



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.05.2013 Bulletin 2013/18

(51) Int Cl.:
B28D 5/00 (2006.01)

(21) Application number: **11187103.4**

(22) Date of filing: **28.10.2011**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(72) Inventor: **Nasch, Philippe**
1052 Le Mont-sur-Lausanne (CH)

(74) Representative: **Zimmermann & Partner**
Josephspitalstr. 15
80331 München (DE)

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

(54) **Wire saw control system and wire saw**

(57) A wire saw control system (1) for operating a wire saw (100) is provided. The wire saw is adapted for cutting a wafer (302, 304, 306, 308). The wire saw control system is configured to control the temperature of a wire (230) of a wire saw and includes a temperature sensor (20) for measuring the temperature of the wire; and a

controller (25) for controlling at least one operating parameter of the wire saw based on the measured temperature. Measuring the temperature particularly includes measuring the temperature distribution. Furthermore, a method for controlling the temperature and for operating a wire saw is provided.

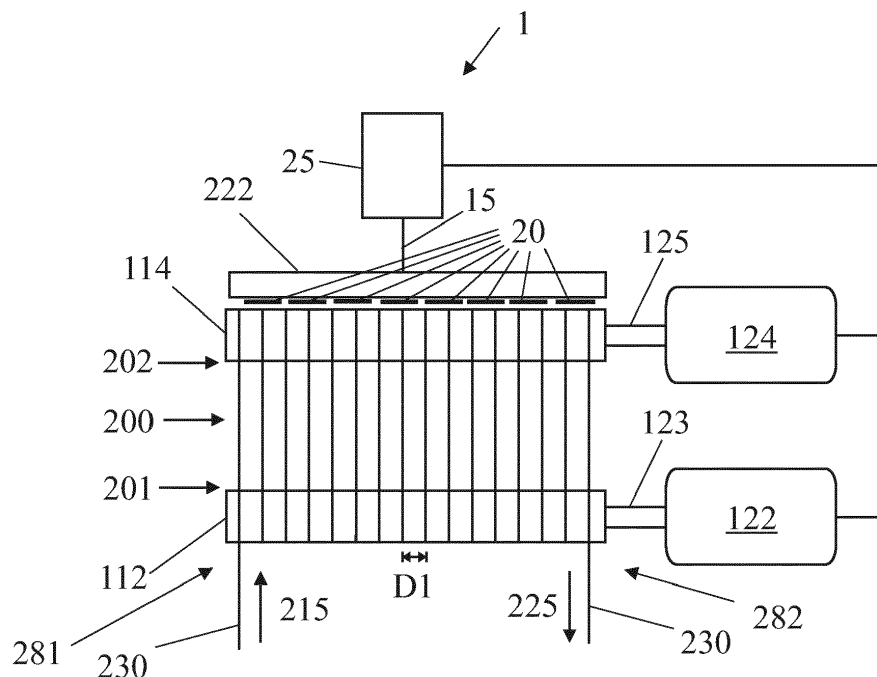


Fig. 2

Description

FIELD OF THE INVENTION

[0001] Embodiments of the present invention relate to a wire saw control system, in particular for controlling the temperature of a wire of a wire saw, and more particular for controlling the temperature distribution of a wire web; a wire saw; a method for controlling the temperature of a wire of a wire saw; and a method for operating a wire saw. Existing wire saws may be retrofitted with the wire saw control system according to the present invention. The present invention particularly relates to multi-wire saws. Wire saws of the present invention are particularly adapted for cutting or sawing hard materials such as blocks of silicon or quartz, e.g., for cutting silicon wafers, for a squarer, for a cropper or the like.

BACKGROUND OF THE INVENTION

[0002] Wire saws are used for cutting blocks or bricks, thin slices, e.g., semiconductor wafers, from a piece of hard material such as silicon. In such devices, a wire is fed from a spool and is both guided and tensioned by wire guide cylinders. The wire that is used for sawing is generally provided with an abrasive material. As one option, the abrasive material can be provided as slurry. This may be done shortly before the wire touches the material to be cut. Thereby, the abrasive is carried to the cutting position by the wire for cutting the material. As another option, the abrasive can be provided on the wire with a coating, e.g. as a diamond wire. For example, diamond particles can be provided on a metal wire with a coating, wherein the diamond particles are imbedded in the coating of the wire. Thereby, the abrasive is firmly connected with the wire.

[0003] The wire is guided and/or maintained tensioned by wire guides. These wire guides are generally covered with a layer of synthetic resin and are scored with grooves having very precise geometry and size. The wire is wound around the wire guides and forms a web or wire web. During the sawing process, the wire is moved with considerable speed. The web generates a force opposite to the advance of a support beam or a support holding the piece to be sawed. During sawing, the piece to be sawed is moved through the wire web wherein the speed of this movement determines the cutting speed and/or the effective cutting area that can be sawed within a given amount of time.

[0004] Generally, there is a tendency to use thinner wires in order to reduce the thickness of the cut and, thereby, to decrease the material wasted. There is also a desire to use diamond wires. These thinner wires and diamond wires are generally more susceptible to damage and, under high strain, the wires may break more easily. Further, there is a desire to increase the cutting speed for improving the throughput of wire saws. The maximum speed for moving the piece through the web and also the

maximum effective cutting area within a given amount of time is limited by several factors including wire speed, hardness of the material to be sawed, disturbing influences, desired precision, and the like. When the speed is increased, the strain on the wire is generally increased as well. Hence, the above-mentioned issues of avoiding damage, undue wear, failure or breakage of the wire are even more critical at higher sawing speeds.

[0005] The advantages of diamond wire, such as a higher achievable sawing speed, can be accompanied by aspects such as a lower resistance to breaking and a higher price per length. When employing diamond wire, measures can be taken to assure that the higher tendency to breaking does not lead to loss in production due to downtimes.

[0006] It is of utter importance to operate the wire saw in a manner so as to avoid or reduce varying sawing quality, varying sawing width, oscillations of the wire, or even breaking of the wire. In the worst case, if a break occurs, unwanted consequences may arise. The loose ends of the wire may move around in the machine in an uncontrollable manner, which might harm the wire guide system or other parts of the machine. Further, if the wire breaks and moves on, it will be torn out of the object to be sawed.

[0007] Still, the sawing process is subject to optimization in order to keep the costs as small as possible. Apart from avoiding inappropriate sawing quality due to, for example, varying wire properties, or even down times due to failure or breakage of the wire, the overall feed rate of the process has to be optimized in order to achieve a maximum through-put.

[0008] Known wire sawing normally includes settings with preset values for the feed rate of ingots through the web, the wire speed, the wire tension entering and exiting the web, the slurry flow-rate, and the slurry temperature. Once the cut start, the slurry density and optionally the slurry viscosity, the slurry temperature, and sometimes the motorization are monitored in order to allow the end-user to follow up process-related parameters. However, it turns out that this does not give sufficient information for optimizing the sawing process.

SUMMARY

[0009] In view of the above, a wire saw control system for operating a wire saw is provided. The wire saw is adapted for cutting a wafer. The wire saw control system is configured to control the temperature of a wire of a wire saw and includes a temperature sensor for measuring the temperature of the wire; and a controller for controlling at least one operating parameter of the wire saw based on the measured temperature.

[0010] According to one aspect, a wire saw including the wire saw control system as described herein is provided. In particular, the wire saw may be a multi-wire saw.

[0011] According to a yet further aspect, an existing wire saw may be retrofitted with the wire saw control sys-

tem as described herein. A method for retrofitting a wire saw is disclosed including providing a wire saw with the wire saw control system as described herein.

