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(54) Title: SHEET WAFER GROWTH STABILIZATION

(57) Abstract: An apparatus for forming a sheet wafer has an enclosure forming an interior chamber, and a crucible within the interior chamber and having a top surface. The crucible is configured to contain a volume of molten material. The apparatus also has a wafer guide spaced from the top surface of the crucible and within the interior chamber. The wafer guide forms a channel for passing a growing sheet wafer.

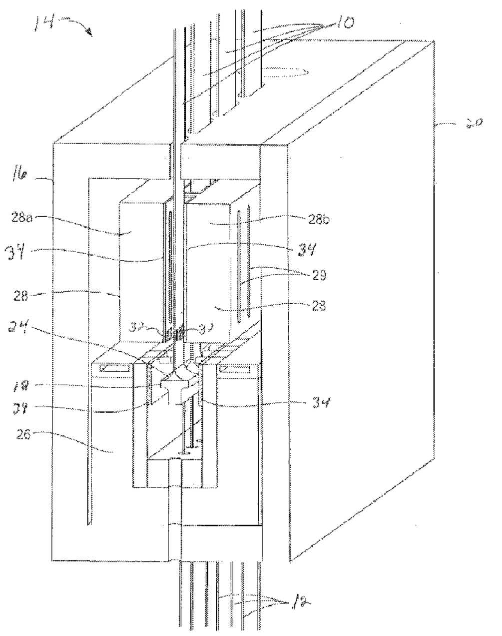

FIG. 3

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SHEET WAFER GROWTH STABILIZATION

RELATED PATENT APPLICATIONS

This application is related to co-pending US Patent Application No. 13/015,047, filed January 27, 2011, attorney docket number 3253/A07, entitled, "Wide Sheet Wafer," the disclosure of which is incorporated herein, in its entirety, by reference.

This application also is related to co-pending US Patent Application No. 13/015,258, filed January 27, 2011, attorney docket number 3253/197, entitled, "Controlling the Temperature Profile in a Sheet Wafer," the disclosure of which is incorporated herein, in its entirety, by reference.

TECHNICAL FIELD

The invention generally relates to sheet wafers and, more particularly, the invention relates to devices and processes for forming sheet wafers.

BACKGROUND ART

Silicon wafers are the building blocks of a wide variety of semiconductor devices, such as solar cells, integrated circuits, and MEMS devices. For example, Evergreen Solar, Inc. of Marlboro, Massachusetts forms solar cells from silicon sheet wafers fabricated by passing two filaments through a crucible of silicon melt. This type of wafer may be referred to as "filament sheet wafers," and are known in the industry as STRING RIBBON™ wafers.

The ribbon pulling technique uses proven processes for producing high quality silicon crystals. Such processes, however, may produce sheet wafers that are warped to some extent (also referred to in the art as "bowed").

SUMMARY OF THE INVENTION

In accordance with one embodiment of the invention, an apparatus for forming a sheet wafer has an enclosure forming an interior chamber, and a crucible within the interior chamber and having a top surface. The crucible is configured to contain a volume of molten material. The apparatus also has a wafer guide spaced from the top surface of the crucible and within the interior chamber. The wafer guide forms a channel for passing a growing sheet wafer.

The apparatus also may have an afterheater region for controlling the temperature within the interior chamber. The wafer guide illustratively may be at least in part within the afterheater region. Among other things, the wafer guide may include a plurality of posts extending from at least two opposing surfaces of the afterheater. Alternatively, or in addition, the wafer guide may include a pair of solid members extending from at least two opposing surfaces of the afterheater.

The crucible further may include molten material (e.g., multi-crystalline silicon) on its top surface. The molten material forms a sheet wafer extending from the crucible, where the wafer sheet cools in a controlled manner as it enters and moves through the afterheater region. The initial cooling is very rapid. The wafer guide post is placed close to the melt surface, but not so close as to substantially affect the cooling of the sheet, particularly during the rapid initial cooling, or to induce additional cooling. The farther away from the meniscus the wafer guide is placed, the less stabilizing influence it will have on movement of the meniscus.

The interior chamber thus may be considered to have a plateau region between the crucible and a post plateau region. The wafer guide illustratively is positioned at least in part within the post plateau region. The location and size of the post plateau region is a function of the molten material the apparatus is designed to use.

The channel is considered to have a length, a height, and a width (i.e., the width is the gap between opposing wafer guides). In some embodiments, the wafer guide includes a plurality of wafer guides that extend inwardly to vary the width of the channel. For example, the channel may have a pair of end regions and a central region. The width of the channel thus may be smaller in the central region than in the pair of end regions. Moreover, the height preferably is much smaller than the length, and/or the channel may have an elongated shape.

The wafer guide should be formed from a material that is capable of sufficiently withstanding anticipated temperatures within the apparatus (e.g., exceeding 1200 degrees C. For example, among other things, the wafer guide may be formed of at least one of silicon carbide and graphite.

In accordance with another embodiment of the invention, a method and apparatus for forming a sheet wafer adds molten material to a crucible within a furnace, and grows a sheet wafer from the molten material with a pair of filaments. The method and apparatus pass at least a portion of the growing sheet wafer through a wafer guide member positioned within a post plateau region of the furnace. To that end, this wafer guide member forms a channel with an elongated shape that passes the growing sheet wafer.

BRIEF DESCRIPTION OF THE DRAWINGS

Those skilled in the art should more fully appreciate advantages of various embodiments of the invention from the following "Description of Illustrative Embodiments," discussed with reference to the drawings summarized immediately below.

Figure 1 schematically shows a sheet wafer configured in accordance of illustrative embodiments of the invention.

Figure 2 schematically shows a perspective view of a portion of a sheet wafer growth system according to illustrative embodiments of the present invention.

Figure 3 schematically shows a partially cut away view of the sheet wafer growth system of Figure 2 with part of the housing removed.

Figure 4 schematically shows a cross-sectional view of a sheet wafer growth system having a guide system within an afterheater according to various embodiments of the present invention.

Figure 5 schematically shows a close-up view of a portion of the furnace.

Figures 6A and 6B schematically show two uses of one type of wafer guide in accordance with illustrative embodiments of the invention.

Figure 7 schematically shows a second type of wafer guide configured in accordance with illustrative embodiments of the invention.

Figure 8 graphically shows the temperature profile within a sample wafer furnace.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

In illustrative embodiments, a sheet wafer furnace has internal structure for limiting the movement of the growing sheet wafer at its local meniscus. This beneficially should significantly mitigate or eliminate one source of potential wafer bow. To that end, the furnace has a plurality of wafer guides strategically located near, but downstream from, the meniscus. When appropriately positioned, the wafer guides minimize wafer movement caused by downstream processes, such as handling and extracting the wafer while it continues to grow. Details of illustrative embodiments are discussed below.

Figure 1 schematically shows a filament sheet wafer 10 configured in accordance illustrative embodiments of the invention. For example, the wafer 10 may be similar to STRING RIBBON wafers, distributed by Evergreen Solar, Inc. of Marlboro, MA. In a manner similar to other filament sheet wafers, this sheet wafer 10 has a generally rectangular shape and a relatively large surface area on its front and back faces.

