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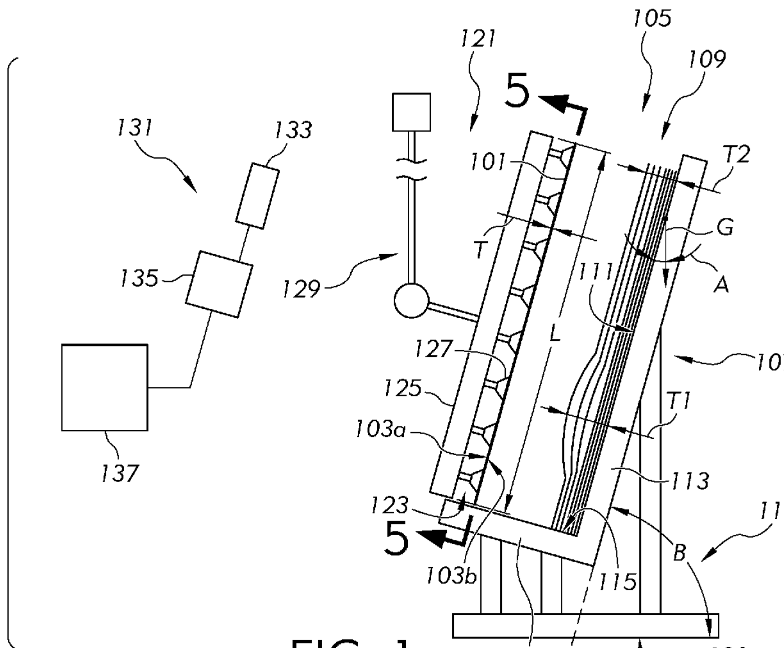

FIG. 1

(57) Abstract: Substrate support apparatus can comprise a monitoring device configured to monitor a position of a suction device of a plurality of suction devices. In some embodiments, substrate packaging apparatus for packaging a leaning stack of substrates can comprise a substrate support structure and a compacting device. In some embodiments, methods can comprise stacking a plurality of substrates to form a leaning stack of substrates, imaging a feature of the leaning stack of substrates, and determining a characteristic of the leaning stack of substrates using information obtained during the imaging. In some embodiments, methods can comprise stacking an additional substrate on a leaning stack of substrates and determining a characteristic of the leaning stack of substrates with the substrate support apparatus while the substrate support apparatus engages the additional substrate.

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SUBSTRATE APPARATUS AND METHODS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 63/049,852 filed on July 9, 2020, the content of which is relied upon and incorporated herein by reference in its entirety.

FIELD

[0002] The present disclosure relates generally to substrate apparatus and methods and, more particularly, to substrate support apparatus, substrate packaging apparatus and methods.

BACKGROUND

[0003] It is known to store substrates as a leaning stack of substrates. Typically, a leaning stack of substrates are produced by successively placing individual substrates against one another until the stack is complete. In some embodiments, the leaning stack of substrates may be packaged for shipment, storage and/or handling. During the process of stacking, undesirable fanning may occur wherein one or more of the substrates in the leaning stack of substrates is not parallel with one or more other substrates in the stack of substrates such that a thickness at one location of the leaning stack of substrates is different than a thickness at another location of the leaning stack of substrates. There is a desire to control fanning of the leaning stack of substrates to maintain the proper positioning of all of the substrates in the leaning stack and/or to protect one or more substrates in the leaning stack of substrates from being damaged due to excessive stress concentrations that may be inherent due to excessive fanning.

SUMMARY

[0004] The following presents a simplified summary of the disclosure to provide a basic understanding of some embodiments described in the detailed description.

[0005] In some embodiments, the substrate support apparatus used to stack the substrate on a leaning stack of substrates can also be used to determine a characteristic (e.g., a fanning) of the leaning stack of substrates. This dual functionality can allow the characteristic to be determined with the substrate support apparatus as each substrate is stacked on the leaning stack of substrates with the substrate support apparatus. Thus, determining the characteristic can be performed in a reduced amount of time and can be performed after each additional substrate is stacked.

[0006] In some embodiments, a compacting device can be used to reduce fanning while stacking the substrates to form the leaning stack of substrates. In some embodiments, a single compacting cycle may be provided that can be beneficial to reduce the fanning while minimizing the time needed to conduct the compacting procedure. In further embodiments, the compacting procedure can comprise two compacting cycles after each substrate is stacked. Two compacting cycles can provide even further reduced fanning when compared to a single compacting cycle. The reduced fanning can also be achieved with reduced compacting pressure during each of the two compacting cycles, thereby reducing potential stress fractures compared to a single compacting cycle using a larger compacting pressure.

[0007] In some embodiments, a substrate support apparatus can comprise a base and a plurality of suction devices. Each suction device of the plurality of suction devices can be movably mounted to the base. The substrate support apparatus can further comprise a monitoring device configured to monitor a position of a suction device of the plurality of suction devices.

[0008] In some embodiments, the monitoring device is configured to monitor the position of the suction device relative to the base.

[0009] In some embodiments, the monitoring device can comprise an ultrasonic sensor.

[0010] In some embodiments, the ultrasonic sensor can be fixedly mounted to the base.

[0011] In some embodiments, each suction device of the plurality of suction devices can be movably mounted to the base to translate along an adjustment direction relative to the base.

[0012] In some embodiments, the plurality of suction devices can comprise a column of suction devices. Each suction device of the column of suction devices can be spaced from another suction device of the column of suction devices along a column axis that is perpendicular to the adjustment direction.

[0013] In some embodiments, at least one suction device of the plurality of suction devices can be independently movable relative to at least one additional suction device of the plurality of suction devices.

[0014] In some embodiments, a substrate packaging apparatus for packaging a leaning stack of substrates can comprise a substrate support structure configured to support the leaning stack of substrates. The substrate support structure can comprise a rear surface configured to support a major surface of a substrate of the leaning stack of substrates. The substrate support structure can further comprise a lower surface extending away from the rear surface and configured to support a lower edge of the substrate of the leaning stack of substrates. The substrate packaging apparatus can further comprise a compacting device comprising a compacting axis extending along a width of the rear surface.

[0015] In some embodiments, the substrate packaging apparatus can comprise a plurality of actuators configured to apply a force to a lower portion of the leaning stack of substrates along the compacting axis.

[0016] In some embodiments, the compacting device can comprise a plurality of actuators configured to apply a varying force to a lower portion of the leaning stack of substrates along the compacting axis.

[0017] In some embodiments, at least one actuator of the plurality of actuators can operate independently of at least one another actuator of the plurality of actuators.

[0018] In some embodiments, the compacting device can comprise a plurality of apertures in communication with a fluid pressure chamber.

[0019] In some embodiments, a method can comprise stacking a plurality of substrates on a substrate support structure to form a leaning stack of substrates. The method can further comprise imaging a feature of the leaning stack of substrates and determining a characteristic of the leaning stack of substrates using information obtained during the imaging.

[0020] In some embodiments, the characteristic of the leaning stack of substrates can comprise a fanning of the leaning stack of substrates.

[0021] In some embodiments, the method can further comprise stacking an additional substrate on the leaning stack of substrates with a substrate support apparatus supporting the additional substrate, and compacting the leaning stack of substrates by engaging the additional substrate with a compacting device.

[0022] In some embodiments, the compacting device can apply pressure along a compacting axis when compacting the leaning stack of substrates.

[0023] In some embodiments, the compacting axis can be positioned along a lower portion of the leaning stack of substrates when compacting the leaning stack of substrates.

[0024] In some embodiments, the compacting device can apply varying pressure to the additional substrate along the compacting axis when compacting the leaning stack of substrates.

[0025] In some embodiments, the compacting device can generate a fluid cushion between the additional substrate and the compacting device when compacting the leaning stack of substrates.

[0026] In some embodiments, the compacting can be conducted while the substrate support apparatus supports the additional substrate.

[0027] In some embodiments, the method can further comprise disengaging the substrate support apparatus from the additional substrate.

[0028] In some embodiments, the disengaging the substrate support apparatus from the additional substrate can occur while compacting the leaning stack of substrates with the compacting device.

[0029] In some embodiments, the method can further comprise disengaging the compacting device from the additional substrate.

[0030] In some embodiments, the method can further comprise reengaging the additional substrate with the compacting device.

[0031] In some embodiments, a method can comprise stacking an additional substrate on a leaning stack of substrates with a substrate support apparatus engaging the additional substrate. The method can further comprise determining a characteristic of the leaning stack of substrates with the substrate support apparatus while the substrate support apparatus engages the additional substrate.

[0032] In some embodiments, a plurality of suction devices of the substrate support apparatus can be removably attached to the additional substrate while stacking the additional substrate on the leaning stack of substrates.

[0033] In some embodiments, the determining the characteristic can comprise moving one suction device of the plurality of suction devices relative to another suction device of the plurality of suction devices.

[0034] In some embodiments, the determining the characteristic can comprise monitoring a position of the one suction device.

[0035] In some embodiments, the position of the one suction device can be monitored with an ultrasonic sensor.

[0036] In some embodiments, the method can further comprise compacting the leaning stack of substrates with a compacting device pressing against the additional substrate.

[0037] In some embodiments, the compacting the leaning stack of substrates can comprise applying pressure to the additional substrate along a compacting axis with the compacting device.

[0038] In some embodiments, the compacting axis can be positioned along a lower portion of the leaning stack of substrates when compacting the leaning stack of substrates.

[0039] In some embodiments, the compacting device can apply varying pressure to the additional substrate along the compacting axis when compacting the leaning stack of substrates.

[0040] In some embodiments, compacting device can generate a fluid cushion between the leaning stack of substrates and the compacting device when compacting the leaning stack of substrates.

[0041] In some embodiments, the compacting can be conducted while the substrate support apparatus engages the additional substrate.

[0042] In some embodiments, the method can further comprise ceasing to apply pressure to the additional substrate with the compacting device over a period of time, and then reapplying pressure to the additional substrate along the compacting axis with the compacting device.

[0043] In some embodiments, the method can comprise disengaging the substrate support apparatus from the additional substrate prior to the reapplying pressure. The reapplying pressure can be conducted while the substrate support apparatus is disengaged from the additional substrate.

[0044] Additional features and advantages of the embodiments disclosed herein will be set forth in the detailed description that follows, and in part will be clear to those skilled in the art from that description or recognized by practicing the embodiments described herein, including the detailed description which follows, the claims, as well as the appended drawings. It is to be understood that both the foregoing general description and the following detailed description present embodiments intended to provide an overview or framework for understanding the nature and character of the embodiments disclosed herein. The accompanying drawings are included to provide further understanding, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments of the disclosure, and together with the description explain the principles and operations thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0045] These and other features, aspects and advantages are better understood when the following detailed description is read with reference to the accompanying drawings, in which:

[0046] **FIG. 1** is a schematic view of a substrate support apparatus placing a supported substrate on a leaning stack of substrates in accordance with aspects of the disclosure;

[0047] **FIG. 2** illustrates a plan view of a substrate to be placed on a leaning stack of substrates of **FIG. 1**;

[0048] **FIG. 3** schematically illustrates an imaging apparatus being used to determine a characteristic of a leaning stack of substrates;

[0049] **FIG. 4** is a schematic view of another substrate support apparatus placing a supported substrate on a leaning stack of substrates in accordance with aspects of the disclosure;

[0050] **FIG. 5** schematically illustrates a base of the substrate support apparatus taken along line **5-5** of **FIGS. 1 and 4**;

[0051] **FIG. 6** schematically illustrates the substrate support apparatus of **FIG. 4** being used to determine a characteristic of a leaning stack of substrates;

[0052] **FIG.** 7 schematically illustrates the substrate support apparatus of **FIG. 4** after the supported substrate is placed on the leaning stack of substrates with a compacting device disengaged from the leaning stack of substrates;

[0053] **FIG. 8** schematically illustrates the substrate support apparatus of **FIG.** 7 after the supported substrate is placed on the leaning stack of substrates with the compacting device pressing against the supported substrate to compact the leaning stack of substrates;

[0054] **FIG. 9** schematically illustrates a sectional view of the compacting device and leaning stack of substrates taken along line **9-9** of **FIG.** 7;

[0055] **FIG. 10** schematically illustrates a sectional view of the compacting device and leaning stack of substrates taken along line **10-10** of **FIG. 8**;

[0056] **FIGS. 11-12** illustrate embodiments of steps of compacting the leaning stack of substrates with the compacting device of **FIGS. 7-10**;

[0057] **FIG. 13** schematically illustrates a sectional view of another embodiment of a compacting device and leaning stack of substrates taken along line **9-9** of **FIG.** 7;

[0058] **FIG. 14** schematically illustrates a sectional view of the compacting device and leaning stack of substrates of **FIG. 13** taken along line **10-10** of **FIG. 8**;

[0059] **FIG. 15** is partial front view of the compacting device of **FIGS. 13-14** taken along line **15-15** of **FIG. 13**;

[0060] **FIG. 16** is a schematic sectional view of the compacting device of **FIGS. 13-15** taken along line **16-16** of **FIG. 15**;

[0061] **FIG. 17** schematically illustrates the compacting device continuing to press against the previously supported substrate of the leaning stack of substrates while the substrate support apparatus is disengaged from the previously supported substrate;

[0062] **FIG. 18** schematically illustrates the compacted leaning stack of substrates of **FIG. 17** after the compacting device is disengaged from the leaning stack of substrates; and

[0063] FIGS. 19-20 are plots comparing experimental results of fanning with respect to the number of substrates as the substrates are stacked in the leaning stack of substrates.

DETAILED DESCRIPTION

[0064] Embodiments will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, this disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0065] In some embodiments, methods of processing substrates in a substrate packaging process can be provided to help monitor the condition of the stack and enhance the quality of the stack of substrates. Substrates of the disclosure can comprise glass substrates, although glass-ceramic, ceramic, silicon substrates, or other substrate material. In some embodiments, the substrate can comprise a glass substrate with a variety of compositions including, but not limited to, soda-lime glass, borosilicate glass, alumino-borosilicate glass, alkali-containing glass, or alkali-free glass. In some embodiments, glass substrates may be produced by separating the glass substrate from a glass ribbon produced by a glass manufacturing apparatus such as a slot draw apparatus, float bath apparatus, down-draw apparatus, up-draw apparatus, press-rolling apparatus or other glass ribbon manufacturing apparatus. Substrates comprising glass substrates can be suitable for further processing into a desired application, e.g., a display application. For example, the glass substrates can be used in a wide range of display applications, including liquid crystal displays (LCDs), electrophoretic displays (EPD), organic light emitting diode displays (OLEDs), plasma display panels (PDPs), or the like. Glass substrates may need to be transported from one location to another. The substrates (e.g., glass substrates) may be transported as a leaning stack of substrates discussed throughout the application. Moreover, interleaf material can optionally be placed between each substrate (e.g., glass substrate) to help prevent contact and therefore preserve the pristine surfaces of the substrate.

[0066] As shown in **FIGS. 1-2**, the substrate **101** (e.g., glass substrate) can comprise a length "**L**" and a width "**W**" perpendicular to the length. As shown in **FIG. 2**, the substrate **101** can comprise an outer perimeter comprising a rectangular shape where the length "**L**" can be defined between two parallel end edges **201a, 201b** and the width "**W**" can be defined between two parallel side edges **203a, 203b**. As shown, each end edge **201a, 201b** can extend in a direction that is perpendicular to the direction in which each side edge **203a, 203b** extends. In some embodiments, the width "**W**" of the substrate **101** can be greater than or equal to about 20 mm, such as greater than or equal to about 50 mm, such as greater than or equal to about 100 mm, such as greater than or equal to about 500 mm, such as greater than or equal to about 1000 mm, such as greater than or equal to about 2000 mm, such as greater than or equal to about 3000 mm, such as greater than or equal to about 4000 mm, although other widths less than or greater than the widths mentioned above can be provided in further embodiments. For example, in some embodiments, the width "**W**" of the substrate **101** can be from about 20 mm to about 4000 mm, such as from about 50 mm to about 4000 mm, such as from about 100 mm to about 4000 mm, such as from about 500 mm to about 4000 mm, such as from about 1000 mm to about 4000 mm, such as from about 2000 mm to about 4000 mm, such as from about 3000 mm to about 4000 mm, such as from about 20 mm to about 3000 mm, such as from about 50 mm to about 3000 mm, such as from about 100 mm to about 3000 mm, such as from about 500 mm to about 3000 mm, such as from about 1000 mm to about 3000 mm, such as from about 2000 mm to about 3000 mm, such as from about 2000 mm to about 2500 mm, and all ranges and subranges therebetween.

