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(54) **Title:** SOLAR CELL PROCESS CARRIER

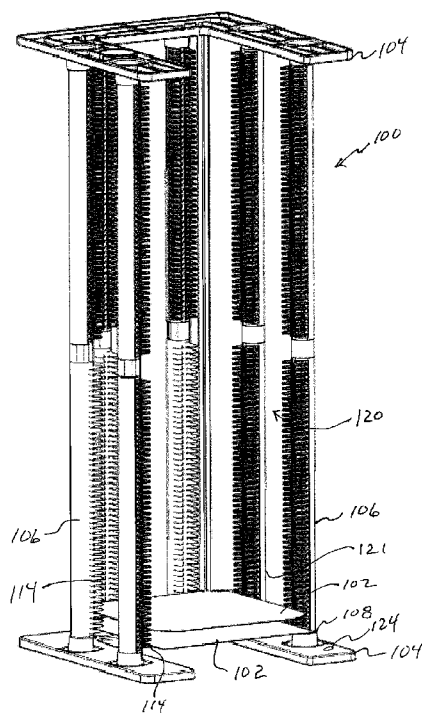


Fig. 6

(57) **Abstract:** A solar cell process carrier for immersion of solar cells into process fluids, the carrier comprising a pair of endwalls with a plurality of rails extending therebetween, the plurality of rails defining a solar cell receiving region, each rail having a base portion and a plurality of teeth arranged sequentially and axially along and extending from said base portion, each tooth having a cell contact area thereon and each rail further having a means for enhancing fluid flow at each of said cell contact areas.



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SOLAR CELL PROCESS CARRIER

RELATED APPLICATIONS

This application claims priority to U.S. Provisional Application 61/309,731, filed March 2, 2010, the contents of same incorporated by reference herein.

5 FIELD OF THE INVENTION

The present invention relates to processing substrates. More particularly, the present invention relates to a process carrier suitable for holding wafers, such as silicon wafers, and particularly solar cell wafers during processing baths.

BACKGROUND OF THE INVENTION

10 As a part of processing silicon wafers into semiconductors the wafers are immersed into various solutions in carriers often known as boats. See, Prior Art Figure 1a, for example, from U.S. Patent No. 4,872,554 originally assigned to Fluoroware, Inc. a predecessor of Entegris, Inc. the owner of the instant application. Such a substrate process carrier 20 has a pair of endwalls 22, 24 with several tubular rails 30 with integral teeth 32 for engaging the
15 substrates extending between the endwalls. The teeth extend from the tubular rails inwardly toward the substrates 34. Such process boats may utilize polymers, such as fluoropolymers, to resist the caustic process fluids utilized in the processing steps. Stiffening members 36 may be embedded in the elongate tubular rails such as by welding the tubular polymer rail pieces of the carrier to the endwalls.

20 The specific processing of solar cells conventionally utilize such carriers or boats, and due to automated processes, have an informal standardization of the positioning of rails and spacing between cells. See Prior Art Figure 2 which is a cross section taken through the carrier at the rails 38 showing one endwall 40 with conventional rail locations 44 for which cell handling equipment has been designed establishing such an informal standardization.
25 Complying with this informal standardization by carrier manufacturers allows processors to use the manufacturers' carriers with minimal or no adjustment or modification of their equipment. The rails have teeth 46 supporting or restraining the solar cells 50

It is very advantageous in processing silicon that the entirety of the surfaces of the wafers, particularly including cells, are uniformly processed with the fluids in which the cells
30 are immersed. The substrate carriers, including solar cell process carriers, have contact areas on teeth positioned on the rails for supporting and restraining the substrates. The

minimization of these contact areas is believed to be beneficial. The process fluids can attach to the carrier, particular at these areas where the carrier interfaces with the cells, after the carrier and substrates are removed from the fluids, extending the contact time of the fluids with the substrates at these areas causing a nonuniformity in fluid action at these areas.

Moreover, when the carrier and substrates are immersed, the contact areas may also reduce the fluid flow at the substrate surfaces at the contact areas causing further nonuniformities in the processing. Moreover, the close proximity of the support rails to the teeth can cause fluid flow disruptions and interference at the edges of the substrates, particularly cells, which can effect further nonuniformities in the fluid processing. The nonuniformities can result in processing defects which are often visible along the edges of the solar cells and are termed "boat marks". It is most desireable to reduce the possibility of defects, including boat marks, by way of carrier design while complying with informal industry standardizations, particularly the rail positions. Known rail teeth configurations are illustrated in Prior Art Figures 3a, 3b, 4a, 4b, 5a, and 5b. The teeth in Prior Art Figures 3a and 3b sequentially alternate on each side of a centerline extending down the rail, the centerline positioned at the points on the rail contacting or closest to the solar cells.

The teeth of Prior Art Figure 4a and 4b have a line contact area defined by two angled surfaces 24, 26 with each sequential tooth being identical. The prior art teeth generally have the teeth extending directly toward the substrate.

SUMMARY OF THE INVENTION

A process carrier for solar cells includes a plurality of cell supports configured as rails extending between a pair of endwalls. Each cell support includes a post with a plurality of teeth extending outwardly therefrom defining a solar cell receiving region with plurality of slots for containing cells. Means for enhancing fluid flow at the areas where the carrier contacts the solar cells are provided on the rails. An axial gap can extend between the teeth, displacing the points of contact with the cells offset from the region defined as the narrowest gap between the rail and the cells, enhancing fluid flow at the edges of the cells. In one embodiment, sequential teeth along a rail can be circumferentially offset from each other on opposite sides of a centerline at the solar cell side of the rail. The rail or post can include a flattened portion where it contacts cells with an axial void extending axially down the rail to reduce circumferential contact with cells and further enhance fluid flow across cells.

A feature and advantage of embodiments of the present invention is a cell support having split and circumferentially separated support teeth. Teeth can be split by an axial gap extending down support between teeth. This reduces the contact between teeth and cells and allows for enhanced fluid flow around cells.

5 Another feature and advantage of embodiments of the present invention is a cell support having split support teeth that are staggered. By providing a vertical offset between adjacent teeth, only a single tooth on each support is used to support each cell. This provides for a further reduction in contact between the teeth and the cells and a further enhancement in fluid flow around the cells.

10 A further feature and advantage of embodiments of the present invention is a cell support having a post with a flattened portion where it contacts cells with an axial void configured as a recess extending down the rail. This reduces the circumferential contact between the supports and cells and provides an additional enhancement of fluid flow around cells and also eliminates sharp contact points that can damage cells.

15 Although specific embodiments herein are described in the context of a process carrier for solar cells, the configurations herein are also intended for use with other silicon wafer process carriers, and carriers for substrates other than silicon.

A feature and advantage of embodiments of the invention is that the axially extending channel is believed to enhance fluid flow at the edges of the substrates to minimize
20 nonuniformities, boat marks, and other defects. The groove and rib features also are believed to minimize the effects of the rail on the fluid flow and thereby reduce the generation of nonuniformities, boat marks, and other defects.

BRIEF DESCRIPTION OF THE DRAWINGS

25 Figure 1a is a prior art substrate process carrier;

Figure 1b is a cross section of a rail base portion and a tooth of the prior art carrier of Figure 1a;

Figure 2 is a cross section through the rails of a prior art solar cell process carrier;

Figure 3a is a cross section of a rail base portion and a tooth of a prior art carrier;

Figure 3b is a side elevational view of the prior art tooth and rail base portion of Figure 3a;

Figure 4a is a cross section of a rail base portion and a tooth of a prior art carrier;

Figure 4b is a side elevational view of the prior art tooth and rail base portion of
5 Figure 4a;

Figure 5a is a cross section of a rail base portion and a tooth of a prior art carrier;

Figure 5b is a side elevational view of the prior art tooth and rail base portion of Figure 5a;

Figure 6 is a perspective view of a solar cell process carrier according to an
10 embodiment of the present invention in a vertical position.

Figure 7 is a perspective view of a solar cell process carrier according to an embodiment of the present invention in a horizontal position.

Figure 8 is a partial top view of a solar cell process carrier according to an embodiment of the present invention.

Figure 9 is a perspective view of a wafer support for a solar cell process carrier
15 according to an embodiment of the present invention.

Figure 10 is a partial side view of the wafer support of Figure 9.

Figure 11 is a perspective view of a wafer support for a solar cell process carrier according to an embodiment of the present invention.

Figure 12 is a partial side view of the wafer support of Figure 11.
20

Figure 13 is a top view of a wafer support for a solar cell process carrier according to an embodiment of the present invention.

Figure 14 is a top view of a wafer support for a solar cell process carrier according to an embodiment of the present invention.

Figure 15 is a top view of a wafer support for a solar cell process carrier according to an embodiment of the present invention.
25

Figure 16 is a partial front view of a solar cell process carrier according to an embodiment of the present invention.

Figure 17 is a perspective view of an endwall for a solar cell process carrier according to an embodiment of the present invention.

Figure 18 is a front view of the endwall of Figure 17.

Figure 19a is a cross section of a rail base portion and a tooth;

5 Figure 19b is an elevational of the rail with the tooth of Figure 19a.

Figure 20a is a cross section of a rail base portion and a tooth;

Figure 20b is an elevational of the rail with the tooth of Figure 20a.