The thickness of the sheet wafer 10 varies and is very thin relative to its length and width dimensions (discussed below). Despite this range, the filament sheet wafer 10 may be considered to have an average thickness across its length and/or width. For example, the sheet wafer 10 may have a thickness ranging from about 80 microns to about 320 microns across its width. Some embodiments have an average thickness of between 100 and 200 microns, such as about 170 microns. The filament sheet wafer 10 may primarily include any of a wide variety of crystal types, such as multi-crystalline, single crystalline, polycrystalline, microcrystalline or amorphous material (e.g., silicon).

As known by those skilled in the art, the filament sheet wafer 10 is formed from a pair of filaments 12 (also referred to as "strings,") substantially encapsulated by silicon (e.g., multi-crystalline or single crystal silicon). The silicon may extend slightly outwardly of the filament 12 to generally form the edge of the sheet wafer 10. Figure 1 illustrates this by showing the filament 12 as dashed lines-in phantom—traversing along the length of the wafer 10.

For purposes of this discussion, the distance between the edges (of the wafer 10) that are parallel with the filaments 12 is considered to be the "width" of the wafer 10. Figure 1 explicitly highlights this dimension. The filaments 12 thus are considered to extend generally perpendicular to the width of the body. The two edges (or sides) forming the width thus may be considered, from the perspective of Figure 1, "left and right edges or sides." In a corresponding manner, Figure 1 also explicitly shows the "length" dimension, which is generally perpendicular to the width—generally parallel with the filaments 12. Again, from the perspective of Figure 1, the two edges or sides forming the length can be considered "top and bottom sides/edges."

The length of the wafer 10 can vary significantly depending upon where automated processes and/or operators cut the sheet wafer 10 as it is growing. Automated processes and/or operators preferably cut/separate the sheet wafer 10 in a manner that produces smaller wafers 10 of generally uniform length. The wafer 10 may have a conventionally sized width, or a width that is larger than those in conventional filament sheet wafers known to the inventors. For example, the width of the wafer 10 may exceed about 140 millimeters. In some embodiments, the wafer 10 has a width of between 145-165 millimeters, or about 156 millimeters.

The process of forming a sheet wafer 10 involves many variables and complexities. In fact, some of these variables can undesirably can cause curvature or bowing in the wafer 10; a form of wafer warping. For example, some conventional sheet wafer techniques grasp a growing sheet wafer 10 before a laser separates a smaller portion from it—to form an individual wafer 10 as shown in Figure 1. This wafer manipulation mechanically moves the base of the growing wafer 10 as it extends from its corresponding crucible of molten material (the meniscus, the "liquid-solid interface," discussed below with respect to Figures 2 and others). This and other such mechanical manipulation can cause the wafer 10 to bow.

If the amount of bowing is too large, then the wafer 10 generally has little commercial value as it will be more prone to breakage during and after fabrication. For example, when used in a solar cell, processes typically screen print silver or some other metal on the front and back faces of the filament sheet wafer 10 (discussed in greater detail below). Many conventional screen print processes require substantially flat wafers 10—otherwise, the screen printing process may shatter the very thin and fragile wafer 10. This can significantly reduce yield, thus increasing costs.

To understand bow, one may consider an ideal filament sheet wafer 10, which is perfectly planar. As discussed above, however, filament sheet wafers 10 often have a varying thickness across their bodies. An ideal, variable-thickness filament sheet wafer 10 thus has its entire body below/between the planes of the thickest parts of the thickness. The thickest parts of the thickness may be considered to form an "ideal plane." In practice, however, regardless of the wafer width, there may be some portions of the body that undesirably bend to cause some edge or side to extend out of the ideal plane.

In illustrative embodiments, the filament sheet wafer 10 has no edge, face, or other portion that extends more than a pre-selected amount out of plane of the ideal plane. For example, the wafer 10 may not extend out of the ideal plane by more than about 2.5 millimeters. Thus, wafer fabrication and quality control processes reject wafers having any part that extends more than about 2.5 millimeters out of the ideal plane. For example, a wafer 10 having an edge that extends about 2.8 millimeters out of plane may be considered as having "a bow of 2.8 millimeters."

One simple way of determining if the bow is less than the maximum permissible amount is to position the wafer 10 on a generally flat conveyer belt, and pass the wafer 10 underneath a bar or member that is about 2.5 millimeters or less above the ideal plane (i.e., about 2.5 millimeters above the highest portion of the top face). For example, some processes conduct this test at about 2.0 millimeters above the ideal plane. If the wafer 10 passes underneath the bar or member, it has acceptable bow and can be used commercially in solar cells. If it does not pass underneath the bar, then it is rejected as having too much bow. It is expected that the edges (and not the faces) of rejected wafers 10 may be most out of plane. There may be interior portions on the face of the wafer 10, however, that are out of plane and can be the cause for the wafer rejection.

Bowing thus is a significant problem. To control bow, the inventors realized that the lateral movement of the growing wafer 10 must be carefully controlled. To that end, the inventors modified the wafer growth furnace to minimize bow from this source.

Specifically, as known by those in the art, filament sheet wafers 10 are grown in high temperature filament sheet wafer growth furnaces. Figure 2 schematically shows a sheet wafer furnace 14 according to various embodiments of the present invention. The furnace 14 may include a housing 16 forming an enclosed or sealed interior (shown in subsequent figures). The interior may be substantially free of oxygen (e.g., to prevent combustion) and include one or more gases, such as argon or other inert gas, that may be provided from an external gas source. The interior includes a resistively heated crucible 18 (as shown in Figures 3-5) for containing molten silicon, and other components for substantially simultaneously growing one or more silicon sheet wafers 10. Although Figure 2 shows four sheet wafers 10, the furnace 14 may substantially simultaneously grow fewer or more of the filament sheet wafers 10. For example, the furnace 14 may grow two wide sheet wafers 10 (also referred to as "crystal sheets 10").

The housing 16 may include a door 20 to allow access to and inspection of the interior and its components, and one or more optional viewing windows 22. The housing 16 also has an inlet (not shown) for directing feedstock material, such as silicon pellets, into the interior of the housing 16 to the crucible 18. It should be noted that discussion of the silicon feedstock and silicon sheet wafers 10 is illustrative and not intended to limit all embodiments of the invention. For example, the sheet wafers 10 may be formed from other materials, e.g., metals, glass, ceramics, or alloys.

Figure 3 schematically shows a partially cut away view of a furnace 14 with part of the housing 16 removed, while Figure 4 schematically shows a cross-sectional view of a growth system with the housing 16 removed. As noted above, the furnace 14 includes the crucible 18 for containing molten material 24 in the interior of the housing 16.

In one embodiment, the crucible 18 may have a substantially flat top surface that may support or contain the molten material 24 (e.g., molten multi-crystal silicon). Alternatively, other embodiments (not shown) of the crucible 18 may have walls for containing the molten material. The crucible 18 includes filament holes (not shown) that allow one or more filaments 12 to pass through the crucible 18. As the filaments 12 pass through the crucible 18, portions of the molten silicon solidify at respective surface menisci (i.e., the liquid-solid interface noted above), thus forming the growing sheet wafer 10 between each respective pair of filaments 12. To facilitate the side-by-side wafer growth, the crucible 18 has an elongated shape with a region for growing sheet wafers 10 in the side-by-side arrangement along its length. Alternative embodiments, however, may grow the wafers 10 in a face to face manner.