[0012] According to a yet further aspect, a method for controlling the temperature of a wire of a wire saw is provided. The wire saw is adapted for cutting a wafer. The method includes measuring the temperature of the wire, determining at least one operating parameter of the wire saw based on the measured temperature, and controlling the wire saw based on the at least one operating parameter.

[0013] According to a yet further aspect, a method for operating a wire saw is provided. The method for operating a wire saw includes the method for controlling the temperature of a wire as described herein.

[0014] Further advantages, features, aspects and details are apparent from the dependent claims, the description and the drawings.

[0015] 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.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] 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:

[0017] Fig. 1 shows a schematic perspective side view of a wire saw control system and a wire saw according to embodiments described herein.

[0018] Fig. 2 shows a schematic perspective top view of a wire saw control system and a wire saw according to embodiments described herein.

[0019] Fig. 3 shows a schematic perspective front side view of an excerpt of a wire saw control system and a wire saw according to embodiments described herein.

[0020] Fig. 4 shows a schematic perspective front side view of an excerpt of a wire saw control system and a wire saw according to embodiments described herein.

[0021] Fig. 5 shows a schematic diagram illustrating the measured temperature of the wire according to a first example.

[0022] Fig. 6 shows a schematic diagram illustrating the measured temperature of the wire according to a second example.

DETAILED DESCRIPTION OF THE INVENTION

[0023] Reference will now be made in detail to the various embodiments of the invention, one or more examples of which are illustrated in the figures. Within the following description of the drawings, the same reference numbers refer to same components. Generally, only the differences with respect to individual embodiments are described. Each example is provided by way of explanation of the invention and is not meant as a limitation of the invention. Further, features illustrated or described as part of one embodiment can be used on or in conjunction with other embodiments to yield yet a further embodiment. It is intended that the description includes such modifications and variations.

[0024] In the following description, a "wire saw control system", or simply "control system", may be understood as a system controlling some or all functions of a wire saw. In particular, this may be done by the controller of the wire saw control system. Generally, a wire saw as understood herein may be a cropper, a squarer, or a wafer cutting wire saw. Typically, the control system is connected to sensors in order to monitor parameters of the machine operation and the sawing process. The wire saw control system includes a temperature sensor and a controller for controlling one or more operating parameters of the wire saw based on the measured temperature. As will be discussed in more detail below, the wire saw control system may also be connected to actuators and devices to steer the electric motors which move the wire. Generally, the wire saw control system may include devices for interaction with an individual in order to receive commands and to report the status of the sawing process. The controller as described herein may also be connected to a computer network to be controlled directly or remotely by an individual or an automated system such as a computer.

[0025] According to embodiments described herein, the methods of operating a wire saw 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. These components can be one or more of the components: motors, wire break detection units, wire tracking devices, and the like, which will be described in more detail below.

[0026] Typically, the wire saw includes a wire guide for transporting and guiding the wire in a wire moving direction. The wire saw control system may provide control of the wire tension. 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 web may contain more than one working area which is defined as an area in which a sawing process is performed. Thus, according to some embodiments described herein, a wire web can have multi-

ple working areas that are formed by one or several wires.

[0027] For instance, as will be illustrated in more detail below with respect to the embodiment of Figs. 1 to 3, the wire saw may include two horizontally oriented wire webs, for instance, including two or four horizontally oriented working areas. In this case, sawing is performed by pushing an ingot in a vertical direction through the wire web defining the working area. Generally, and not limited to any specific embodiment described herein, the phrase "cutting a wafer" particularly includes "cutting an ingot into wafers". It is possible that sawing is undertaken at the same time at the upper working area and the lower working area. 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.

[0028] For modern wire saws like croppers, squarers, 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. According to some embodiments, the movement of the wire is only unidirectional, i.e., always in the forward direction. According to other embodiments, the movement may include a movement in the backward direction, in particular, the movement can be a back-and-forth movement of the wire in which the movement direction of the wire is amended repeatedly.

[0029] For unwinding the wire at the desired wire speed, the feed spool with unused wire 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.

[0030] In embodiments, which can be combined with other embodiments described herein, the wires may have different diameters depending on the type of device. In an embodiment pertaining to a squarer, the wire diameter may be from about 250 μm to about 450 μm , e.g., 300 μm to 350 μm . In an embodiment pertaining to a wafer cutting wire saw, the wire diameter may be from 80 μm to 180 μm , more typically from 120 μm to 140 μm . For all of the former, a twisting of the wire might increase the risk of breaking of the wire or of damaging the coating, so that a twist-free operation is advantageous.

[0031] By using diamond wire, 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, respectively from

20 $\mu\text{m/s}$ to 40 $\mu\text{m/s}$, typically from 28 $\mu\text{m/s}$ to 36 $\mu\text{m/s}$ for embodiments pertaining to a squarer.

[0032] 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.

[0033] The wire may be wound on wire guides, herein referred to also as guide cylinders, which are normally grooved with constant pitch, forming a horizontal net of parallel wires or wire web. The wire guides are rotated by drives that cause the entire wire-web to move at a relatively high speed of, for instance, 5 to 20 m/s. If desired, several high flow-rate nozzles may feed the moving wires with slurry. A slurry as understood herein refers to a liquid carrier with suspended abrasion particles (e.g., particles of silicon carbide). As mentioned, during the cutting action, the ingot may be pushed through the wire web. Alternatively, the ingot may be stationary while the wire web is pushed through it. A wire feed spool provides the required new wire and a wire take-up spool stores the used wire.

[0034] Normally, after traveling through the entire wire saw, the wire exits the operation area of the wire saw at a diameter reduced in comparison to its initial diameter before the sawing process. The wear in wire is process dependant. In particular, the higher the cut rate, the higher the resulting temperature, the higher the wire wear.

[0035] It is desired to optimize the productivity of the wire saw, such as the overall through-put or the feed rate, by reducing the number of changes of the spools, in particular of the wire feed spool providing unused wire, by operating the slicing process at a high but safe speed, and by avoiding down times due to wire failure. At the same time, it is desired to avoid unsatisfactory sawing results due to overheated wires and to maintain a safety margin with respect to wire breakage.

[0036] The inventors could find out that geometrical parameters, such as the mean wafer thickness and/or the wafer thickness variation, are degraded during the process of sawing several wafers, and in particular from one working area of the wire saw to the other. The degradation follows when reversing the wire's movement direction. Since the available information about today's sawing process is, as discussed in the background part of the present disclosure, rather limited, the reason behind this degradation was hard to discover.

[0037] Technically, the wire path, from loop to loop, slices one or more ingots at a working area, and is transported by the guide cylinders to further working areas, or the same working area again. Typically, the wire web slices one or more ingots at an upper working area, is then transported to the lower working area, and slices one or more ingots at the lower working area. Hereafter,

the wire is normally transported back to the upper working area. In the event that the movement direction is changed during sawing, instead of being transported to the next working area, the wire might be transported back to the working area from which it arrives.

[0038] During sawing, the wire is heated inside the ingots where the abrasion takes place, that is, typically inside the wafers. Thus, the wire heats up while cutting the ingot. Outside the ingot, the wire cools down by exchanging heat with its surroundings such as the slurry, air, and the guide cylinders or further wire guides.

[0039] When examining the wire's temperature, the inventors could find out that, according to known wire saw processes, the wire's temperature differs between one side of the working area, i.e. the side where the wire arrives from the feed spool, and the other side, i.e. the side where the wire is moved to the take-up spool afterwards. From a process point of view, if the wire temperature increases from one side of the wire saw to the other, temperature-related effects associated with the wire are changing. This leads to undesired effects with some of them being discussed in the following.