Figure 21a is a cross section of a rail base portion and a tooth;

Figure 21b is an elevational of the rail with the tooth of Figure 21a.

10 Figure 22a is a cross section of a rail base portion and a tooth;

Figure 22b is an elevational of the rail with the tooth of Figure 22a.

Figure 22c is an elevational of the opposite side of the rail to that illustrated in Figure 22b.

Figure 23a is a cross section of a rail base portion and a tooth;

15 Figure 23b is an elevational of the rail with the tooth of Figure 23a.

DETAILED DESCRIPTION OF THE DRAWINGS

Figures 6 and 7 depict a process carrier 100 for holding substrates, particularly solar cells 102, during a process bath processing the solar cells 102. Generally the cells will be inserted and withdrawn when the carrier is vertical and with the cells horizontal as shown in
20 Figure 6. When immersed in process fluid, the carrier is horizontal as shown in Figure 7. Process carrier 100 includes a pair of parallel spaced endwalls 104 with a plurality of cell supports configured as rails 106 extending therebetween. Endwalls 104, also depicted in Figures 17 and 18, include a plurality of receiving apertures 108 for receiving and aligning the wafer supports 106. In one embodiment, endwalls 104 can be generally U-shaped in order to
25 provide an open path for the etching fluid to the bottommost and topmost solar cells 102. Endwalls 104 can also include a bottom surface 110 having a plurality of raised pads 112 that help to better align the bottom of the endwall 104 to a reference datum. Each cell support 106 is defined by a post 113 with a plurality of spaced teeth 114 for holding cells 102 and can be held within receiving apertures 108 with fasteners 116. Process carrier 100 can also include a

pair of structural supports 118 extending between the endwalls 104 for providing increased structural rigidity to the carrier 100. Generally structural support may be provided by rigid metal bars or rigid polymers, such as Polyetheretherketone, that are embedded within polymers resistant to the processing fluids. Fluoropolymers, including PFA and PTFE are
5 believed to be suitable.

Referring to Figure 8 (depicted with only one endwall 104 for the sake of clarity) and Figure 16, in one embodiment process carrier 100 can include six cell supports 106 arranged around three sides of the endwalls 104 providing an open front 120 for insertion of solar cells 102. Solar cells 102 can be inserted into process carrier 100 by introducing them through
10 open front 120 into a cell receiving region 121 and into slots 122 defined between the spaced teeth 114 of cell supports 106. The receiving region defined as having the depth and width of cell to be carried therein and extending from the bottommost slot to the uppermost slot. Cells 102 can be stacked in an axially spaced relationship defined by the teeth 114. In some embodiments, process carrier 100 can include a colored information plug 124 that identifies
15 the particular solar cells 102 contained in process carrier 100.

Referring to Figures 9 and 10, teeth 114 can extend axially along cell support 106. In one embodiment as shown, there can be an axially gap 126 or fluid flow channel 127 extending between teeth 114, such that each slot 122 for containing a cell 102 includes a pair of split teeth 114 for supporting the cell 102. Such a configuration results in enhanced fluid
20 flow around the cells, which provides for fewer etching defects and reduced contact between the teeth and the cells. The fluid flow channel 127 is defined by the separated teeth, whether two side by side on the rails or whether the teeth sequentially alternate, and the surface of the rail between the teeth on each side of a centerline 129. The centerline of the rail is where the rail engages, that is contacts the substrates, or closest thereto. A rib or groove may extend
25 down the centerline in certain embodiments.

In another embodiment depicted in Figures 11 and 12, teeth 122 can be axially split by gap 126 and can also be staggered such that adjacent teeth 114 are vertically offset from each other. In such a configuration, each slot 122 for containing a cell 122 includes a single tooth 114 for supporting the cell 102. This results in further enhanced fluid flow around the cells
30 and reduction of contact between the teeth and the cells.

The embodiments of both Figures 9 and 11 utilize two axially extending rows 137 of teeth and define the channel 127, along with the surface of the rail, the linear surface strip 139

that extends between the rows of teeth. The channel is believed to enhance fluid flow at the edges of the substrates to minimize nonuniformities, boat marks, and other defects.

Referring now to Figure 13, there can be seen a cell support 106 according to an embodiment of the present invention. As noted previously, cell support 106 is defined by a post 113 with a plurality of spaced teeth 124, two rows, having an axially gap 126 extending therethrough that define a fluid flow channel 127. Post 113 can have a generally circular cross-section with a relatively flattened portion 128 where the post 113 makes contact with a cell 102. Flattened portion 128 reduces the likelihood of damage to cells 102 because it eliminates sharp corners at the points of circumferential contact between posts 113 and cells 102. Post 113 can also include a void 130, configured as a groove, extending axially through post at flattened portion 128, defining a pair of bumps 132 that contact a cell 102. Void 130 serves at least two beneficial purposes. First, it provides an additional fluid flow path allowing access by the etching fluid to the cells. Second, it reduces the area of circumferential contact between the posts 113 and cells 102. This second advantage reduces the potential for damage to the cells due to contact with the posts. In other embodiments depicted in Figures 14 and 15, post 113 can include an outward bump 134 that reduces circumferential contact with the cell or can include a continuous generally flat contact surface 136. In other embodiments two or more grooves may extend axially down the rail, either in-between a pair of rows of teeth or adjacent to a row of teeth.

Solar cells 102 can be processed using process carrier 100 either manually or with an automated process. First the cells are loaded into the process carrier 100 by inserting them through open front 120 and into slots 122. Once the desired number of solar cells has been loaded, the carrier can be inserted into the process bath. After remaining in the process bath for the desired period of time, the process carrier and solar cells can be removed from the bath.

Referring to Figures 19a and 19b, alternating teeth are illustrated with a central rib and a centrally extending gap.

Referring to Figures 20a and 20b, dual teeth are illustrated with a central extending axial between the teeth.

Referring to Figures 21a and 21b, an oblong complex and non-symmetrical tooth is illustrated.

Referring to Figures 22a, 22b, and 22c, an oblong complex and non-symmetrical tooth is illustrated.

Referring to Figures 23a to 25, an oblong complex and non-symmetrical tooth 200 is illustrated in a carrier 202. This tooth has a pair of flattened portions 206, 208 defining a rounded rib 210 extending down the portion of the rail nearest the substrate, for example the solar cell 212. The tooth also has a substrate engagement surface 216. Notably the majority, or substantially all of the engagement surface is outside of a profile cast on to the substrate by the rail in a direction normal to the edge 220 of the substrate. The profile is illustrated by the dashed lines 222 and 224. The tooth also has a slight inward curvature, inward toward the substrate. Referring to Figure 24, this offsetting of the engagement surface 216 allows for modifying the support points on the substrate carrier. Due to the standardization of equipment for handling solar cell substrates, moving the rails to modify the substrate support points is not generally possible. In this case, positioning the finger portion 230 with the support surfaces 216 of the teeth 200 closer to the lower edge 234 of the substrate is believed to allow usage of less dramatic structure or minimal tooth structure on the lower rails 236 on the bottom side 238 of the carrier 202.

Referring particular to Figure 25, the tooth 200 has an apex 250 through which a line drawn through the center 252 of the rail, has an angle 256 from a line 258 drawn normal to the edge of the cell through the rail center, of 30 to 45 degrees preferably. In other embodiments the angle is 25 to 50 degrees from the normal line 258. The length of the tooth is preferably about one diameter of the rail base portion. "About" being defined as within 15% of the diameter. In other embodiments the tooth length is less than the diameter of the rail base portion. In other embodiments the tooth length is greater than the diameter of the rail base portion.

Although described with reference to a process carrier for immersing solar cells in a process bath, it should be noted that supports as described herein can also be used in transport carriers and any other type of container for supporting solar cells. Similarly, although described with respect to solar cells, the present invention could be used with any other type of substrate, such as semiconductor wafers. The present invention can be assembled by welding molded tubular polymer, such as fluoropolymers, rail portions together and to the endwalls with a rigid insert inserted in the tubing. See U.S. Patent No. 4,872,554 for suitable construction details.

The present invention may be embodied in other specific forms without departing from the spirit of any of the essential attributes thereof. Therefore, the illustrated embodiments should be considered in all respects as illustrative and not restrictive, reference being made to the appended claims rather than to the foregoing description to indicate the
5 scope of the invention.

CLAIMS

1. A solar cell process carrier for immersion of solar cells into process fluids, the carrier comprising a pair of endwalls with a plurality of rails extending therebetween, the plurality of rails defining a solar cell receiving region, each rail having a base portion and a plurality of teeth arranged sequentially and axially along and extending from said base portion, each tooth having a cell contact area thereon and each rail further having a means for enhancing fluid flow at each of said cell contact areas, the means for enhancing fluid flow at the contact areas comprising at least one the following:

a) a rib extending axially along the outer surface of the rail base portion at the position nearest to or positioned at the solar cell receiving region;

b) a groove extending axially along the surface of the rail base portion at the position nearest to or positioned at the solar cell receiving region;

c) a rib extending axially along the outer surface of the rail base portion at the position nearest to or positioned at the solar cell receiving region, the teeth extending sequentially along the rail alternate on each side of the rib, the alternating teeth defining a gap that extends the length of the rail where the teeth are present; and

d) a channel defined by two rows of teeth extending axially down the rail base portion, the rows separated by defining a linear strip of the surface of the rail.

e) offsetting a row of teeth such that the substrate tooth contact surface is mostly outside the profile of the rail base portion on the substrate, the profile cast in a normal direction to the substrate.