To at least in part control the temperature profile in its interior, the furnace 14 has insulation that is formed based upon the thermal requirements of the regions in the housing 16. For example, the insulation is formed based on 1) the region containing the molten material 24 (i.e., the crucible 18), and 2) the region containing the resulting growing sheet wafer 10 (the afterheater 28, discussed below and in greater detail in incorporated patent application number 13/015,047). To that end, the insulation includes a base insulation 26 that forms an area containing the crucible 18 and the molten material 24, and an afterheater 28 positioned above the base insulation 26 (from the perspective of the drawings).

The afterheater 28 is important to the bowing issue—it is where the just formed wafer 10 cools from very high temperatures toward ambient temperatures. Ideally, the afterheater 28 causes the rate of change of cooling in both the X and Y directions across the wafer 10 to be substantially constant. The inventors have configured the afterheater 28 toward that end. Again, see the above noted incorporated '047 patent application for more details on various embodiments of the afterheater 28.

In some embodiments, the furnace 14 also may include a gas cooling system that supplies gas from an external gas source (not shown), through a gas cooling manifold, to gas jets 30. The gas cooling system may provide gas to further cool the growing sheet wafer 10 and control its thickness. For example, as shown in Figures 3-5, the gas cooling jets 30 may face toward the growing sheet wafer 10 in the area above the crucible 18—toward the above noted meniscus extending from the melt and containing the wafer 10.

To mitigate wafer bow, the furnace 14 has a plurality of wafer guides 32 strategically positioned within its interior. To that end, in each lane of the furnace 14, the wafer guides 32 are positioned very close to, but not too close to, their corresponding meniscus (i.e., close to where the meniscus will be when operating). As discussed in greater detail below, the wafer guides 32 are positioned to minimize their impact on the temperature profile within the furnace 14 and yet, stabilize the growing wafer 10 as much as possible.

Specifically, Figures 3-5 all show a pair of wafer guides 32 configured in accordance with illustrative embodiments of the invention. These wafer guides 32 substantially mechanically retain the growing wafer 10 in its ideal location—near the meniscus extending from the molten material 24. In other words, the wafer guides 32 ideally compensate for downstream mechanical manipulation (of the growing wafer 10) that can move the base of the wafer 10 and thus, the wafer 10 at the meniscus. The wafer guides 32 thus can constrain wafer motion in one or two dimensions—perpendicular and/or parallel to the length of the meniscus.

While Figures 3-5 show portions only, Figure 6A schematically shows a complete front view of one wafer guide. The wafer guide 32 mechanically connects with the interior surface of the afterheater 28 at its ends 34, and has a body 36 that spans between its ends 34. For additional structural support, some embodiments of the wafer guide 32 secure to the afterheater 28 at other areas (e.g., near the central portion of its body 34). As discussed below, the growing wafer 10 can contact the surfaces of any of its corresponding guides 32. To minimize contact, however, the inventors designed the height of the wafer guides 32 to be very small relative to their length.

The height of the guides 32 may be selected as a function of channel width, and vice versa. For example, it is anticipated that a channel 38 with a large width (e.g., two times the average width of the wafer 10) and a large height operates in a manner that corresponds with a channel 38 with a small width and a small height.

The wafer guides 32 should be formed from a material that can withstand high temperatures commonly expected within a wafer furnace 14. For example, those temperatures commonly exceed 1400 degrees Centigrade. Accordingly, among other things, the wafer guides 32 can be formed from graphite or silicon carbide.

As the other figures show, the two main interior walls of the afterheater 28 each support one wafer guide. Each wafer guide 32 thus directly opposes a corresponding wafer guide 32 to form an elongated channel 38 through which the growing wafer 10 can pass. This channel 38 can be closed at its ends, or open at its ends. In illustrative embodiments, the channel 38 provides very little clearance for the wafer 10 to pass. For example, if the maximum thickness of the wafer 10 is about 190 microns, then the wafer channel 38 may have a thickness of only about 195-200 microns. Of course, other embodiments may have wider wafer channels 38.

The channel 38 thus can have a uniformly sized width. Accordingly, the channel width should be greater than the largest anticipated thickness of the growing wafer 10. As noted above, however, many sheet wafers 10, including the one of Figure 1, has a varying thickness across its width. Accordingly, the wafer guides 32 can be secured to the afterheater 28 to vary the thickness of the channel 38 across its length. For example, the end of a filament sheet wafer 10 may be much thicker than that same wafer 10 along its longitudinal axis—near the center of its width. Illustrative embodiments thus may configure the wafer guides 32 so that the channel 38 is wider at its ends than it is near its center. Thus, in this example, the channel thickness reduces when traversing from one end 34 toward the center.

In fact, the channel thickness can be varied at many locations to more closely track the varying thickness of the growing wafer 10. The inventors anticipate that such a varying thickness channel 38 will provide improved results during the wafer growth process. Of course, those skilled in the art will pre-set the dimensions and geometry of the channel 38 based upon the anticipated size and shape of the growing wafer 10, which depends upon the properties of the molten materials used to form the wafer 10.

As noted above, the wafer guides 32 can be used in multilane wafer growth furnaces 14. For example, each lane of a four lane wafer furnace 14 preferably has wafer guides 32 for constraining movement of the growing wafer 10 in the manner described. Figure 6B schematically shows one such embodiment, in which each lane of a two lane wafer furnace 14 has wafer guides 32 for reducing wafer bow in the desired manner. It should be noted that Figure 6B shows only one side of the afterheater 28. Accordingly, a corresponding oppositely positioned side of the afterheater 28 having corresponding wafer guides 32 completes the necessary structure for adequately constraining wafer movement.

A number of design constraints suggest a way for using wafer guides 32 to reduce wafer bow. Primarily, positioning an additional piece of material so close to the meniscus undesirably can act as an insulator that impedes appropriate cooling of the wafer 10. This can result in defective wafers that are too thin and fragile. When confronted with this problem, the inventors discovered that reducing the size of the wafer guides 32 mitigated the cooling problem and yet, provides the same functionality.

Accordingly, rather than using continuous wafer guides 32, the inventors discovered that a plurality of carefully positioned posts/pins/members (hereinafter “posts 40”) extending from the afterheater walls can provide correspondingly beneficial result—these posts 40 form a discontinuous wafer guide. In fact, if properly positioned (discussed below), the discontinuous wafer guide 32 can deliver the beneficial result of restraining undesired wafer movement without significantly impacting the temperature profile. To that end, Figure 7 schematically shows one afterheater wall of a two lane wafer furnace 14 implementing this type of wafer guide 32. As with Figure 6A, a corresponding half of the afterheater 28 acts with the afterheater 28 portion shown to form the channel 38 that limits the undesired wafer movement.

To more closely match the varying thickness of the wafer 10, the posts 40 can extend different distances from the afterheater wall, thus effectively forming a variable thickness channel 38. Moreover, the posts 40 can have different surface areas for contacting the growing sheet wafer 10. Each post 40 can have a corresponding, directly oppositely mounted post. Alternatively, or in addition, the posts 40 on each side can be offset from one another.

It should be noted that this discussion mentions wafer guides 32 on each wall of the afterheater 28 as one example. Alternative embodiments, however, position a wafer guide 32 on one wall of the afterheater 28 only. This may be particularly useful when physical downstream manipulation of the growing wafer 10 urges movement in one direction only (e.g., toward the wafer guide). In addition, in other embodiments, one half of the afterheater 28 could have a solid wafer guide, while the other half of the afterheater 28 could have a discontinuous wafer guide 32 as shown by Figure 7. Yet other embodiments may have discontinuous and continuous wafer guides 32 on the same side of the afterheater 28.

