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(54) **Wire bow monitoring system for a wire saw**

(57) A wire bow monitoring system (10) for a semi-conductor wire saw device (100) is described. The wire bow monitoring system (10) includes a sensor arrangement (20) configured to be positioned adjacent to a wire

(30) of the wire saw device (100), wherein the sensor arrangement (20) is adapted to detect a bow of the wire (30), wherein the sensor arrangement (20) includes at least one of an inductive sensor (22), a capacitive sensor (22) and a contact sensor (22).

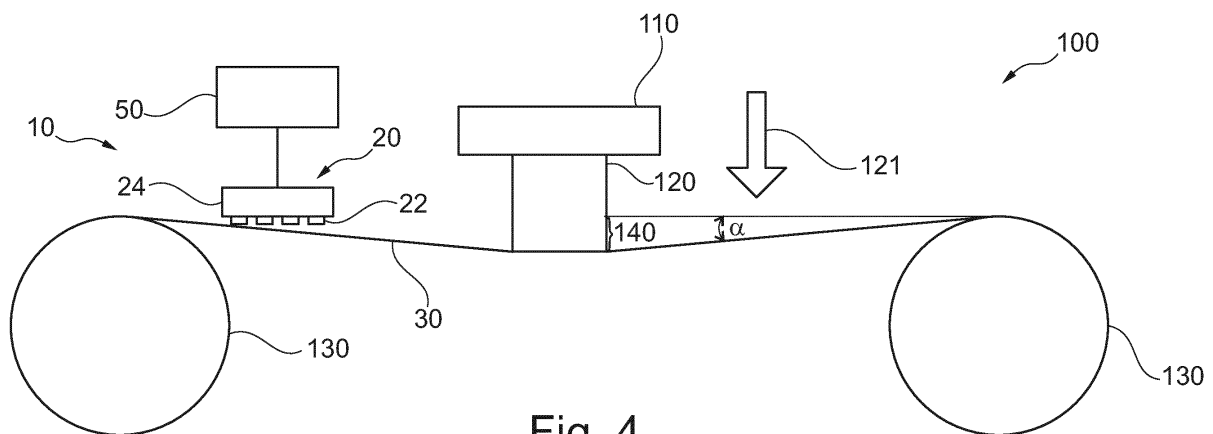


Fig. 4

Description**FIELD**

5 **[0001]** Embodiments of the present disclosure relate to a wire bow monitoring system, a semiconductor wire saw device, and a method for monitoring a wire bow. In particular, embodiments of the present disclosure relate to a wire bow monitoring system, a wire saw device, and a method for monitoring a wire bow for sawing semiconductor materials used for solar cells.

10 **BACKGROUND**

[0002] Semiconductor wire saws, or synonymously called "wire saws", "wire saw devices" or "semiconductor wire saw devices" herein, are used to cut workpieces of hard materials, e.g. silicon. Workpieces or ingots are cut or wafered using wire saws for cropping, squaring, or slicing.

15 **[0003]** In such devices a wire is fed from a spool and is guided and tensioned by wire guide cylinders. Different types of wire may be used in wire saws, e.g. those used in combination with silicon carbide particles in a slurry, and diamond wire often used in combination with a coolant. Generally, a hard material such as silicon carbide or diamond abrade the workpiece to make the cut.

20 **[0004]** During cutting, the wire is moved rapidly along its length, which is also called horizontally" herein, and the workpiece is moved comparatively slowly by a workpiece supply plate or table in a cutting direction substantially perpendicular (herein also called "vertically") to the direction of the wire. A vertical force of the wire on the workpiece is thus applied along the cutting direction, and the reactive force of the workpiece on the wire causes the wire to be deformed or bowed in the direction opposite to the cutting direction. If the wire bow increases, at a certain value of the bow it may lead to a breakage of the wire, which requires a time consuming exchange of the wire. Breakage of the wire and subsequent exchange thereof reduces the overall efficiency of the wire saw. On the other hand, stopping the cutting process in intervals in order to measure the bow by an operator is time and cost consuming.

25 **[0005]** Therefore, there is a need to reduce the occurrence of wire breakage or avoid it completely in order to achieve higher efficiency of the wire saw.

30 **SUMMARY**

[0006] In light of the above, a wire bow monitoring system for a wire saw device, a wire saw device, a method for monitoring a wire bow in a wire saw device, and a method for operating a wire saw device are provided.

35 **[0007]** According to an aspect, a wire bow monitoring system for a semiconductor wire saw device is provided. The wire bow monitoring system comprises a sensor arrangement configured to be positioned adjacent to a wire of the wire saw device, wherein the sensor arrangement is adapted to detect a bow of the wire, wherein the sensor arrangement comprises at least one of an inductive sensor, a capacitive sensor and a contact sensor.

40 **[0008]** According to a further aspect, a method for monitoring a wire bow in a semiconductor wire saw device is provided. The method for monitoring a wire bow comprises conducting at least one of an inductive measurement, a capacitive measurement and a contact measurement of a wire; detecting a bow of the wire.

[0009] According to a further aspect, a method for operating a semiconductor wire saw device is provided. The method includes setting at least one wire saw device parameter and cutting a workpiece by means of the wire. The method furthermore includes monitoring the wire bow of the wire as described herein and adjusting the at least one wire saw device parameter if the wire bow exceeds a threshold value.

45 **[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 invention are also directed at methods by which the described apparatus operates. It includes method steps for carrying out every function of the apparatus.

50 **[0011]** The information about a bow provided by monitoring of a wire bow is particularly useful to adjust a table speed and/or a cutting speed, thereby minimizing wear and breakage of the wire and maximizing throughput and cut yield.

[0012] Further advantages, features, aspects and details that can be combined with the above embodiments are evident from the dependent claims, the description and the drawings.

55 **BRIEF DESCRIPTION OF THE DRAWINGS**

[0013] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments. The

accompanying drawings relate to embodiments of the invention and are described in the following:

[0014] Fig. 1 shows a schematic cross-sectional view of a wire bow monitoring system for a wire saw device according to embodiments described herein;

[0015] Fig. 2 shows a schematic cross-sectional view of a wire bow monitoring system for a wire saw device according to embodiments described herein;

[0016] Fig. 3 shows a schematic cross-sectional view of a wire bow monitoring system in a wire saw device according to embodiments described herein;

[0017] Fig. 4 shows a schematic cross-sectional view of a wire bow monitoring system in a wire saw device, wherein the wire of the wire saw device is bowed;

[0018] Fig. 5 shows a schematic view of a sensor board of a wire bow monitoring system according to embodiments described herein;

[0019] Fig. 6 shows a schematic cross-sectional view of a wire bow monitoring system in a wire saw device according to embodiments described herein;

[0020] Fig. 7 shows a schematic cross-sectional view of a wire bow monitoring system in a wire saw device according to embodiments described herein;

[0021] Fig. 8 shows a schematic cross-sectional view of a wire bow monitoring system in a wire saw device according to embodiments described herein;

[0022] Fig. 9 shows a schematic cross-sectional view of a wire bow monitoring system in a wire saw device according to embodiments described herein;

[0023] Fig. 10 shows a schematic cross-sectional view of a wire bow monitoring system in a wire saw device according to embodiments described herein;

[0024] Fig. 11 shows a schematic cross-sectional view of a wire bow monitoring system in a wire saw device according to embodiments described herein;

[0025] Fig. 12 shows a schematic cross-sectional view of a wire bow monitoring system for a wire saw device according to embodiments described herein;

[0026] Fig. 13 shows a flow diagram of a method for monitoring a wire bow in a wire saw device according to embodiments described herein; and

[0027] Fig. 14 shows a flow diagram of a method for monitoring a wire bow in a wire saw device according to further embodiments described herein.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028] Reference will now be made in detail to the various embodiments of the invention, one or more examples of which are illustrated in the figures. Each example is provided by way of explanation and is not meant as a limitation. 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.

