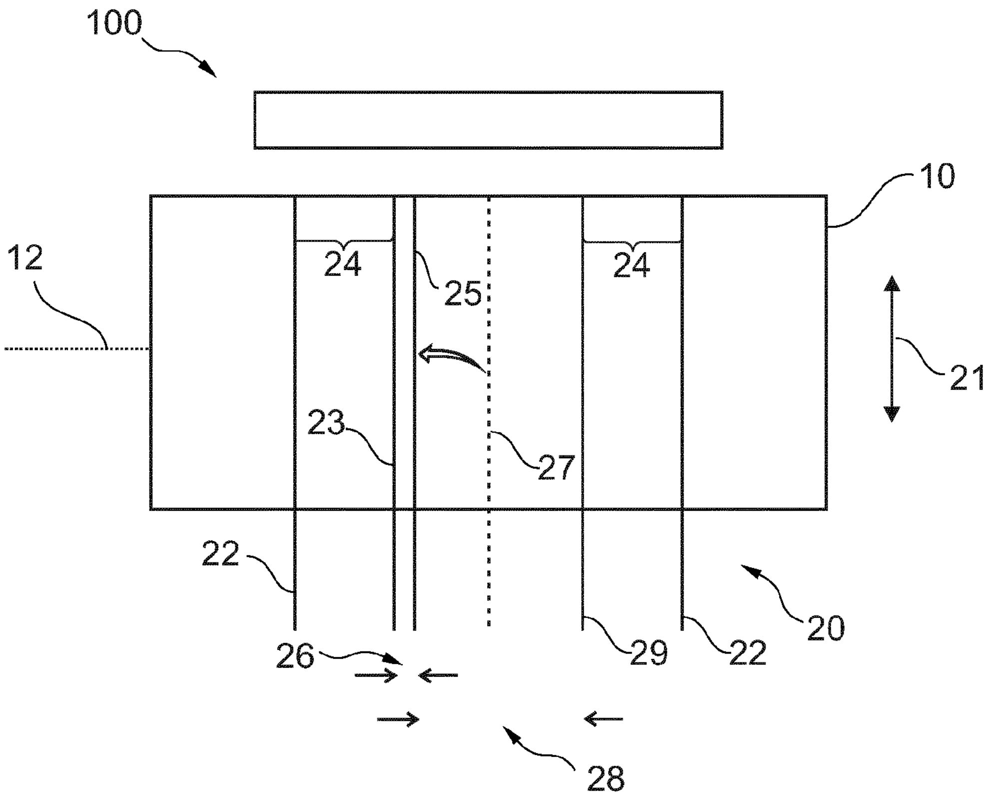
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Fig. 2

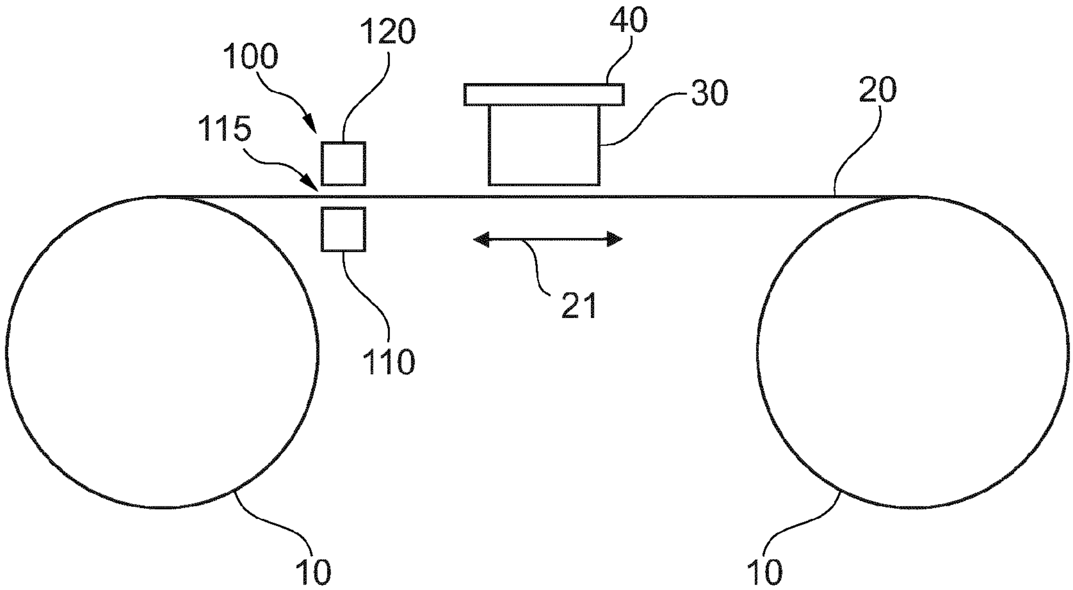
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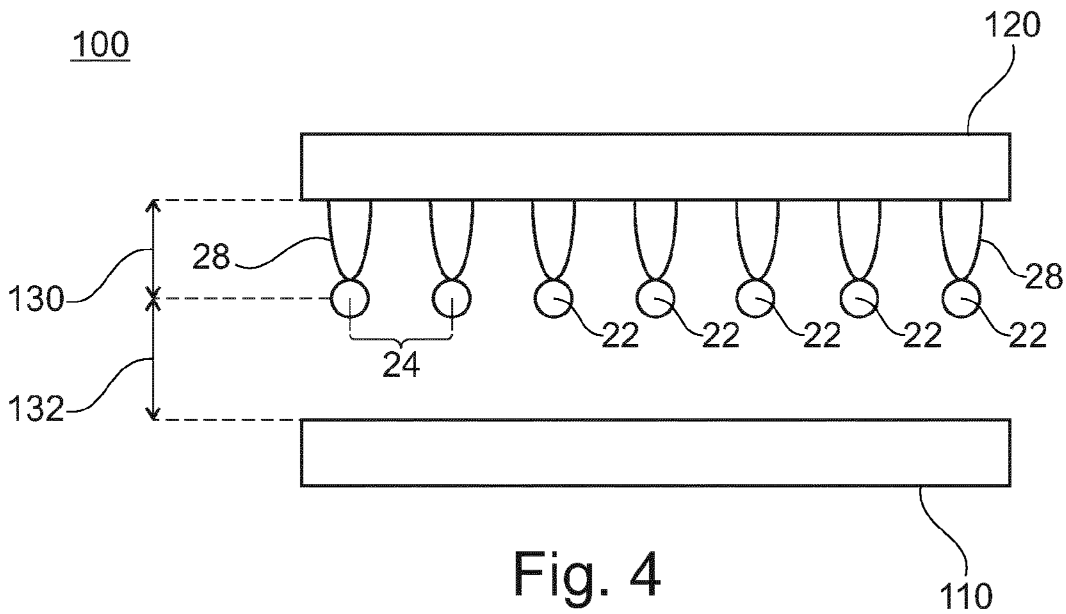
Fig. 3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110