Moreover, some embodiments do not mount the wafer guides 32 to the afterheater 28. For example, the wafer guides 32 can be mounted directly to the interior chamber wall. Alternatively, the wafer guides 32 can be only partly within the afterheater 28.

Regardless of their form, wafer guides 32 nevertheless may adversely impact the temperature profile if placed too close to the meniscus. This may lead one to position the wafer guides 32 too far from the meniscus to adequately stabilize the wafer 10. When confronted with this problem, the inventors discovered that there is an intermediate point within the furnace 14 that can optimally stabilize the wafer 10 and yet, not significantly impact the temperature profile.

Specifically, Figure 8 graphically shows, by example, the temperature profile within an operating wafer furnace 14 forming filament sheet wafers 10 with multi-crystalline silicon. This furnace 14 in this example moves the wafer 10 upwardly at a rate of about 24 millimeters per minute. The x-axis shows the time of wafer movement relative to the top of the meniscus, while the y-axis shows the temperature at the corresponding location within the furnace 14 at that time.

As shown, the temperature at the top of the meniscus is nearly 1400 degrees Centigrade. The temperature sharply drops off shortly thereafter to about 1250 degrees Centigrade, where it remains in a plateau state for about 15-16 seconds. The region in the furnace 14 where the temperature sharply drops (from about 0-3 seconds) is referred to herein as the “sharp drop region,” while the region of the furnace 14 where the temperature plateaus (roughly from about 3-19 seconds) is referred to herein as the “plateau region.” This plateau region in this furnace 14 generally corresponds with the furnace interior region beneath the afterheater 28 (from the perspective of the figures). Within the plateau region, the heat flow between the ribbon and the surroundings is a very delicate balance dominated by radiant heat flow. Accordingly, there is very little cooling at this region of the furnace 14. Positioning the wafer guides 32 in this region thus may interfere with this delicate radiant heat balance.

From about 19 seconds to about 60 seconds, the temperature generally linearly decreases. In fact, the wafer 10 generally linearly cools much longer than 60 seconds (e.g., 10 minutes). The figure thus stops at 60 seconds for convenience only. This linearly decreasing region is referred to herein as the "post plateau region." Accordingly, to avoid the plateau region, the wafer guides 32 of this example illustratively are positioned in the post plateau region, which corresponds to about 19 to about 60 seconds, or more. To better stabilize the growing wafer 10 and yet minimize heat profile impact, the wafer guides 32 are positioned as close to the plateau region as possible (e.g., in the post plateau region corresponding with about 21-22 seconds). As another example, the wafer guides 32 could be positioned in the post plateau region corresponding to about 29 seconds. This region could be at the base/entry of the afterheater 28. In one furnace 14, for example, this region is spaced about 22 millimeters from the surface of the crucible 18. Although they should stabilize the growing wafer 32 at any distance from the meniscus, it is expected that the wafer guides 32 perform better when at the lower/earlier portions of the post plateau region.

Of course, discussion of specific temperatures and locations of the wafer guides 32 is by example only. Since those skilled in the art position the wafer guides 32 as a function of the material making up the wafer 10 (among other things), the actual position may vary as a function of the material contained by the crucible 18.

Illustrative embodiments therefore mechanically constrain certain undesired motion of a sheet wafer 10 as it grows from its crucible 18. This should mitigate one significant source of bowing inherent in many prior art sheet wafer growth processes.

Although the above discussion discloses various exemplary embodiments of the invention, it should be apparent that those skilled in the art can make various modifications that will achieve some of the advantages of the invention without departing from the true scope of the invention.

What is claimed is:

1. An apparatus for forming a sheet wafer, the apparatus comprising:

an enclosure forming an interior chamber;

a crucible within the interior chamber and having a top surface, the crucible configured to contain a volume of molten material; and

a wafer guide spaced from the top surface of the crucible and within the interior chamber, the wafer guide forming a channel for passing a growing sheet wafer.

2. The apparatus as defined by claim 1 further comprising an afterheater region for controlling the temperature within the interior chamber, the wafer guide being at least in part within the afterheater region.

3. The apparatus as defined by claim 2 wherein the wafer guide comprises a plurality of posts extending from at least two opposing surfaces of the afterheater.

4. The apparatus as defined by claim 2 wherein the wafer guide comprises a pair of elongated members extending from at least two opposing surfaces of the afterheater.

5. The apparatus as defined by claim 1 wherein the interior chamber includes a plateau region and a post plateau region, the plateau region being between the crucible and the post plateau region, the wafer guide being positioned at least in part within the post plateau region.

6. The apparatus as defined by claim 1 wherein the channel has a length and a width, the wafer guide comprising a plurality of wafer guides that extend inwardly to vary the width of the channel.

7. The apparatus as defined by claim 6 wherein the channel has a pair of end regions and a central region, the width of the channel being smaller in the central region than in the pair of end regions.

8. The apparatus as defined by claim 1 wherein the channel has a length, a width, and a height, the height being smaller than the length.

9. The apparatus as defined by claim 1 wherein the interior chamber includes a plateau region and a post plateau region, the wafer guide being at least in part positioned in the post plateau region, the post plateau region location being a function of the molten material.

10. The apparatus as defined by claim 1 wherein the channel has an elongated shape.

11. The apparatus as defined by claim 1 wherein the wafer guide comprises at least one of silicon carbide and graphite.

12. A method of forming a sheet wafer, the method comprising:

adding molten material to a crucible within a furnace;

growing a sheet wafer from the molten material with a pair of filaments; and

passing at least a portion of the growing sheet wafer through a channel formed by a wafer guide member positioned within a post plateau region of the furnace, the channel having an elongated shape that passes the growing sheet wafer.

13. The method as defined by claim 12 wherein the growing sheet wafer contacts the wafer guide as it passes through the channel.

14. The method as defined by claim 12 wherein the wafer guide comprises a plurality of posts.

15. The method as defined by claim 12 further comprising an afterheater spaced from the crucible, the wafer guide being at least in part within the afterheater.

