US 20080017316A1

(19) **United States**

(12) **Patent Application Publication**

Bailey et al.

(10) **Pub. No.: US 2008/0017316 A1**

(43) **Pub. Date: Jan. 24, 2008**

(54) **CLEAN IGNITION SYSTEM FOR WAFER SUBSTRATE PROCESSING**

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(73) Assignee: **Accretech USA, Inc.**, Bloomfield Hills, MI

(21) Appl. No.: **11/825,671**

(22) Filed: **Jul. 6, 2007**

Related U.S. Application Data

(60) Continuation-in-part of application No. 11/131,611, filed on May 18, 2005, which is a division of application No. 10/401,074, filed on Mar. 27, 2003, now Pat. No. 6,936,546.
Continuation-in-part of application No. 11/230,261, filed on Sep. 19, 2005.
Continuation-in-part of application No. 11/230,263, filed on Sep. 19, 2005.
Continuation-in-part of application No. 11/417,297, filed on May 2, 2006.

(60) Provisional application No. 60/819,521, filed on Jul. 7, 2006. Provisional application No. 60/376,154, filed on Apr. 26, 2002.

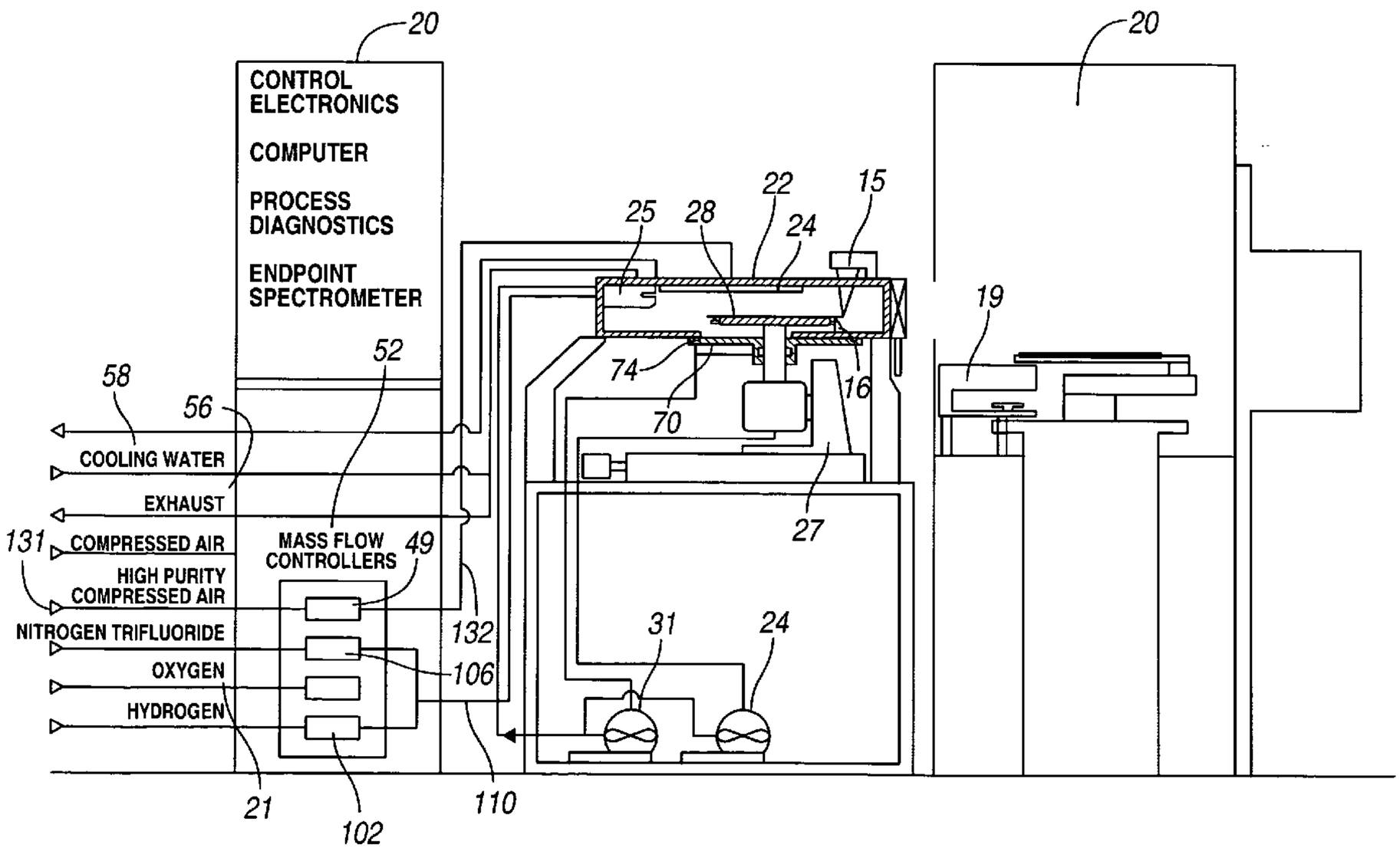
Publication Classification

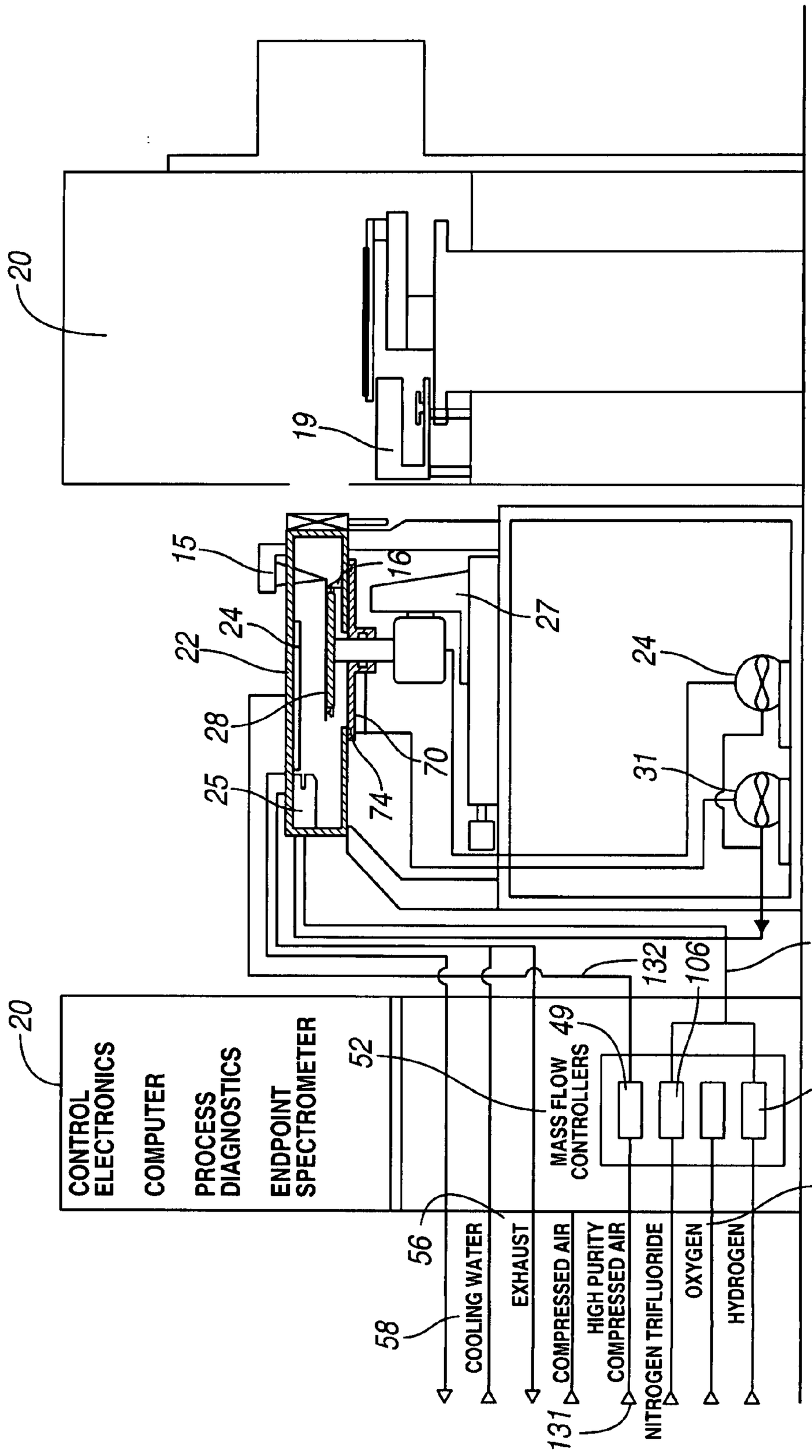
(51) **Int. Cl.**
C23F 1/00 (2006.01)
F23Q 7/22 (2006.01)

(52) **U.S. Cl.** **156/345.29**; 431/258

(57) **ABSTRACT**

An edge area of the substrate processing device is disclosed. The edge area being processed is isolated from the remainder of the substrate by directing a flow of an inert gas through a plenum near the area to be processed thus forming a barrier while directing a flow of reactive species at an angle relative to the top surface of the substrate towards the substrate edge area thus processing the substrate edge area. A flow of oxygen containing gas into the processing chamber together with a negative exhaust pressure may contribute to the biasing of reactive species and other gases away from the non-processing areas of the substrate. A clean ignition system is used to ignite the combustion flame.