[0040] Firstly, an increase of the temperature leads to thermal elongation of the wire. However, an elongated wire, in particular an inhomogeneously elongated wire, has several drawbacks. In particular, the tension is released due to the elongation. It is, however, desired to avoid or at least to reduce different tensions within the wire web.

[0041] Secondly, an increased temperature may also amend the friction coefficient between the wire and the guide cylinders. Several effects may occur. For instance, the wire may stick to the guide cylinder for a cross-section exceeding the intended angle. For instance, a wire saw according to embodiments described herein may generally include four guide cylinders. Typically, each guide cylinder changes the wire's movement direction at 90°. Due to undesired sticking of the wire to the cylinder, it may occur that the wire adheres to one or more guide cylinders for more than 90°, for instance, 92°. Once the wire loses the adherence to the guide cylinder, it bounces back from the guide cylinder to the desired path. This "stick-slip" behavior may lead to vibrations and oscillations, to a loss of tension in the wire, and in the worst case, to wire breakage.

[0042] Thirdly, in those embodiments described herein wherein sawing is supported by a slurry, the wire's surface tension and wettability may depend on the temperature. Thus, the slurry transport by the wire to the ingot, in particular in terms of amount of slurry transported, may be different when the wire's temperature is increased as compared to a non-increased temperature. This, in turn, leads to a different abrasion property and may, in the worst case, result in inappropriate sawing results.

[0043] Thus, the present disclosure provides a temperature sensor for measuring the temperature at the wire saw. In particular, the present disclosure provides one or more temperature sensors capable of measuring

the temperature distribution over at least portions of the wire web, typically over the complete web from the wire's entrance to the wire's exit. A temperature distribution as understood herein includes at least two, typically at least five temperature values measured at different locations of the wire web. According to typical embodiments, the several temperature sensors are equally spaced apart from each other.

[0044] According to embodiments, the wire web temperature is measured by means of miniaturized temperature sensors. According to embodiments, the temperature sensors according to the present disclosure are mounted on a transverse rack that typically extends across the vertical portion of the web. A rack as understood herein typically includes a board, a solid body or a housing, which may be of plastic, metal or any other suitable material. According to embodiments, the measured information about the temperature, in particular about the temperature distribution over the web, is fed back to the controller of the wire saw in order to control one or more sawing parameters.

[0045] For instance, it may turn out that the wire's temperature increases over the web from the wire's entrance towards the wire's exit. That is, at least some of the undesired effects discussed previously might occur and result in inappropriate sawing results, or, in the worst case, even in an operation stop. Therefore, the controller for controlling at least one of the operating parameters of the wire saw based on the measured temperature could, for instance, reduce the wire's speed in order to optimize the process control and/or to avoid any such situation. Generally, and not limited to the present embodiment, reducing the wire's speed may be accompanied by reducing the feed rate, i.e., the speed of the table pushing the ingots through the wire web.

[0046] According to present embodiments, one or more of the optimum operation parameters are found in-situ during the sawing process. Typically, the one or more of the optimum operation parameters are constantly (for instance, in predetermined time intervals) updated in dependence of the actually measured wire temperature. Generally, and not limited to any embodiment, the wire saw may be operated in a closed-loop manner wherein the one or more operating parameters are constantly adapted based on the one or more measured temperatures.

[0047] For instance, it is possible to reduce the wire speed based on the measured temperature. It is also possible that the outcome of the temperature measurement is such that the operating parameter can remain unchanged because the wire temperature, in particular the wire temperature distribution over the web, is satisfactory.

[0048] According to aspects of the present disclosure, at least one series of temperature sensors typically mounted on a horizontal rack is provided. Typically, the rack is oriented perpendicular to the orientation of the wire. The one or more temperature sensors are typically

provided in one of the vertical sections of the wire path.

[0049] According to aspects, it is possible to measure the temperature distribution of the web. In particular, it is possible to measure how the web temperature of the wire evolves when the wire is moved from the wire's entrance to the wire's exit. Generally, and not limited to any particular embodiment, the wire's entrance and the wire's exit, as understood herein, can refer to the entrance and exit of the slicing room within which the wire saw is positioned and the sawing process is performed. From a more general viewpoint, however, the wire's entrance refers to that side of the wire web where unused wire is supplied, and the wire's exit refers to that side of the wire web after sawing.

[0050] In other words, typical embodiments of the present disclosure provide measuring the actual wire temperature evolution throughout the web from the entrance to the exit. This information can be used to control one or more of the operating parameters, in particular, to modify one or more of the operating parameters. For instance, the one or more of the operating parameters may be chosen from the table speed, the wire speed, the slurry flow rate, and/or the slurry temperature. It is also possible that the wire saw provides an inlet for a cooled gas, such as compressed and/or cooled air. If gas is used for cooling the wire, during expansion of the gas, typically, the Joule-Thomson effect is employed. Apart from air, further gases can be utilized. Hence, a further operating parameter can be the input amount and/or temperature of the cooling gas. The one or more operation parameters are typically controlled such that the temperature of the wire web throughout the entire web is maintained at a constant temperature or follows a selected trend.

[0051] Fig. 1 shows a schematic side view of a wire saw 100 including the wire saw control system 1 according to embodiments, and Fig. 2 shows a schematic top view of the wire saw 100 including the wire saw control system 1 according to embodiments. The wire saw control system 1 includes at least one temperature sensor 20 measuring the temperature of the wire. The temperature sensor 20 is typically connected to a controller 25 via a cable or wireless connection 15. The controller 25 is configured to control the sawing process.

[0052] The wire saw 100 has a wire guide device including four wire guide cylinders 112, 114, 116, 118. Typically, wire guide cylinders 112, 114, 116, 118 are covered with a layer of synthetic resin and are scored with grooves having very precise geometry and size. The distance between the grooves, or the pitch of the grooves, determines the distance D1 between two adjacent strings or lines of wire 230. The distance D1 minus the wire's diameter sets an upper limit for the thickness of the slices cut by the wire saw.

[0053] For example in the event that a third media such as slurry is used, the slices may be about 10 μm to 40 μm thinner than the difference of the distance between D1 and the wire's diameter. Typically, the wire thickness is between 120 μm and 140 μm while distance D1 is from

230 μm to 450 μm , typically in the range of 330 μm to 370 μm . As an example, the grooves may have a pitch or distance of below 300 μm . According to some embodiments, which can be combined with the other embodiments described herein, the pitch or distance of the groove results in spacing between adjacent wires of about from 110 μm to 350 μm , typically 190 μm to 250 μm . In light of the above, embodiments described herein may provide a large cutting area and a high cutting rate

[0054] According to different embodiments, which can be combined with other embodiments described herein, the pitch, i.e. the distance between grooves, can be in a range of 330 μm to 370 μm , for example 350 μm or below; the distance between adjacent wires can be in a range of 110 μm to 350 μm , for example, 190 μm to 250 μm or even 220 μm or less; and/or the resulting wafer thickness can be in a range of 120 μm to 250 μm , for example, 180 μm to 220 μm or even 200 μm or below. Thereby, it should be noted that the groove pitch and the groove geometry is typically adapted to a wire thickness and wire type and is adapted to the wafer thickness.

[0055] Furthermore, each wire guide cylinder 112, 114, 116, 118 may be connected to a motor or drive. In order to reduce the complexity of the figures, in Fig. 1 only motor 126 is shown, and in Fig. 2 only motors 122 and 124 are shown. The motors are connected to the respective guide cylinders. For instance, motor 122 may be connected to the guide cylinder 112, motor 124 may be connected to the guide cylinder 114, and motor 126 may be connected to the guide cylinder 116. Furthermore, the motors 122, 124, 126 may be controlled by the controller 25 via a cable or wireless connection, such as connection 16 illustrated in Fig. 1.