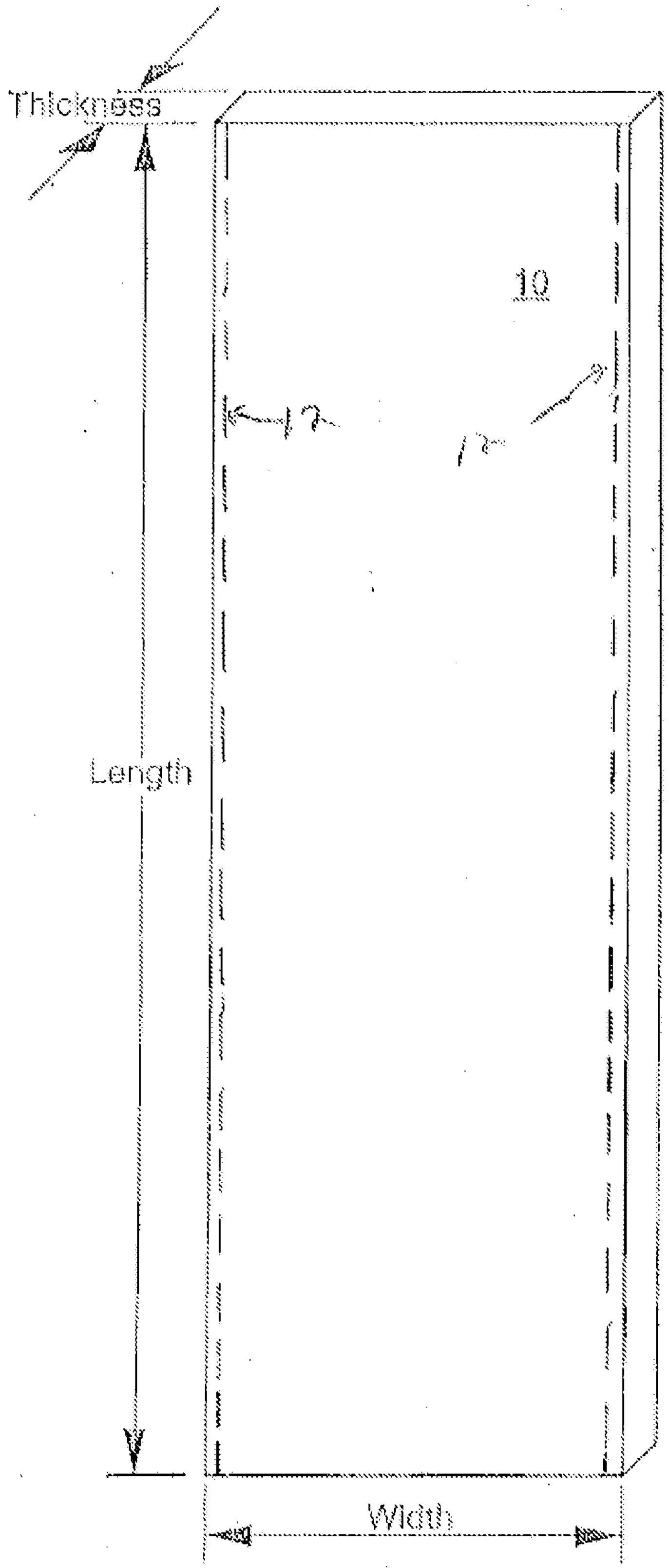

FIG. 1

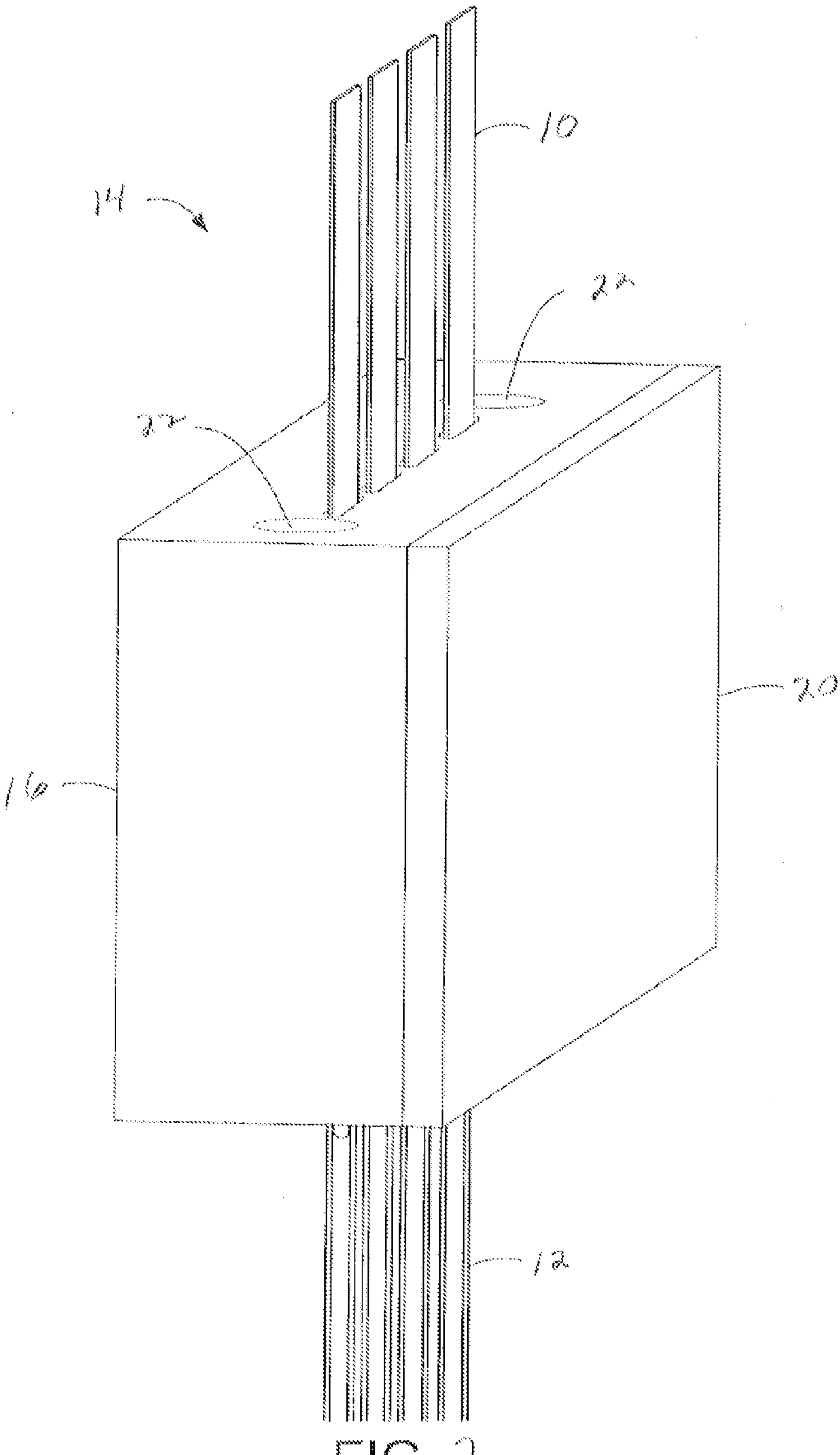

FIG. 2

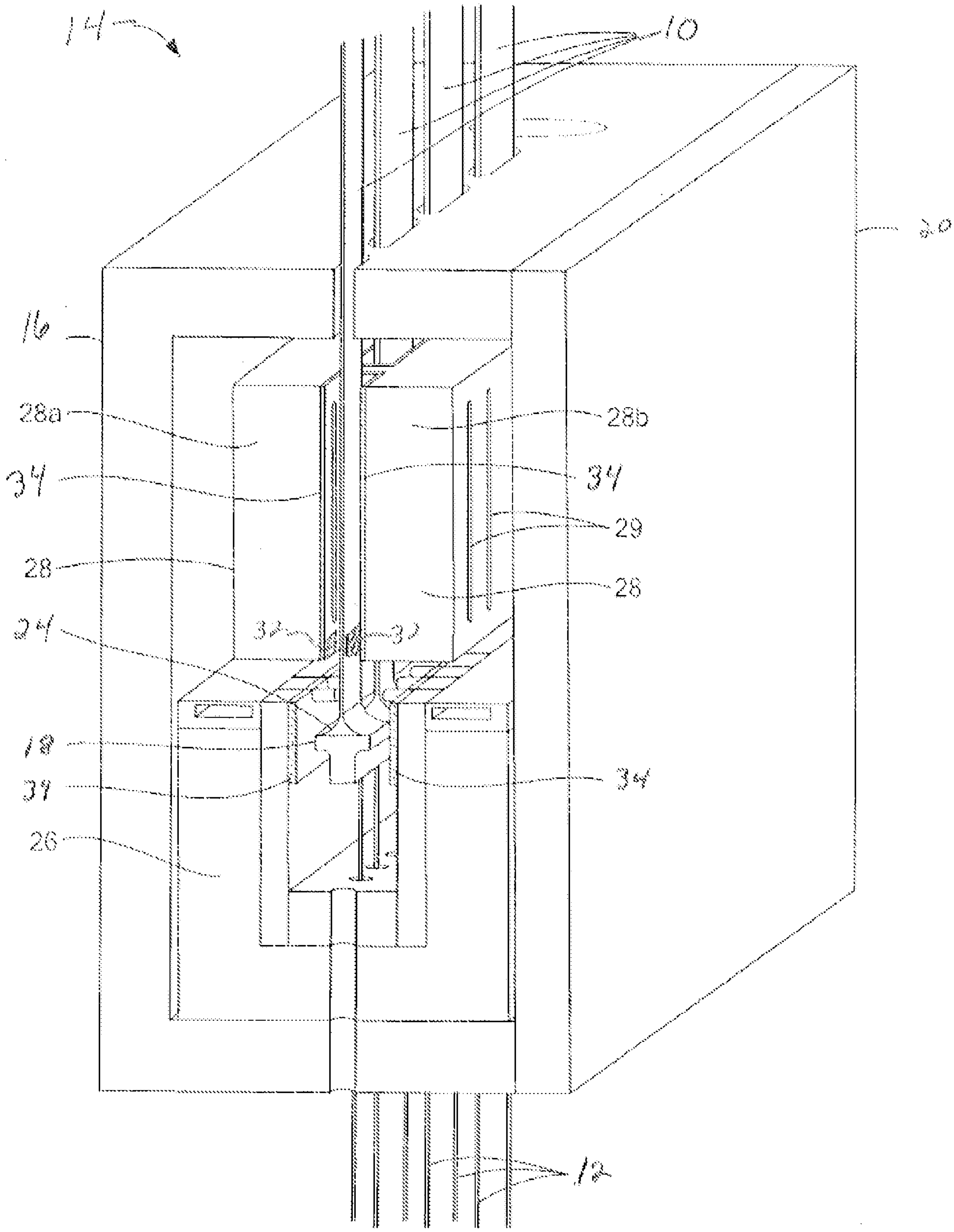