[0029] Herein, wire saw, wire saw device, wire sawing device, and wire cutting device are used interchangeably. Herein, workpiece support plate and workpiece supply plate are used interchangeably. Herein, the terms sawing and cutting are used interchangeably; and wafer-cutting wire saw and waferer are used interchangeably. Herein, a workpiece may comprise one or more separate pieces, for example a plurality of semiconductor pieces or ingots. Herein, the wire saw is adapted to perform the cutting by use of a single wire, multiple wires, one or more rows of one or more wires, or one or more webs of one or more wires. The term "wire" may refer to multiple wires.

[0030] Herein, workpiece supply plate, workpiece support plate, supply plate, and support plate are used interchangeably. Herein, the phrase "wire portion within the workpiece" and "wire within the workpiece" are used interchangeably.

[0031] According to an embodiment, a wire bow monitoring system for a wire saw device is provided. The wire bow monitoring system includes a sensor arrangement configured to be positioned adjacent to a wire of the wire saw device. The sensor arrangement is adapted to detect a bow of the wire. The sensor arrangement includes at least one of an inductive sensor, a capacitive sensor and a contact sensor.

[0032] Accordingly, by gaining the wire bow information according to the present disclosure, the wire bow monitoring system and the wire saw device allows the automatic adjustment of the cutting process in real time. Furthermore, the wire bow measurement is an excellent indicator for cutting efficiency.

[0033] Fig. 1 shows a wire bow monitoring system 10 for a wire saw device according to an embodiment. The wire bow monitoring system includes a sensor arrangement 20. The sensor arrangement 20 is adapted to be positioned adjacent to a wire of the wire saw device and is adapted to detect a bow of the wire.

[0034] The sensor arrangement includes at least one of an inductive sensor, a capacitive sensor and a contact sensor. Reference number 22 shall refer to the sensor, independent of whether it is an inductive sensor, capacitive sensor or a contact sensor.

[0035] The inductive sensor and the capacitive sensor are typically adapted to sense the vicinity of the wire if it is iron

based. The one or more sensors may be digital or analog. The measurement outcome, also called "measurement result" or "measurement" herein, of the at least one inductive or capacitive sensor may be continuous (in the case of the analog sensor) or digital (in the case of a digital sensor). If the outcome is continuous, it is typically an indication for the absolute distance between the sensor and the wire, for instance, with m denoting the measurement outcome, and x denoting the distance between the sensor and the wire, x may be represented as function of m , i.e., $x=f(m)$. According to typical embodiments, this function is linear.

[0036] In those embodiments where the outcome is digital, the sensor may respond with, for instance, 0 if the distance between the sensor and the wire is below a threshold distance, and the sensor may respond with 1 if the distance is above the threshold value. The threshold distance, also called "threshold value" herein, may be pre-set, for instance by an operator during or before the cutting process, or it may correspond to the sensing distance of the sensor, i.e., the sensor is capable to detect the presence of the wire only up to the sensing distance. For instance, the threshold value may be between 0.1 mm and 1.0 mm, particularly between 0.2 mm and 0.6 mm.

[0037] The term "digital sensor" shall thus be understood as any arrangement, which includes a sensor that provides a digital measurement outcome. It is typically irrelevant whether the electronics is digital or analogous. The provision of a digital sensor is particularly advantageous when a multitude of sensors are provided with their measurement outcomes typically evaluated jointly.

[0038] According to embodiments, the sensor arrangement includes a plurality of sensors. Typically, all sensors of the plurality of sensors are the same sensor type. For instance, the sensor arrangement may be provided either with a plurality of inductive sensors, or a plurality of capacitive sensors, or a plurality of contact sensors. The one or more sensors of the present disclosure, without limitation to any embodiment described herein, are typically in communication with a control unit, such as control unit 50 in Fig. 2. The communication may particularly be a data communication, in particular from the sensor to the control unit wherein the one or more sensors provide the control unit with the measurement results.

[0039] The control unit may evaluate the one or more measurement results. The control unit may additionally or alternatively trigger a reaction. In order to do so, in typical embodiments, the control unit is adapted to be in communication with the wire saw device for initiating a reaction of the wire saw device as a response to the bow measurement results. According to embodiments, the control unit, such as control unit 50 of Fig. 2, is the control of the wire saw device. However, it is also possible that the wire bow monitoring system is provided with a separate control unit that is in data communication with the control unit of the wire saw device.

[0040] The provision of several sensors on the sensor arrangement as illustrated in Fig. 2 (where four sensors 22 are depicted) may particularly be advantageous to measure not only the presence of a bow in the wire but also a value corresponding to the dimension of the bow. For instance, all of the sensors may be either inductive sensors or capacitive sensors. The value corresponding to the dimension may particularly be an angle of the wire as compared to a wire orientation in an unstressed situation of the wire, as will be exemplified below in more detail.

[0041] Fig. 3 shows a wire bow monitoring system 10 for a wire saw device 100 according to embodiments. The wire saw device 100 is exemplarily shown as including a wire 30, which is guided by two wire guides 130 (also called "guide cylinders" or "pulleys") along its length. As will become evident in Fig. 5, the wire may be arranged in parallel, forming wire rows or a wire web. The wire provided forms a wire web in particular in the cutting area of the wire saw. Thereby, the term "wire web" normally relates to the web formed by the wire between two guide cylinders. It should be understood that a wire may form more than one wire web which is defined as an area in which a sawing process is performed. Thus, according to some embodiments described herein, the one or more wires may form multiple wire webs, for instance two wire webs both adapted for cutting a workpiece. A workpiece or an ingot 120 is mounted to a table 110, which is configured to move against the wire 30 in order to cut the ingot.

[0042] The wire guides are typically adapted to rotate in order to transport the wire. The wire guides are normally 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. It is typical that the wire saw is operated between 10 m/s and 15 m/s during standard operation whereas the speed may be smaller during start and stop. Also, in the event of a back and forth movement of the wire, the wire is decelerated from time to time in order to accelerate it in the opposite direction.

[0043] During cutting, the wire moves substantially along its longitudinal length. The term "substantially" shall particularly embrace vibrations or the like. The movement is typically relatively rapidly in comparison to the typical perpendicular motion of the workpiece, such as a semiconductor ingot. The wire motion can alternatively be in a reciprocating manner, in which the motion of the wire along its length is in periodically reversed direction. In operation, the wire is brought into contact with a workpiece 120 to cut the workpiece, for instance, into a plurality of wafers.

[0044] According to different implementations, the wire or wires forming a wire web can be moved relative to the workpiece, the workpiece can be moved relative to the wire or wire web, or the wire and the workpiece can both be moved relative to each other.

[0045] When the workpiece and the wire (such as the wire web) are pressed relatively against each other, the resulting force exerted by the workpiece on the wire causes the wire to become bowed. The orientation of the wire bow coincides

with the cutting direction. When the wire bow increases too much, it may lead to a breakage of the wire. In order to avoid such a situation, embodiments described herein allow the detection of a bow before it becomes too large, and furthermore, allow triggering an adequate reaction in order to avoid a breakage of the wire. Such a reaction could be, for instance, the reduction of the speed of the workpiece against the wire and/or an increase in the wire speed. Further reactions could encompass an amendment in the amount of provided slurry or the slurry composition etc.