[0056] According to some embodiments, each guide cylinder is driven by a motor. According to embodiments, each motor may be adapted for performing a back-and-forth movement of the wire. It is also possible that the movement direction of the wire is not altered during sawing as illustrated by the arrows referred to with numbers 215, 225 in Fig. 1. In embodiments, as those shown in Figs. 1 and 2, the wire guide cylinders 112, 114, 116, 118 each are directly driven by motors. Generally, each wire guide cylinder may be directly mounted to a motor shaft of the corresponding motor, such as shafts 123, 125 in Fig. 2. In some embodiments, one or more of the motors are water-cooled.

[0057] During the cutting action, one or more ingots 302, 304, 306, 308 may be pushed through the wire web in order to slice it. This is indicated by the arrows sandwiched between ingots 302, 304, and 306, 308, respectively. Typically, the one or more ingots are supported by a table (not shown) which can be moved with a speed which is called "table speed" herein. Alternatively, the ingots 302, 304, 306, 308 may be stationary while the wire web is pushed through it. According to embodiments, the one or more ingots are sliced into a multitude of wafers, such as at least 500 or even more. Typical lengths of the ingots are in the range of up to 250 mm,

in particular in the case of multi-crystalline Silicon, and up to 500 mm, in particular in case of mono-crystalline Silicon.

[0058] According to typical embodiments, a wire feed spool 134 is provided with a wire 230 reservoir. The wire feed spool 134, if still complete, typically holds several hundred kilometers of wire. During operation of the wire saw, the wire is fed to the sawing process by the wire feed spool 134. The wire's entrance is denoted with reference number 281 herein. For instance, the wire saw could be positioned within a slicing chamber and the wire could have to pass a lock. The same can apply to the wire's exit which is denoted by reference number 282 herein.

[0059] The wire 230 is fed to the guide cylinders 112, 114, 116, 118 from the wire feed spool 134. A wire take-up spool 138 may be provided on which the used wire 230 is recoiled. In the embodiments, the rotational axis of wire feed spool 134 and take-up spool 138 are parallel to the rotational axes of the wire guide cylinders 112, 114, 116, 118. Accordingly, typically no deflection pulley or similar device is required for feeding the wire to the wire guide 110. Due to the zero degree angle on the wire, the risk of wire breakage can be reduced. Typically, further devices such as low inertia pulleys (not shown) and tension arms (not shown), for wire tension regulation with optional digital coders on the tension arms, may be provided.

[0060] During operation of the wire saw, one or more motors, such as motor 126, may drive the wire guide cylinders 112, 114, 116, 118 so that the wire guide cylinders rotate about their longitudinal axis. In those embodiments where the wire is moved in a back-and-forth fashion, the forth movement may take place for a first time interval or a first distance that is equal to or larger than the second time interval or second distance for which the back movement of the wire takes place. In the case of a larger first time interval or first distance, despite an alternating back-and-forth movement of the wire, the wire is slowly transported from the wire feed spool 134 to the wire take-up spool 138.

[0061] The wire 230 is spirally wound about the wire guide cylinders 112, 114 and forms a layer of parallel wires between the two wire guide cylinders. This layer is typically referred to as a wire web 200. In the embodiments illustrated, four wire webs are provided. Sawing takes place using at least one wire web, typically using two wire webs at the same time (as illustrated in Fig. 1). The number of parallel wire portions typically corresponds to the number of cuts. For instance, the wire may be wound up in such a way that the resulting wire web includes 100 wire portions arranged in parallel. A wafer pushed through this web of 100 wires is sliced into 101 pieces.

[0062] In one embodiment, one of the motors, e.g. motor 126, serves as a master motor whereas the remaining motors connected to the other guide cylinders 112, 114, 118 serve as slave motors. In other words, master motor 126 may control the operation of the slave motors so that

the slave motors follow master motor 126. Thus, synchronicity of operation of the motors provided is improved and can be maintained during the sawing process.

[0063] According to some embodiments, which can be combined with other embodiments described herein, two or more spools are provided for forming at least one wire web. For example, two, three or even four spools can be used to provide the wire. Thereby, according to different embodiments a method of sawing thinner wafers, e.g., in a range of 100 μm to 170 μm can be provided. Typically, the thinner wafers can also be sawed at higher speed, such as having a material feed rate is in the range of 2 $\mu\text{m/s}$ to 12 $\mu\text{m/s}$, typically about 5 $\mu\text{m/s}$ to 7 $\mu\text{m/s}$.

[0064] Compared to a single wire system, the load on each wire can be reduced by having two or more spools and, thus, two or more wires. Generally, for a single wire web the load is increased as compared to a dual wire web due to the increase of the wafer surface area to wire surface area. The increased load can result in lower cutting speeds. Accordingly, using two or more wires can increase the cutting speed, e.g., such that an effective cutting area or a cutting area rate of 12 m^2/h or more can be provided.

[0065] The top perspective of Fig. 2 allows the reader to recognize that a plurality of temperature sensors 20 may be provided according to embodiments of the present disclosure. For instance, at least five or even at least ten temperature sensors may be provided. Typically, the temperature sensors are aligned in a row along the rack 222. The rack supporting the temperature sensors 22 is typically oriented perpendicular to the wire's orientation. Each temperature sensor may be configured to measure the temperature of one wire portion. According to other embodiments, and not limited to the embodiment of Fig.2, each temperature sensor may be configured to measure the temperature of several parallel wire portions.

[0066] According to typical embodiments, the one or more temperature sensors are noncontact sensors, i.e., they are configured to measure the temperature without contacting the wire. In particular, the temperature sensor may be configured to register radiation in the infrared range, and shall be called infrared sensor herein. For instance, the infrared sensor can be an infrared camera. The temperature sensor, such as an infrared sensor or camera, may additionally be equipped with an analysis unit for analyzing the measurement, in particular, for deducing the actual temperature of the wire from its emitted radiation. For instance, and not limited to this example, the temperature may be calculated according to the Stefan-Boltzmann law from the measured infrared power radiated by each wire portion.

[0067] However, according to other embodiments, it may be sufficient to measure the emitted power and to control the one or more of the operating parameters based on this outcome. Given the relation between emitted power P and temperature T according to $P = \sigma T^4$ (with σ being the Stefan-Boltzmann constant), measuring

the emitted power or any other temperature related value shall generally be included by the phrase "measuring the temperature" according to the present disclosure. Accordingly, a temperature sensor as understood herein may be any sensor capable of measuring a temperature, an emitted radiation or power, or any other temperature related physical quantity. "Temperature related physical quantities" as understood in this context shall refer to quantities that have a known relation to the temperature, such as the the power (via the Stefan-Boltzmann law).

[0068] The analysis of the sensor measurement may be done by the controller 25. In the embodiments wherein an infrared sensor covers several wire portions, the analysis unit (or the controller) may be configured to assign the respective measured temperature to the respective wire portion.

[0069] According to embodiments, the one or more temperature sensors, in particular the infrared temperature sensor, may be equipped with means for cleaning the optical channels, such as by air purging. Thereby, it is possible to operate the saw according to the present disclosure in a maintenance-free or maintenance-low manner.

[0070] According to embodiments, the information gathered about the temperature is fed back to the controller in a continuous loop. It is generally possible to use intelligent signal processing which, according to the present understanding, particularly includes the use of mathematical models in order to predict the further temperature evolution. For instance, the controller could be adapted to apply a linear regression based on the measured temperature values in order to predict the temperature behavior in dependence of possible further adjustments of the one or more operating parameters.