2. A solar cell process carrier for immersion of solar cells into process fluids, the carrier comprising a pair of endwalls with a plurality of rails extending therebetween, the plurality of rails defining a solar cell receiving region, at least one of said plurality of rails having a base portion and a plurality of teeth arranged sequentially and axially along and extending from said base portion, each tooth on said at least one of said plurality of rails having a cell contact area thereon and said cell contact area is displaced substantially or entirely outside of a profile cast onto the wafer by the rail, the profile extending in a direction normal to the edge of the cell positioned at said rail, said profile having a width equal to the

diameter of the rail at said tooth, the diameter measured in a direction parallel to the edge of the cell at said tooth.

3. A solar cell process carrier having rails with a plurality of teeth thereon for
5 defining slot for holding solar cells therein, the teeth extending in a direction 30 to 45 degrees from a normal line through the center of the rail and normal to the edge of a cell seated at the tooth.

4. The base portion of the rail profile projected inwardly at each tooth in a direction
10 normal with respect to the edge of the cell, the tooth having a cell engagement surface that contacts the cell when the cell is seated thereon, the tooth oriented such that the cell engagement surface is substantially outside the rail profile projected inwardly.

5. A solar cell process carrier for immersion of solar cells into process fluids, the
15 carrier comprising a pair of endwalls with a plurality of rails extending therebetween, the plurality of rails defining a solar cell receiving region, each rail having a base portion and a plurality of teeth arranged sequentially and axially along and extending from said base portion, each tooth having a cell contact area thereon and each rail further having a rib extending axially along the outer surface of the rail base portion at the position to engage a
20 cell seated at the tooth, the rib having an open area directly above and at the rib and extending linearly the along the rail the length of the cell receiving region.

6. A solar cell process carrier for immersion of solar cells into process fluids, the
carrier comprising a pair of endwalls with a plurality of rails extending therebetween, the
25 plurality of rails defining a solar cell receiving region, each rail having a base portion and a plurality of teeth arranged sequentially and axially along and extending from said base portion, each tooth having a cell contact area thereon and each rail further having a groove extending axially along the outer surface of the rail base portion at the position to engage a cell seated at the tooth, the rib having an open area directly above and at the rib and extending
30 linearly along the rail the length of the cell receiving region.

7. A solar cell process carrier for immersion of solar cells into process fluids, the carrier comprising a pair of endwalls with a plurality of rails extending therebetween, the plurality of rails defining a solar cell receiving region, each rail having a base portion and a
5 plurality of teeth arranged sequentially and axially along and extending from said base portion, each tooth having a cell contact area thereon and each rail further having a rib extending axially along the outer surface of the rail base portion at the position to engage a cell seated at the tooth, the rib having an open area directly above and at the rib and extending linearly along the rail the length of the cell receiving region, the teeth extending sequentially
10 along the rail alternate on each side of the rib, the alternating teeth defining a gap that extends linearly the length of the rail where the teeth are present.

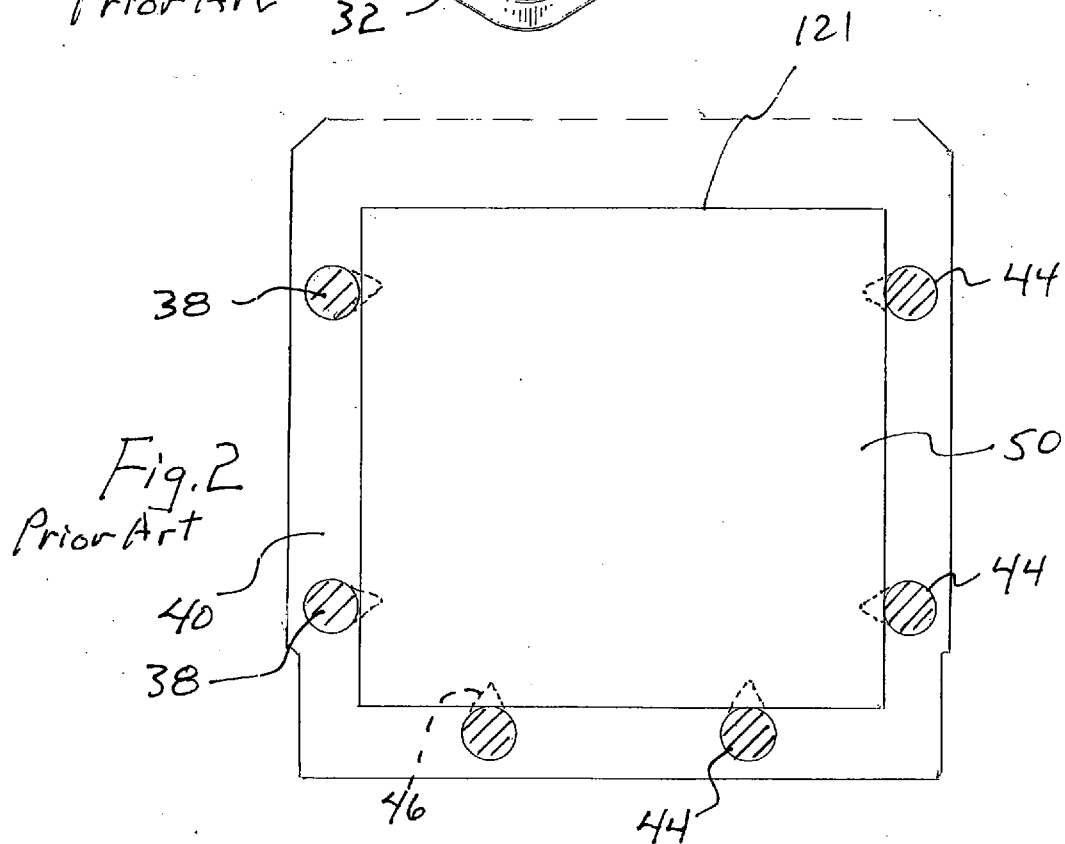
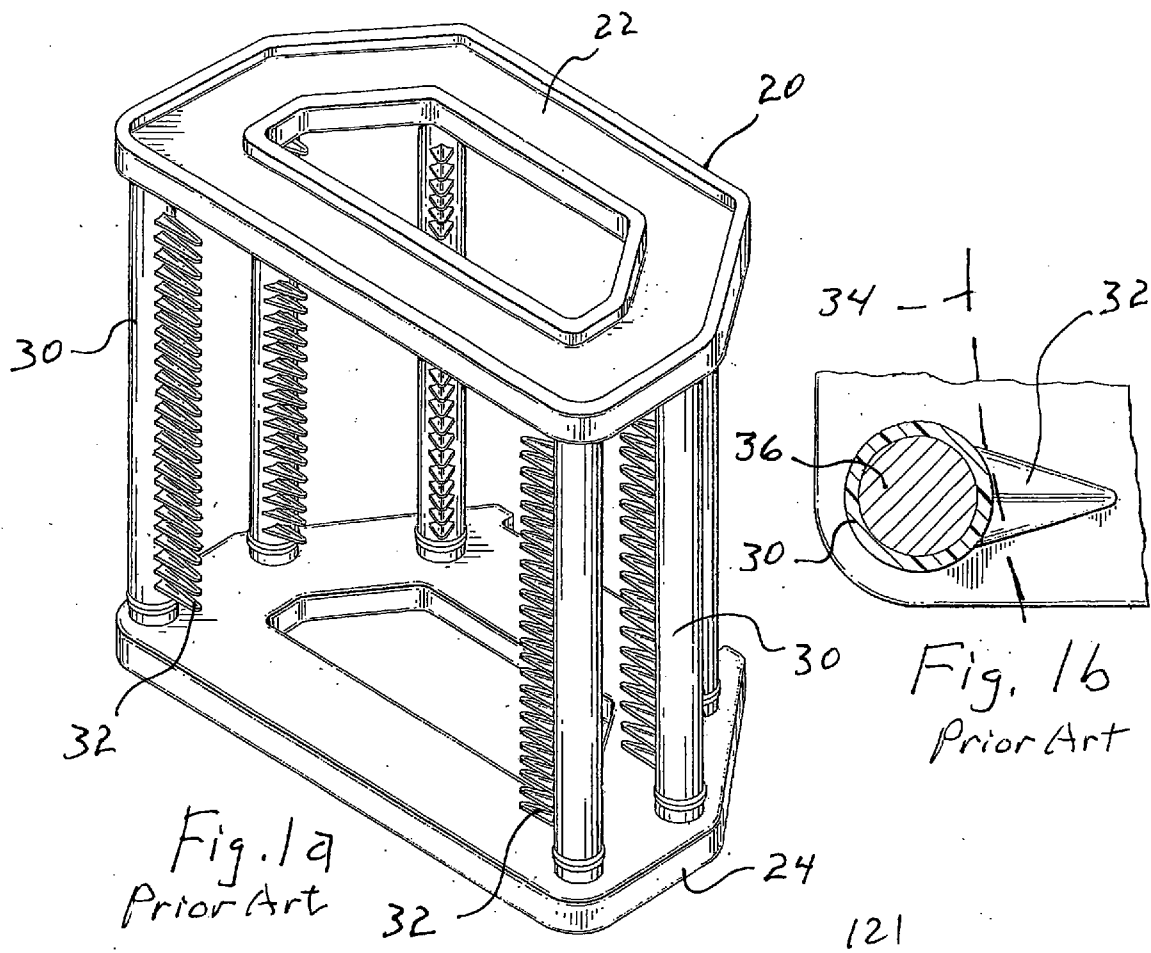
8. A solar cell process carrier for immersion of solar cells into process fluids, the carrier comprising a pair of endwalls with a plurality of rails extending therebetween, the
15 plurality of rails defining a solar cell receiving region, each rail having a base portion and a plurality of teeth arranged sequentially and axially along and extending from said base portion, the teeth position on both sides of a centerline extending down the rail thereby defining two rows of teeth, a channel defined intermediate the two rows and the rail at the centerline.