[0046] According to several embodiments described herein, such as shown in Fig. 3, the wire saw monitoring system 10 includes a sensor arrangement 20 and a control unit 50. The sensor arrangement 20 is configured to be positioned adjacent to the wire 30 and may include a sensor board 24 with several sensors 22 mounted to it. The number of sensors can be at least 2, at least 4, or even at least 8, 10 or even 16. The sensors 22 are configured to detect the wire bow. The data measured and collected by the sensors is typically forwarded to the control unit 50 where it may be further processed, such as evaluated. For instance, logic levels (i.e., 0 or 1 outcomes) of each sensor may be used to monitor a progression of the wire bow.

[0047] Fig. 4 shows the same embodiment wherein the wire (web) undergoes a bow due to the workpiece being pressed in the cutting direction. As illustrated in Figs. 3 and 4, according to embodiments with several digital sensors, the logic states of all the sensors are typically the same if there is no wire bow or only a small wire bow. "Small" in this context means that the wire bow does not exceed a threshold value for the wire-sensor distance.

[0048] During the cutting process, however, when the table 110 is moved in the cutting direction (indicated by arrow 121 in Fig. 4), the wire bow may increase and the logic states of one or more of the sensors may also change. For instance, the two sensors closer to the workpiece (i.e., in the embodiments illustrated with respect to Figs. 3 and 4, the two sensors to the right) may indicate the result that the distance between these sensors and the wire is above the threshold value whereas the two sensors further away from the workpiece (i.e., the two sensors to the left in Figs. 3 and 4) may still sense a distance between the wire and the sensor that is below the threshold value. From these results, it is possible to gain information about the bow dimension of the wire, in particular, about the angle α (depicted in Fig. 4) between the wire in the actual bowed position and a non-bowed wire, or the absolute bow length L that will be discussed below in more detail.

[0049] For instance, if the sensor arrangement includes four sensors in the longitudinal wire direction as illustrated in Figs. 3 and 4 (notwithstanding the number of sensors in the perpendicular direction, as will be discussed with respect to the embodiments illustrated in view of Fig. 5), and if the sensors are digital sensors, the threshold value of the sensors may be selected such that the following information can be gained:

Signal sensor 1	Signal sensor 2	Signal sensor 3	Signal sensor 4	Interpretation
0	0	0	0	$\alpha < 2^\circ$
0	0	0	1	$2^\circ < \alpha < 4^\circ$
0	0	1	1	$4^\circ < \alpha < 6^\circ$
0	1	1	1	$6^\circ < \alpha < 8^\circ$
1	1	1	1	$\alpha > 8^\circ$
any other signal constellation				failure

[0050] As shown in the table, if all sensors show a 0 response, there is no wire bow or only a small wire bow (such as below 2°). If the sensor closest to the workpiece measures a distance above the threshold value resulting in a measurement result 1, whereas the distance between the other sensors and the wire is still below the threshold value, i.e. 0, then this result can be interpreted as an angle α of larger than 2° but below 4° . Similar considerations apply to the further measurement results depicted in the further rows of the shown table. Once all sensors respond with 1, the distance between all sensors and the wire is above the threshold value which, in the shown non-limiting example of the table, has to be interpreted as a bow angle of more than 8° . Evidently, at least this information should trigger a reaction such as an amendment of at least one wire saw device operation parameter.

[0051] It shall be appreciated that this embodiment with the four sensors in the longitudinal length of the wire and their threshold settings resulting in the angle α distribution as shown in the table is only for illustrative purposes. It is evident to the skilled person that any other constellation and values may be comparably suitable.

[0052] Whereas the example above uses the angle α as indication for the dimension of the wire bow, it is also possible to deduce the absolute bow length L from the measurement results. The absolute bow length L refers to the maximal deviation of the wire from its rest position in the cutting direction. The absolute bow length L is exemplarily illustrated in Fig. 4 and denoted with reference number 140.

[0053] For instance, if the sensor arrangement includes four sensors in the longitudinal wire direction as illustrated in

Figs. 3 and 4 (notwithstanding the number of sensors in the perpendicular direction), and if the sensors are digital sensors, the threshold value of the sensors may be selected such that the following information can be gained:

Signal sensor 1	Signal sensor 2	Signal sensor 3	Signal sensor 4	Interpretation
0	0	0	0	$L < 3\text{mm}$
0	0	0	1	$3\text{mm} < L < 6\text{mm}$
0	0	1	1	$6\text{mm} < L < 9\text{mm}$
0	1	1	1	$9\text{mm} < L < 12\text{mm}$
1	1	1	1	$L > 12\text{mm}$
any other signal constellation				failure

[0054] Furthermore, the sensor arrangement or the wire saw as described herein may be configured to trigger a reaction, such as an amendment of the operational status of the wire saw, such as at least one operation parameter, in dependence of the measurement results. With reference to the example illustrated with respect to the tables above, no reaction may be triggered as long as the bow angle α is below 6° , or the absolute bow length is below 9 mm. Once the angle exceeds 6° , or the absolute bow length L exceeds 9 mm, the speed of the wire may be increased, such as by 10%, and/or the cutting speed (i.e., the moving speed of the workpiece in the cutting direction) may be reduced, such as by 10%. Once the angle exceeds 8° , or the absolute bow length L exceeds 12 mm, the speed of the wire may be increased even more, such as by at least 20%, and/or the cutting speed may be reduced even more, such as by at least 20%. Alternatively, once a maximal bow angle is measured (such as at least 8° or at least 12 mm absolute bow length in the present example), and not limited to the present example, the wire saw device may be halted and/or an operator may be alarmed.

[0055] It shall furthermore be mentioned that any other measurement result, such as that all sensors measure the distance between them and the wire as being below the threshold value with one intermediate sensor, or a sensor further away from the workpiece than at least part of the other sensors, indicating a distance above the threshold value, this has to be interpreted as a failure of the system. This is because the bow is always in the direction of the cutting direction. In other words, neither do negative angles α represent a situation that happens in practice nor is it possible that a sensor senses a smaller distance than its neighbor further away from the workpiece.

[0056] By using the information about the logic states of the sensors, the control unit 50 determines the value of the wire bow and controls the wire saw device so as to avoid a breakage of the wire.

[0057] According to embodiments, the control unit 50 is configured to adjust a wire speed and/or a table speed depending on the wire bow. The control may be a feedback loop control.

[0058] According to embodiments, the sensor arrangement further includes at least one sensor board, wherein the sensors are mounted to the sensor board in at least two rows. Such an arrangement is illustrated with respect to Fig. 5 wherein four rows of sensors in an orientation perpendicular to the wire are illustrated, and four rows of sensors in an orientation substantially parallel to the wire orientation are illustrated.

[0059] As used herein, the term "row of sensor" refers particularly to an arrangement where the sensors of different rows are spaced apart from each other, such as in a direction substantially perpendicular to the wire orientation and/or an orientation substantially parallel to the wire orientation. "Substantially" in this context typically includes a deviation of 20° , more typically 10° .

[0060] According to embodiments described herein, notwithstanding the number of sensors in the wire direction, at least two sensors, typically at least four sensors are provided arranged in a row in the direction perpendicular to the wire direction. In other words, each sensor provides information about different wires. Thereby it is possible to locate a local bow of, for instance, only one wire that is blocked by a dirt inclusion in the ingot. Such an inclusion is typically very hard and thus difficult to cut through. Hence, the cutting of all the other wires proceeds without any problems whereas said one wire remains stuck at the inclusion so that the bow dimension of this wire increases while the ingot is pushed in the cutting direction. According to this embodiment, such a disastrous bow development can be measured and the control can trigger a reaction, as described.