[0067] The substrate **101** (e.g., glass substrate) can comprise a first major surface **103a** and a second major surface **103b** facing opposite directions and defining a thickness "**T**" (e.g., average thickness) of the substrate **101**. In some embodiments, the thickness "**T**' of the substrate **101** can be less than or equal to about 2 millimeters (mm), less than or equal to about 1 millimeter, less than or equal to about 0.5 millimeters, for example, less than or equal to about 300 micrometers (μm), less than or equal to about 200 micrometers, or less than or equal to about 100 micrometers, although other thicknesses may be provided in further embodiments. For example, in some embodiments, the thickness "**T**' of the substrate **101** can be from about 50 μm to about 750 μm, from about 100 μm to about 700 μm, from about 200 μm to about 600 μm, from about 300 μm to about 500 μm, from about 50 μm to about 500 μm, from about 50 μm to about 700 μm, from about 50 μm to about 600 μm, from about 50 μm to about 500 μm, from about 50 μm to about 400 μm, from about 50 μm to about 300 μm, from about 50 μm to about 200 μm, from about 50 μm to about 100 μm, including all ranges and subranges of thicknesses therebetween.

[0068] FIGS. 1, 3-4, 6-8, and 17-18 illustrate embodiments a substrate support rack **107** of embodiments of substrate packaging apparatus **105, 401** in accordance with aspects of the disclosure. The substrate support rack **107** can be configured to support a leaning stack **109** of substrates **101**. The substrate support rack **107** can comprise a rear surface **111** configured to support a major surface **103b** of a substrate **101** of the leaning stack **109** of substrates **101**. For example, as shown, in some embodiments, a rear plate **113** can comprise the rear surface **111**. The rear plate **113** can comprise a continuous plate or a lattice of support members defining the rear surface **111**. The substrate support rack **107** can further comprise a lower surface **115** extending away from the rear surface **111** and configured to support a lower edge of the substrate **101** of the leaning stack **109** of substrates **101**. For example, as shown, in some embodiments, a lower plate **117** can comprise the lower surface **115**. The lower plate **117** can comprise a continuous plate or a lattice of support members defining the lower surface **115**. As shown, the lower surface **115** can extend away from the rear surface **111** at substantially 90° although the lower surface **115** can extend away from the rear surface **111** at other angles in further embodiments. The rear plate **113** and/or lower plate **117** can comprise stainless steel, plastic, wood, or other material that can support the leaning stack **109** of substrates **101**. As further shown in **FIG. 1**, the rear surface **111** can extend at an angle "**A**" relative to a direction "**G**" of gravity. The angle "**A**" can range from greater than 0° to about 60°, such as from greater than 0° to about 45°, such as greater than 0° to about 30°, such as greater than 0° to 20°, such as from greater than 0° to 20°, and all ranges and subranges therebetween. In further embodiments, the angle "**A**" can range from about 10° to about 60°, such as from about 10° to about 45°, such as from about 10° to about 30°, such as from about 10° to 20°, and all ranges and subranges therebetween. In further embodiments, the angle "**A**" can range from about 20° to about 60°, such as from about 20° to about 45°, such as from about 20° to about 30°, and all ranges and subranges therebetween. For purposes of this application, a stack of substrates is considered a "leaning stack of substrates" if a substrate in the stack of substrates has a major surface that is oriented at any one of the above angles "**A**" relative to "**G**" gravity. Thus by stacking substrates against the rear surface **111** that extends at an angle "**A**" relative to the direction "**G**" of gravity within the ranges discussed above, the stack of substrates can comprise a leaning stack of substrates supported by the substrate support rack **107**. For example, a major surface of a rear substrate in the leaning stack of substrates can be supported against the rear surface **111** and, like the rear surface **111**, can be supported at an orientation where the major surface of the of the rear substrate extends at an angle "**A**" relative to the direction "**G**" of gravity within the ranges discussed above. Consequently, the stack of substrates would be considered a leaning stack of substrates since at least the major surface of the rear substrate extends at an angle "**A**" relative to the direction "**G**" of gravity within the ranges discussed above.

[0069] As shown, a stand **119** may be designed to support the rear surface **111** at the desired angle "**A**". For example, the stand **119** can support the position of the rear plate **113** and the lower plate **117** relative to one another and support the weight of the rear plate **113**, the lower plate **117**, and the leaning stack **109** of substrates **101**. In some embodiments, the stand **119** can comprise a support surface **120** that may rest on a horizontal surface such that the support surface **120** is perpendicular to the direction "**G**" of gravity. In some embodiments, an angle "**B**" between the support surface **120** and the rear surface **111** can equal to the angle "**A**" subtracted from 90°.

[0070] The substrate packaging apparatus **105** shown in **FIG. 1** can comprise a substrate support apparatus **121** configured to help build the leaning stack **109** of substrates **101** on the substrate support rack **107**. In some embodiments, as shown, the substrate support apparatus **121** can comprise a plurality of suction devices **123** mounted to a base **125**. **FIG. 5** illustrates one embodiment of the base **125** that is viewed along line 5-5 of **FIG. 1.** As shown, the base **125** can include to parallel side rails **503a, 503b** that can support the suction devices **123** along respective columns of suction devices. The parallel side rails **503a, 503b** can be mounted to a center rail **505** that can be manipulated by the robot **129** (see **FIG. 1**). In some embodiments, the suction devices **123** can each comprise a suction cup **127**. The suction cups **127** can be placed in communication with a fluid source to control the suction associated with each suction cup **127** to cause selective attachment and release to the first major surface **103a** of the substrate **101**. In some embodiments, a vacuum (e.g., from a negative pressure source) can be associated with one or more of the suction cups. The vacuum can be used to increase the attachment force between the suction cup and the first major surface **103a**. In further embodiments, the vacuum source can be adjustable to increase or decrease the attachment force. In some embodiments, the fluid source may comprise a positive pressure source to eject the substrate from the suction cup once the substrate is properly placed on the leaning stack of substrates. In some embodiments, the fluid source (e.g., positive pressure source and/or negative pressure source) may provide the same positive pressure/vacuum force for all the suction cups of each column or may provide the same positive pressure/vacuum force for all of the suction cups of all columns. In further embodiments, one or more suction cups may have a suction force that can be operated independently of the other suction cups.

[0071] In operation, the robot **129** may move the base **125** and corresponding suction devices **123** to pick a substrate **101** to be stacked. The substrate to be picked can be traveling along a conveyor, can be separated from a ribbon after the ribbon is produced, or other locations. In order to pick the substrate **101**, the robot **129** can manipulate the base **125** until the suction cups **127** of the suction devices **123** engage the first major surface **103a** of the substrate **101**. It will be appreciated that the suction cups **127** can be engaged adjacent the outer side edges **203a, 203b** (see **FIG. 2**) of the substrate to help maintain the pristine nature of the central portion of the major surface **103a** of the substrate **101**. As shown in **FIG. 1**, the robot can move the substrate **101** into position such that it is added to the leaning stack **109** of substrates **101** in the leaning orientation.

[0072] After a significant number of substrates **101** have been stacked, fanning may unfortunately occur where one location of the leaning stack **109** has a maximum thickness "**T1**" in a direction perpendicular to the rear surface **111** that is greater than a minimum thickness "**T2**" of another location of the leaning stack **109** in the direction perpendicular to the rear surface **111**. As shown, the location with the greatest thickness "**T1**" can be located at an intermediate location of the leaning stack **109** although the greatest thickness "**T1**" may be positioned near or at the upper end of the leaning stack **109** or near or at the lower end of the leaning stack **109**. Throughout the application, fanning is considered a difference between the maximum thickness "**T1**" and the minimum thickness "**T2**".

[0073] In some embodiments, an overall fanning may exist across the entire surface area of leaning stack **109** of substrates wherein the entire leaning stack **109** of substrates includes a single maximum thickness "**T1**" and a single minimum thickness "**T2**" wherein the overall fanning of the leaning stack **109** of substrates is considered the difference between the single maximum thickness "**T1**" and the single minimum thickness "**T2**". In further embodiments, a lengthwise fanning may vary at different positions along the width "**W**" of the substrate **101**. For instance, a lengthwise fanning may exist at a location along the width along a linear lengthwise axis extending through the location in a direction of the length "**L**" of the outer substrate **101** of the leaning stack **109** of substrates **101**. In such examples, the lengthwise fanning at a location along the width "**W**" is considered the difference between the maximum thickness "**T1**" along the linear lengthwise axis passing through the location and the minimum thickness "**T2**" along the linear lengthwise axis passing through the location.

[0074] FIGS. 4 and 6-8 illustrate additional embodiments of a substrate support apparatus **403** of the substrate packaging apparatus **401**. The substrate support apparatus **403** can comprise the base **125** (e.g., as illustrated and described with reference to **FIG. 5**), and a plurality of suction devices **405**. Each suction device **405** of the plurality of suction devices **405** can be movably mounted to the base **125**. In some embodiments each suction device **405** of the plurality of suction devices can be movably mounted to the base **125** to translate along an adjustment direction relative to the base **125**. For example, as shown in **FIG. 4**, each suction device **405** of the plurality of suction devices **405** can translate along a first adjustment direction **407a** to extend relative to the base **125** and/or a second adjustment direction **407b** to retract relative to the base **125**. As shown, in some embodiments, each suction device **405** can comprise a guide rod **409** slidably mounted to the base **125** with the suction cup **127** positioned at one end of the guide rod **409**. In some embodiments, although not shown, each suction device **405** may comprise a biasing device (e.g., compression spring) may bias each suction device **405** in the first adjustment direction **407a** to the extended position shown in **FIG. 4**.

[0075] As shown in **FIG. 4**, the substrate support apparatus **403** can also comprise a base. For example, the base **125** discussed with respect to **FIG. 5** above can also comprise a base of the substrate support apparatus **403** taken along line **5-5** of **FIG. 4**. The base **125** can include to the parallel side rails **503a, 503b** that can support the suction devices **405** along respective columns of suction devices. While two columns of suction devices are illustrated, in further embodiments, three or more columns of suction devices may be provided. For example, the base **125** can include three or more parallel side rails that can support the suction devices. In some embodiments, a plurality of the suction devices **405** (see **FIG. 4**) can comprise the first column of suction devices **405** positioned along a first column axis **501a** of the first column. In some embodiments, the plurality of suction devices **405** can further comprise the second column of suction devices **405** positioned along a second column axis **501b** of the second column. Although not shown, in some embodiments, the plurality of suction devices can comprise three or more columns of suction devices positioned along a corresponding column axis. As shown in **FIG. 5**, each suction device **405** of the plurality of suction devices **405** can be spaced apart from another suction device **405**. For example, each suction device **405** can be positioned between a pair of suction devices **405** that are each adjacent the suction device **405**. The column axis **501a, 501b** can be perpendicular to the adjustment direction **407a, 407b** of the suction devices **405**. In some embodiments, the parallel side rails **503a, 503b** can be mounted to the center rail **505** that can be manipulated by the robot **129**. While two parallel side rails **503a, 503b** are illustrated, in further embodiments, three or more parallel side rails may be provided (e.g., mounted to the center rail **505**) that can be manipulated by the robot **129**. A corresponding column axis may be provided with each of the parallel side rails where suction devices of may be spaced apart along a corresponding column axis. In some embodiments, the suction devices **405** can each comprise the suction cup **127**. The suction cups **127** can be placed in communication with a fluid source to cause selective attachment and release to the first major surface **103a** of the substrate **101**.

[0076] In some embodiments, at least one suction device of the plurality of suction devices **405** can be independently movable relative to at least one additional suction device of the plurality of suction devices **405**. For example, at least one suction device **405** shown in **FIG. 4** can be moved along the adjustment directions **407a, 407b** while one or more of the remaining suction devices of the plurality of suction devices remain stationary relative to the base **125**. In some embodiments, each suction device can be independently movable relative to the remaining suction devices (e.g., along the adjustment directions **407a, 407b**).

[0077] As shown in **FIGS. 4 and 6-8**, the substrate support apparatus **403** can also comprise a monitoring device **411** configured to monitor a position of a suction device **405** of the plurality of suction devices **405**. In some embodiments, the monitoring device **411** can be configured to monitor the position of the suction device **405** relative to the base **125**. For example, the monitoring device may be designed to monitor the position of the guide rod **409** relative to the base **125**. In some embodiments, the monitoring device may be designed to monitor the suction cup **127** of the suction device **405**, either directly or by monitoring the position of the guide rod **409** relative to the base **125**. In some embodiments, the monitoring device may comprise a proximity sensor able to monitor a position of the suction device **405** relative to the base **125** without physical contact although physical contact sensors may also be incorporated in accordance with aspects of the disclosure. Embodiments of a proximity sensor can include optical sensors (e.g., laser sensors), ultrasonic sensors or other types of proximity sensors. As shown schematically in **FIG. 4**, in some embodiments, the monitoring device **411** may comprise an ultrasonic sensor **413** configured to monitor a position of the suction device **405** relative to the base **125** without requiring physical contact between the suction device **405** and the base **125** to monitor the position. In some embodiments, the proximity sensor (e.g., ultrasonic sensor **413**) may be fixedly mounted to the base **125** to monitor a position of a portion of the suction device **405** relative to the base. In some embodiments, an end of the guide rod **409** may be provided with a flag **415** extending across the sensing path of the proximity sensor. For example, as shown, ultrasonic waves **417a** may travel to intersect with the flag **415** positioned across the sensing path of the ultrasonic sensor **413**. The reflected ultrasonic waves **417b** reflecting off the flag **415** can then travel back to be sensed by the ultrasonic sensor **413**. Signals can then be sent back to a processor **137** to calculate the position of the flag **415** of the suction device **405** relative to the base **125**. Although not shown, the ultrasonic sensor may be mounted to the guide rod (e.g. at the end of the guide rod) wherein the ultrasonic waves are reflected off the base **125**. However, fixedly mounting the ultrasonic sensor to the base **125** can simplify the construction of the device as the communication path from the ultrasonic sensor **413** to the processor **137** can be supported by the base **125**.

[0078] As shown, the monitoring device may monitor a position of one or any plurality of suction devices of the plurality of suction devices. For example, as shown in **FIG. 4**, the monitoring device **411** can monitor the position of each suction device **405** of the plurality of suction devices **405** relative to the base **125**. For instance, as shown, each suction device **405** of the plurality of suction devices **405** may be provide with a proximity sensor (e.g., ultrasonic sensor). Providing each suction device **405** with a sensor (e.g., proximity sensor) can allow tracking of each suction device independently in embodiments where one or all of the suction device **405** can independently move relative to one another.