20

9. The carrier of claim 8 wherein the rail has a outwardly protruding and axially extending rib along the centerline.

10. The carrier of claim 8 wherein the rail has an inwardly extending groove
25 axially extending along the centerline inbetween the two rows of teeth.

11. The carrier of claim 10, further comprising a pair of ribs positioned on each side of the groove.



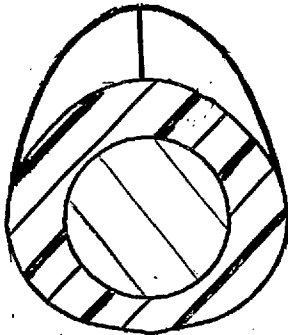


Fig. 3a
Prior Art

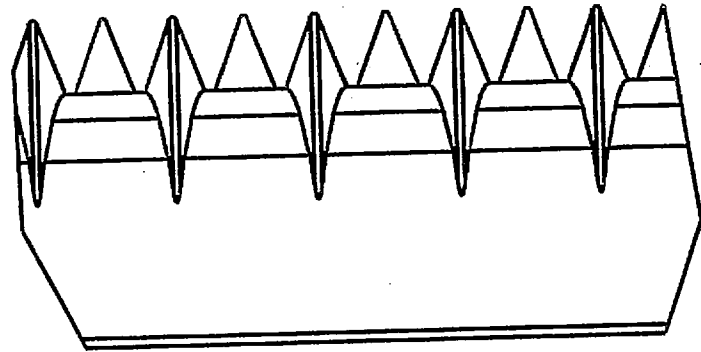


Fig. 3b
Prior Art

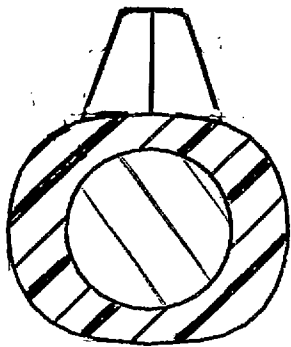


Fig. 4a
Prior Art

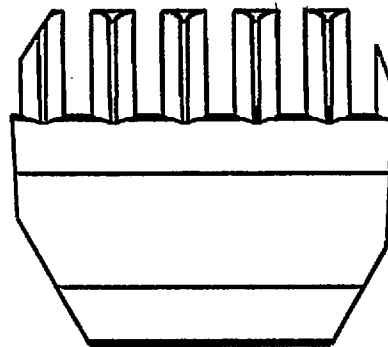


Fig. 4b
Prior Art

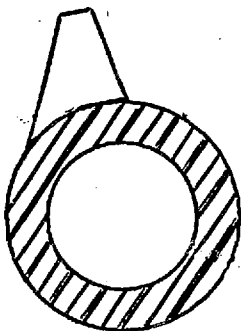


Fig. 5a
Prior Art

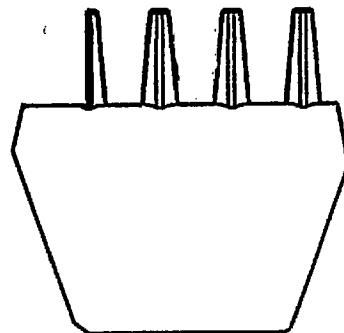
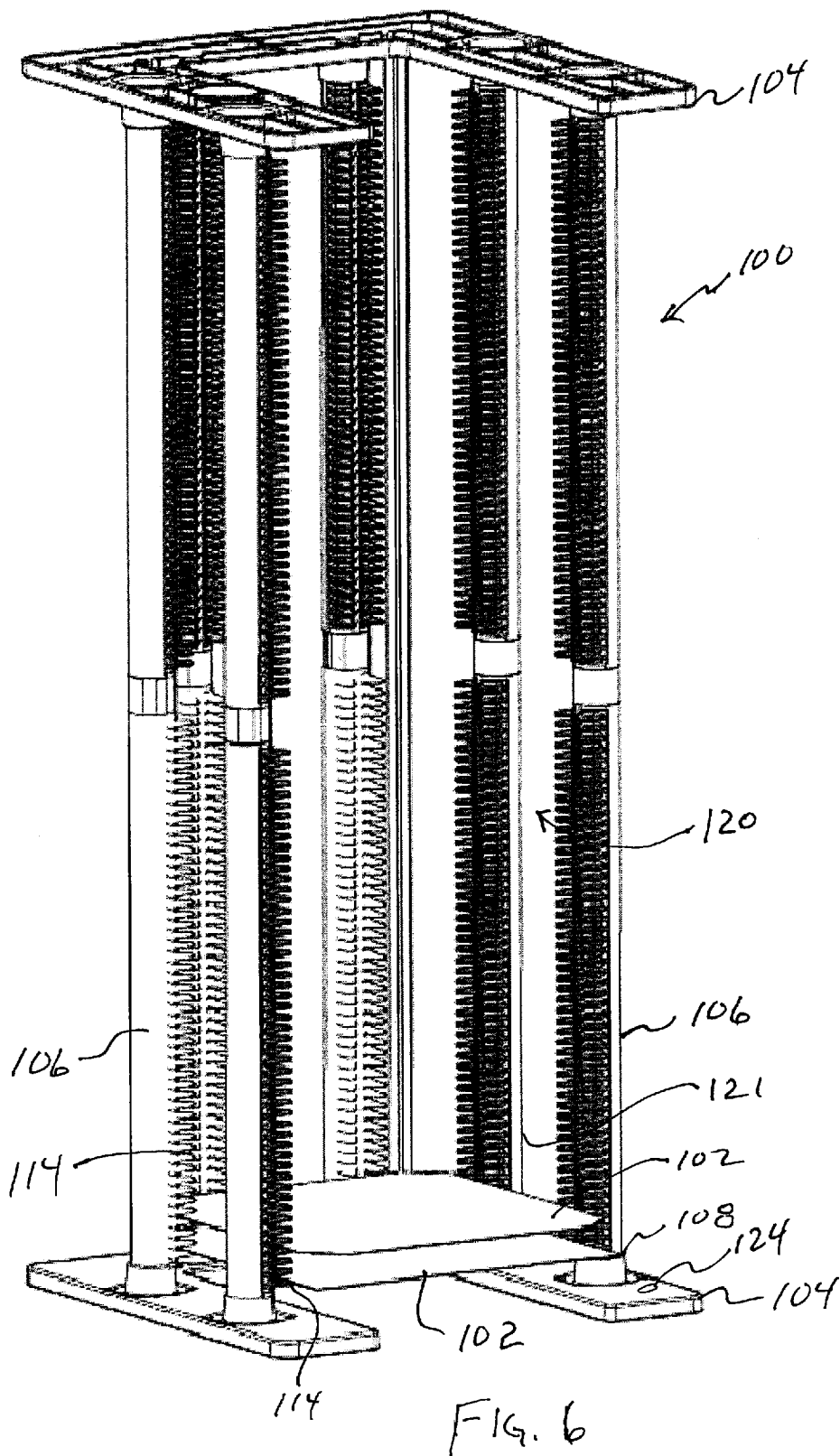
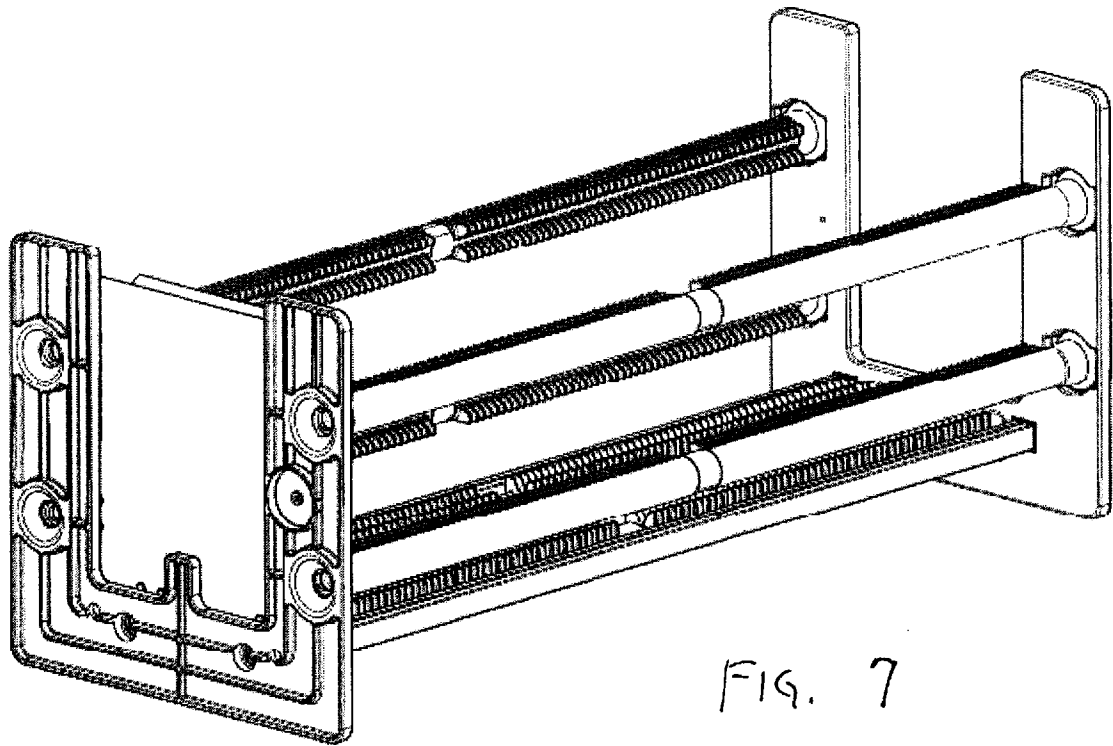