[0071] For instance, a proportional-integral-derivative controller (PID controller) may be used as a generic control loop feedback mechanism (controller). The PID controller might calculate an "error" value as the difference between the measured temperature and a desired set-point. The controller attempts to minimize the "error" by adjusting the at least one operating parameter.

[0072] Fig. 3 shows a front view of an excerpt of an embodiment of a wire saw control system 1 for a wire saw. In Figs. 3 and 5, for illustration purposes, wire portions in front of the device are shown (as dotted lines). The temperature sensors 20 cannot be recognized in the given perspective because they are located behind the rack 222.

[0073] It is typical that the controller 25 initiates a reaction if the temperature measurement is not satisfactory. For instance, the absolute value of the temperature measurement can be too high. Furthermore, the temperature distribution throughout the web can be too irregular, e.g., the temperature at the exit's side can inacceptably be higher than at the entrance's side of the wire web. Such a reaction can generally and not limited to the present embodiment be a reduction of the wire speed and/or table speed. Alternatively or additionally, such a

reaction can be an increase of the amount of slurry and/or a decrease of the temperature of the slurry provided to the wire. Generally, and not limited to the present embodiment, the wire saw of the present disclosure may have one or more slurry nozzles for providing the wire with slurry.

[0074] The temperature sensor is typically positioned adjacent to the wire portion which shall be monitored or supervised. Typically, the one or more temperature sensors are positioned adjacent to a wire web portion that is not used as a working area. In particular, let the two horizontally oriented webs be used for the sawing processes, then the temperature sensor is typically positioned at one or both of the vertically arranged wire webs. According to embodiments, the at least one temperature sensor is positioned between two working areas.

[0075] According to typical embodiments, a multitude of temperature sensors is provided. This particularly applies to wire saws that include two or more wires. In such a case, typically, at least one temperature sensor per wire, typically several (at least two) temperature sensors per wire are provided. In operation, each wire is measured by the at least one temperature sensor. Generally, and not limited to the embodiment including two or more wires, the two or more temperature sensors may be operated by the same controller 25.

[0076] According to yet further embodiments, which can be combined with other embodiments, thinner wires can be used, for example wires having a thickness of maximally 120 μm or maximally 80 μm . Thereby, the cutting area is increased. Typically, in the case of sawing supported by a slurry, the wire thickness reduces during usage of the wire. Thus, if a single wire is used for a larger cutting area, there is a risk that the wire is thinned fast until breakage of the wire results. Accordingly, the use of two wires to build a wire web, for example, a continuous wire web, on the one hand reduces the load on the wire and thereby allows for higher cutting speeds and, on the other hand, allows for thinner wires, which allows for smaller wire distance and thereby increased cutting area.

[0077] Generally, and not limited to any embodiment, each temperature sensor is adapted to inspect at least one wire portion. According to typical embodiments, in particular in the case of infrared sensors, each sensor is capable of measuring the temperature or a temperature related physical quantity such as the radiation of several wire portions. In particular, each temperature sensor may cover a multitude of wire portions, typically from 4 to 100 parallel wire portions, more typically from 20 to 50 wire portions. Typically, the multitude of temperature sensors, such as two, three, or more, are substantially arranged in a row.

[0078] According to embodiments, it is desired to gather information about the temperature distribution of the web, or a power or radiation distribution of the web. Hence, in this case, it is typical to provide at least two temperature sensors. For instance, as shown in Fig. 4, one temperature sensor 20 may be provided at the en-

trance side to gather information about the temperature of a wire portion or several wire portions prior to or at the beginning of the slicing (as from wire's viewpoint). In addition, it is possible to position another temperature sensor 20 at the exit side of the wire saw to gather information about the temperature of the wire after a multitude of cuts. An extra analysis unit (not shown), as described previously, or the controller 25 may then evaluate the measurement results in order to find out the temperature increase from the entrance towards the exit.

[0079] In embodiments described herein the distance between the wires is from 110 μm to 350 μm . The distance between the temperature sensor 20 and the wire 230 portions is dependent on a plurality of factors, e.g. of the employed type of temperature sensor, their technical specifications, the type and thickness of wire etc. Typically, the distance is typically from 0.2 mm to 20 mm, more typically from 1 mm to 10 mm.

[0080] In an embodiment, the controller causes the operation of the wire saw to change by at least one operation parameter in case of an inappropriate temperature and/or temperature distribution. For exceptional temperatures, it is furthermore possible that the camera control unit additionally signals an alarm, such as by means of a beeper, a horn, a loudspeaker or a light emitting device. The unit may also send a signal to an external device via a computer network or the like. The location of an overheated wire portion or the complete wire web temperature distribution may be displayed graphically via a graphical representation of the wire web including the plurality of wire portions.

[0081] In an embodiment, the controller is adapted to distinguish between different grades of inappropriate temperatures and/or temperature distribution. The controller or an additional analysis unit is, in embodiments, adapted to decide if the measured temperature and/or temperature distribution should result in a change of one or more of the operating parameters of the wire saw, or not.

[0082] Typically, a deviation from the desired temperature and/or temperature distribution up to a first threshold might cause the controller to keep the operating parameters unchanged. A deviation from the desired temperature and/or temperature distribution of more than a first threshold value might cause a first change of at least one operating parameter wherein the first change is typically comparably small. A deviation from the desired temperature and/or temperature distribution of more than a second threshold value might cause a second change of an operating parameter wherein the second change is typically larger than the first change and so on.

[0083] A change of one or more operation parameters may include one or more of the following actions. Firstly, according to embodiments, the wire speed, possibly in combination with the table speed, may be reduced as a reaction. Secondly, according to embodiments, another reaction may be to increase the amount of slurry provided to the wire. Thirdly, according to embodiments, another

reaction may be to reduce the temperature of the slurry provided to the wire. Fourthly, another reaction may be to increase the amount of cooling air or gas directed to the wire for cooling down. Lastly, in the case of an extreme temperature change, which is generally desired to be avoided in practice by the previously described actions, the operation may be halted.

[0084] It is possible to define threshold values that might be stored in a data storage unit that may be part of or associated with the wire saw control system, such as the controller thereof. For instance, controller 25 illustrated in the figures may be provided with such a data storage (not shown). The wire saw control system may be adapted for comparing the measured temperature values of the wire with the stored threshold values. In dependence of the result, an action may be triggered.

[0085] For instance, a set of threshold values may be defined including, for example, a first threshold value, a second threshold value and a third threshold value. Whereas the first threshold value might refer to a temperature sensor position at or close to the entrance side, the second threshold value might refer to a temperature sensor position in the middle of the wire web, and the third threshold value might refer to a temperature sensor position at or close to the exit side of the wire saw. Once any of the threshold values is exceeded by the actually measured temperature values, a reaction of the controller, such as a redefinition of an operating parameter such as the wire speed and/or table speed, may be triggered. Generally, and not limited to the present embodiment, the wire and/or table speed may be reduced by at least 3%, typically 5% or even more.

[0086] According to further embodiments, the measured temperatures at several positions of the web are compared and, maybe independent of their absolute values, a reaction is triggered once the relative difference of the measured temperatures exceeds a threshold value. That is, the temperature distribution can be analyzed and the control of at least one operating parameter may be based on differences in the temperature distribution.