[0079] In some embodiments, the substrate packaging apparatus **105, 401** may be provided with a compacting device. For purposes of discussion, embodiments of the substrate packaging apparatus **401** of **FIGS. 4, and 6-18** will be discussed as optionally comprising a compacting device **701** (**FIG. 9-12**), **1301** (**FIG. 13-16**). Although not shown, the substrate packaging apparatus **105** of **FIGS. 1 and 3** can also comprise a compacting device **701, 1301** with similar or identical features and functionality discussed more fully below. As shown in **FIGS. 9 and 13**, the compacting device **701, 1301** can comprise a compacting axis **901** extending along the width "**WR**" of the rear surface **111**. In some embodiments, the outer surface of the press member can comprise the compacting axis. As shown in **FIGS. 9 and 13**, the width "**WR**" of the rear surface **111** can be substantially the same as the width "**W**" of the substrate **101** (see **FIG. 2**) although the width "**WR**" of the rear surface **111** can be greater than or less than the width "**W**" of the substrate **101** in further embodiments. Providing a width "**WR**" of the rear surface **111** that is greater than or equal to the width "**W**" of the substrate **101** can help fully support the entire width of the substrate **101**, thereby reducing stress concentrations and possible damage to the substrate **101**. In some embodiments, the compacting axis **901** can comprise a substantially straight compacting axis **901**. For example, in some embodiments, the rear surface **111** can comprise a substantially flat surface wherein a substantially straight compacting axis **901** can help evenly distribute compacting force across the width of the substrate **101** during a compacting procedure. In further embodiments, the rear surface **111** can comprise a convex or concave surface wherein the flat surface (represented by the straight line at **111** in **FIGS 9 and 13**) would be curved and represented by an arcuate line. Providing the rear surface as a convex or concave surface may help flex the stack of substrates into a curved shape corresponding to the convex or concave rear surface. Flexing the substrates into a curved orientation can strengthen the substrates and/or help prevent shifting of the substrates relative to the rear surface **111**. In embodiments where the rear surface **111** is a concave or convex surface, the compacting axis **901** may comprise curved axis with a shape matching the curved shape of the convex or concave rear surface along the width "**WR**" of the rear surface.

[0080] In some embodiments, the compacting device can comprise at least one actuator. For example, as shown in **FIG. 7**, a base member **703** of the compacting device can comprise at least one actuator configured to extend and retract a press member **705, 1305** defining the compacting axis **901** of the compacting device **701, 1301**. As shown, in some embodiments, the compacting device **701, 1301** may comprise an abutment device **904, 1304** that includes the press member **705, 1305**. In some embodiments, the actuator of the base member **703** can provide an extension in direction **707a** and a retraction in direction **707b** of the abutment device **904, 1304**. In some embodiments, the directions **707a, 707b** can be substantially perpendicular to the rear surface **111**. In further embodiments, in addition or alternative to the actuator of the base member, the abutment device **904, 1304** can comprise one or more actuators **903** (see **FIG. 9**) configured to provide extension/retraction in directions **707a, 707b** of the press member **705, 1305** relative to a support member **907**. In some embodiments, as shown, the one or more actuators **903** can selectively extend rods **902**, and the press member **705, 1305** associated with the rods **902** in direction **707a**. As shown, in some embodiments, the compacting device **701, 1301** can comprise a plurality of actuators configured to apply a force to the lower portion of the leaning stack **109** of substrates **101** along the compacting axis **901**.

[0081] As shown in **FIGS. 9 and 13**, in some embodiments, the one or more actuators **903** can of the compacting device **701, 1301** can comprise a plurality of actuators **903**. As shown, in some embodiments, the plurality of actuators **903** can comprise a row of actuators **903** that are sequentially spaced apart with each actuator **903** of the plurality of actuators positioned next to one adjacent actuator or between two adjacent actuators. In some embodiments, each actuator of the plurality of actuators **903** configured to apply a varying force to the lower portion of the leaning stack **109** of substrates **101** along the compacting axis **901** although each actuator may apply the same force in further embodiments. In addition or alternatively, in some embodiments, at least one or all of the actuators of the plurality of actuators can operate dependently or independently of at least one another actuator (e.g., all of the other actuators). For example, if the press member comprises a single rigid press member, all of the actuators of the plurality of actuators **903** may operate at the same time and provide the same force such that the length of the press member moves in the extension/retraction directions **707a, 707b**. In further embodiments, as shown in **FIGS. 11-12**, the press member **705** can comprise a flexible press member where part of the press member may be moved in the extension/retraction directions **707a, 707b** relative to another part of the press member. In still further embodiments, the press member may comprise a segmented press member where a plurality of segments of the press member are configured to move relative to one another. For example, as shown in **FIG. 13**, the press member **1305** can comprise segments **1307a, 1307b, 1307c** that can be moved relative to one another in the extension/retraction directions **707a, 707b**.

[0082] In some embodiments, as shown in **FIG. 10**, the press member **705** can be designed to physically contact the lower portion of the outer substrate of the leaning stack **109** of substrates **101** when applying force to the lower portion of the leaning stack **109** of substrates **101**. In alternative embodiments, as shown in **FIG. 14**, the press member **1305** may be designed to apply force to the lower portion of the leaning stack **109** of substrates **101** in a contactless manner where the press member **1305** produces a fluid cushion **1401** that applies force to the lower portion of the outer substrate of the leaning stack **109** of substrates without the press member **1305** physically contacting the outer substrate of the leaning stack **109** of substrates **101**. Applying force in a contactless manner can help prevent damage to the substrates that might otherwise occur of the press member physically contacts the substrate(s). As shown in **FIGS. 15-16**, the compacting device can provide the press member **1305** with a plurality of apertures **1501** in communication with a fluid pressure chamber **1601**. As shown in **FIG. 15**, the plurality of apertures can comprise a pattern of apertures **1501** spaced apart to provide the desired fluid cushion configuration in use. Furthermore, as shown in **FIG. 16**, in some embodiments, the fluid pressure chamber **1601** may comprise multiple fluid pressure chambers although a single fluid pressure chamber may be provided in further embodiments. Each pressure chamber **1601** can comprise one or more inlet ports **1602** pressurized fluid to enter the pressure chamber **1601**. If multiple pressure chambers are provided, the pressurized fluid within each chamber may be adjusted relative to one another to provide a fluid cushion having varying characteristics along the overall length of the press member **1305**. As shown in **FIG. 16**, each segment **1307a, 1307b** may comprise one or more pressure chambers that can be pressurized independently to allow each segment to apply a unique fluid cushion. Providing a plurality of apertures **1501** associated with a corresponding pressure chamber can also be beneficial to help provide more control over the characteristics of the fluid cushion (e.g., pressure profile applied by the fluid cushion).

[0083] In some embodiments, methods of the disclosure can include stacking a plurality of substrates **101** on a substrate support structure (e.g., substrate support rack **107**) to form the leaning stack **109** of substrates **101**. In some embodiments, the robot **129** can be provided that can pick an individual substrate **101**, such as a glass substrate, from a conveyor belt or other location or can support the substrate while it is separated from a ribbon during a ribbon (e.g., glass ribbon) forming process. The robot **129** can then manipulate the substrate into the appropriate orientation such that, as shown in **FIG. 1**, the substrate **101** supported by the substrate support apparatus **121** is substantially parallel to the rear surface **111** and/or the existing leaning stack **109** of substrates. As shown in **FIG. 1**, in some embodiments, the plurality of suction cups **127** may be removably attached to the substrate **101** while supporting the substrate and moving the substrate to be stacked with other substrates in the leaning stack **109** of substrates. In some embodiments, a negative pressure source can be placed in communication with the suction area of the suction cup to further enhance and maintain the attachment of the suction cup to the substrate help prevent inadvertent detachment of the suction cups from the substrate **101**. Once the robot **129** has properly placed the supported substrate, the suction cups can release the substrate. For example, a positive pressure source can increase the pressure within the suction area of the suction cup to cause the suction cup to release the substrate in the proper position. The robot can then be retracted out of the vicinity of the leaning stack **109** of substrates as shown in **FIG. 3**.

[0084] In some embodiments, methods of the disclosure can further comprise determining a characteristic of the leaning stack of substrates without contacting any of the substrates **101**. For example, as shown in **FIG. 3**, the robot **129** can be removed from the vicinity of the leaning stack **109** of substrates. Then, an imaging apparatus **131** can be used to image a feature of a substrate **101** (e.g., outermost substrate) and then determine a characteristic of the leaning stack **109** of substrates **101** using information obtained during the imaging. In some embodiments, the characteristic of the leaning stack **109** of substrates **101** can comprise a fanning of the leaning stack **109** of substrates **101**. In some embodiments, the fanning can comprise the overall fanning of the leaning stack **109** of substrates **101**. For example, the overall fanning can comprise "**T2**" subtracted from "**T1**" wherein the greatest thickness "**T1**" of the leaning stack **109** of substrates **101** may not be aligned with the smallest thickness "**T2**" along the same linear axis extending in a direction of the length "**L**". Thus, the overall fanning can comprise one value associated with the surface area of a major surface of the outermost substrate. In further embodiments, the fanning can comprise a lengthwise fanning that can comprise "**T2**" subtracted from "**T1**" wherein the "**T1**" is aligned with "**T2**" along the same linear axis extending in a direction of the length "**L**". In such embodiments, the leaning stack **109** of substrates **101** can comprise a lengthwise fanning at each location along the width of the leaning stack **109** of substrates **101**.

[0085] In one embodiment, as shown in **FIGS. 1 and 3**, the fanning can be determined by the imaging apparatus **131**. In some embodiments, the imaging apparatus **131** can comprise the illustrated digital image correlation device that can comprise a source of light **133** and a pair of cameras **135**. One available imaging apparatus **131** can comprise an ARAMIS digital image correlation device available from Trilion Quality

Systems. The digital image correlation device can be designed to determine the three-dimensional position of various markers associated with the outer surface of the leaning stack **109** of substrates **101**. In some embodiments, the markers can comprise reflective tabs adhered to the major surface of the substrate **101**. For example, referring to **FIG. 2**, a plurality of markers **205** can be aligned in two columns **207a, 207b** along a linear axis **209a, 209b** extending in a direction **211** of the length "**L**". In such an example, the imaging apparatus **131** can determine the lengthwise fanning at two locations along the width "**W**" of the substrate **101**. In some embodiments, the markers **205** can be provided on one or more of the substrates **101**. In further embodiments, a substrate including the markers **205** can be reused to conduct multiple periodic measurements. For instance, the substrate including the markers **205** can be placed with the substrate support apparatus **121** to conduct the fanning measurement. Once the imaging apparatus **131** has completed the measurement, the substrate support apparatus **121** can remove the substrate including the markers **205** and then continue stacking additional substrates if appropriate. Such measurements can be designed to measure the fanning after stacking a selected number of substrates (e.g., after stacking 10, 20, 40, 60, etc. substrates). Furthermore, although the substrate with the markers can comprise the same type of substrate as the substrates in the leaning stack **109** of leaning substrates, in further embodiments, the substrate with the markers **205** can comprise a different material that may be more durable or less expensive than the substrates stacked in the leaning stack **109** of substrates **101**.

[0086] As shown in **FIG. 3**, once the substrate with the markers **205** is placed, light **301** emitted from an illumination device **133** of the digital image correlation device can reflect off of each of the markers **205** to be detected by a pair of cameras **135** spaced apart from one another (not shown) along the width "**W**". The reflected light received by the cameras **135** is then processed by a processor **137** to determine the location of the markers **205** and output to an output device **303** such as a storage unit for digitally storing the data or a display device for visually displaying the data. As shown, the results from each periodic measurement with the digital correlation device can be displayed in a graph with the vertical axis **305** indicating the marker number and the horizontal axis **307** indicating the thickness of the leaning stack **109** of leaning substrates **101**. As shown, the last measurement illustrates the maximum stack thickness "**T1**" of about 46 at marker #5 and a minimum stack thickness "**T2**" of about 32 at marker #1 wherein the lengthwise fanning at the last measurement is about 14 (i.e., 46-32). In some embodiments, an alarm may sound if the fanning reaches a predetermined maximum allowable fanning. In further embodiments, the substrate support apparatus **121** may discontinue loading additional substrates **101** once the fanning reaches a predetermined maximum allowable fanning.

[0087] FIGS. 4 and 6 illustrate further embodiments of determining a characteristic of a leaning stack **109** of substrates **101**. As shown, the substrate support apparatus **403** can be used to stack multiple substrates **101**, wherein the characteristic can be determined while stacking the next substrate onto the leaning stack **109**. For example, **FIG. 4** shows, the stacking an additional substrate **101** being supported and engaged by the substrate support apparatus **403** on a leaning stack **109** of substrates. In some embodiments, the first and second columns of suction cups **127** (see **FIG. 5**) can be selectively attached to portions of a major surface of the substrate **101** (e.g., the outer edge portions of the major surface). By engaging the outer portions, the pristine nature of the central portion of the major surface may be maintained without damage due to scratches or other imperfections that may be introduced by the suction cups **127**. In some embodiments, the suction cups **127** can be placed in communication with a fluid source to control the suction associated with each suction cup **127** to cause selective attachment and release to the first major surface **103a** of the substrate **101**. In some embodiments, a vacuum source can be associated with one or more of the suction cups. The vacuum source can be used to provide a suction that increases the attachment force between the suction cup to the first major surface **103a**. In further embodiments, the vacuum source can be adjustable to increase or decrease the attachment force. In some embodiments, the fluid source may comprise a positive pressure source to eject the substrate from the suction cup once the substrate is properly placed on the leaning stack of substrates. In some embodiments, the fluid source (e.g., pressure source and/or vacuum source) may provide the same pressure/vacuum force for all the suction cups of each column or may provide the same pressure/vacuum force for all of the suction cups of all columns. In further embodiments, one or more suction cups may have a suction force that can be operated independently of the other suction cups.

[0088] In operation, a robot **129** may move the base **125** and corresponding suction devices **123** to pick a substrate **101** to be stacked. The substrate to be picked can be traveling along a conveyor, can be separated from a ribbon after the ribbon is produced, or other locations. In order to pick the substrate **101**, the robot **129** can manipulate the base **125** until the suction cups **127** of the suction devices **123** engage the first major surface **103a** of the substrate **101**. It will be appreciated that the suction cups **127** can be engaged adjacent the outer side edges **203a, 203b** of the substrate to help maintain the pristine nature of the central portions of the major surface **103a** of the substrate **101**. As shown in **FIG. 1**, the robot can move the substrate **101** into position such that it is added to the leaning stack **109** of substrates **101** in the leaning orientation.

[0089] As shown in **FIG. 6**, the characteristic of the leaning stack **109** of substrates can be determined with the substrate support apparatus **403** while the substrate support apparatus **403** engages the additional substrate **101** and prior to disengagement of the placed additional substrate **101** from the substrate support apparatus **403**. As discussed previously, the plurality of suction devices **405** of the substrate support apparatus **103** can be removably attached to the additional substrate while stacking the additional substrate on the leaning stack of substrates. As shown in **FIG. 4**, the substrate support apparatus **103** can be moved in direction **402** by the robot **129**. In some embodiments, each suction device of the plurality of suction devices **405** may move in a first adjustment direction **407a** or a second adjustment direction **407b** relative to one or more other suction device(s) of the plurality of suction devices **405** and relative to the base **125**. As such, the supported additional substrate **101** can conform to the shape of the outer stacked substrate of the leaning stack **109** of substrates while the suction devices **405** can independently move relative to one another and relative to the base **125**. Indeed, each suction device **405** may be biased outwardly (e.g. by a compression spring) so that the suction devices compress and thereby conform the supported additional substrate **101** to match the shape of the outer most substrate of the stack of substrates. As schematically shown in **FIG. 6**, the increased thickness of the leaning stack **109** of substrates **101** at "**T1**" can cause the corresponding suction devices **405** to move in the second adjustment direction **407b** such that the corresponding suction cup **127** retracts toward the base **125**. As the suction device **405** moves in the second adjustment direction

407b, the corresponding guide rod **409** causes the corresponding flag **415** to move away from the base **125** in the second adjustment direction **407b**. In some embodiments, a sensor such as the illustrated ultrasonic sensor **413** can monitor the position of the suction device **405**. For instance, as shown in **FIG. 4**, ultrasonic waves **417a** may be emitted from the ultrasonic sensor **413** and bounced off the flag **415** and back toward the sensor as reflected ultrasonic waves **417b** to be sensed by the ultrasonic sensor **413**. Signals can then be sent back to a processor **137** to calculate the position of the flag **415** of the suction device **405** relative to the base **125**. In such a way, the corresponding characteristic (e.g., fanning) can be determined by monitoring the position of each suction device **405**. In some embodiments, these positions can be relayed to the output device **303** discussed above such as a storage unit for digitally storing the data or a display device for visually displaying the data. In some embodiments, an alarm may sound if the fanning reaches a predetermined maximum allowable fanning. In further embodiments, the substrate support apparatus **403** may discontinue loading additional substrates **101** once the fanning reaches a predetermined maximum allowable fanning.