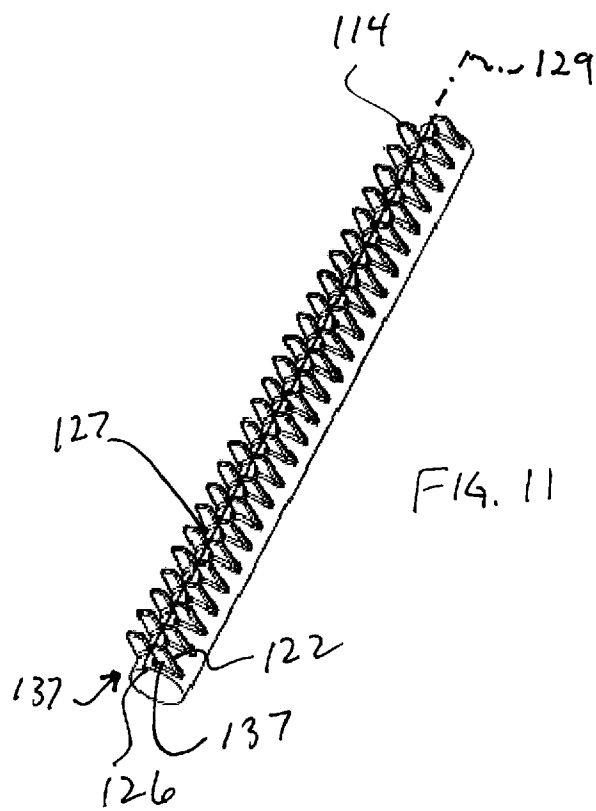
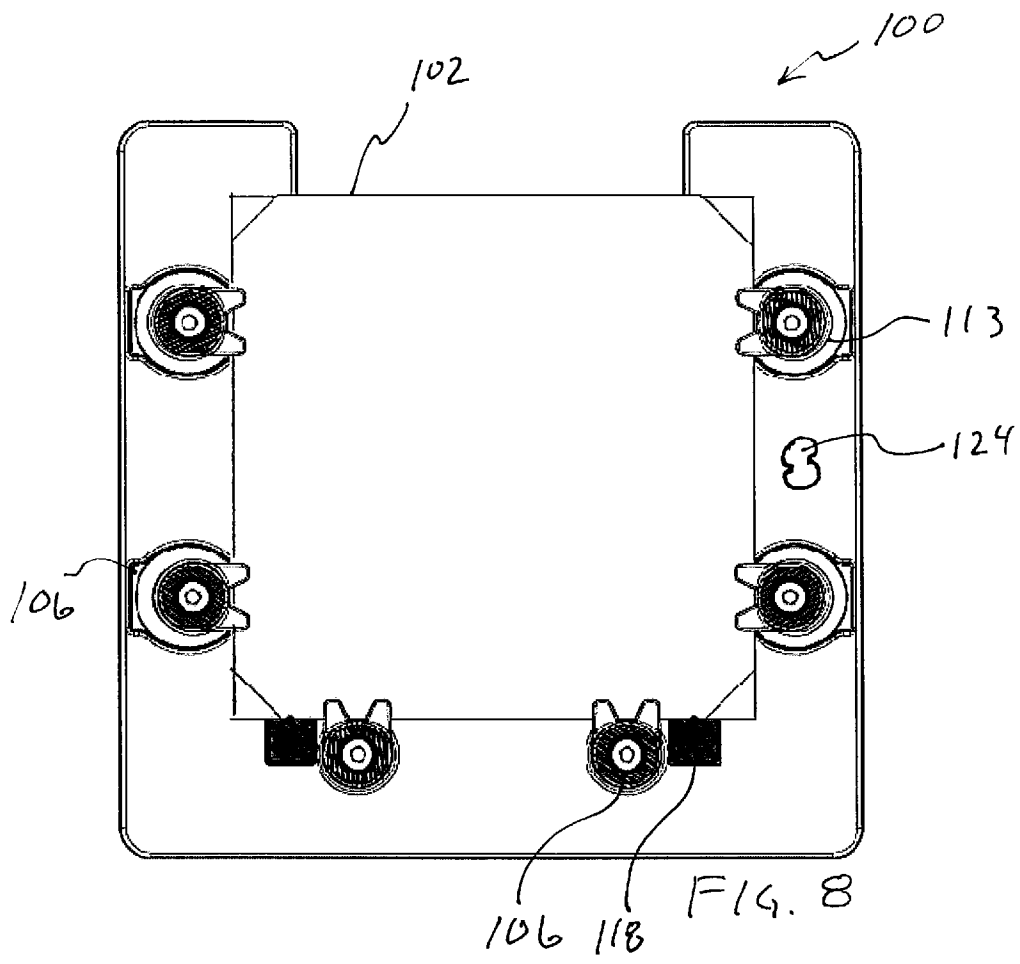
Fig. 5c
Prior Art

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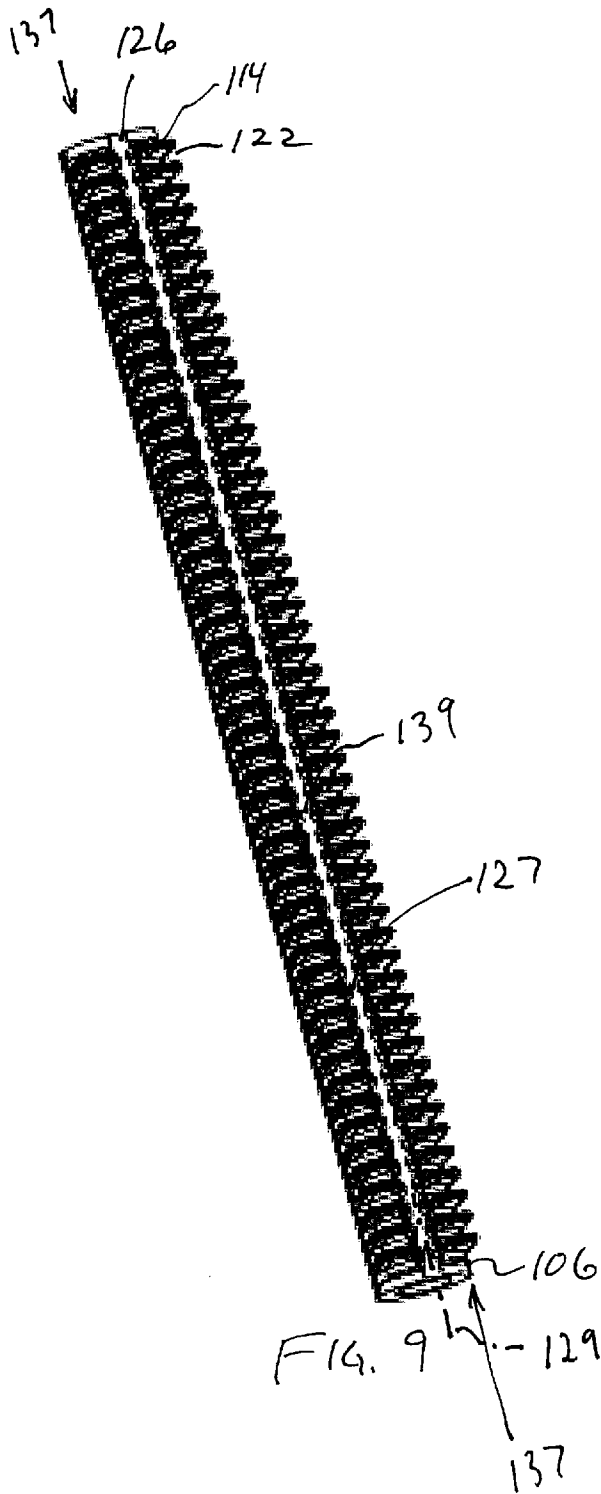