FIG. 3

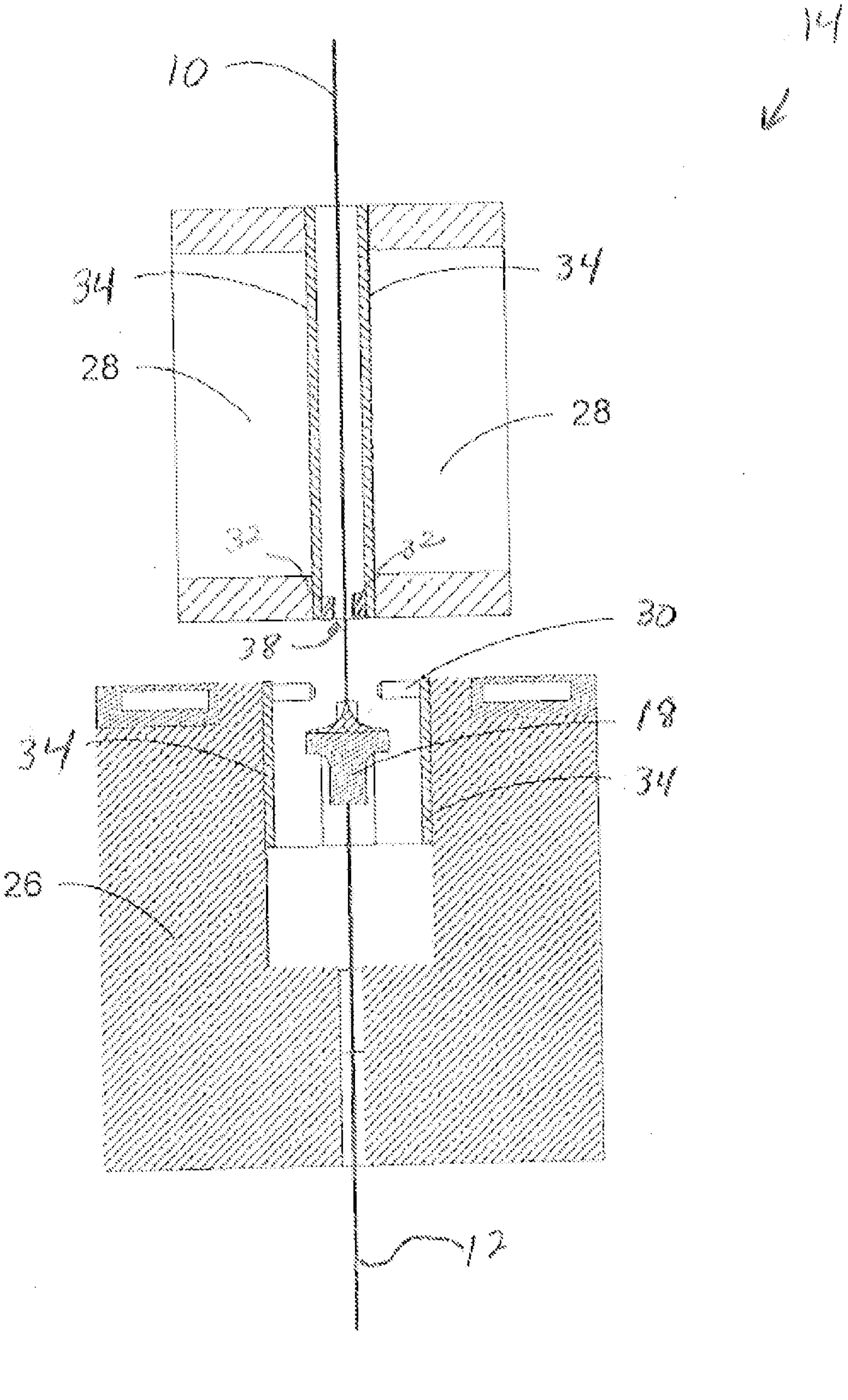

FIG. 4

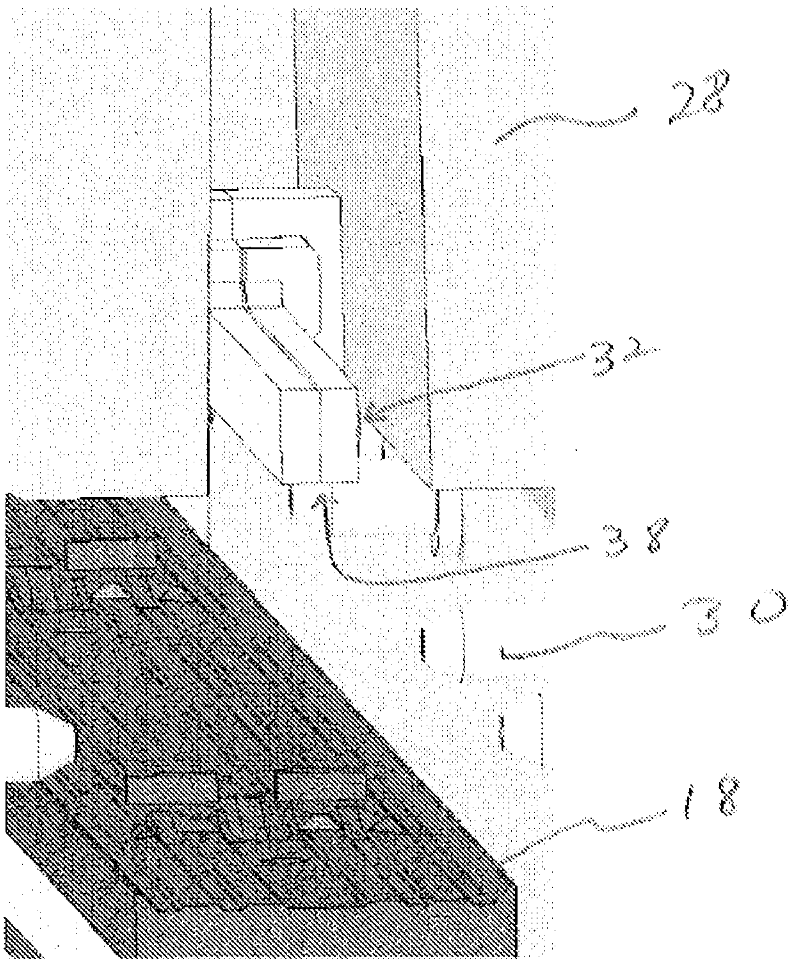

Fig. 5

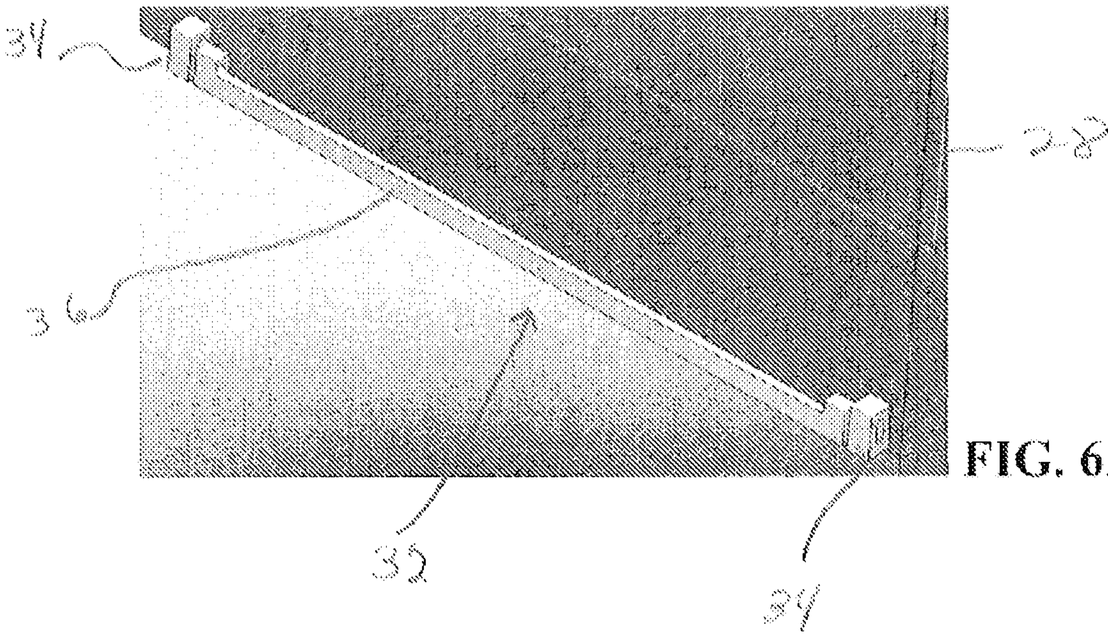