[0090] In some embodiments, one may select from either the imaging apparatus **131** of **FIG. 1** or the monitoring device **411** of **FIG. 4** to determine a characteristic (e.g., fanning) of a leaning stack **109** of substrates. However, in some embodiments, the monitoring device **411** can monitor each substrate **101** as it is added to the leaning stack **109** of substrates and does not require placement of a substrate with markers **205** for periodic monitoring. Thus, the monitoring device **411** can provide continuous feedback, and therefore quickly discover developing issues with fanning and does not require process interruption or additional expense involved with providing a substrate with markers **205** that can only feasibly provide periodic testing.

[0091] Methods of the disclosure can also comprise a compacting device designed to reduce fanning of the leaning stack of substrates. In some embodiments, compacting devices of the disclosure may be used in combination with the imaging apparatus **131** of **FIGS. 1-3**. In further embodiments, compacting devices of the disclosure may be used in combination with the substrate support apparatus **403** and monitoring device **411** of **FIG. 4**.

[0092] Embodiments of compacting devices **701, 1301** used in combination with the substrate support apparatus **403** and monitoring device **411** of **FIG. 4** will now be discussed with the understanding that the compacting devices may similarly or identically used in combination with the imaging apparatus **131** of **FIGS. 1-3**. Referring to **FIG. 7**, the substrate support apparatus **403** can place an additional substrate **101** engaged and supported by the suction devices **405** on the leaning stack **109** of substrates **101**. Once placed, as shown in **FIGS. 7 and 9**, the abutment device **904, 1304** may be extended in direction **707a** by an actuator of the base member **703** in order to bring the press member **705, 1305** near the leaning stack **109** of substrates **101**. As shown in **FIG. 10**, one or more actuators **903** can provide extension of the press member **705, 1305** in direction **707a** by the rods **902** until the press member **705, 1305** presses and applies force to the substrate **101** engaged and supported by the substrate support apparatus **403**. As shown in **FIGS. 8 and 10**, the force applied by the press member **705, 1305** acts to compact the leaning stack **109** of substrates **101**.

[0093] As shown in **FIG. 8**, the leaning stack **109** of substrates **101** can be compacted with the press member **705, 1305** of the compacting device **701, 1301** pressing against the substrate **101** to compact the leaning stack **109** of substrates **101** while the substrate **101** is still being engaged and/or supported by the substrate support apparatus **403**. Although not shown, some alternative embodiments may disengage the substrate support apparatus **403** from the supported substrate prior to initially contacting the previously supported substrate with the press member **705, 1305** of the compacting device **701, 1301**. However, disengaging the substrate support apparatus **403** from the substrate while compacting the leaning stack of substrates with the compacting device can help assist removing the substrate support apparatus **403** from the leaning stack of substrates without inadvertently pulling one or more of the substrates away from the stack as the substrate support apparatus is removed. Indeed, the press member **705, 1305** can act to hold the supported substrate in place while the substrate support apparatus **403** is pulled away form the stack, thereby maintaining the compact configuration and reducing inadvertent fanning that may otherwise occur when pulling the substrate support apparatus **403** out of contact with the leaning stack **109** of substrates **101**. **FIG. 17** demonstrates embodiments where the substrate support apparatus **403** is pulled away while the press member **705** of the compacting device **701, 1301** continues to press against the outer substrate in the leaning stack **109** of substrates **101**.

[0094] FIG. 18 illustrates disengagement of the compacting device **701, 1301** from the outer substrate of the leaning stack **109** of substrates **101**. In some embodiments, the process can comprise a single compacting cycle where the compacting device **701, 1301** presses against the placed outer substrate a single time. After disengagement of the compacting device **701, 1301** (see **FIG. 18**), the substrate support apparatus **403** can place yet an additional substrate on the leaning stack **109** of substrates **101** and similarly proceed, as discussed above, to perform a single compacting cycle to again compact the leaning stack **109** of substrates **101** with compacting device **701, 1301**. The process and then proceed until the stack is complete after a predetermined number of substrates have been stacked or after a predetermined maximum fanning level is detected.

[0095] In alternative embodiments, two or more compacting cycles may be performed on a substrate placed on the leaning stack of substrates. For example, after disengagement of the press member **705, 1305** of the compacting device **701, 1301** from the outer substrate of the leaning stack **109** of substrates **101**, a second compacting cycle can be performed wherein the press member **705, 1305** reengages the same outer substrate by again extending in direction **707a** as shown in **FIG. 17**. In some embodiments, methods can apply pressure to the outer substrate of the leaning stack **109** of substrates **101** with the press member **705, 1305** of the compacting device **701, 1301** over a period of time to compact the leaning stack **109** of substrates **101**, then the compacting device **701, 1301** can cease applying pressure to the substrate over a period of time (e.g., by retracting the press member **705, 1305** as shown in **FIG. 18**), and then reapply the pressure to the same substrate along the compacting axis **901** with the compacting device **701, 1301** (as shown in **FIG. 17**). In some embodiments, the substrate support apparatus can be disengaged from the outer substrate prior to the reapplying pressure, wherein the reapplying pressure is conducted while the substrate support apparatus is disengaged from the additional substrate (e.g., see **FIG. 17**). In alternative embodiments, the substrate support apparatus can remain engaged with the outer substrate throughout the two or more compacting cycles (e.g., see **FIG. 8**).

[0096] FIGS. 19-20 are plots of experimental results comparing fanning (represented by the vertical y-axis, e.g., in millimeters) with respect to the number of substrates in the leaning stack of substrates (represented by the horizontal x-axis). **FIG. 19** represents two experimental runs of stacking 330 substrates in a leaning stack of substrates where packing performance was measured periodically after a number of substrates have been stacked. Plot **1901** represents an experimental run where without compacting while plot **1903** represents an experimental run with a single compacting cycle of 30 pounds per square inch (207 Kilopascal) applied to a lower portion of the leaning stack of substrates after each substrate is stacked. As shown, comparing stacking with a single compacting cycle (see plot **1903**) with stacking without compacting (see plot **1901**), the single compacting cycle can significantly reduce the fanning from greater than 7 millimeters (mm) to less than 4 mm.

[0097] FIG. 20 represents two experimental runs of stacking 110 substrates in a leaning stack of substrates where packing performance was measured periodically after a number of substrates have been stacked. Plot **2001** represents an experimental run with a single compacting cycle of 30 pounds per square inch (207 Kilopascal) applied to a lower portion of the leaning stack of substrates after each substrate is stacked. Plot **2003** represents an experimental run with two compacting cycles after each substrate is stacked wherein each compacting cycle of the two compacting cycles applied 10 pounds per square inch (69 Kilopascal) to a lower portion of the leaning stack with a 5 second delay between each compacting cycle of the two compacting cycles. As shown, comparing stacking with a two compacting cycles (see plot **2003**) with stacking with one compacting cycle (see plot **2001**), stacking with two compacting cycles can significantly reduce the fanning from about 12 mm to about 6 mm.

[0098] Thus, as shown by **FIG. 19**, a single compacting cycle using a pressure of 30 pounds per square inch (207 Kilopascal) applied to the lower portion of the leaning stack can provide reduced fanning compared to stacking without a single compacting cycle. Furthermore, as shown by **FIG. 20**, even further increased performance can be achieved with two compacting cycles with only 1/3 the pressure applied to the lower portion of the leaning stack. In some embodiments, a single cycle may be used to reduce fanning where there is a desire to quickly form the stack of substrates with improved fanning. Furthermore, while two cycles may take additional time to produce the stack of substrates, performing two cycles at lower pressure after placement of each substrate on the leaning stack of substrates can further reduce fanning while also reducing the chance of stress fractures due to the lower pressure used when compacting the leaning stack of substrates.

[0099] As discussed above, the single compacting cycle can use the press member to apply a pressure of 30 pounds per square inch (207 Kilopascal) to the leaning stack of substrates although, in some embodiments, the pressure may be anywhere ranging from about 10 pounds per square inch (psi) (69 Kilopascal) to about 80 psi (552 Kilopascal), such as from about 20 psi (138 Kilopascal) to about 40 psi (276 Kilopascal). As discussed above, the each cycle of the two compacting cycles can use the press member to apply a pressure of 10 psi (69 Kilopascal) to the leaning stack of substrates although, in some embodiments, the pressure may be anywhere ranging from about 5 psi (34 Kilopascal) to about 20 psi (138 Kilopascal), such as from about 8 psi (55 Kilopascal) to about 12 psi (83 Kilopascal).

[00100] In some embodiments, the compacting axis **901** can extend along the outer surface of the press member **705, 1305**. In further embodiments, the outer surface of the press member **705, 1305** may include the compacting axis **901**, wherein the compacting the leaning stack **109** of substrates **101** comprises applying pressure to the substrate supported by the substrate support apparatus **403** along the compacting axis **901** with the compacting device **701, 1301**. As shown in **FIGS. 7-8**, the compacting axis **901** can be positioned along a lower portion of the leaning stack **109** of substrates **101** when compacting the leaning stack of substrates. In some embodiments, the lower portion of the leaning stack of substrates can comprise the lower 50%, 40%, 30%, 20% or 10% of the length "**L**" of the leaning stack **109** of substrates **101**. Although not show, the compacting axis **901** may be located in a central portion or upper portion of the leaning stack **109** of substrates. In still further embodiments, a plurality of press members may be provided at a lower portion, central portion, and/or upper portion of the leaning stack **109** of substrates.

[00101] In some embodiments, the compacting device can apply a substantially constant pressure along the length of the compacting axis when compacting the leaning stack of substrates. For example, as shown, in **FIG. 9**, in some embodiments, all of the actuators **903** can substantially equally force the press member **705** extension direction **707a** such that the entire outer surface of the press member **705** simultaneously engages the outer surface of the outer substrate **101** of the leaning stack **109** (e.g., along the entire width "**W**" of the leaning stack **109** of substrates). As shown in **FIG. 10**, the press member **705** may maintain a substantially constant compacting pressure along the width "**W**" of the leaning stack **109** of substrates to provide uniform packing along the width "**W**" of the leaning stack **109**. In some embodiments, the press member **705** can be substantially rigid to allow consistent pressure to be applied by the press member **705** between the rods **902**. In some embodiments, the press member **705** can comprise plastic, metal, or other material.

[00102] In some embodiments, the compacting device can apply varying pressure to the additional substrate along the compacting axis **901** when compacting the leaning stack of substrates. For example, in some embodiments, the press member **705** may be flexible or segmented to allow outer portions of the press member **705** to engage the outer substrate at different times. For example, as shown in **FIGS. 11-12**, the press member **705** may begin contacting one side of the outer substrate and then continue to successively engage the outer substrate across the width "**W**" until the other side is reached. In an alternate embodiment, an intermediate portion of the outer substrate may be engaged wherein the press member **705** continues to successively engage additional portions in opposite directions towards the opposed sides of the outer substrate. In such a manner, fanning may be reduced as gas (e.g., air) can be squeezed out of the stack without being trapped as gas pockets within the stack. In some embodiments, once the engagement is complete, a constant pressure can be maintained across the width "**W**" of the leaning stack **109** of substrates to provide consistent compacting of the leaning stack **109**.

[00103] In some embodiments, the method may include compacting without direct contact between the press member and the outer substrate. For example, as shown in **FIG. 15**, the press member **1305** may include a plurality of apertures **1501** designed to provide a fluid cushion between the press member **1305** and the outer substrate. In operation, gas (e.g., compressed air) may be introduced through thee inlet port into the fluid pressure chamber **1601**. The fluid pressure chamber **1601** can supply a uniform flow of compressed gas through the apertures **1501** in fluid communication with the fluid pressure chamber. As shown, in some embodiments, the press member **1305** may comprise the plurality of segments **1307a, 1307b, 1307c**. In some embodiments, the construction of each segment **1307a, 1307b, 1307c** may be similar although different constructions may be provided in further embodiments. Furthermore, although a plurality of segments are shown, a single segment may be provided in further embodiments. However, multiple segments can allow independent control of the pressure within each pressure chamber **1601** of each segment that can provide different air cushion profiles due to the differing rates that the pressurized gas may flow through the apertures **1501**. Multiple segments may also allow independent movement of each segment **1307a, 1307b, 1307c** in direction **707a** to allow successive engagement of the press member **1305** with the outer substrate (e.g., to prevent excessive fanning by avoiding trapped gas pockets). As shown in **FIG. 14**, the press member **1305** may generate a fluid cushion **1401** (e.g., air cushion) between the leaning stack **109** of substrates **101** and the press member **1305** of the compacting device **1301** when compacting the leaning stack **109** of substrates **101**. In some embodiments, the fluid cushion **1401** can facilitate application of force to the leaning stack **109** of substrates **101** without actually mechanically contacting any of the substrates.

[00104] It should be understood that while various embodiments have been described in detail with respect to certain illustrative and specific examples thereof, the present disclosure should not be considered limited to such, as numerous modifications and combinations of the disclosed features are possible without departing from the scope of the following claims.

What it claimed is:

1. A substrate support apparatus comprising:

a base;

a plurality of suction devices, each suction device of the plurality of suction devices movably mounted to the base; and

a monitoring device configured to monitor a position of a suction device of the plurality of suction devices.

2. The substrate support apparatus of claim 1, wherein the monitoring device is configured to monitor the position of the suction device relative to the base.

3. The substrate support apparatus of any one of claims 1-2, wherein the monitoring device comprises an ultrasonic sensor.

4. The substrate support apparatus of claim 3, wherein the ultrasonic sensor is fixedly mounted to the base.

5. The substrate support apparatus of any one of claims 1-4, wherein each suction device of the plurality of suction devices is movably mounted to the base to translate along an adjustment direction relative to the base.

6. The substrate support apparatus of claim 5, wherein the plurality of suction devices comprises a column of suction devices, wherein each suction device of the column of suction devices is spaced from another suction device of the column of suction devices along a column axis that is perpendicular to the adjustment direction.

7. The substrate support apparatus of any one of claims 5-6, wherein at least one suction device of the plurality of suction devices is independently movable relative to at least one additional suction device of the plurality of suction devices.

8. A substrate packaging apparatus for packaging a leaning stack of substrates, the substrate packaging apparatus comprising:

a substrate support structure configured to support the leaning stack of substrates, the substrate support structure comprising a rear surface configured to support a major surface of a substrate of the leaning stack of substrates, and a lower surface extending away from the rear surface and configured to support a lower edge of the substrate of the leaning stack of substrates; and

a compacting device comprising a compacting axis extending along a width of the rear surface.

9. The substrate packaging apparatus of claim 8, wherein the compacting device comprises a plurality of actuators configured to apply a force to a lower portion of the leaning stack of substrates along the compacting axis.

10. The substrate packaging apparatus of claim 8, wherein the compacting device comprises a plurality of actuators configured to apply a varying force to a lower portion of the leaning stack of substrates along the compacting axis.

11. The substrate packaging apparatus of any one of claims 9-10, wherein at least one actuator of the plurality of actuators operates independently of at least one another actuator of the plurality of actuators.

12. The substrate packaging apparatus of claim 8, wherein the compacting device comprises a plurality of apertures in communication with a fluid pressure chamber.

13. A method comprising:

stacking a plurality of substrates on a substrate support structure to form a leaning stack of substrates;

imaging a feature of the leaning stack of substrates; and

determining a characteristic of the leaning stack of substrates using information obtained during the imaging.