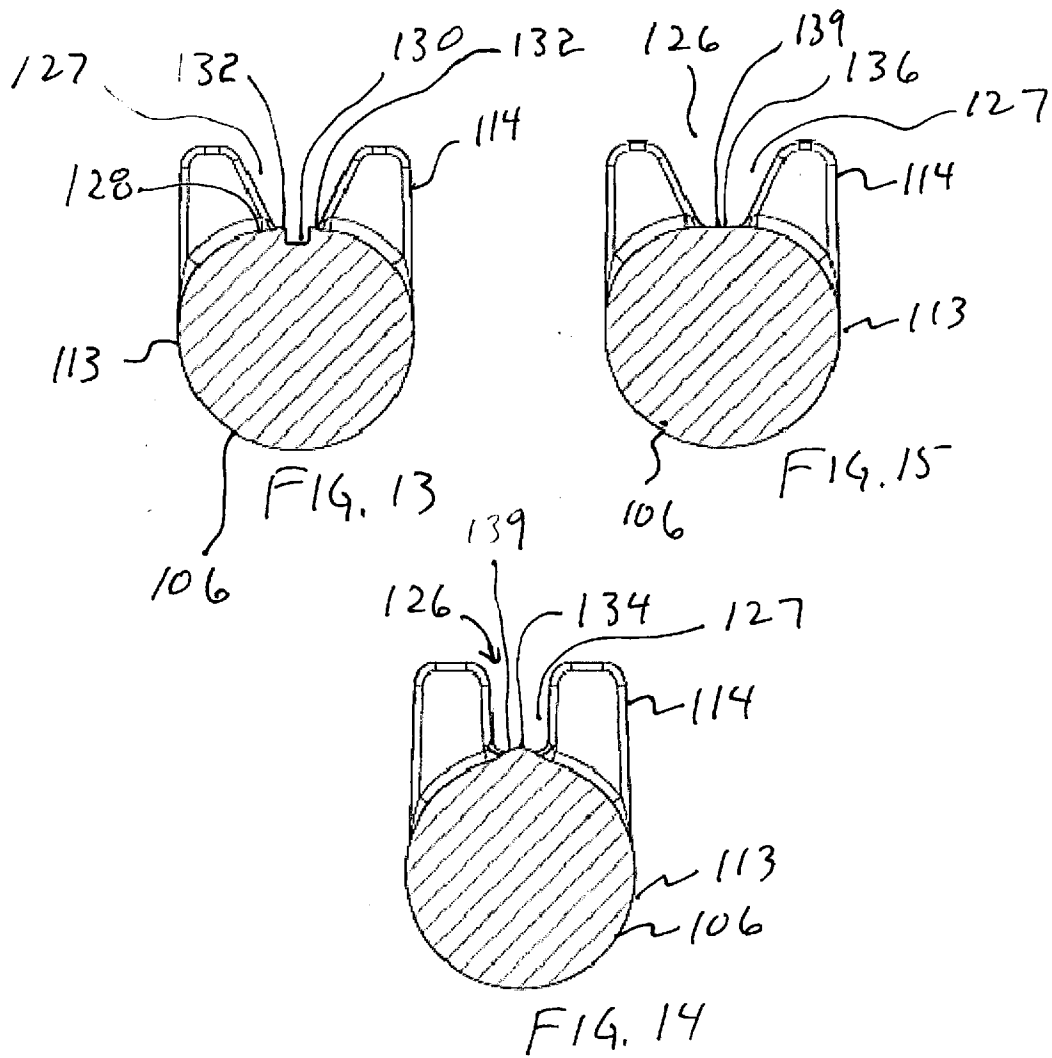
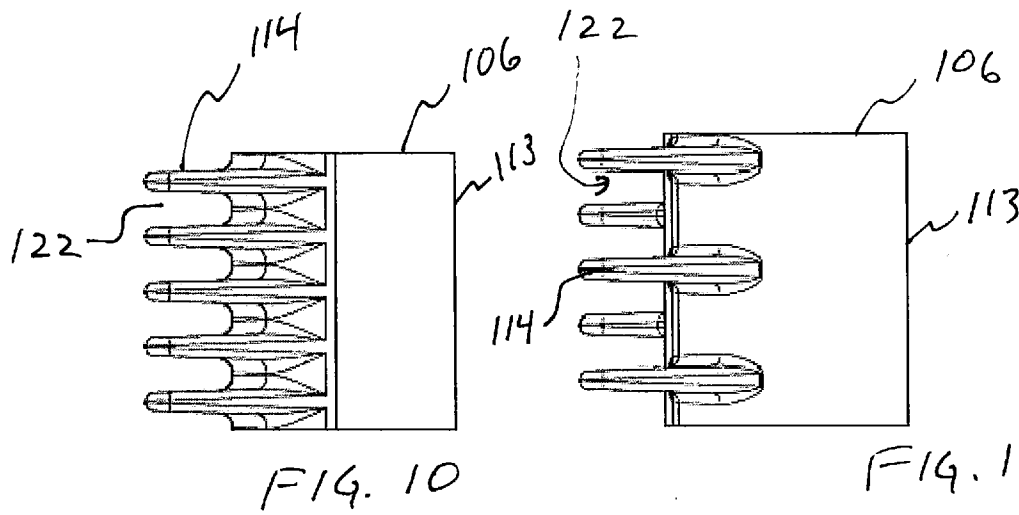
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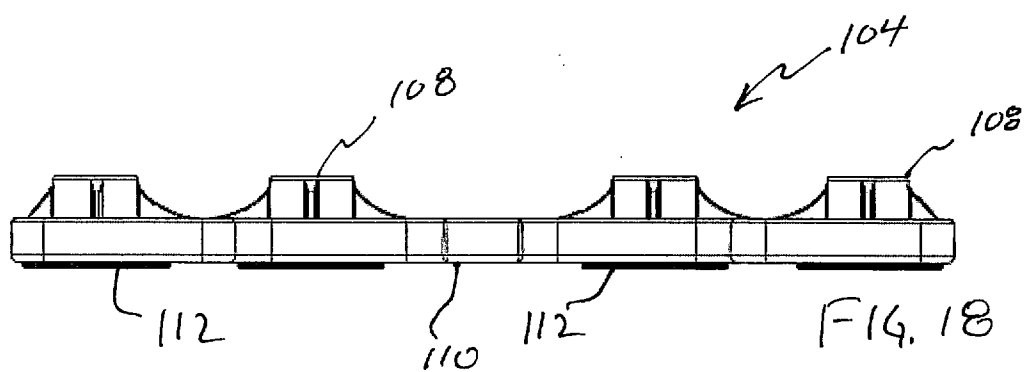
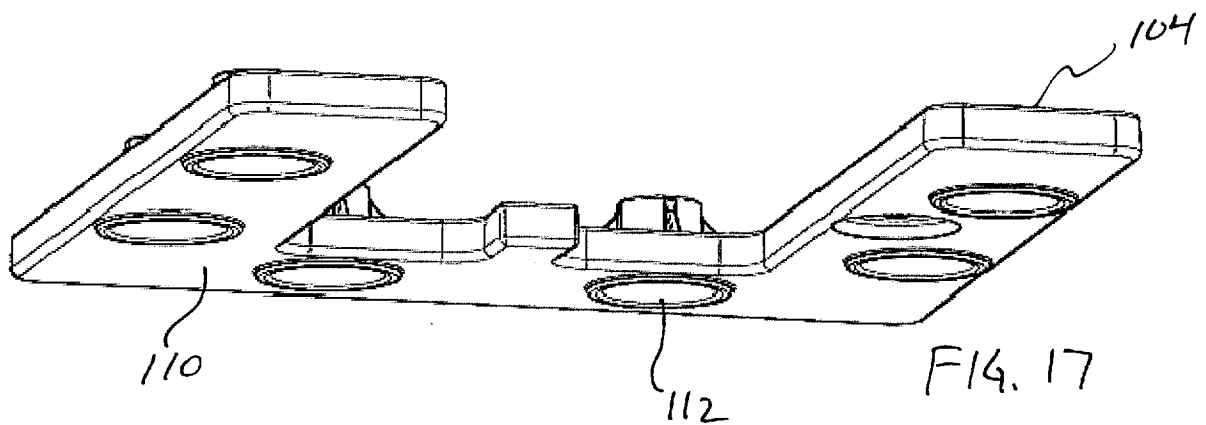
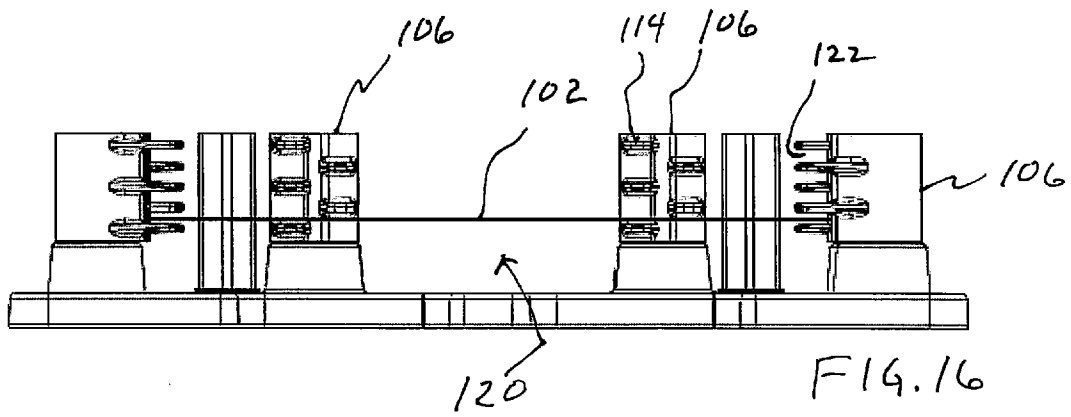