[0061] Fig. 5 shows a schematic view of the sensor board 24 with 4×4 sensors 22 mounted to it. Generally, and not limited to any embodiment, the overall numbers of sensors are typically be calculated as k times n with k and n both being positive integers, wherein, for instance, k denotes the number of sensors in the orientation substantially parallel to the wire orientation, and n denotes the number of sensors in the orientation substantially perpendicular to the wire orientation. For instance, the number of sensors arranged substantially perpendicular to the wire orientation may be at least two, at least four, or at least six. Additionally or alternatively, the number of sensors arranged substantially parallel

to the wire orientation may be at least two, at least four, or at least six. The overall number of sensors may be up to 20 or even 30. Additionally or alternatively, it may be at least 9 or 16.

[0062] As exemplarily illustrated in Fig. 5, the sensors may be positioned in a diagonal pattern on the board. A diagonal pattern requires at least four sensors arranged in a parallelogram-type fashion. In particular, and not limited to any embodiment described herein, each sensor is centered above or below a wire that is different than the wire that all the other sensors are centered above or below.

[0063] According to embodiments, the multitude of sensors can particularly be inductive sensors or capacitive sensors. Inductive sensors are particularly beneficial in that they are insensitive to water, oil, dirt, non-metallic particles, target color, ability to withstand high shock and vibration environments.

[0064] Typically, structured wire or diamond wire is utilized for the wire saw device of the present disclosure. The wire may be monofilament steel wire. According to some embodiments, the wire is from approximately 80 to 350 micrometer, for example 120 micrometer steel gauge wire. According to some embodiments, the structured wire is a crimped wire, wherein, for example, saw wire being made of a metallic wire being provided with a plurality of crimps. Diamond wire is a wire with a coating, wherein diamond particles are embedded in the coating.

[0065] According to embodiments described herein, the methods of operating and/or controlling the wire bow monitoring system and the wire saw device can be conducted by means of computer programs, software, computer software products and the interrelated controllers, which can typically have a CPU, a memory, a user interface, and input and output means being in communication with the corresponding components of the wire saw device. These components can be one or more of the following components: motors, wire break detection units, wire tracking devices, and the like, which will be described in more detail below.

[0066] For modern wire saws like croppers, squarers, wafering systems, or multi-wire saws, there is the desire to cut the hard material such as semiconductor material, for example, silicon, quartz, or the like at high speed. The wire speed, that is the speed of the wire moving through the wire saw can be, for example, 10 m/s or even higher. Typically, the wire speed can be in a range of 10 to 15 m/s. However, higher wire speeds, such as of 20 m/s, 25 m/s or 30 m/s can also be desirable. For unwinding the wire at the desired wire speed, the feed spool with unused wire typically rotates with a rotation speed of up to several thousands rotations per minute. For example, 1000 to 2000 rpm can be provided for unwinding the wire.

[0067] It is possible that sawing is undertaken at the same time at the upper wire web and the lower wire web, if any. The wire web may be arranged horizontally, as illustrated in the figures herein. The wire saw may furthermore include two vertically arranged webs. According to some embodiments, the vertically arranged webs are used for transporting the wire between the horizontally oriented working areas. During transport between the working areas the wire can cool down. According to other embodiments, the working areas are oriented vertically.

[0068] According to typical embodiments, a multi-wire saw is used. A multi-wire saw allows high productivity and high quality slicing of silicon wafers for the semiconductor and photovoltaic industries. A multi-wire saw includes typically a high-strength steel wire that may be moved uni-directionally (i.e., only in the forward direction) or bi-directionally (i.e., backwards and forwards) to perform the cutting action. The wire may be provided with diamonds on its surface. By using diamond wire according to the present disclosure, the throughput may be increased by a factor of 2 or even more in comparison to conventional steel wire. The speed with which the material to be sawed is moved relatively to the moving wire may be referred to as the material feed rate. The material feed rate in the embodiments described herein may be in the range of 2 $\mu\text{m/s}$ to 15 $\mu\text{m/s}$, typically about 6 $\mu\text{m/s}$ to 10 $\mu\text{m/s}$ for a wafer cutting wire saw.

[0069] According to embodiments, at least one sensor for measuring the wire bow is movably arranged. By moving the at least one sensor it is possible to follow the wire and thus to maintain a high sensing accuracy. This is because the measurement results are of higher quality in the proximity of the sensor than further away.

[0070] As a control operation of the embodiments described herein it is possible to position the one or more sensor at a selectable distance to the wire, for instance, when there is no workpiece cut and the wire is in an unbowed position. Once cutting starts and the wire bows, in dependence of the sensor signal, the control may move one or more of the at least one sensor to follow the bow. For instance, the control may be adapted to guide the one or more sensor in such a way that their distance to the wire remains constant. It is possible to deduce the dimension of the bow from the distance that the one or more sensors are moved in order to keep the distance constant.

[0071] According to embodiments, not all of the sensors are movably arranged but only some of them.

[0072] As mentioned already, according to embodiments, the wire bow monitoring system includes a control unit adapted to control the sensor arrangement and/or the wire saw device depending on the data received from the sensor arrangement. According to embodiments, the wire bow monitoring system further includes an actuator adapted to change a distance between the sensor arrangement and the wire.

[0073] According to embodiments, the sensor arrangement further includes at least a rod, wherein the sensor is mounted to the rod, or the plurality of sensors are mounted to the rod, for instance, in a row. The rod may be movable.

[0074] Fig. 6 shows a schematic view of a wire bow monitoring system for a wire saw device according to embodiments. The sensor arrangement includes a movable rod 40 having sensors 22 mounted thereto. The sensors may be contact

sensors, inductive sensors, or capacitive sensors. As shown, and not limited to the embodiment of Fig. 6, the sensors are mounted to the rod in a row. A linear actuator 60 may generally and not limited to the embodiment of Fig. 6 be provided to allow the rod 40 to be movable in the cutting direction, as indicated by the arrows 105 in Fig. 6, and vice versa. The actuator is typically in data communication with the control unit of the wire bow monitoring system or the wire saw device.

[0075] Due to the use of a linear actuator, the zero position is automatically detected. According to embodiments, the linear actuator is a stepper which drives a screw ball. Because of the use of a linear actuator, the wire bow distance may be measured with a high accuracy. Not limited to this embodiment, the wire bow measurement results may be memorized in order to provide functional information about the wire bow in dependence of the time. This information may be useful for learning to better understand the cutting process and particularly the bow creation, in particular in view of other cutting parameters, such as wire speed, wire tension, amount of provided slurry, and table speed.

[0076] It is also possible to couple the wire bow system according to embodiments described herein with a wire breakage detection system. For instance, an existing wire breakage detection system may already include sensors that can be beneficially used also for the wire bow detection as described herein.

[0077] According to embodiments, the sensor is a contact sensor. The contact sensor may be positioned close to the wire, for instance, at position X. The interpretation of position X may be as follows: Should the wire's bow increase such that it arrives at position X, a reaction of the wire saw device should be triggered.

[0078] When during the cutting process the wire bow increases, the wire comes in contact with the rod 40 over the contact sensors (see Fig. 7). As a response, the control unit drives the linear actuator in order to move down the rod away from the wire by one increment, until there is no contact between the rod and the wire (see Fig. 8). The position of the actuator and of the rod is evaluated and maybe memorized by the control unit. Due to the linear actuator the wire bow can be measured with a very good accuracy as a function of time. For instance, the rod may be electronically connected to the control unit of the wire bow monitoring system and/or of the wire saw device. Using the information about the wire bow the control unit can adjust wire saw operating parameters such as wire speed or table speed in order to reduce the wire bow and to avoid wire breakage.