14. The method of claim 13, wherein the characteristic of the leaning stack of substrates comprises a fanning of the leaning stack of substrates.

15. The method of any one of claims 13-14, further comprising stacking an additional substrate on the leaning stack of substrates with a substrate support apparatus supporting the additional substrate, and compacting the leaning stack of substrates by engaging the additional substrate with a compacting device.

16. The method of claim 15, wherein the compacting device applies pressure along a compacting axis when compacting the leaning stack of substrates.

17. The method of claim 16, wherein the compacting axis is positioned along a lower portion of the leaning stack of substrates when compacting the leaning stack of substrates.

18. The method of any one of claims 16-17, wherein the compacting device applies varying pressure to the additional substrate along the compacting axis when compacting the leaning stack of substrates.

19. The method of any one of claims 15-18, wherein the compacting device generates a fluid cushion between the additional substrate and the compacting device when compacting the leaning stack of substrates.

20. The method of any one of claims 15-19, wherein the compacting is conducted while the substrate support apparatus supports the additional substrate.

21. The method of any one of claims 15-20, further comprising disengaging the substrate support apparatus from the additional substrate.

22. The method of claim 21, wherein the disengaging the substrate support apparatus from the additional substrate occurs while compacting the leaning stack of substrates with the compacting device.

23. The method of any one of claims 15-22, further comprising disengaging the compacting device from the additional substrate.

24. The method of claim 23, further comprising reengaging the additional substrate with the compacting device.

25. A method comprising:

stacking an additional substrate on a leaning stack of substrates with a substrate support apparatus engaging the additional substrate, and

determining a characteristic of the leaning stack of substrates with the substrate support apparatus while the substrate support apparatus engages the additional substrate.

26. The method of claim 25, wherein a plurality of suction devices of the substrate support apparatus are removably attached to the additional substrate while stacking the additional substrate on the leaning stack of substrates.

27. The method of claim 26, wherein the determining the characteristic comprises moving one suction device of the plurality of suction devices relative to another suction device of the plurality of suction devices.

28. The method of claim 27, wherein the determining the characteristic comprises monitoring a position of the one suction device.

29. The method of claim 28, wherein the position of the one suction device is monitored with an ultrasonic sensor.

30. The method of any one of claims 25-29, further comprising compacting the leaning stack of substrates with a compacting device pressing against the additional substrate.

31. The method of claim 30, wherein the compacting the leaning stack of substrates comprises applying pressure to the additional substrate along a compacting axis with the compacting device.

32. The method of claim 31, wherein the compacting axis is positioned along a lower portion of the leaning stack of substrates when compacting the leaning stack of substrates.

33. The method of any one of claims 31-32, wherein the compacting device applies varying pressure to the additional substrate along the compacting axis when compacting the leaning stack of substrates.

34. The method of any one of claims 30-33, wherein the compacting device generates a fluid cushion between the leaning stack of substrates and the compacting device when compacting the leaning stack of substrates.

35. The method of any one of claims 30-34, wherein the compacting is conducted while the substrate support apparatus engages the additional substrate.

36. The method of any one of claims 30-35, further comprising ceasing to apply pressure to the additional substrate with the compacting device over a period of time, and then reapplying pressure to the additional substrate along the compacting axis with the compacting device.

37. The method of claim 36, further comprising disengaging the substrate support apparatus from the additional substrate prior to the reapplying pressure, wherein the

reapplying pressure is conducted while the substrate support apparatus is disengaged from the additional substrate.

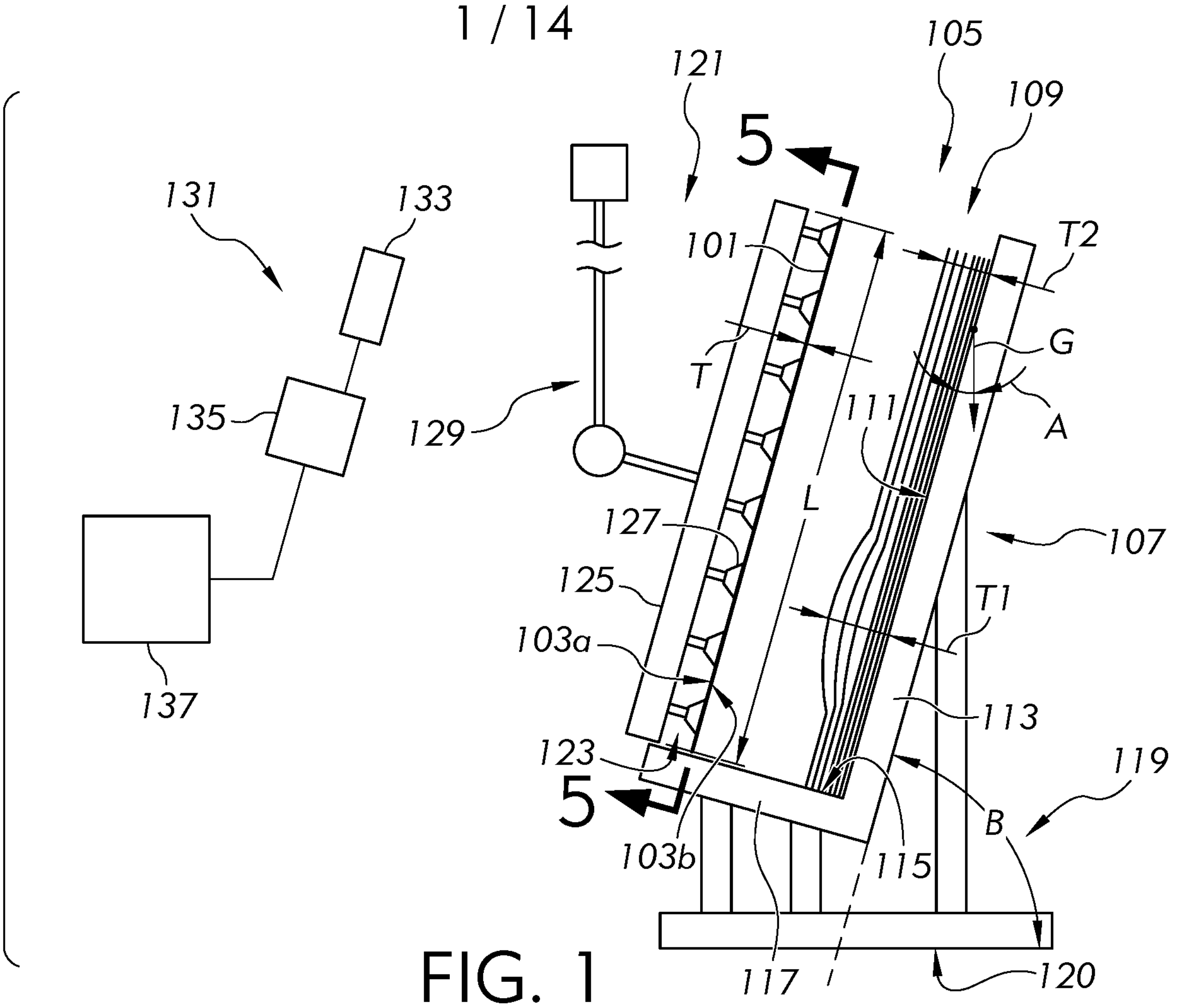
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FIG. 1

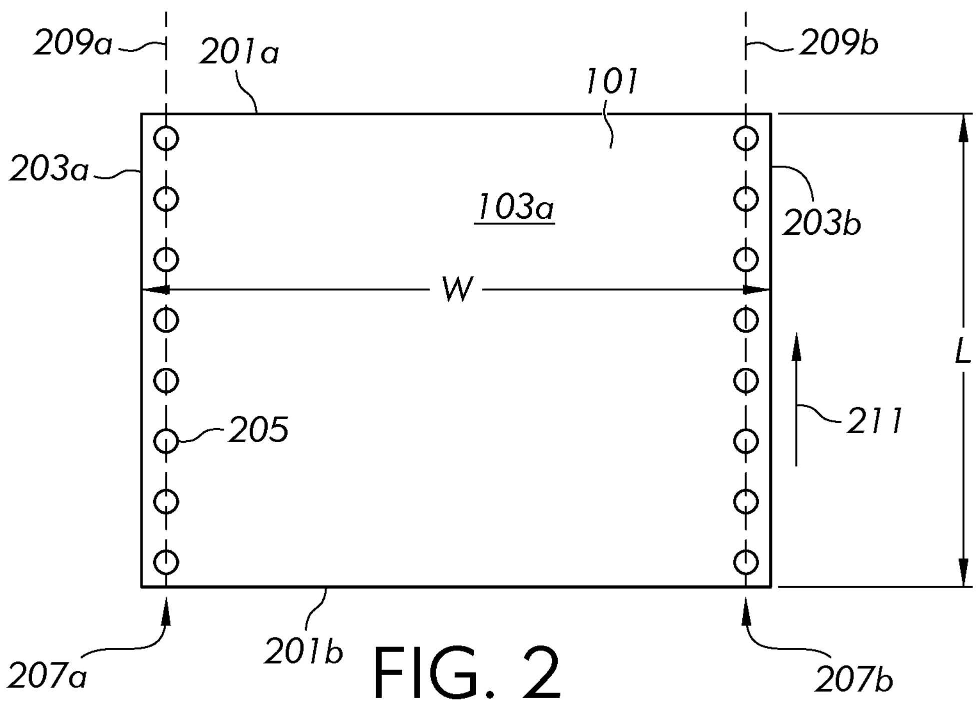
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FIG. 2

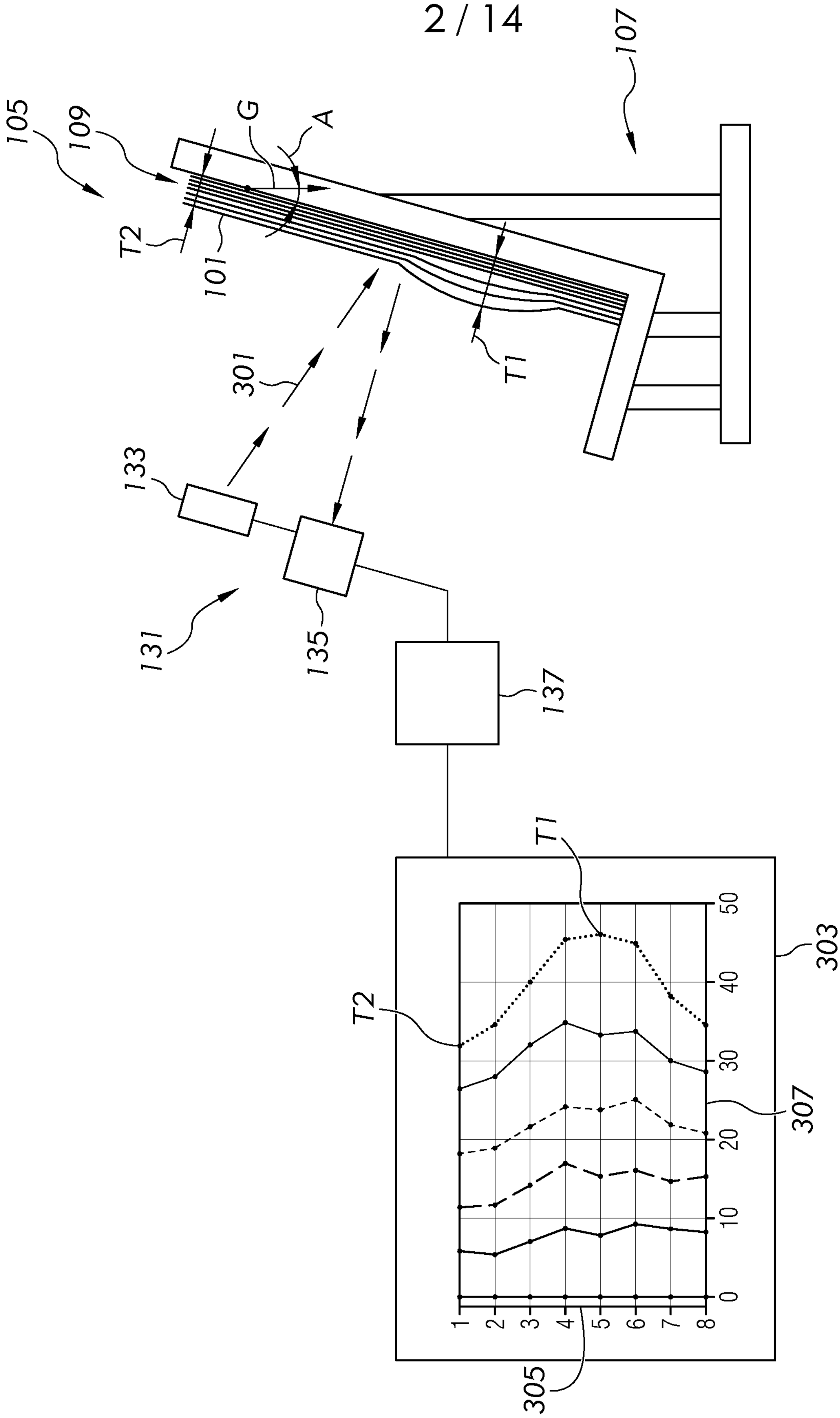
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FIG. 3

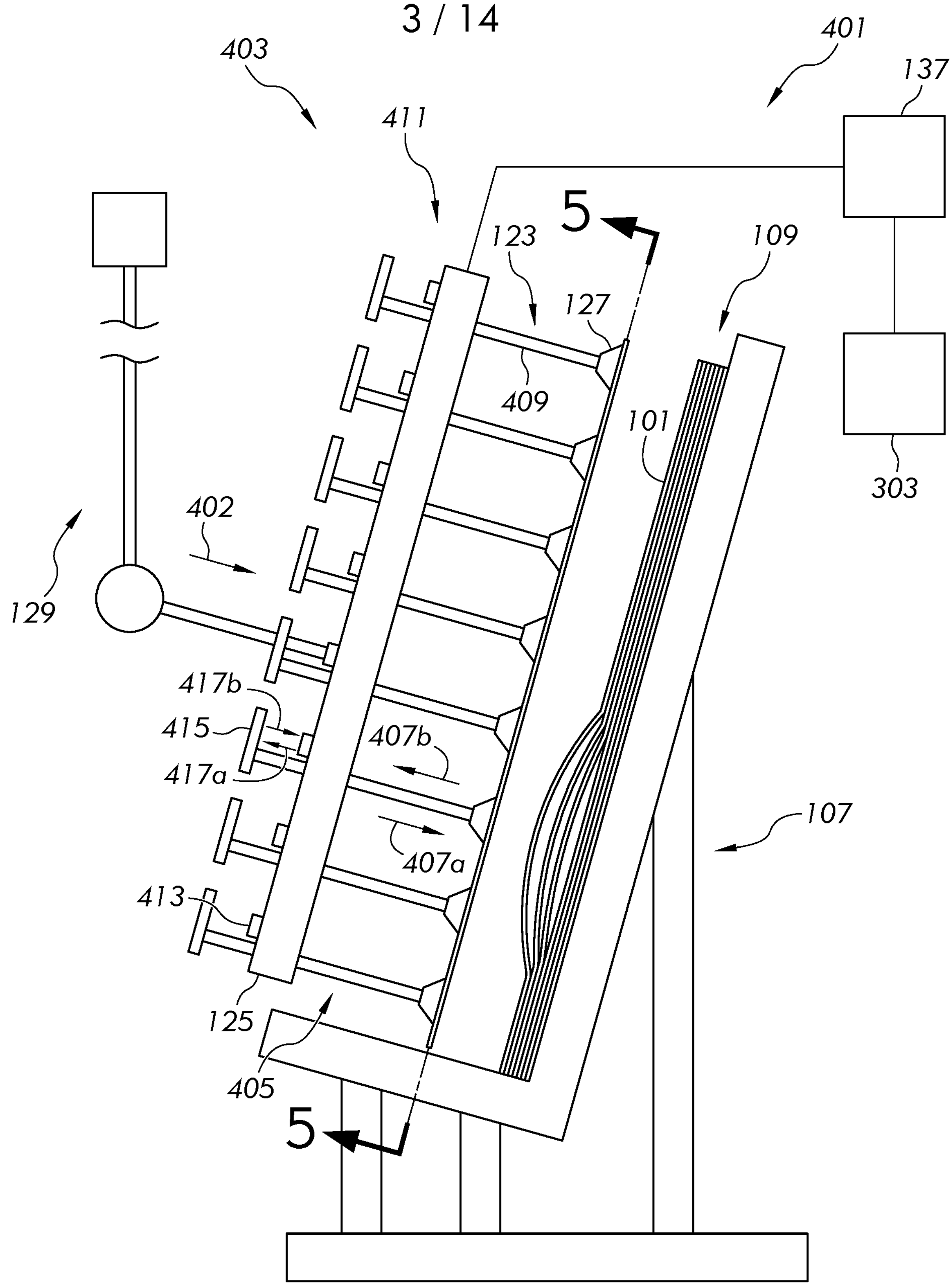
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FIG. 4