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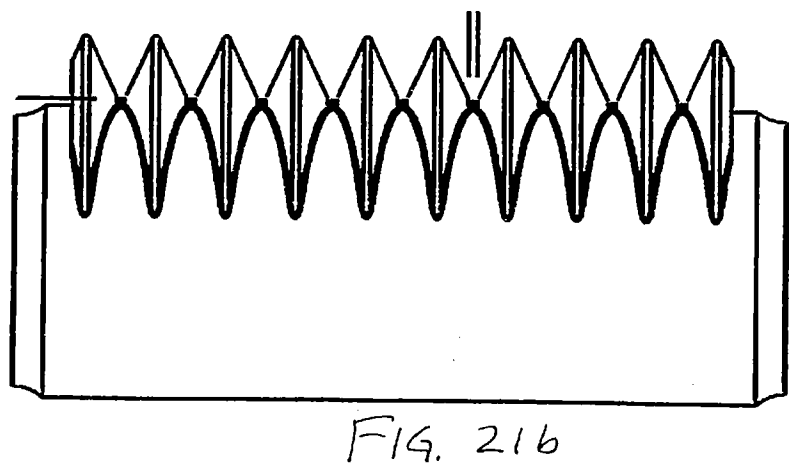
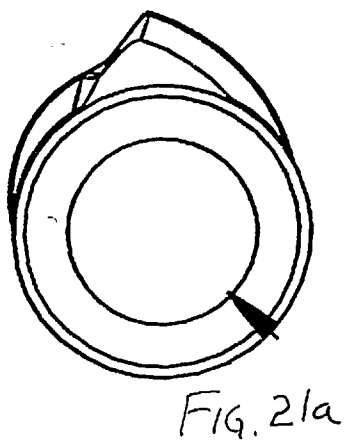
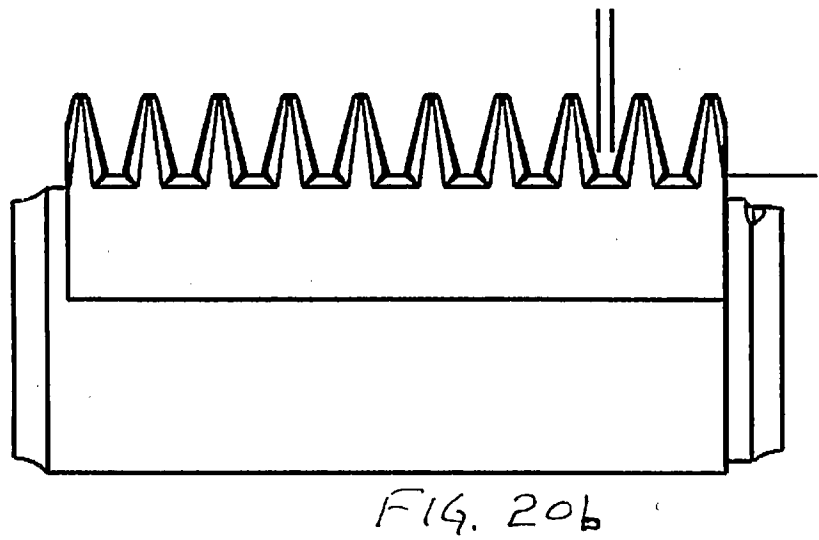
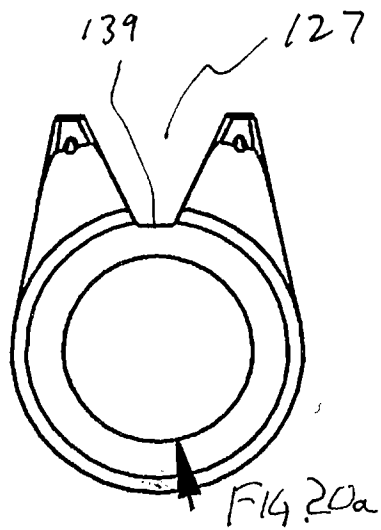
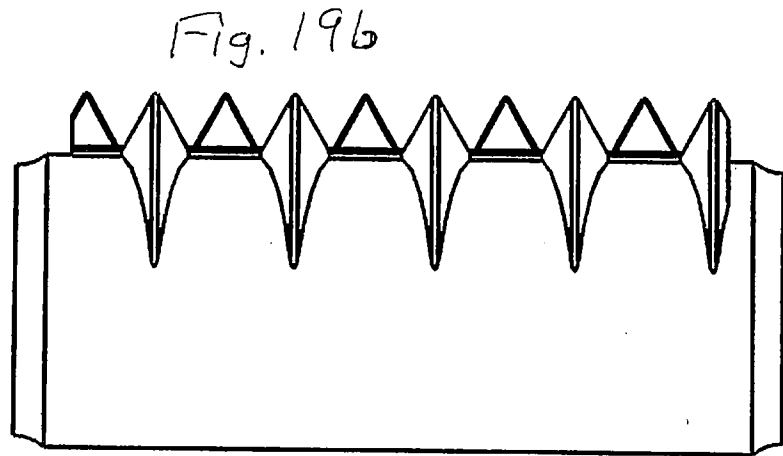
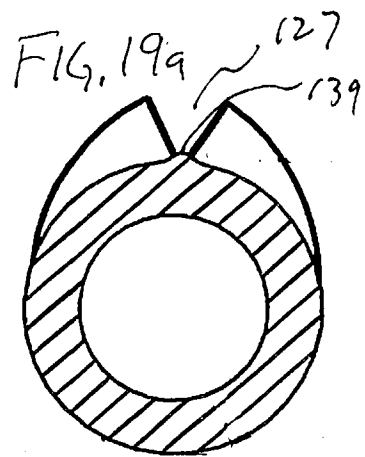


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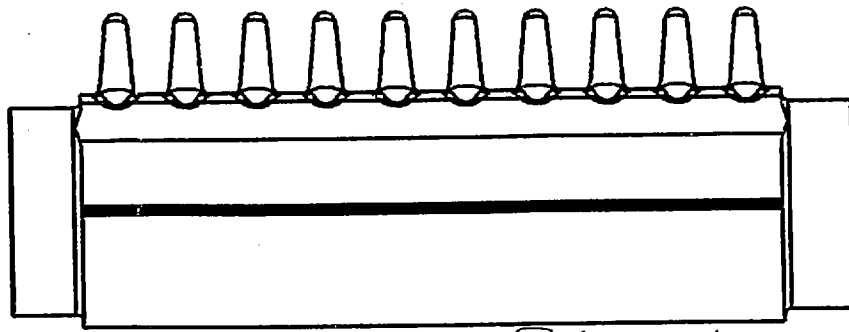