[0087] Whereas the embodiments described so far have referred to discrete threshold values, it is generally possible to define a function that relates at least one operation parameter of the wire saw, such as the wire speed, to the measured temperature or measured temperature distribution (or an equivalent distribution, e.g., a emitted power distribution). For example, let $t(x)$ be the measured temperature in dependence of the location x within the wire web, and let v be the speed with which the wire saw is operated, then the wire saw shall be operated with a speed that is a function of the temperature function $t(x)$, that is, according to $v = f(t(x))$.

[0088] For instance, in the event of large differences of the temperature within the web, i.e., $dt(x)/dx \gg 0$, the speed of both the wire and the table may be reduced. In the event of a substantially even temperature distribution, i.e. $dt(x)/dx \approx 0$, the speed may be kept constant or even increased. Obviously, these exemplary relations typically

relate to situations below that maximum speed with which the wire saw can be normally operated. Furthermore, instead of the speed, further operating parameters as described herein can be used.

[0089] Hence, the present disclosure provides a measurement of the actual wire temperature as a result of an on-going sawing process. It generally allows undertaking immediate actions, in particular, to reduce larger temperature discrepancies within the wire web. The temperature sensor is typically adapted to allow for a fast acquisition system in real-time. For instance, in the event of an infrared camera, it may be adapted to allow for a fast picture acquisition system in real-time. The information obtained may then be used to maintain the operating parameters, to slow down, or to accelerate the table speed and/or the wire speed. It is possible that dedicated software displays the temperature and/or temperature distribution and provides means for automatic machine regulation.

[0090] Fig. 5 illustrates the temperature T of a portion of the wire in dependence of the time t according to a first example. The wire portion's temperature before the first cut (including two adjacent ingots to be sliced in one working area, as shown in Fig. 1) is at a first temperature T_1 . The temperature during the first cut is increased up to the temperature T_2 due to the abrasion. When the wire portion is transported to the next working area, the wire can cool down to a temperature between T_1 and T_2 . Then, the wire portion is used for another cut (once more two ingots at one working area) so that the temperature increases to T_3 which is larger than T_2 . After this slicing, the wire is moved to the next working area. During the time of movement it can cool down, however, it does not cool down sufficiently. Hence, during the next cut (two ingots at one working area), the wire's temperature is increased to T_4 which is again larger than T_3 .

[0091] The described first example has the drawbacks as described previously. In particular, the wire's temperature is increased throughout the web so that the temperature distribution is inhomogeneous. In particular, the risk of thermal expansion and an inappropriate amendment of the friction coefficient can harm the sawing process.

[0092] Hence, according to embodiments of the present disclosure, the temperature of the wire is measured at various locations. For instance, the temperature can be measured at the location between two working areas which would correspond to times t_{m1} , t_{m2} , and t_{m3} in the temperature-time-diagram of Fig. 5. Since the temperature at these locations steadily increases ($t_{m3} > t_{m2} > t_{m1}$), the controller could amend at least one operating parameter of the wire as a reaction, for instance, it could increase the provided amount of slurry by 10% in order to avoid such a temperature increase.

[0093] Fig. 6 shows a second example of a temperature-time-diagram of a wire portion during the sawing process wherein the method as described herein is applied in order to avoid a situation as shown in the first example. Although this example refers to a sawing proc-

ess of two ingots in one working area at the same time, it is to be understood that the described embodiments include sawing of any other number of ingots in one working area at the same time, in particular of one ingot. As in the first example, the wire portion has a temperature T_1 before the first cutting takes place. When the wire portion is used for the slicing (two ingots in one working area), its temperature goes up to temperature T_2 due to the abrasion. After that, the wire is transported to the next working area and can cool down during the transport. In the present example, it cools down to temperature T_1 again. Thus, the next cut heats the wire up again but only to temperature T_2 . This process is continued. As it is apparent for the skilled reader, the temperature distribution over the wire web is thus constant. Temperature sensors as discussed herein at positions corresponding to times t_{m1} , t_{m2} , and t_{m3} in Fig. 6 all measure the same or highly similar temperature.

[0094] Hence, the second example refers to a situation in which the controller can keep the operating parameters as they are set if a constant temperature distribution is desired. Once the illustrated curve changes, the controller might need to amend one or more operating parameters of the wire saw.

[0095] In summary, the present disclosure allows to monitor the temperature evolution of the wire from loop to loop across the web from the entrance side to the exit side. It allows adapting the slicing process for supporting a steady thermal balance (i.e. a constant temperature) or a prescribed wire temperature profile across the web. It furthermore allows qualifying cooling efficiency of the wire web by the cooling nozzles and/or additional cooling capabilities such as cooled compressed air.

[0096] 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 saw control system (1) configured to control the temperature of a wire (230) of a wire saw (100), the wire saw being adapted for cutting a wafer (302, 304, 306, 308), the wire saw control system comprising:
 - a) a temperature sensor (20) for measuring the temperature of the wire (230);
 - b) a controller (25) for controlling at least one operating parameter of the wire saw based on the measured temperature.
2. The wire saw control system according to claim 1, wherein the temperature sensor (20) is an infrared sensor.

3. The wire saw control system according to any of the preceding claims, comprising a plurality of temperature sensors (20), optionally at least five temperature sensors. 5
4. The wire saw control system according to any of the preceding claims, wherein the plurality of temperature sensors are mounted to a rack (222), wherein the rack is preferably aligned perpendicular to the wire orientation. 10
5. The wire saw control system according to any of the preceding claims, wherein the wire forms a wire web (200), and the wire saw control system is configured to measure a temperature distribution of the web. 15
6. The wire saw control system according to claim 5, wherein the at least one operating parameter is amended when the temperature difference within the temperature distribution exceeds a threshold value. 20
7. The wire saw control system according to any of the preceding claims, wherein the at least one operating parameter is selected from the group consisting of wire speed, table speed, slurry flow rate, slurry temperature, cooling air flow rate, and cooling air temperature. 25
8. A wire saw (100) comprising the wire saw control system (1) according to any of the preceding claims. 30
9. A method for controlling the temperature of a wire of a wire saw, the wire saw being adapted for cutting a wafer, the method comprising: 35
 - a) measuring the temperature of the wire;
 - b) determining at least one operating parameter of the wire saw based on the measured temperature; and
 - c) controlling the wire saw based on the at least one operating parameter. 40
10. The method for controlling the temperature according to claim 9, wherein the operating parameter is selected from the group consisting of wire speed, table speed, slurry flow rate, slurry temperature, cooling air flow rate, and cooling air temperature. 45
11. The method for controlling the temperature according to any of claims 9 or 10, wherein the temperature is measured by measuring the infrared radiation emitted by the wire. 50
12. The method for controlling the temperature according to any of claims 9-11, wherein measuring the temperature of the wire includes measuring the temperature of the wire at two or more, optionally five or more wire positions. 55
13. The method for controlling the temperature according to any of claims 9-12, wherein the wire forms a wire web, and measuring the temperature of the wire includes measuring the temperature distribution of the wire web.
14. The method for controlling the temperature according to claim 13, wherein the at least one operating parameter is amended when the temperature difference within the temperature distribution exceeds a threshold value.
15. A method for operating a wire saw comprising the method for controlling the temperature of the wire according to any of claims 10-14.