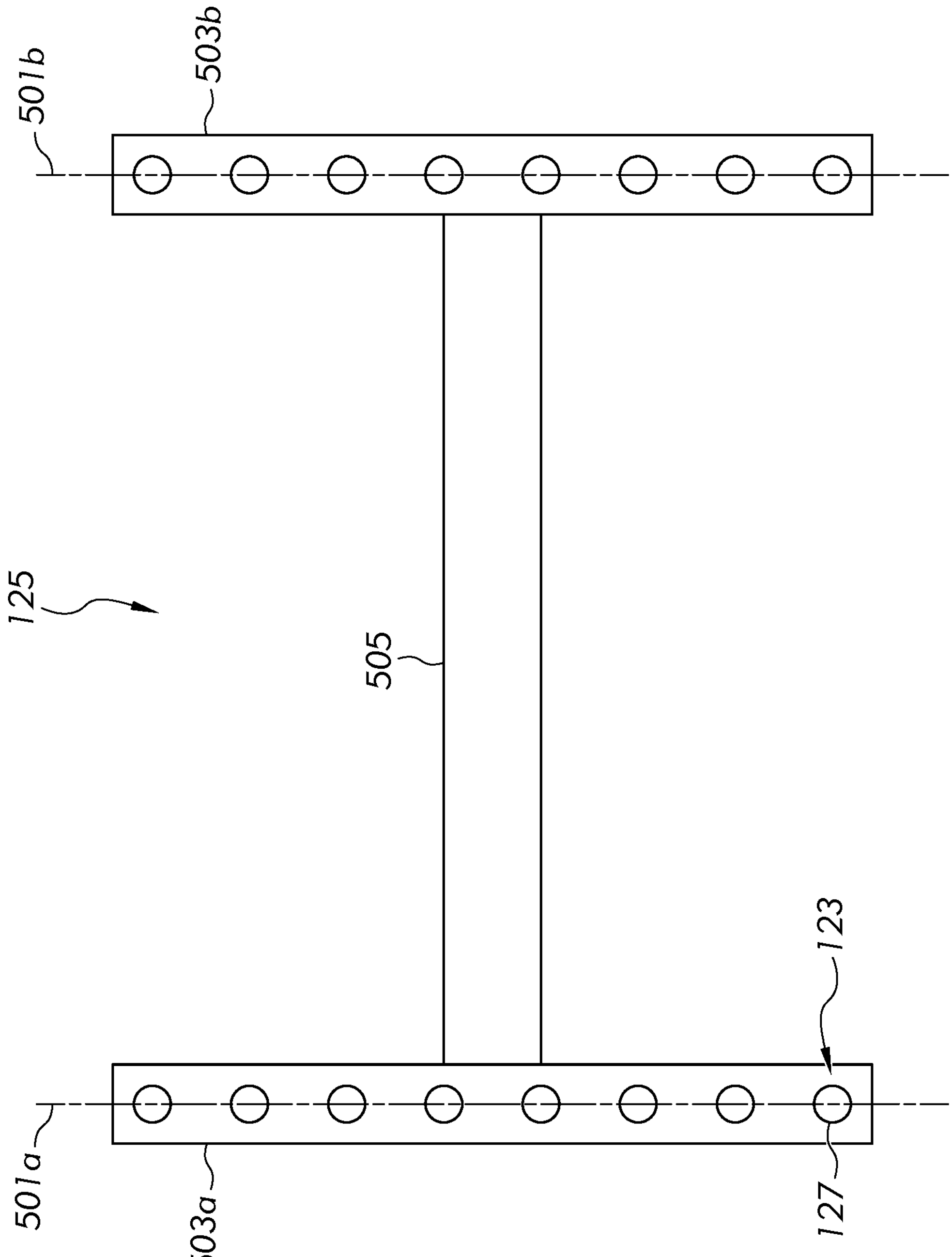


FIG. 5

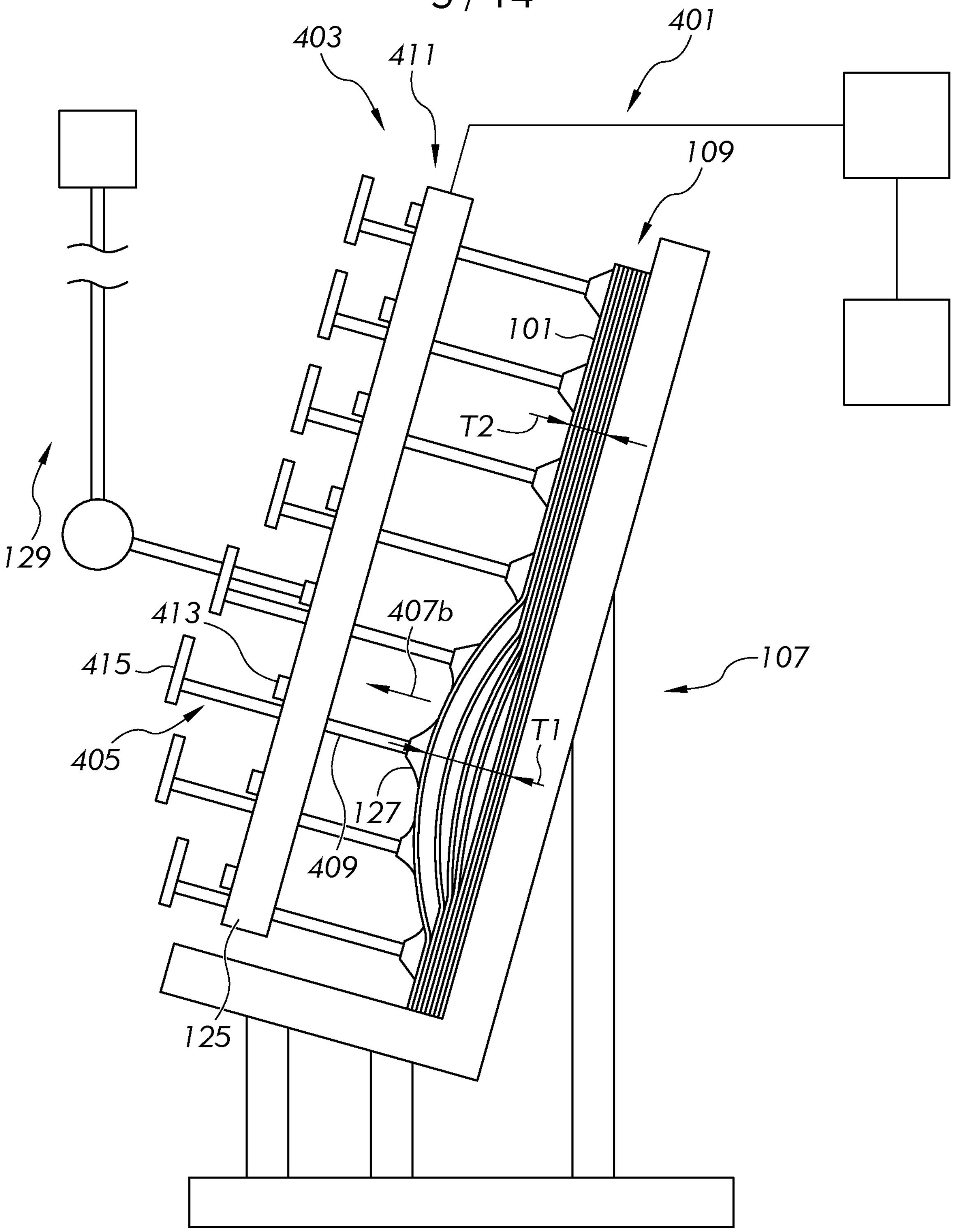
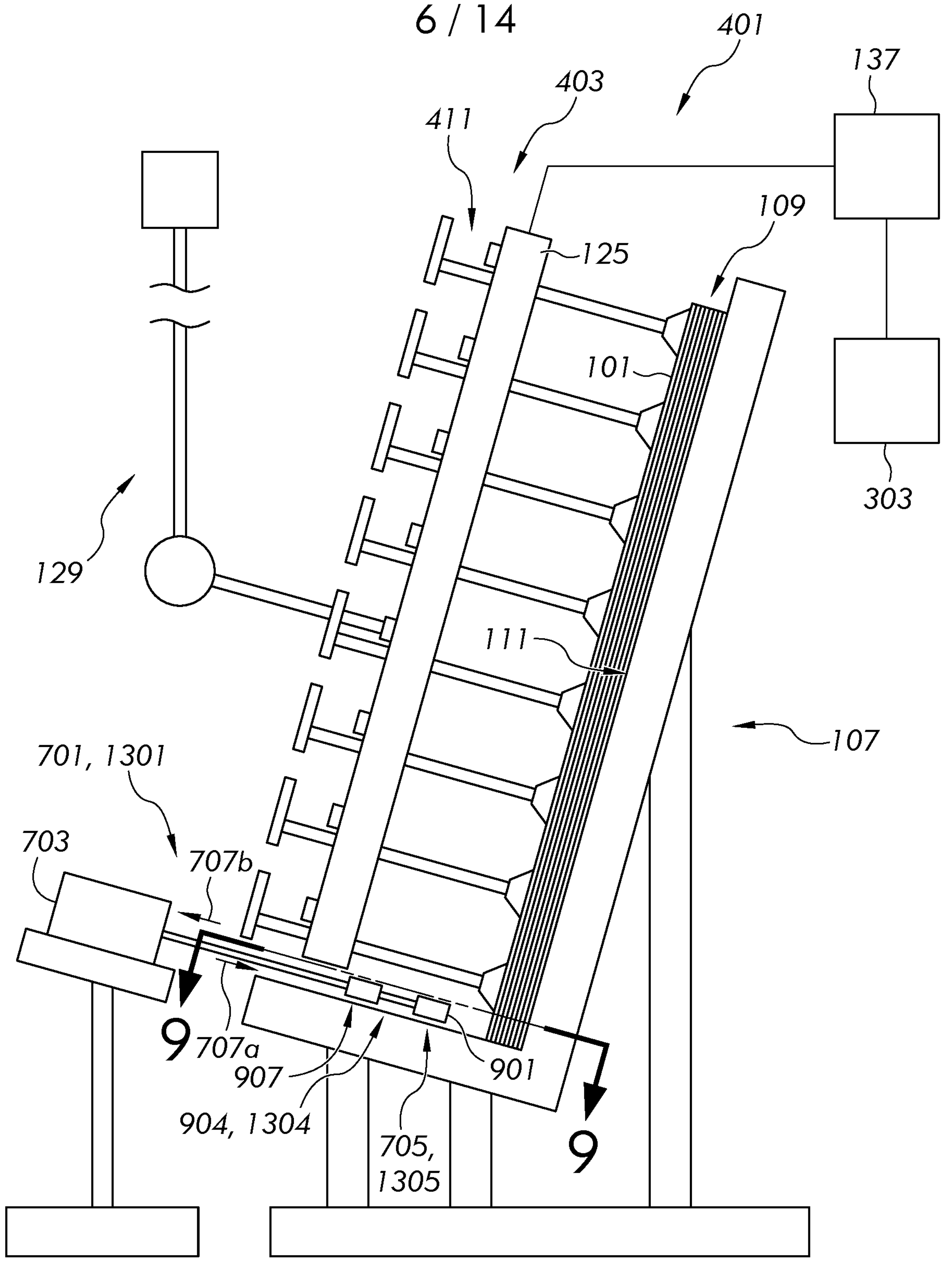


FIG. 6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1305
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FIG. 7