[0079] The embodiment illustrated with respect to Figs. 7 and 8 also exemplify that, according to general embodiments described herein, at least one sensor may be provided on each side of the workpiece. Thereby, it is possible to detect the bow building up at both sides of the workpiece. Where the standard situation may be a symmetrical bow around the center of the workpiece, asymmetric bow creation may be detected by these embodiments. Not only the bow dimension might be used to trigger a reaction of the wire saw device, but also the level of asymmetry of the bow might be used to trigger a reaction.

[0080] A further example of the present disclosure is illustrated with respect to Figs. 9-11. The figures show a workpiece 120 to be cut that is pushed by the table 110 towards the wire 30 web. Two sensors 22, i.e., one sensor for each side of the workpiece, are positioned on a rod 40. Furthermore, an actuator schematically shown as 60 may be linked to the rod 40 to move the rod in the cutting direction or vice versa.

[0081] In the absence of a wire bow, the sensors, for instance, inductive sensors, detect the presence of the wire (see Fig. 9). When the wire bow increases during the cutting process and the wire moves away from the sensors, at least one sensor 22 senses an increase of the distance between the sensor and the wire. This may happen when the sensor signal exceeds or underruns a selectable threshold value. In the event of an analogous sensor, the increase of the distance is steadily measured. Accordingly, with increasing distance of the wire, the output of the sensor changes (see Fig. 10). As a response, the actuator is moved in the bow direction, i.e., the cutting direction that is denoted with arrows 70 in Fig. 10. For instance, the actuator may move the rod by one increment in order to bring the rod 40 and the sensors closer to the wire again. The information gained from the sensor and the necessary movement distance may be used to deduce the extension of the wire bow and to thereby avoid wire breakage by triggering an appropriate reaction, as discussed, upon wire bow extension that overruns a threshold value. The current position of the actuator may be memorized by the wire bow monitoring system.

[0082] According to embodiments combinable with all other embodiments described herein, the one or more sensor(s) may be pivotably positioned. The axis of rotation of the one or more sensor(s) is typically perpendicular to the wire orientation. In case there is a wire web, the axis of rotation is typically parallel with the plane formed by the wire web. The sensor(s) may be pivoted by pivoting the rod to which the one or more sensor(s) is mounted to.

[0083] Such an embodiment is exemplarily illustrated in Fig. 11 wherein the rod 40 is rotatable around its axis. The rotation is illustrated with arrows 45. The shown rotation direction of the sensor, i.e. clockwise rotation of the left sensor and counter-clock wise rotation of the right sensor, correspond to a situation wherein the bow increases, and the sensors follow this increase by an increase of their rotation angle. Generally, the pivotably arranged sensors are adapted to be controlled or, are controlled, respectively, such that the alignment of the sensor surface with regard to the wire can remain substantially constant despite an amendment in the bow. "Substantially" in this context includes a deviation of not more than 5°, typically not more than 2°.

[0084] Typically, the sensor has a surface that is oriented parallel to the wire in order to obtain optimum measurement

results. If the wire starts to bow, and the sensor orientation remains unchanged, the wire will no longer be parallel to the sensor surface with the result that the wire has different distance to the sensor in dependence on the position on the sensor. This may, in some embodiments, reduce the sensing quality. By adapting the orientation of the sensor, the sensing quality can remain at a high quality.

[0085] According to embodiments, the control unit is adapted to pivot the sensor in dependence of the position of the wire. This may be done synchronously with moving the sensor translationally, i.e., up and down in the orientation of the exemplary embodiments of the figures, to follow the wire bow, such as by moving the rod up and down. Since an optimum sensor orientation may be known for every bow dimension, and since this information may be stored in the control unit of the wire bow monitoring system of the wire saw device, such as in a memory unit of the control unit, the control unit may adapt the rotation angle of the sensor as a function of the dimension of the bow. Typical rotation angles of the sensor correspond to the bow angle α . They are typically up to 20°, or only up to 15°.

[0086] As illustrated in the embodiment of Fig. 11, as the linear actuator and the rod move down by one increment, the rod may be rotated by one angle increment in order to optimize both the sensing distance between the sensors and the wire and the sensor orientation with respect to the wire.

[0087] Fig. 12 depicts a cross-sectional side view of the embodiments of Figs. 10 and 11. In particular, it becomes apparent that all sensors may be pivoted synchronously. For instance, the sensors 22 may be arranged on one board 40 that is rotated as a whole.

[0088] According to further embodiments, a wire saw device is provided, including a wire bow monitoring system according to the embodiments described above. In particular, the wire saw may be adapted to cut one, two, three or even four workpieces such as an ingot synchronously. Furthermore, typical wire saws as described herein are provided with four guide cylinders for guiding the wire wherein two webs are formed and used as cutting area. Consequently, according to embodiments, at least one sensor arrangement as described herein may be provided for each of the two webs adapted for cutting workpieces.

[0089] According to embodiments, as described in detail already, a method for monitoring a wire bow in a wire saw device is provided. The method for monitoring a wire bow includes conducting at least one of an inductive measurement, a capacitive measurement and a contact measurement of a wire. The method furthermore includes detecting a bow of the wire. In particular, detecting may include evaluating the measurement results, in particular by means of a control unit.

[0090] According to embodiments, the control unit controls the sensor arrangement and/or the wire saw device depending on the data received from the sensor arrangement.

[0091] Figs. 13 and 14 shall illustrate the methods according to the present disclosure. Fig 13 shows a flow diagram of a method for monitoring a wire bow in a wire saw device according to embodiments described herein. The method includes conducting at least one of an inductive measurement, a capacitive measurement and a contact measurement of a wire (block 101); and detecting or determining a bow of the wire (block 102). Fig. 14 depicts a similar embodiment, with the added step of controlling a sensor arrangement and/or a wire saw device (block 103) using the data received from the sensor arrangement.

[0092] While the foregoing is directed to embodiments of the invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims

1. A wire bow monitoring system (10) for a semiconductor wire saw device (100), comprising:

a sensor arrangement (20) configured to be positioned adjacent to a wire (30) of the wire saw device (100), wherein the sensor arrangement (20) is adapted to detect a bow of the wire (30), wherein the sensor arrangement (20) comprises at least one of an inductive sensor (22), a capacitive sensor (22) and a contact sensor (22).

2. The wire bow monitoring system according to claim 1, wherein the sensor arrangement (20) comprises a plurality of sensors (22).

3. The wire bow monitoring system according to any of the preceding claims, wherein the sensor arrangement (20) comprises at least one of a plurality of inductive sensors, a plurality of capacitive sensors and a plurality of contact sensors.

4. The wire bow monitoring system according to any of the preceding claims, wherein the sensor arrangement (20) further comprises at least one sensor board (24), wherein the sensors (22) are mounted to the sensor board (24) in at least two rows.