FIG. 6A

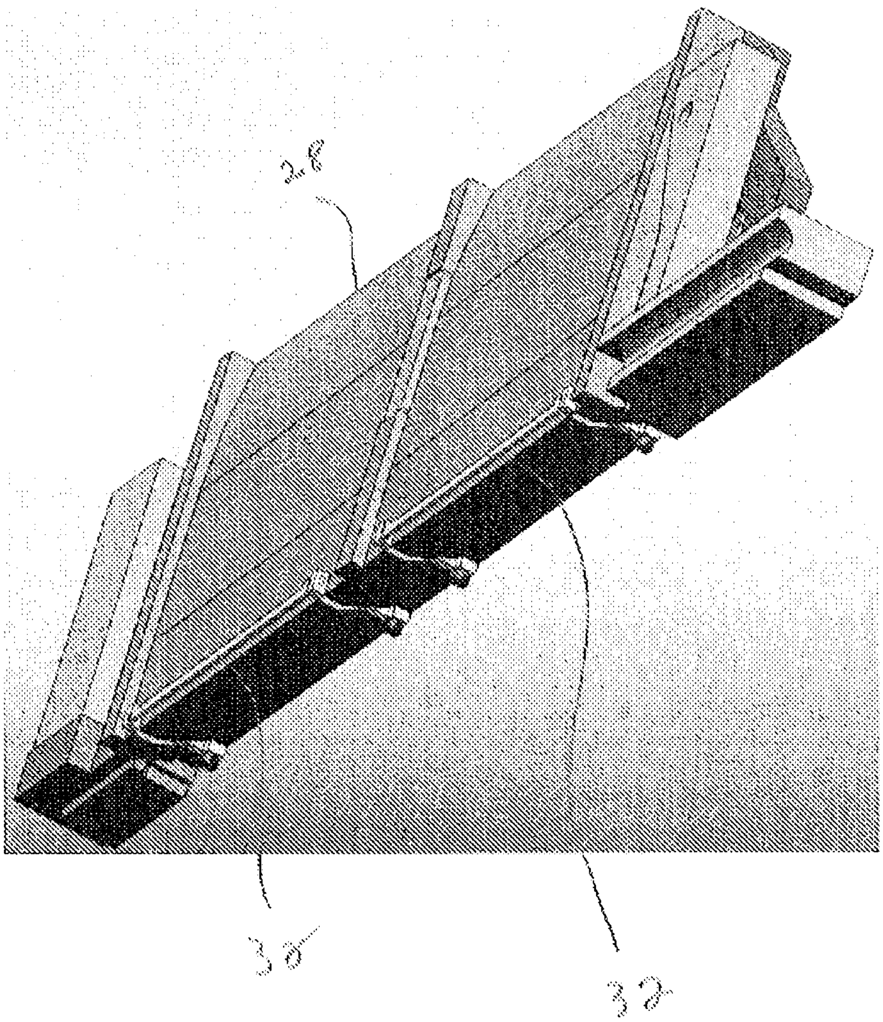

FIG 6B

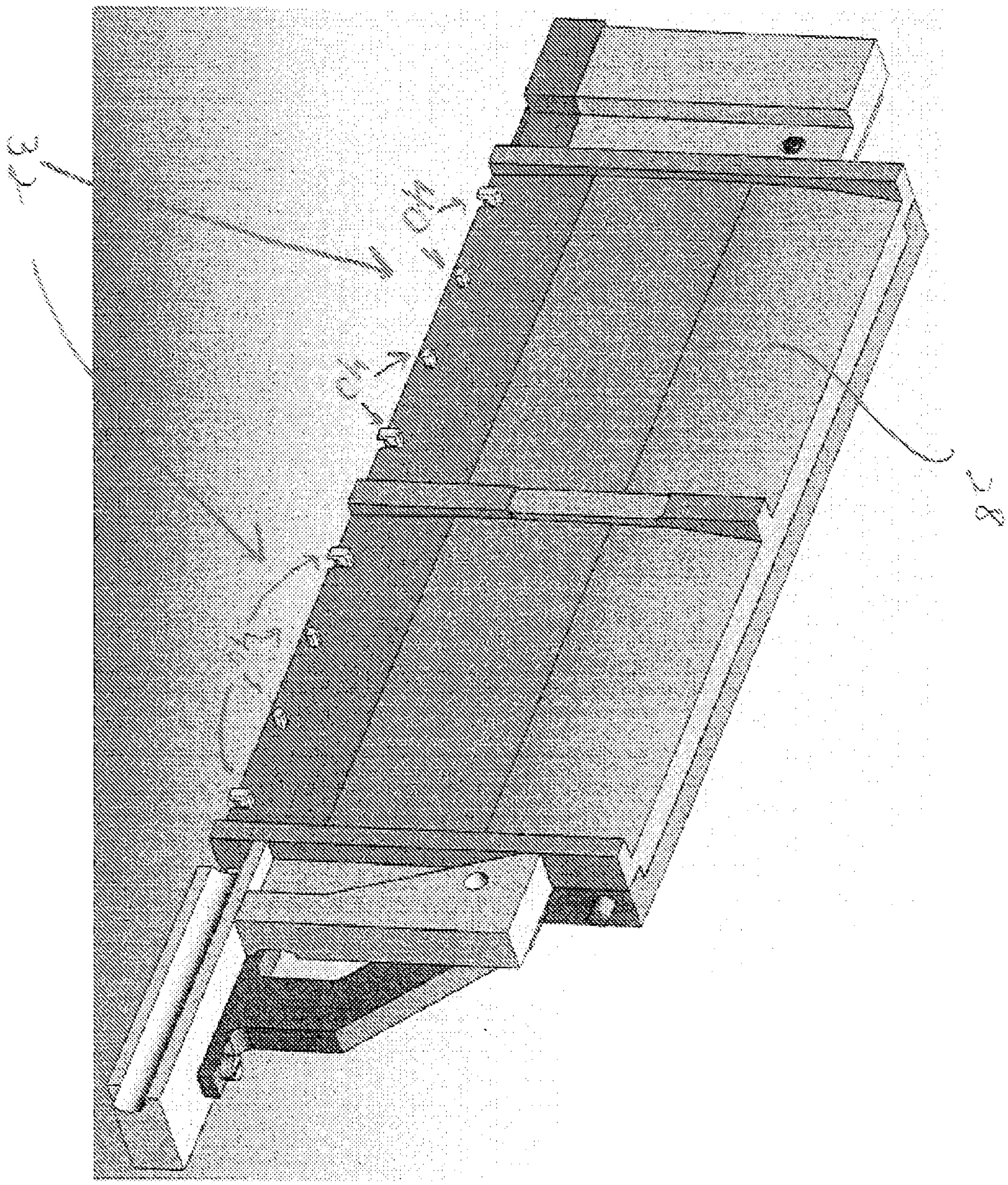

FIG. 7