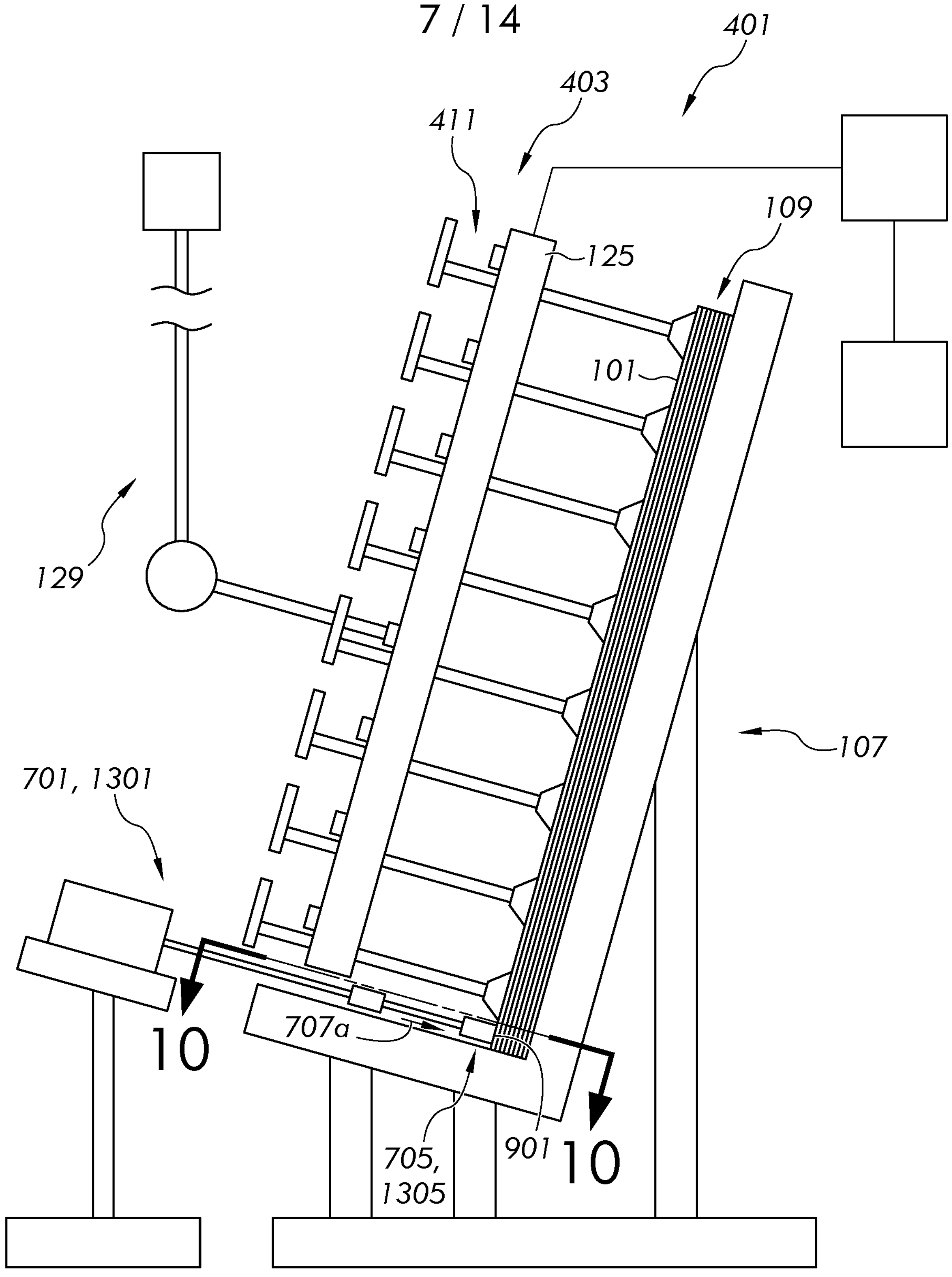

FIG. 8

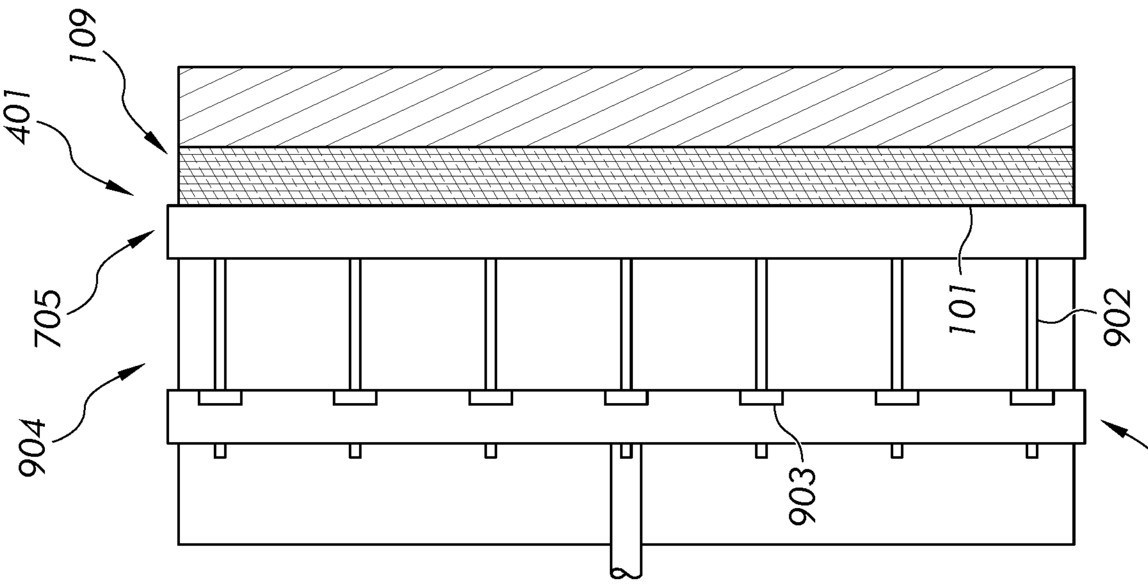
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FIG. 10

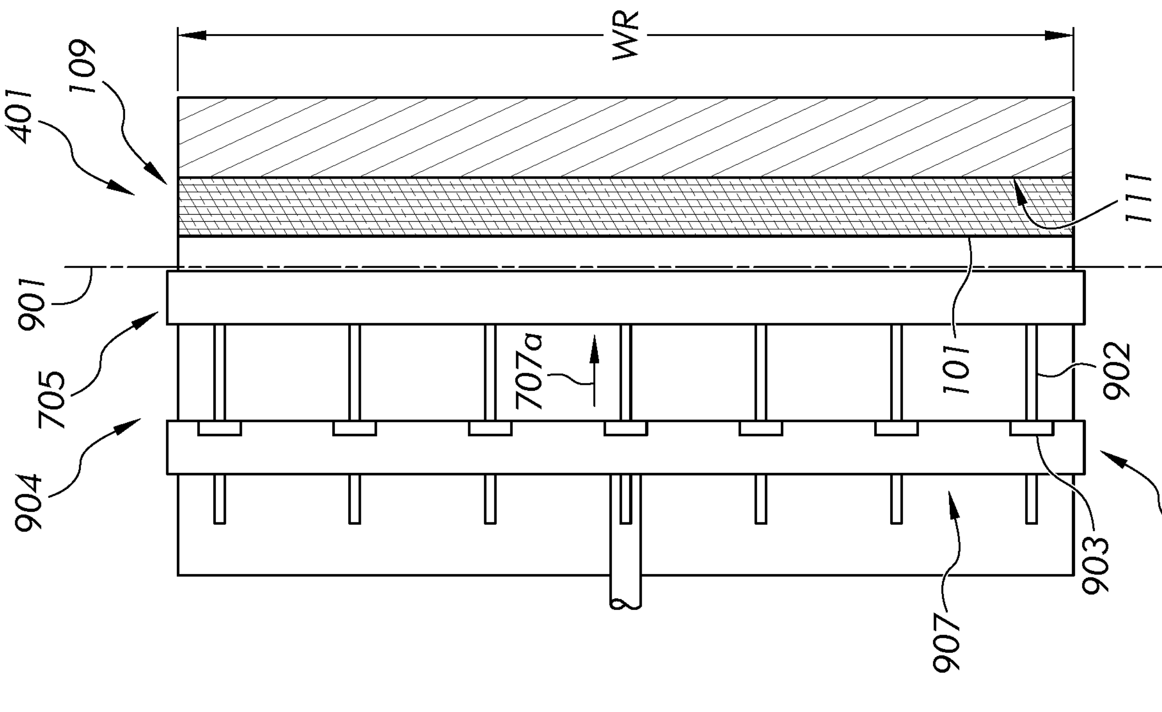
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FIG. 9

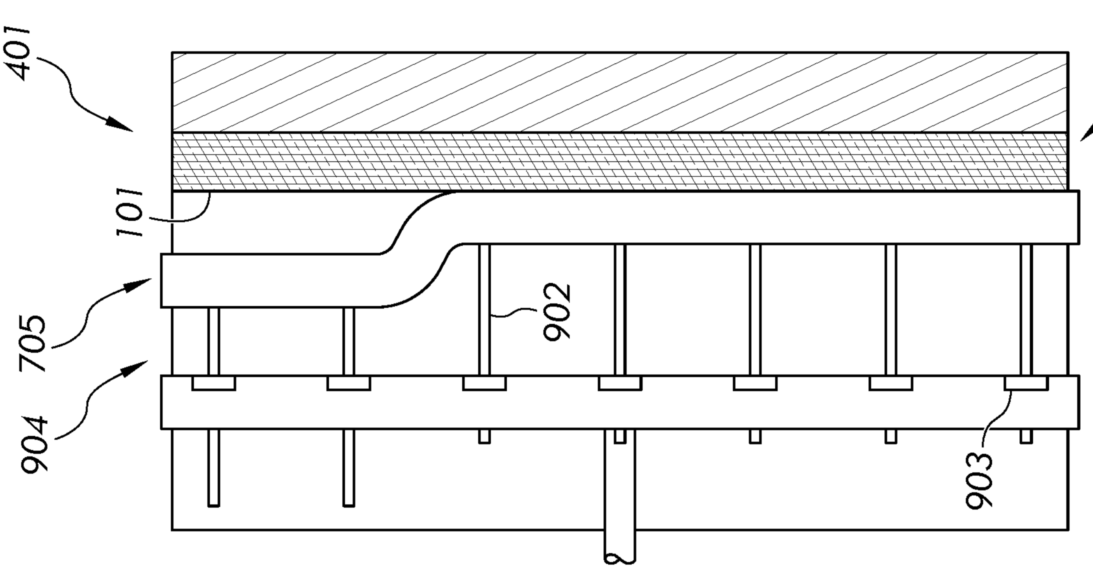

FIG. 12

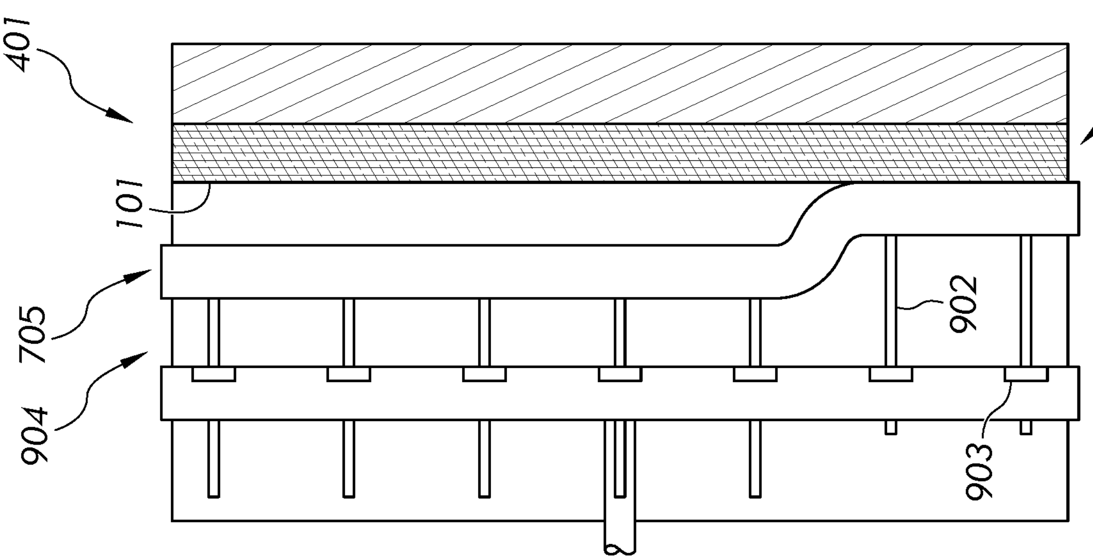

FIG. 11

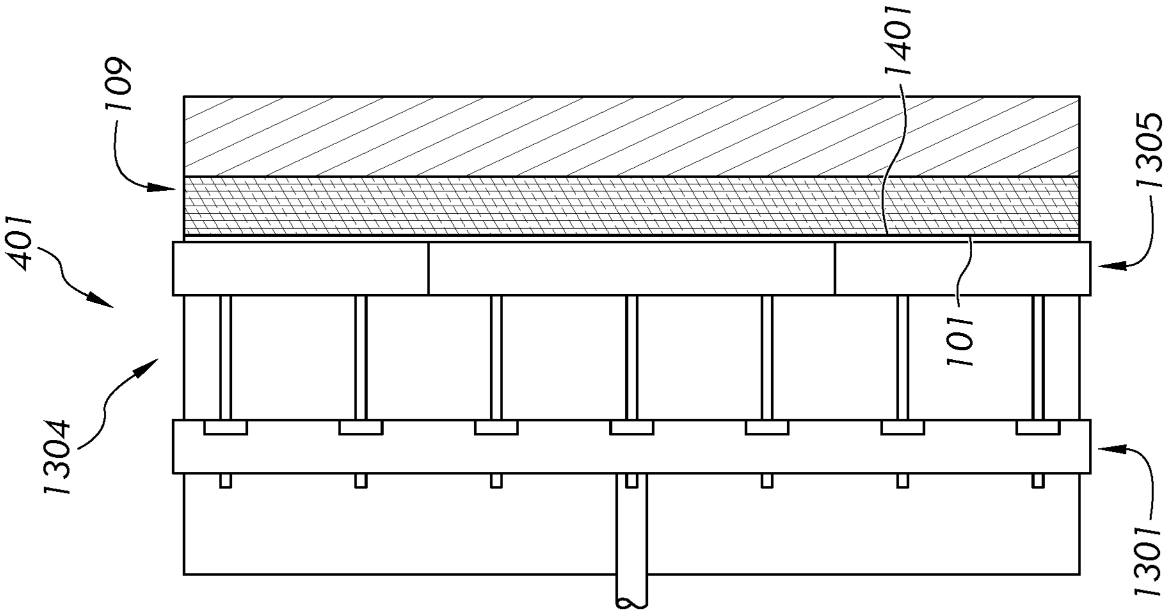
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FIG. 14

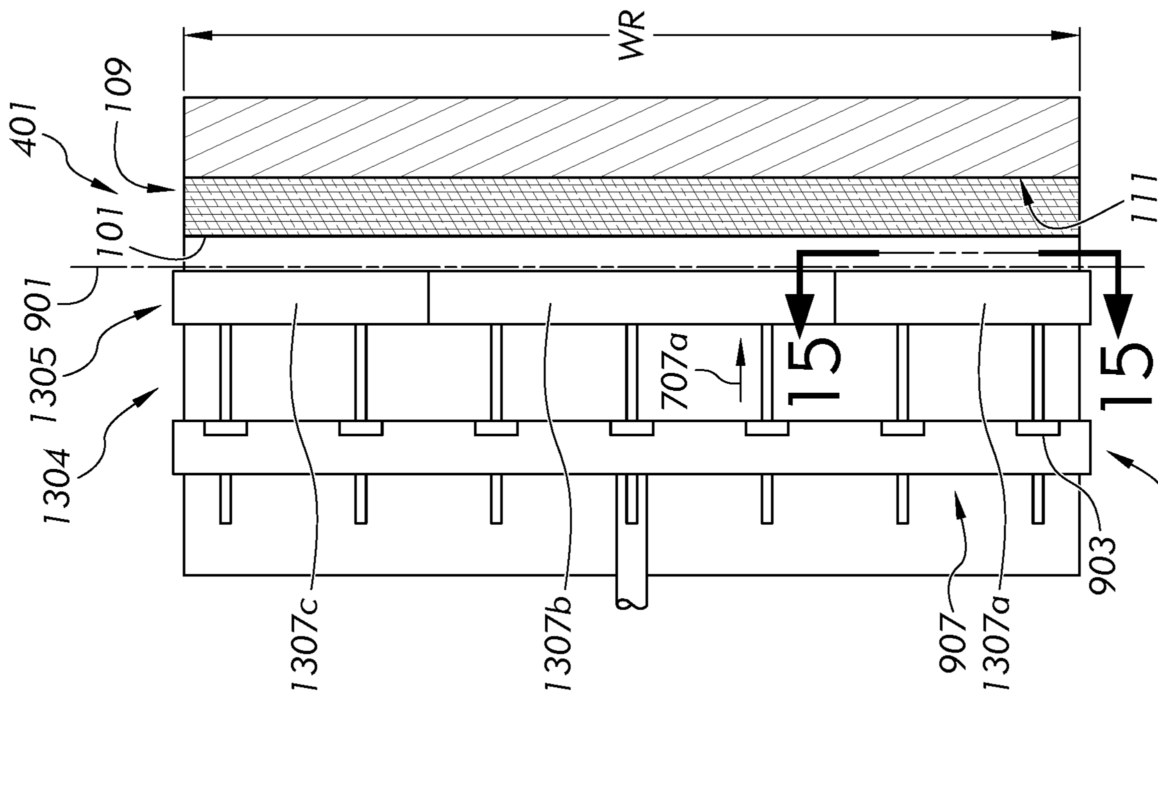
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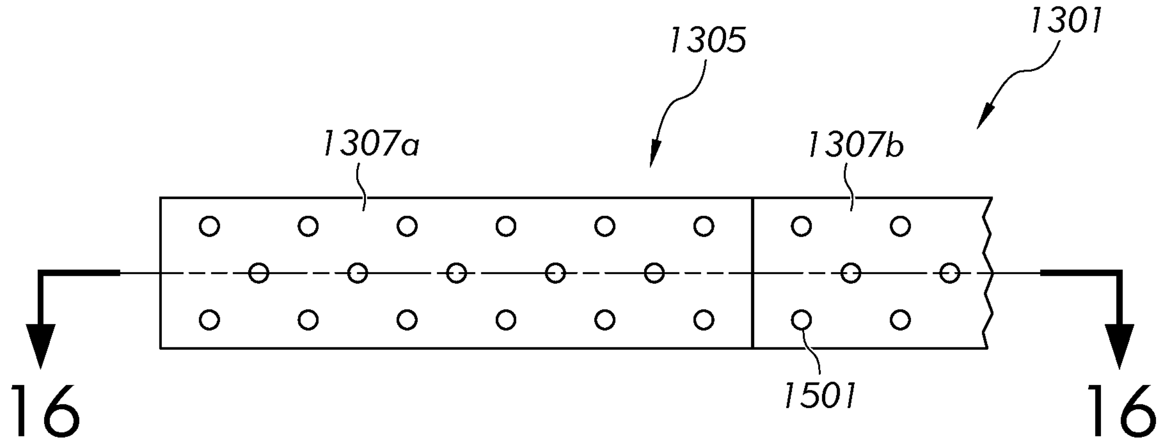
FIG. 13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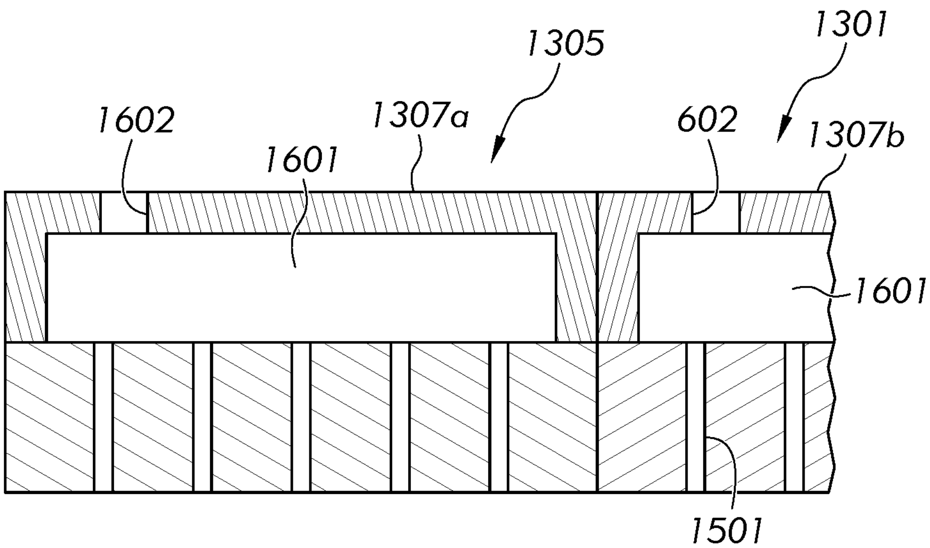
1501
16