5. The wire bow monitoring system according to claim 4, wherein the sensors (22) are positioned on the sensor board in a diagonal pattern.
6. The wire bow monitoring system according to any of the preceding claims, wherein at least one sensor is movably and/or pivotably arranged.
7. The wire bow monitoring system according to any of the preceding claims, wherein the sensor arrangement further comprises at least one movable rod (40), wherein the sensors (22) are mounted to the rod in a row.
8. The wire bow monitoring system wherein the sensors are either digital sensors or analog sensors.
9. The wire bow monitoring system according to any of the preceding claims, further comprising a control unit (50) adapted to control the sensor arrangement (20) and/or the wire saw device depending on the data received from the sensor arrangement.
10. The wire bow monitoring system according to any of the preceding claims, further comprising an actuator adapted to change a distance between the sensor arrangement and the wire; and/or an actuator adapted to rotate the sensor.
11. A wire saw device, comprising a wire bow monitoring system according to any of the preceding claims.
12. A method for monitoring a wire bow in a semiconductor wire saw device, comprising conducting at least one of an inductive measurement, a capacitive measurement and a contact measurement of a wire; detecting a bow of the wire.
13. The method for monitoring a wire bow according to claim 12, wherein a control unit controls a sensor arrangement and/or the wire saw device depending on the data received from the sensor arrangement.
14. The method for monitoring a wire bow in a semiconductor wire saw device according to any of the claims 12-13, wherein several measurements are conducted synchronously, and wherein the measurement results of the several measurements are jointly evaluated in order to gain information about the wire bow dimension.
15. A method for operating a semiconductor wire saw device, comprising:
 - setting at least one wire saw device operation parameter;
 - cutting a workpiece by means of a wire;
 - monitoring a wire bow of the wire according to any of claims 12-14; and
 - adjusting the at least one wire saw device parameter if the wire bow exceeds a threshold value.