FIG. 22b

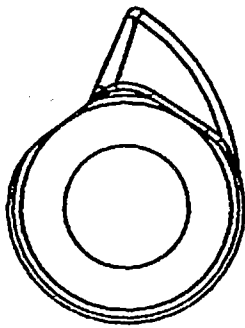


FIG. 22a

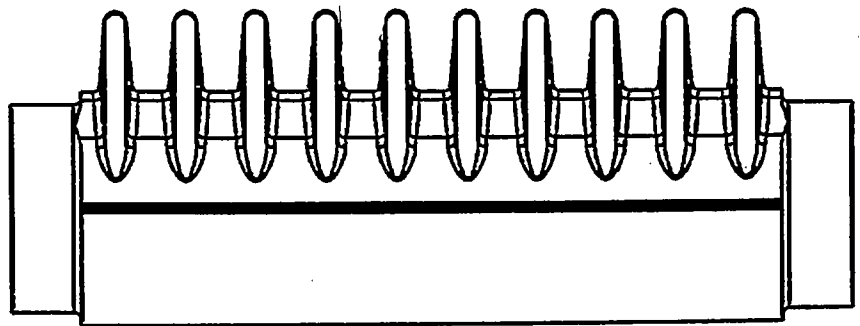


FIG. 22c

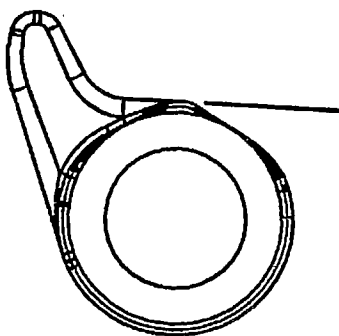


FIG. 23a

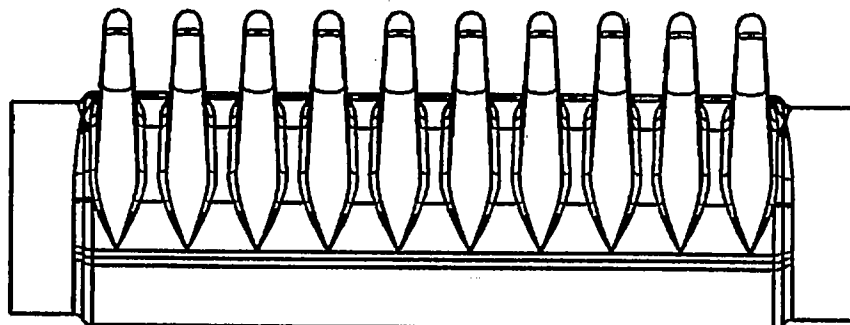
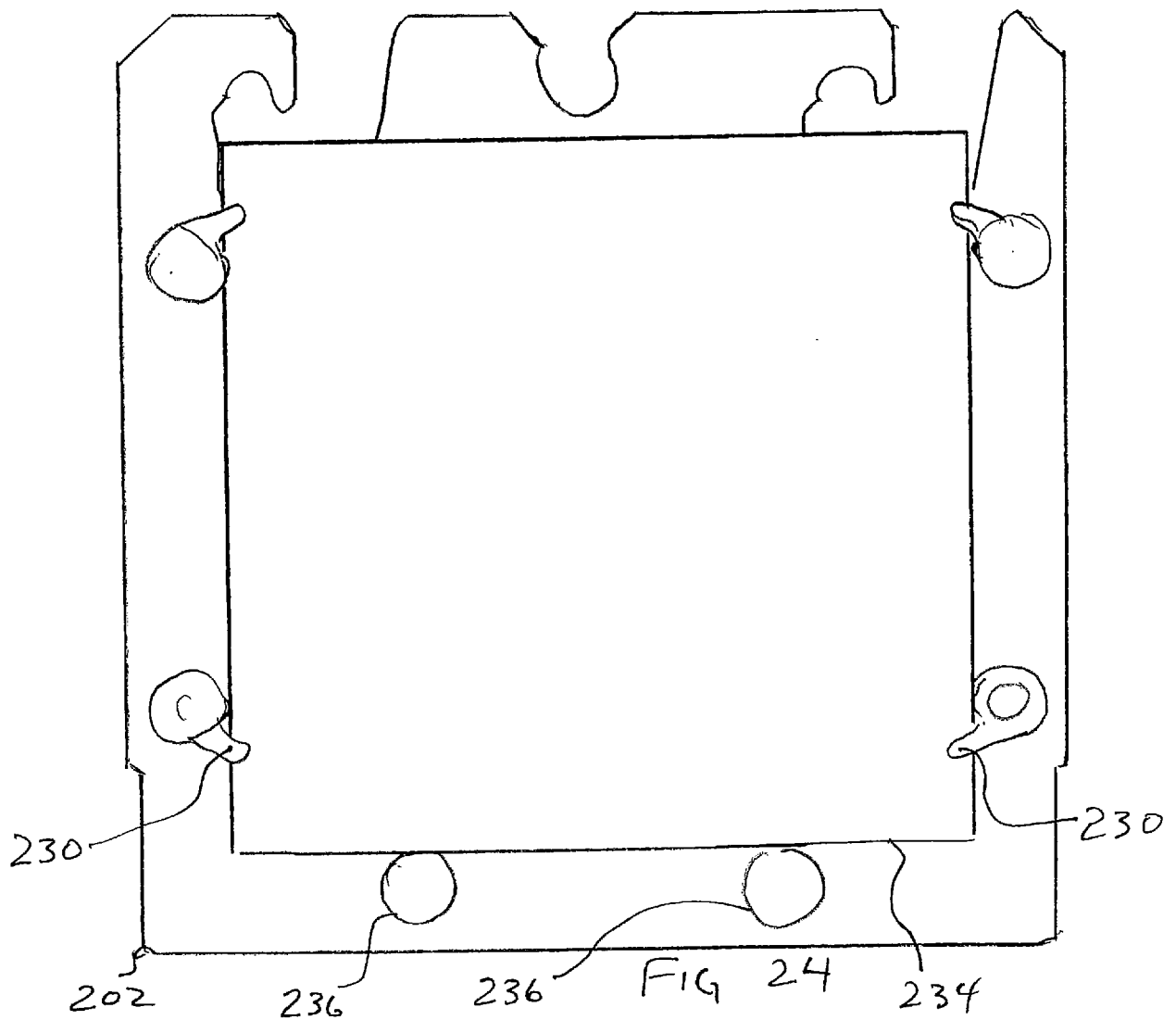
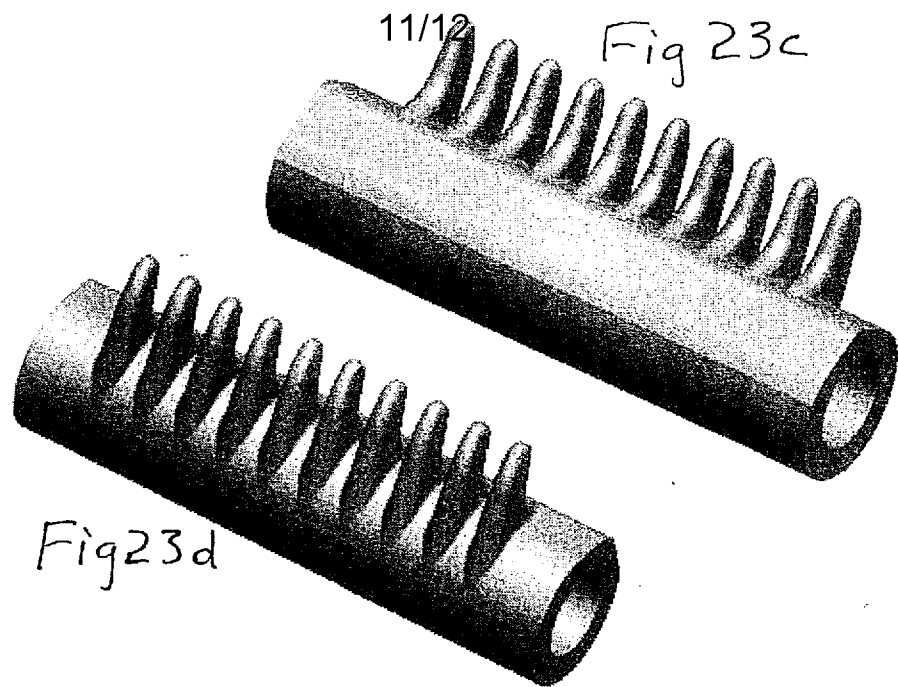


FIG. 23b



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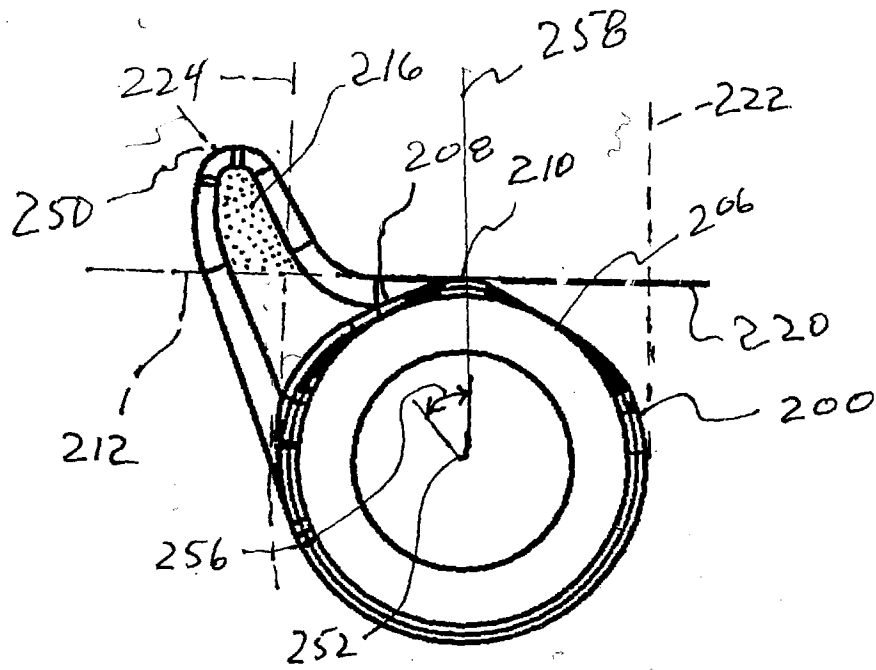


FIG. 25