FIG. 15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1602
1307a
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1601
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FIG. 16

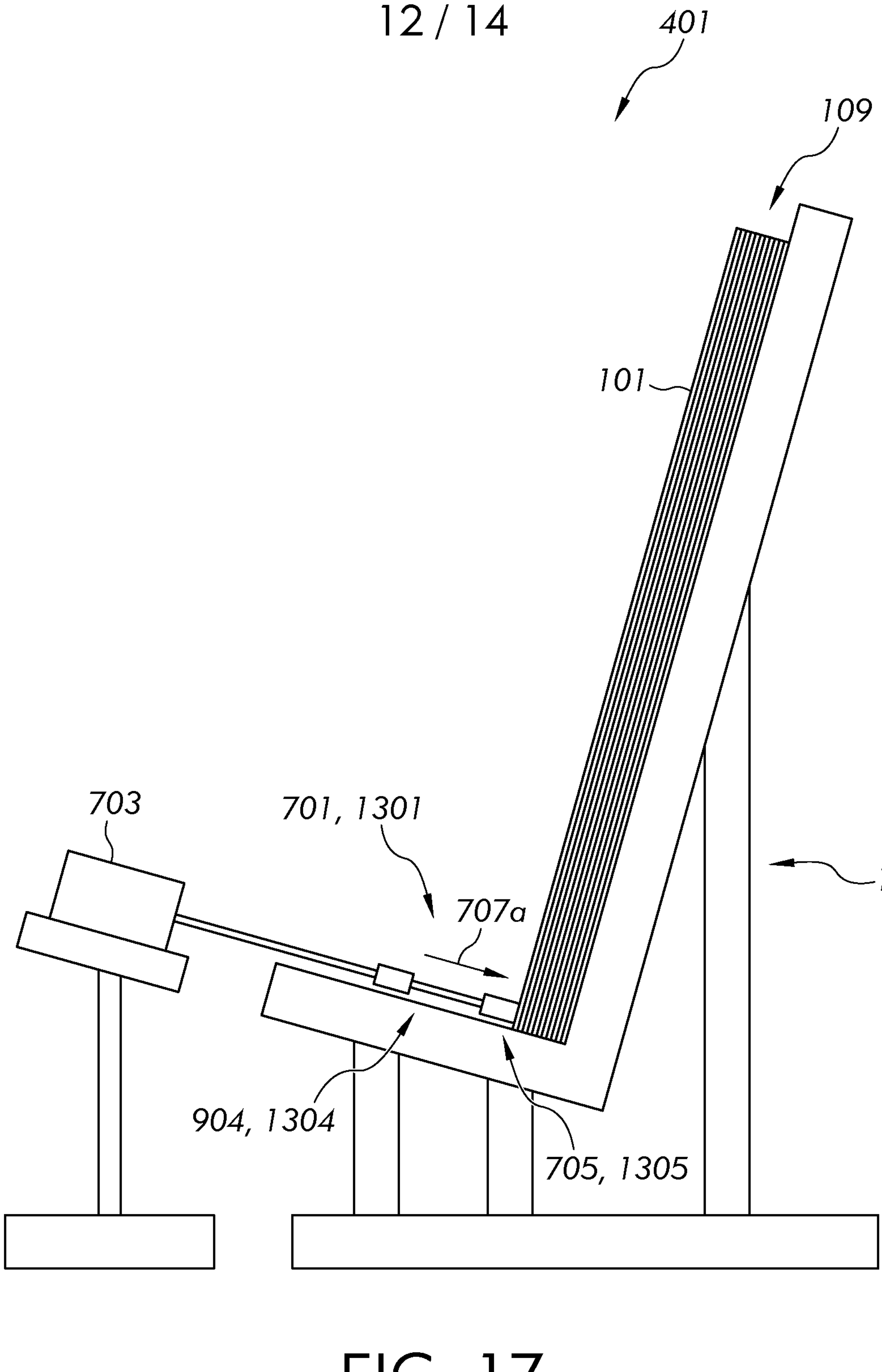

FIG. 17

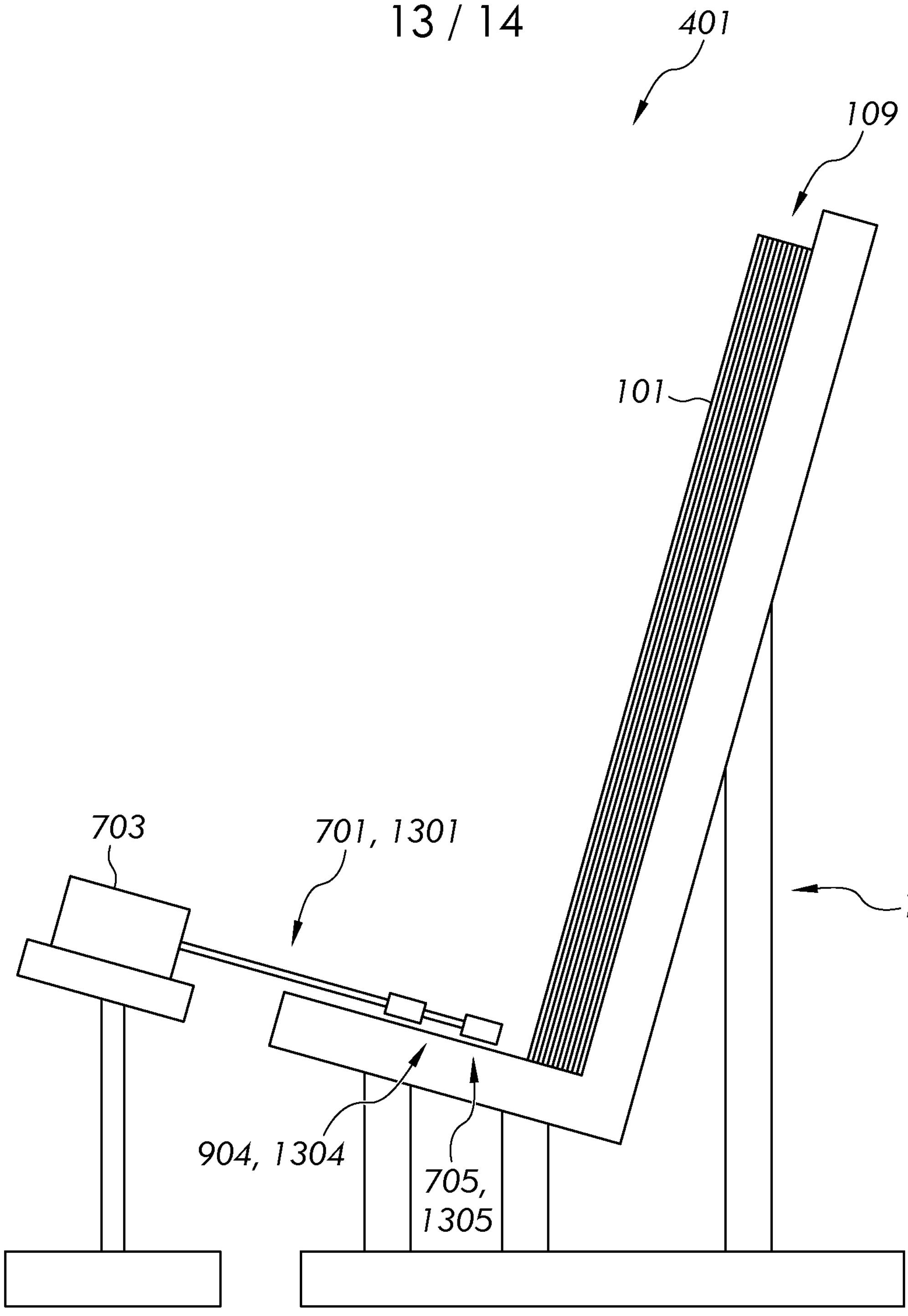

FIG. 18

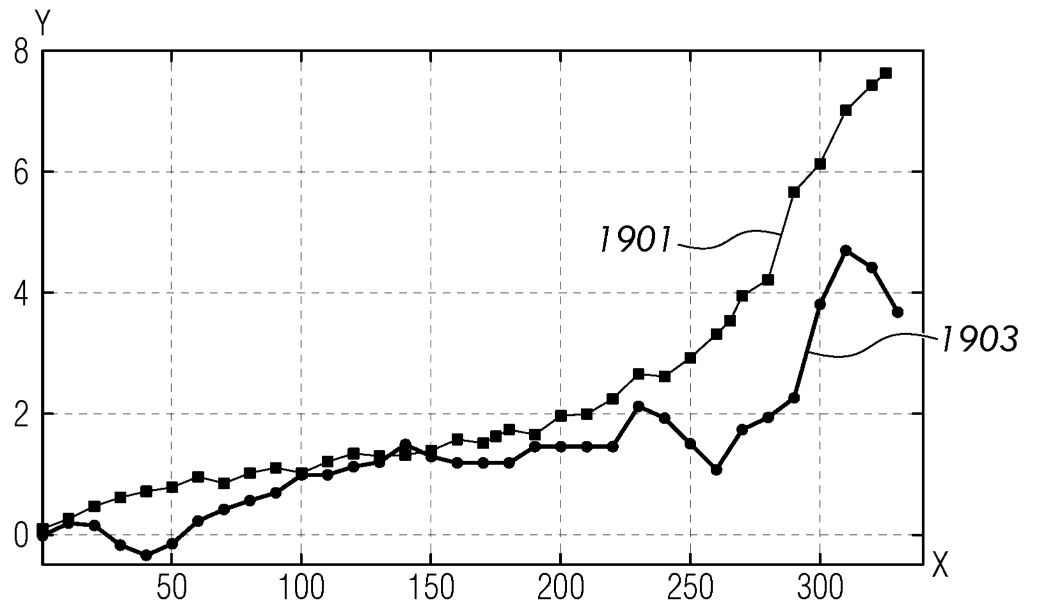
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FIG. 19

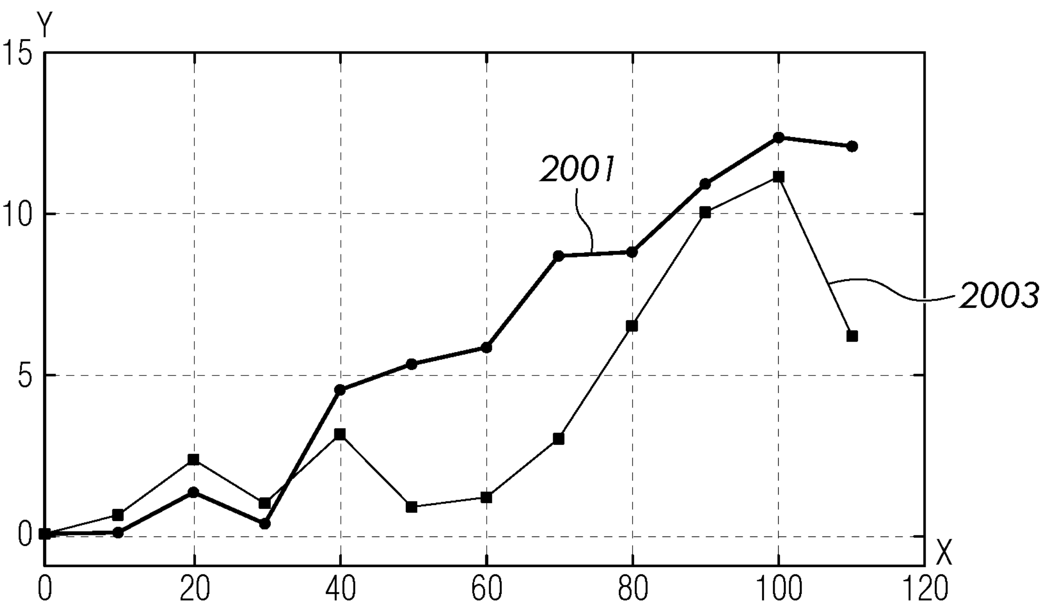
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FIG. 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/039528

A. CLASSIFICATION OF SUBJECT MATTER

B65B 35/50(2006.01)i; **B65B 35/18**(2006.01)i; **B65B 57/00**(2006.01)i; **B65B 25/14**(2006.01)i; **B65B 63/02**(2006.01)i; **B65B 65/02**(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B65B 35/50(2006.01); B24B 49/00(2006.01); B65G 47/91(2006.01); B65H 3/08(2006.01); B65H 3/28(2006.01); B65H 3/52(2006.01); H05K 13/04(2006.01); H05K 13/08(2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: substrate, suction devices, monitoring device, compacting device, leaning stack

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4703925 A (JELINEK et al.) 03 November 1987 (1987-11-03) column 7, line 49 – column 8, line 15, column 13, line 19 – column 14, line 12; and figures 3, 12-15	1-7
A		15-37
X	US 2015-0102553 A1 (XEROX CORPORATION) 16 April 2015 (2015-04-16) paragraphs [0039]-[0044]; claim 8; and figures 3-5	8-12
X	US 2007-0224918 A1 (TERADA et al.) 27 September 2007 (2007-09-27) paragraphs [0037]-[0071]; and figures 4, 6-7, 9A-9C, 12	13-14
A	CN 110950073 A (SHENZHEN MICRONIC TECHNOLOGY CO., LTD.) 03 April 2020 (2020-04-03) claims 1-9; and figures 1-4	1-37
A	JP 2007-042834 A (MATSUSHITA ELECTRIC IND. CO., LTD.) 15 February 2007 (2007-02-15) paragraphs [0016]-[0044]; and figures 1-5	1-37

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
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- "E" earlier application or patent but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 October 2021	**18 October 2021**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office **189 Cheongsa-ro, Seo-gu, Daejeon** **35208, Republic of Korea**	**BAHNG, SEUNG HOON**
Facsimile No. **+82-42-481-8578**	Telephone No. **+82-42-481-5560**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2021/039528

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