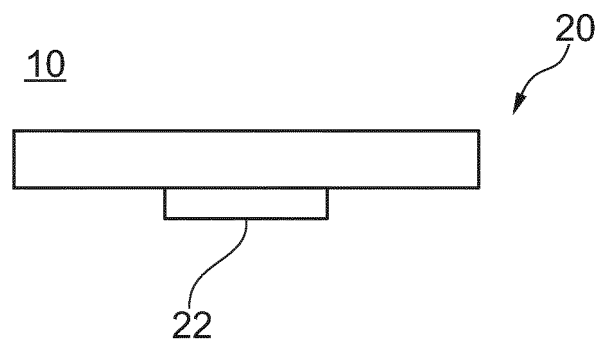


Fig. 1

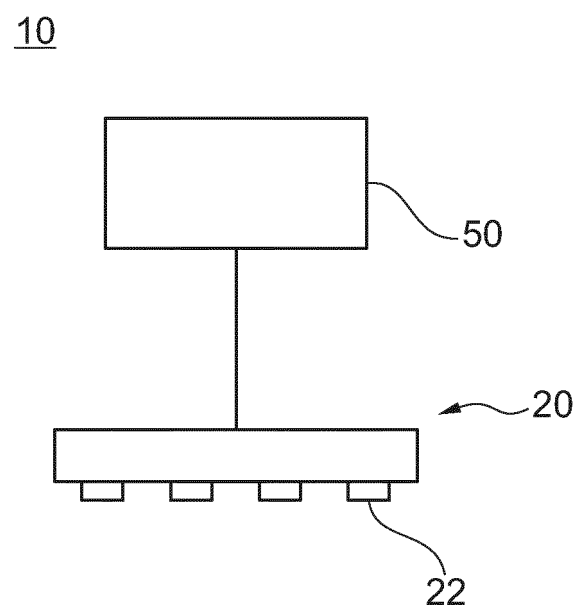


Fig. 2

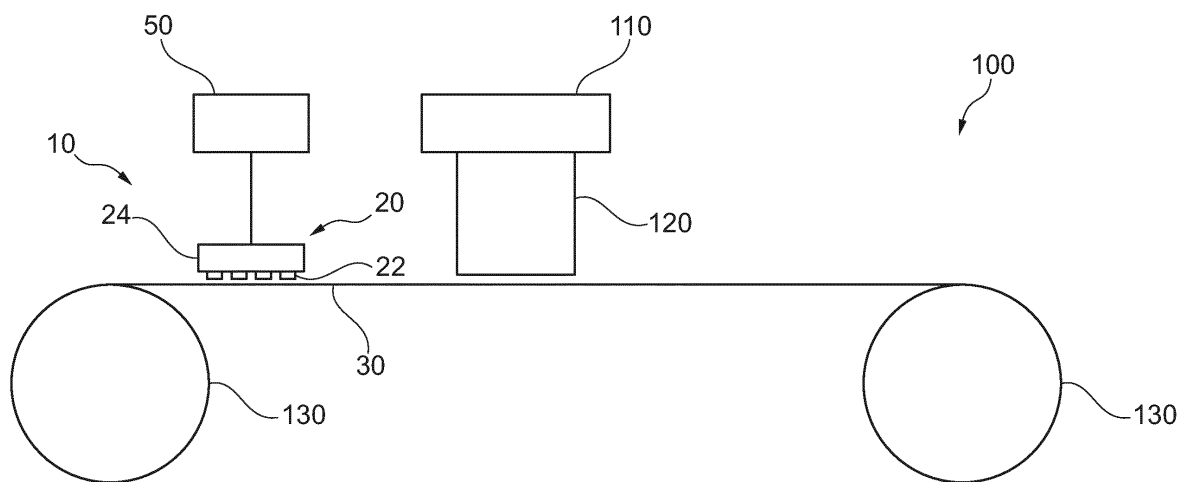


Fig. 3

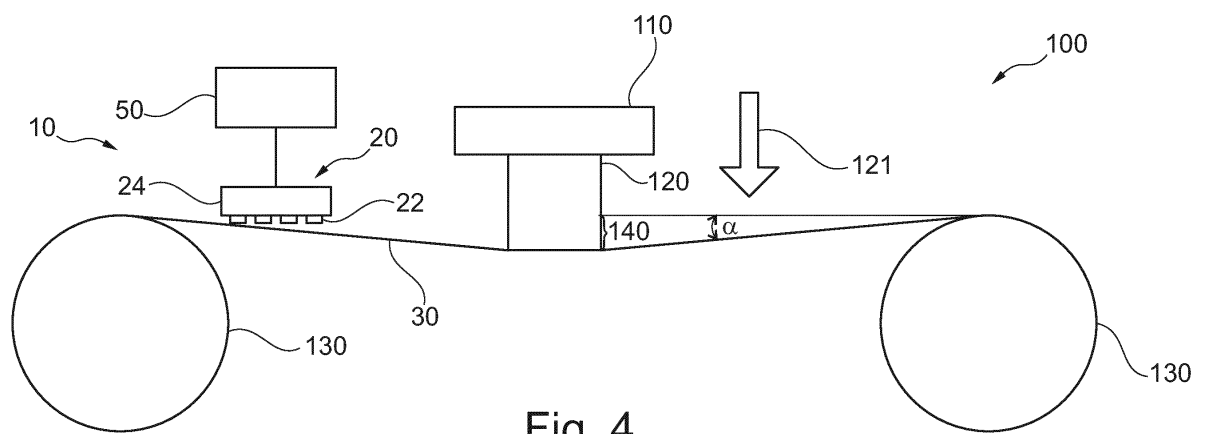


Fig. 4

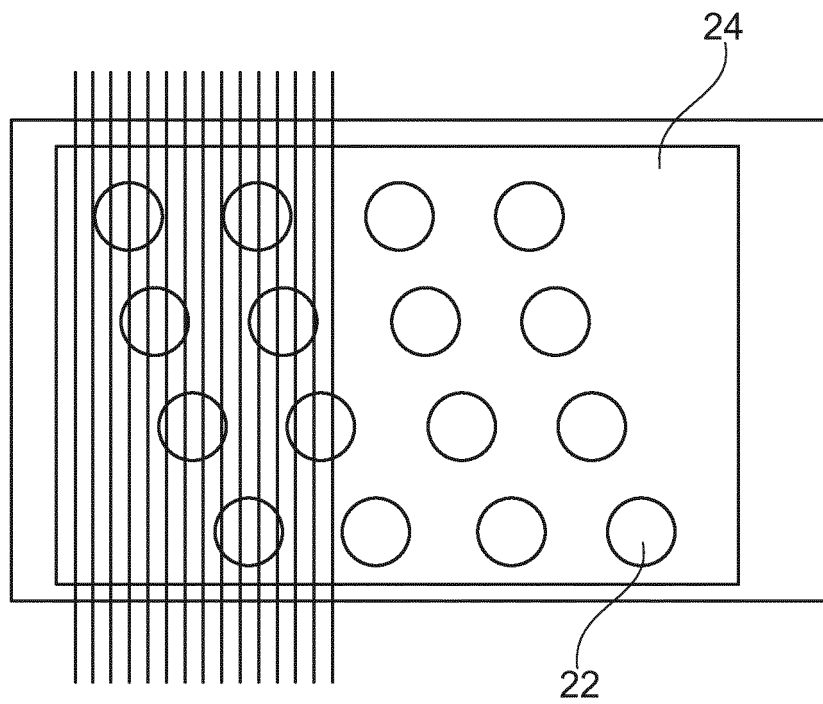


Fig. 5

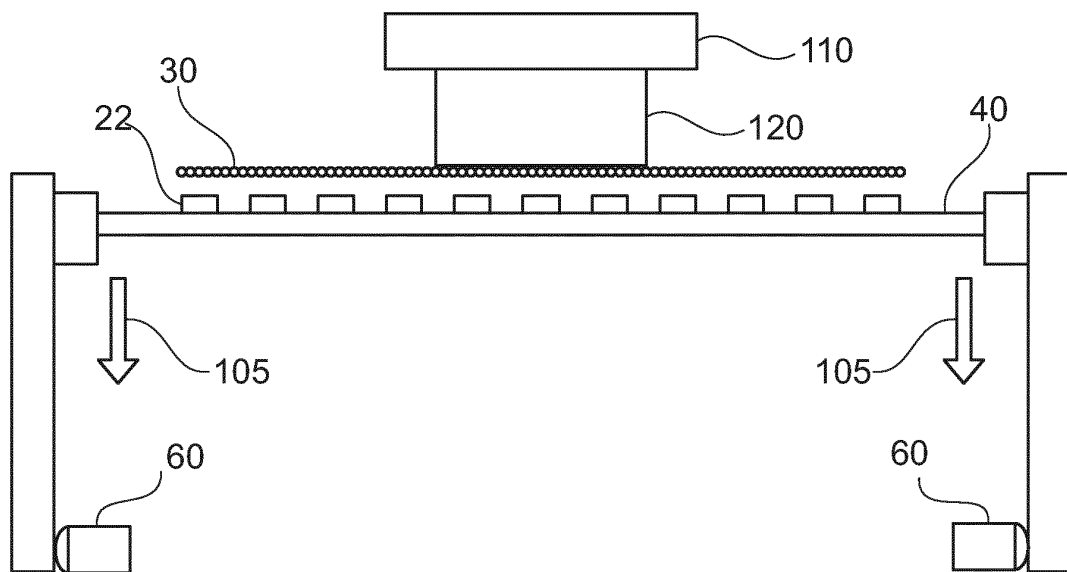


Fig. 6

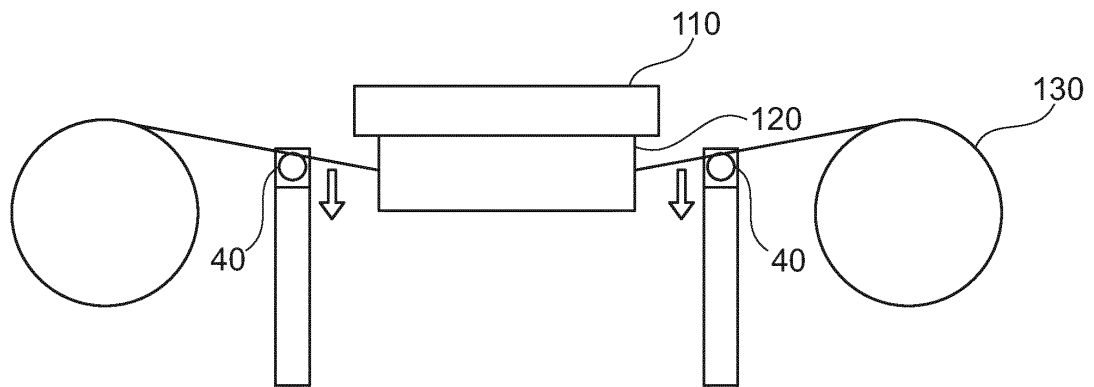


Fig. 7

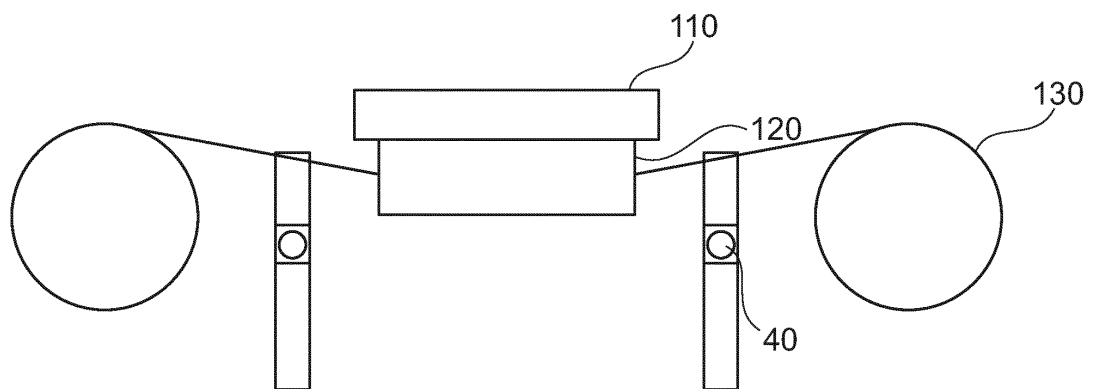


Fig. 8

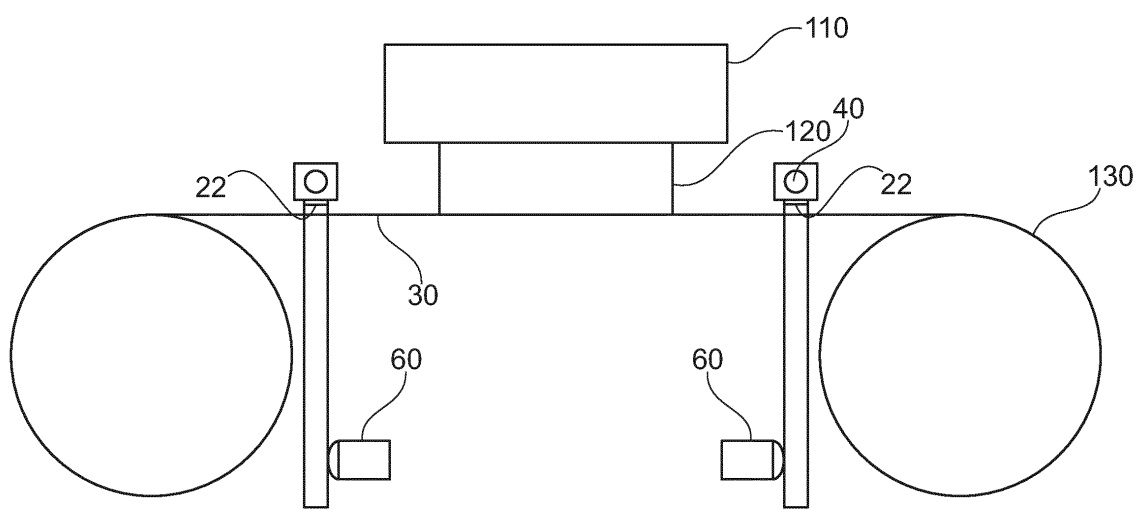


Fig. 9

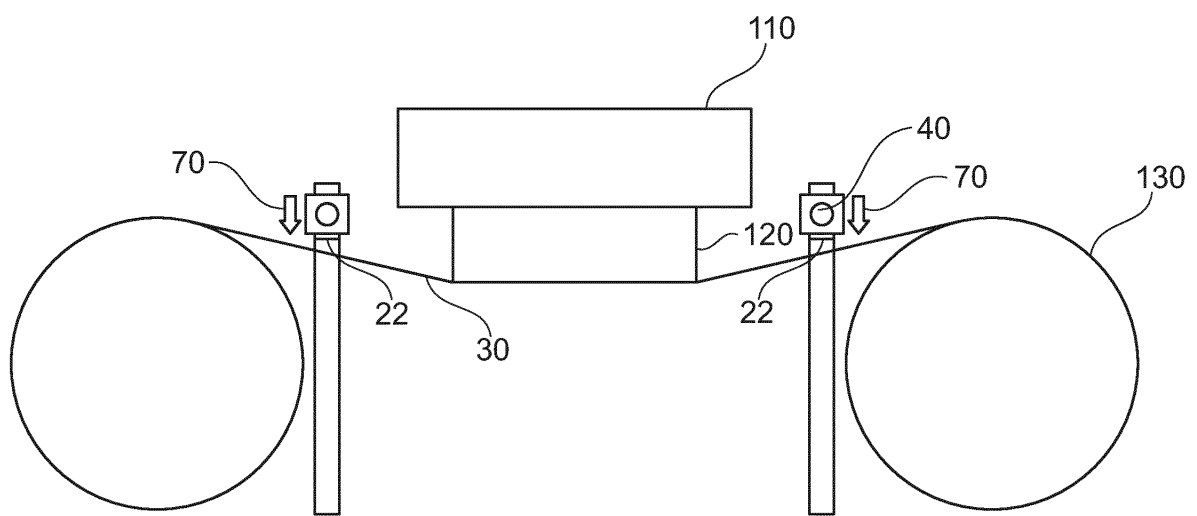


Fig. 10

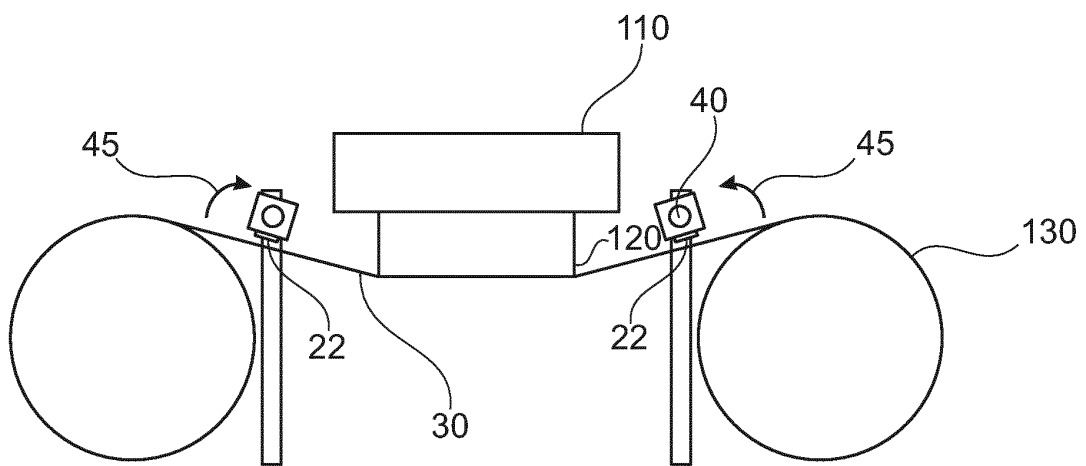


Fig. 11