Fig. 4

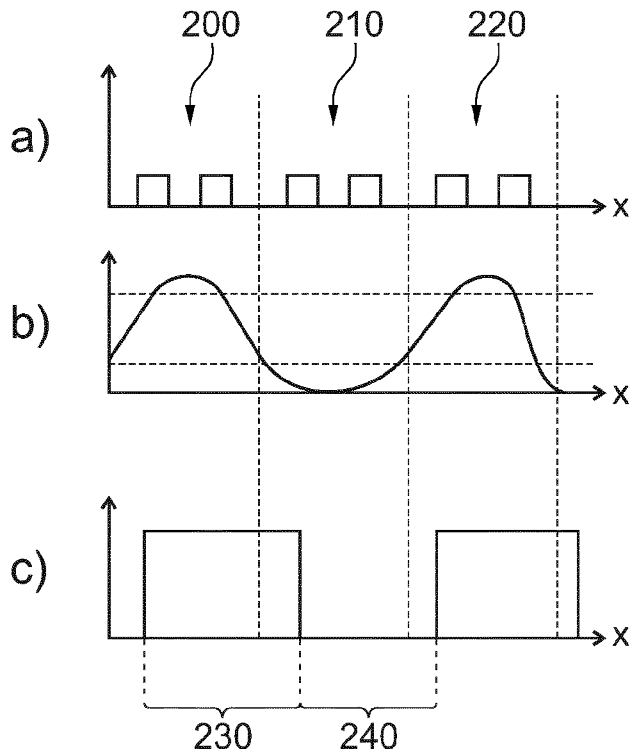

Fig. 5

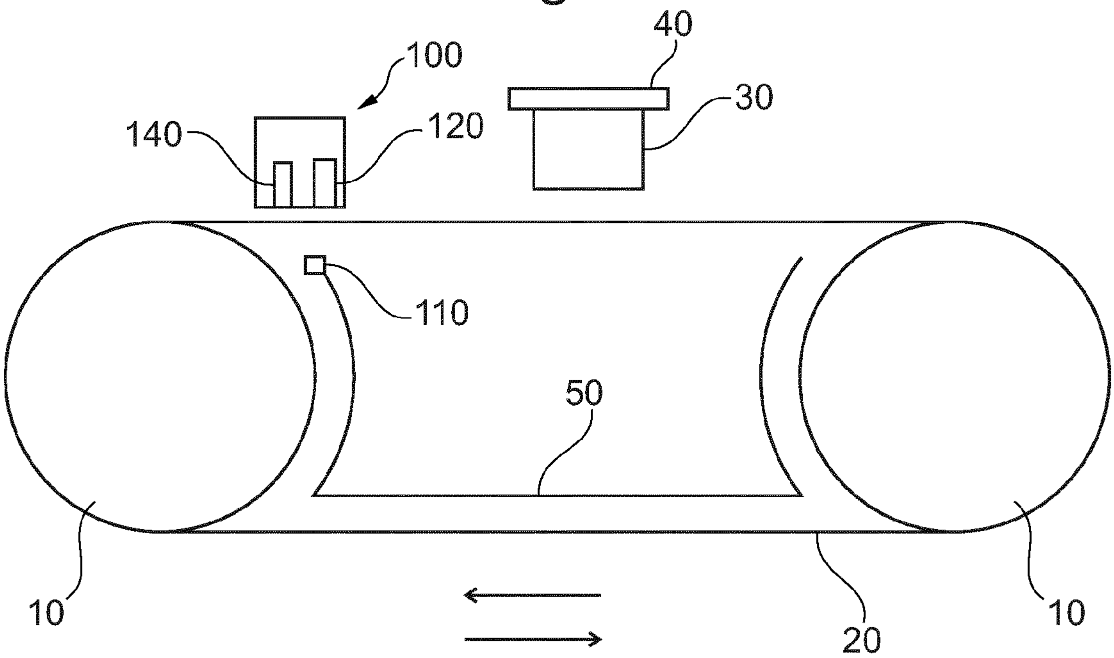

Fig. 6

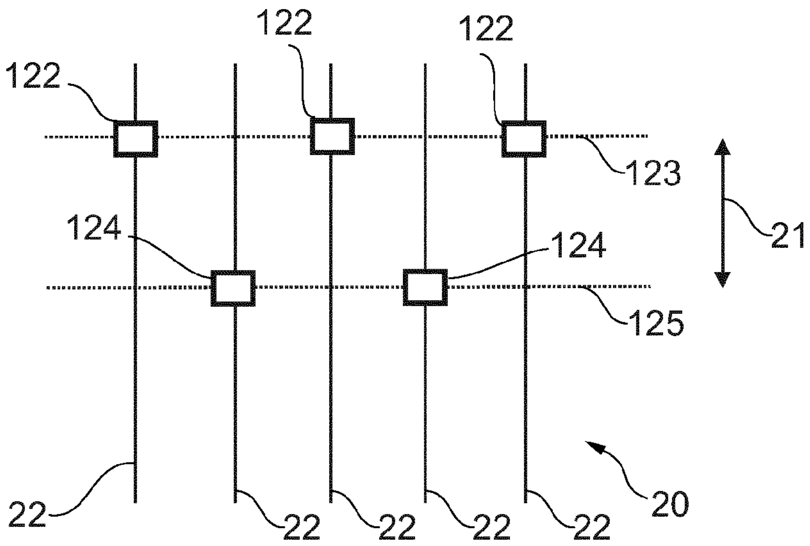

Fig. 7

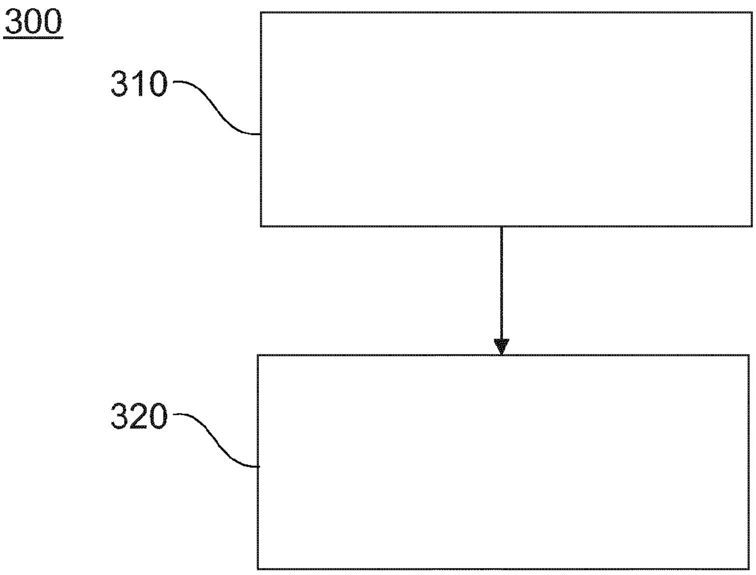

Fig. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 14 19 0926

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2014/167392 A1 (MEYER BURGER AG [CH]) 16 October 2014 (2014-10-16) * paragraphs [0038] - [0042], [0081], [0083], [0087]; figures *	1-15	INV. B28D5/04 B28D5/00
X	WO 2011/070386 A1 (APPLIED MATERIALS INC [US]; ROSSET JEAN-MARC [CH]; SCHULER REMY [CH]) 16 June 2011 (2011-06-16) * paragraphs [0044], [0045]; figures *	1-15	
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TECHNICAL FIELDS SEARCHED (IPC)

B28D

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	11 June 2015	Popma, Ronald

CATEGORY OF CITED DOCUMENTS

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11-06-2015

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