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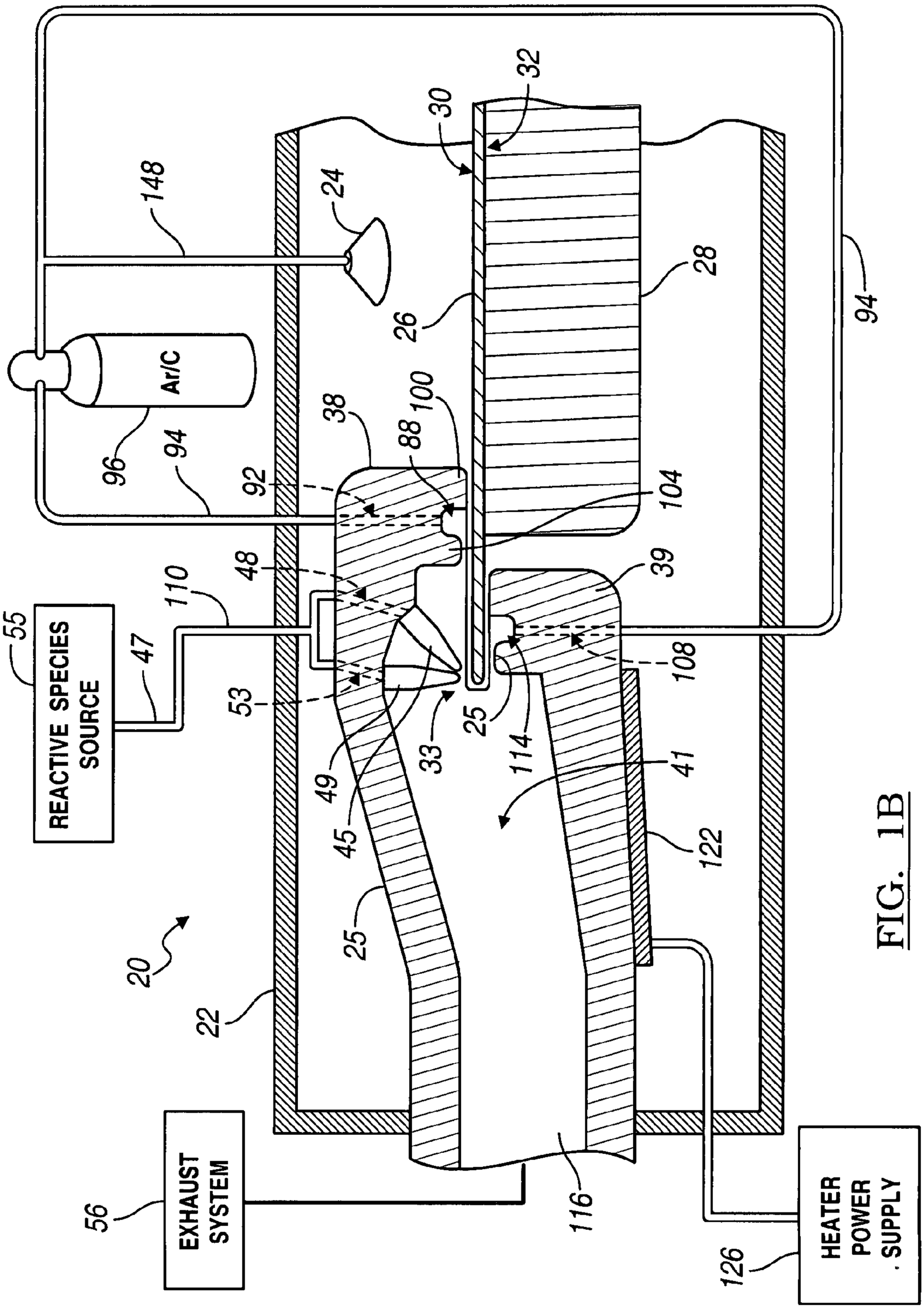
CONTROL ELECTRONICS
COMPUTER
PROCESS DIAGNOSTICS
ENDPOINT SPECTROMETER
MASS FLOW CONTROLLERS
COOLING WATER
EXHAUST
COMPRESSED AIR
HIGH PURITY COMPRESSED AIR
NITROGEN TRIFLUORIDE
OXYGEN
HYDROGEN