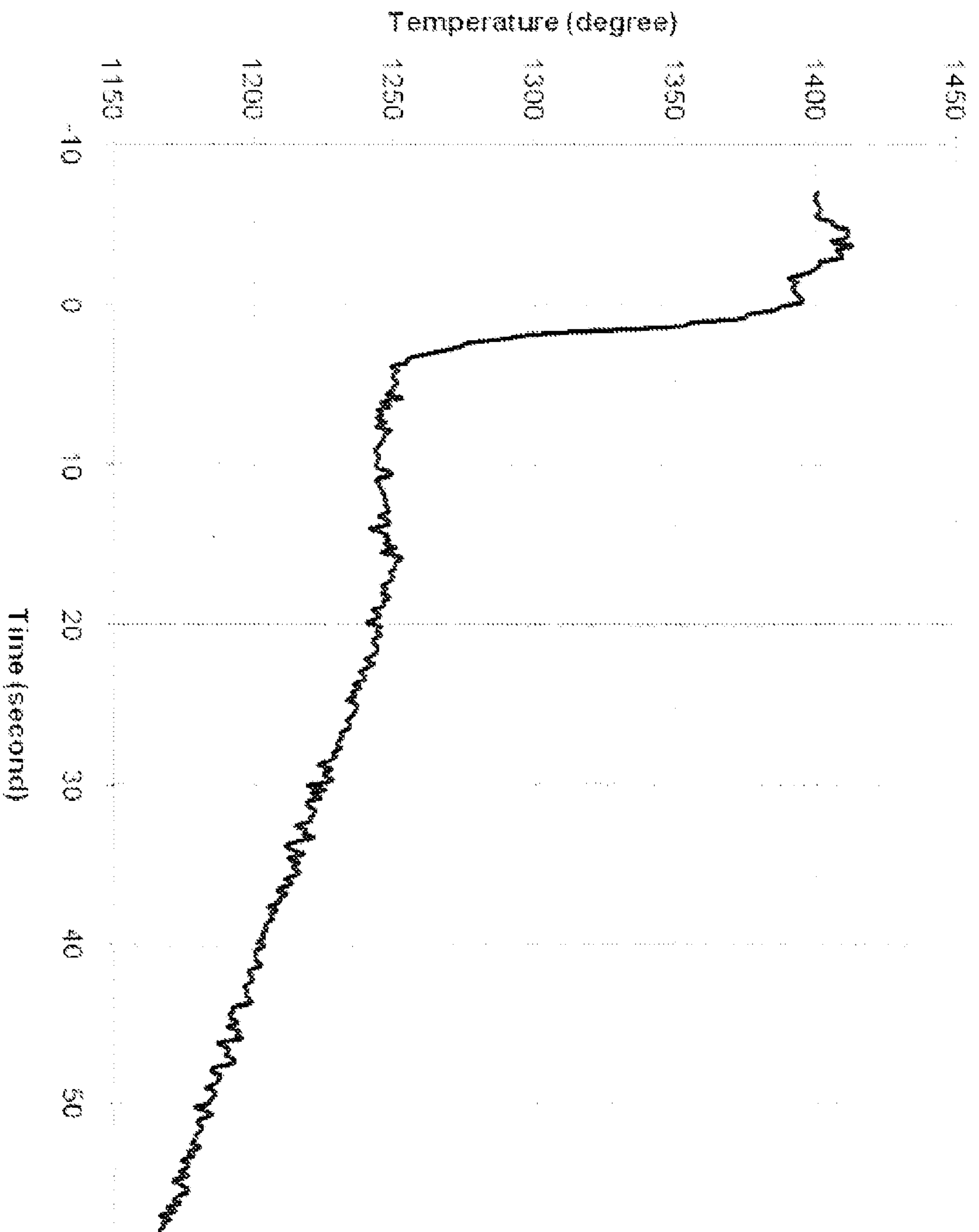
Temperature (degree)
1150
1200
1250
1300
1350
1400
1450
-10
0
10
20
30
40
50
60
Time (second)

FIG. 8