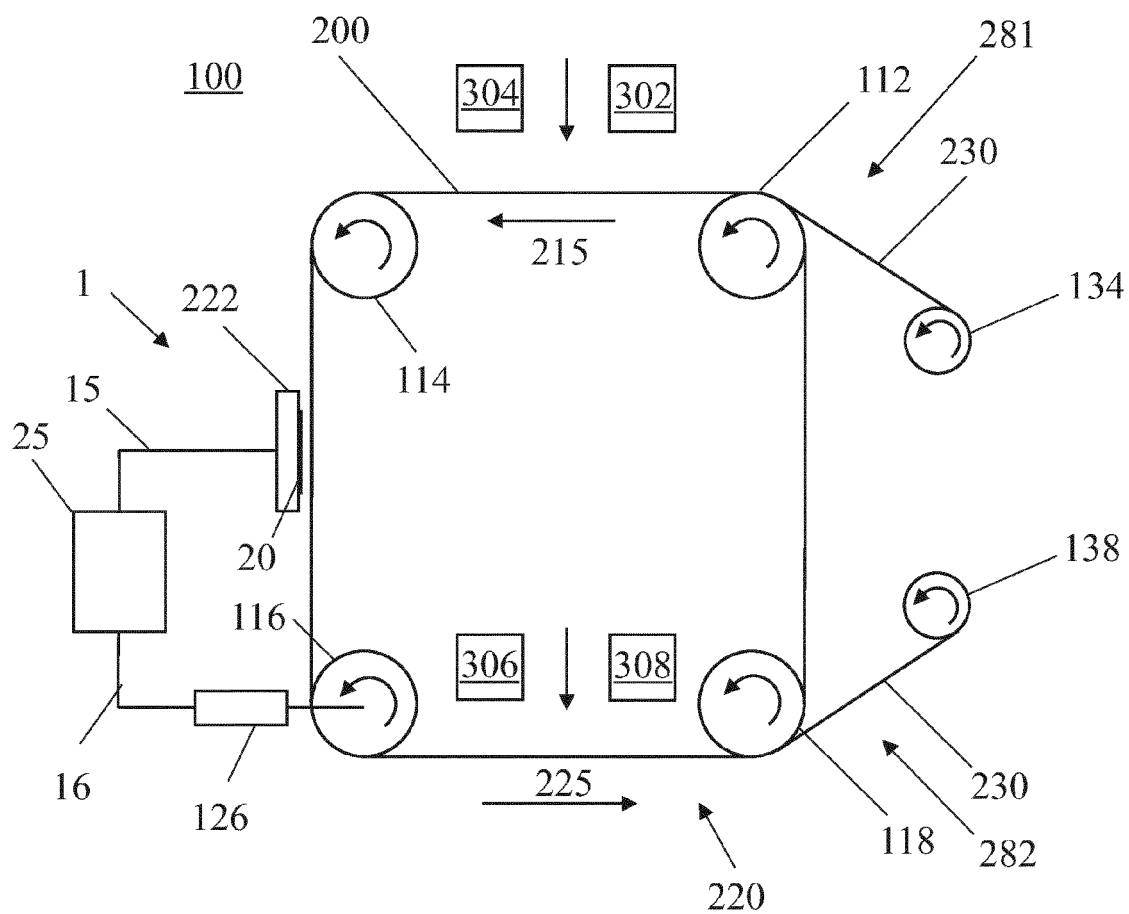


Fig. 1

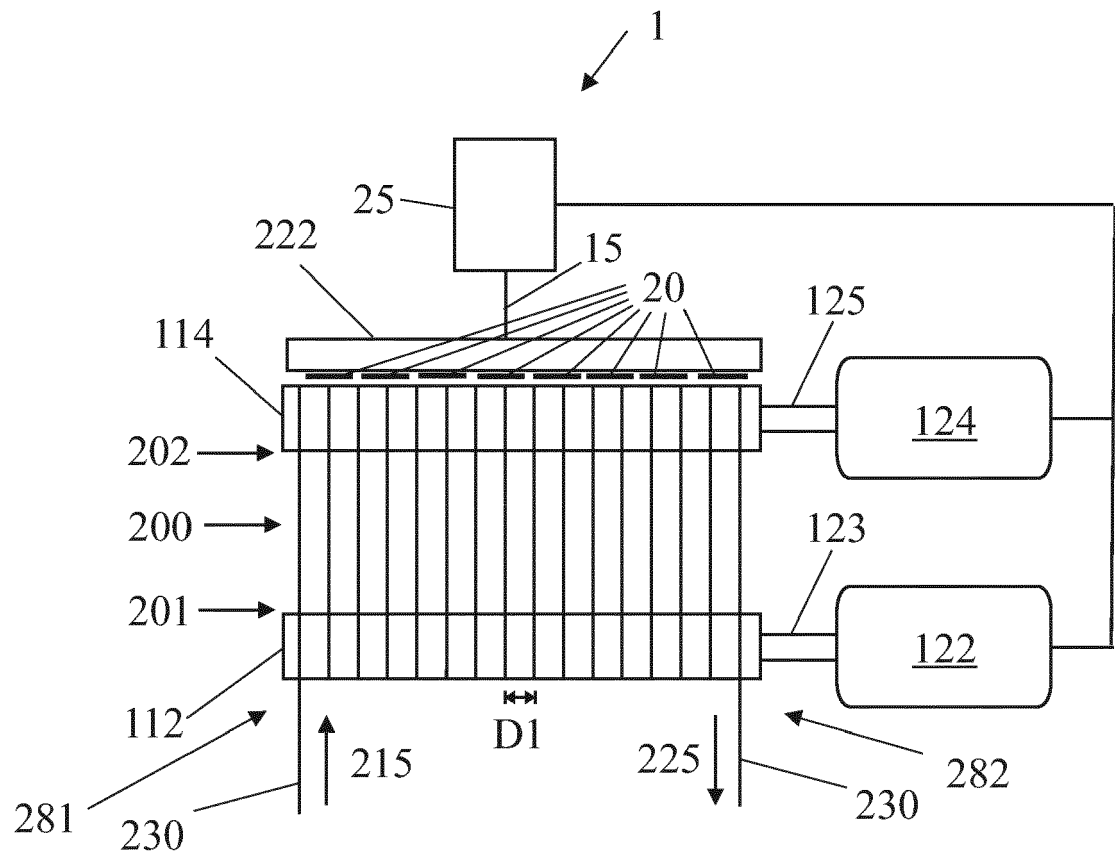


Fig. 2

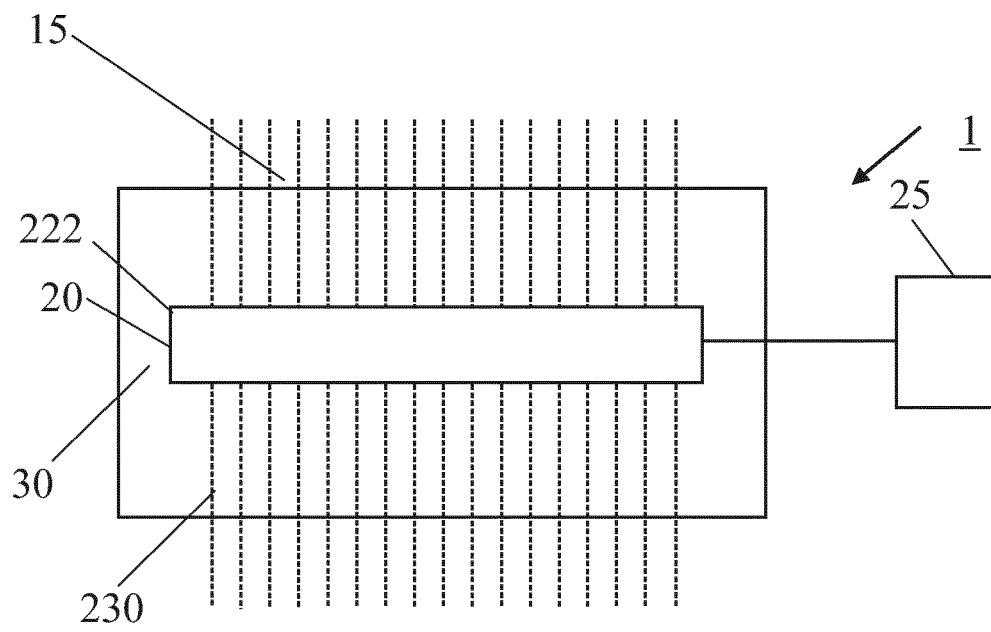


Fig. 3

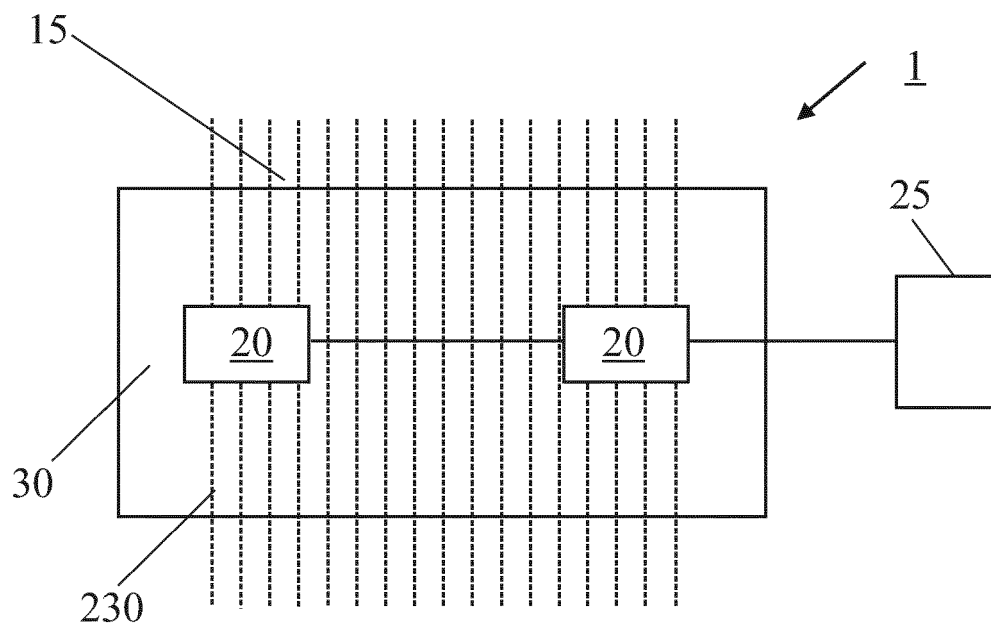


Fig. 4

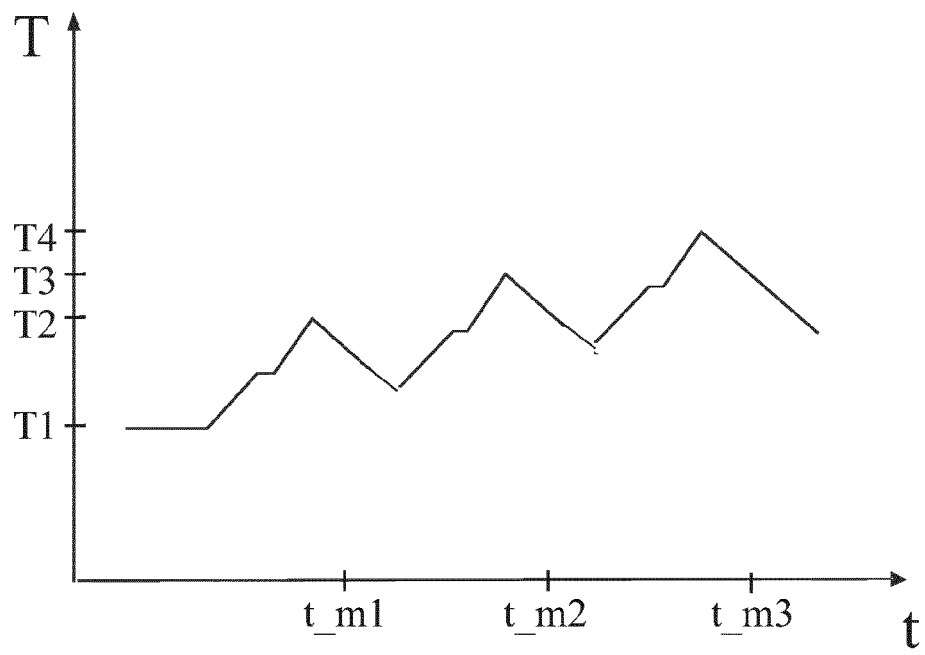


Fig. 5

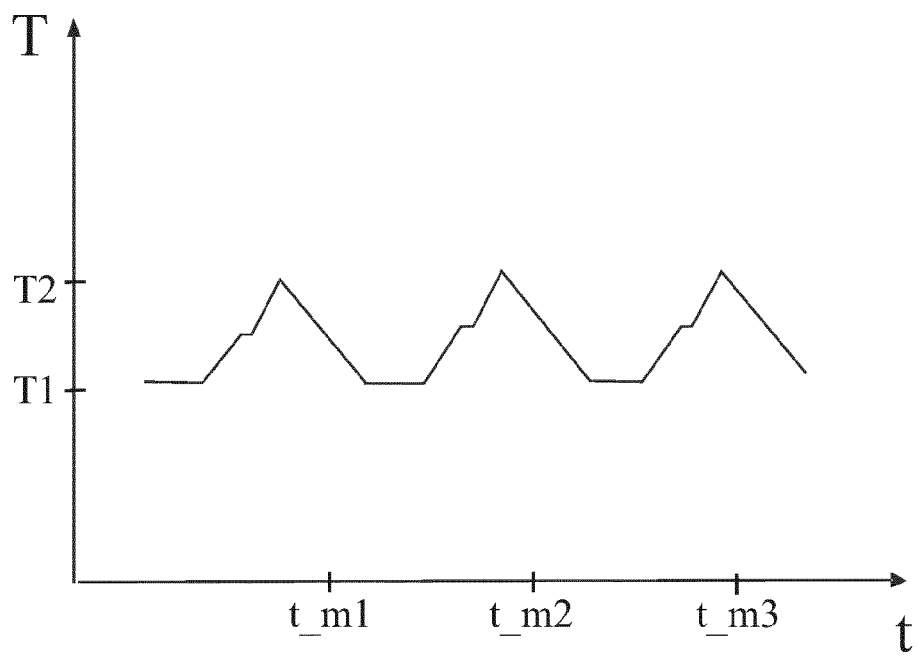


Fig. 6



EUROPEAN SEARCH REPORT

Application Number
EP 11 18 7103

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	JP 7 001442 A (SHINETSU CHEMICAL CO) 6 January 1995 (1995-01-06) * abstract *	1,9	INV. B28D5/00
A	----- US 6 357 330 B1 (DASS M LAWRENCE A [US] ET AL) 19 March 2002 (2002-03-19) * abstract *	1,9	
A	----- US 2011/126813 A1 (HODSDEN JOHN B [US] ET AL) 2 June 2011 (2011-06-02) * abstract *	1,9	
			TECHNICAL FIELDS SEARCHED (IPC)
			B28D
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 2 May 2012	Examiner Vaglianti, Giovanni
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			

 1
EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 11 18 7103

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

02-05-2012

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
JP 7001442	A	06-01-1995	JP	2967896 B2	25-10-1999
			JP	7001442 A	06-01-1995

US 6357330	B1	19-03-2002	NONE		

US 2011126813	A1	02-06-2011	NONE		