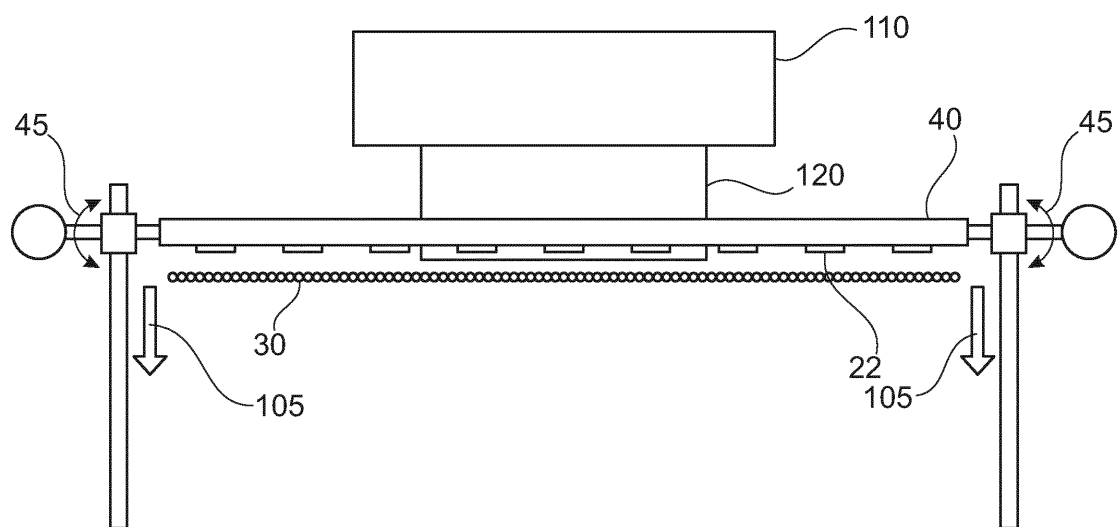


Fig. 12

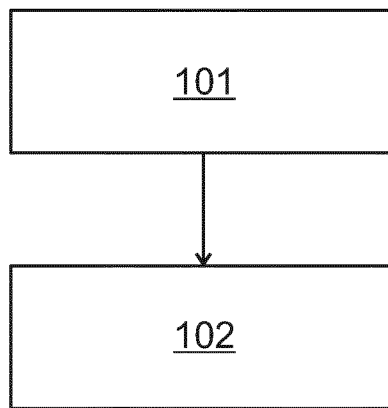


Fig. 13

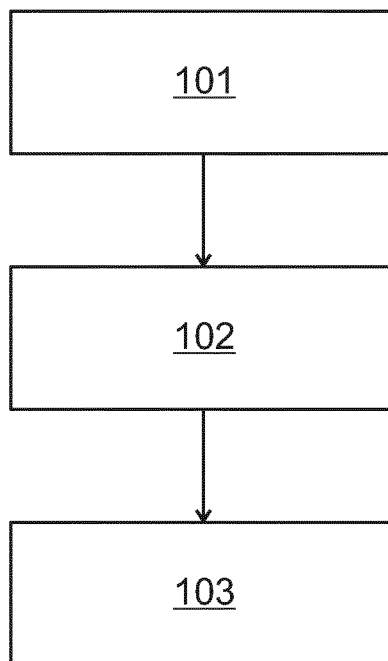


Fig. 14



EUROPEAN SEARCH REPORT

Application Number
EP 12 18 4353

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A	* paragraphs [0027], [0031], [0039] - [0041], [0054], [0058], [0059], [0061] * * figures 1,2,3,6-8 *	7,8	
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			B28D
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 21 January 2013	Examiner Chariot, David
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82