FIG. 1A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EXHAUST SYSTEM
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126
HEATER POWER SUPPLY
REACTIVE SPECIES SOURCE

FIG. 1B

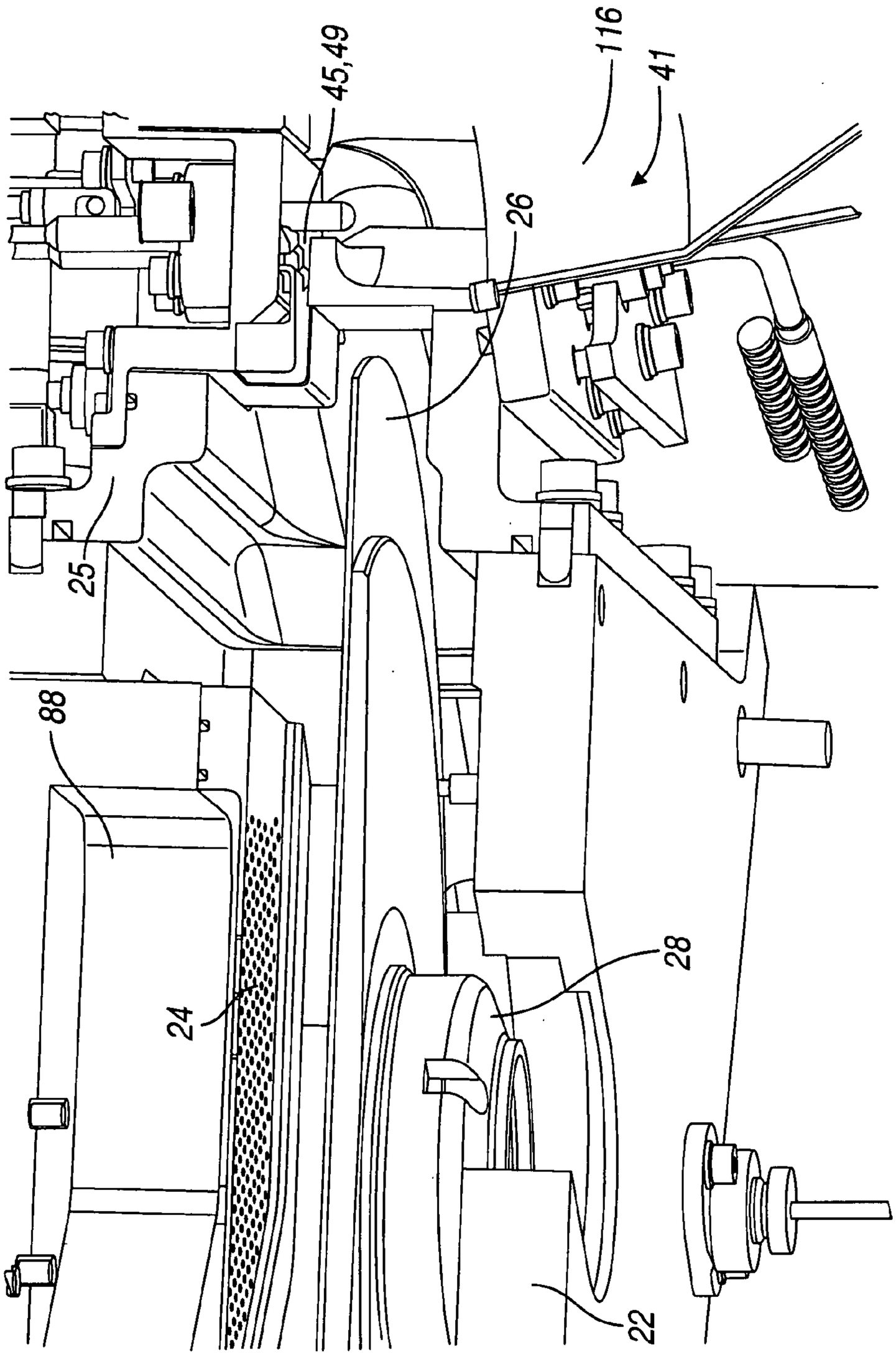


FIG. 1C

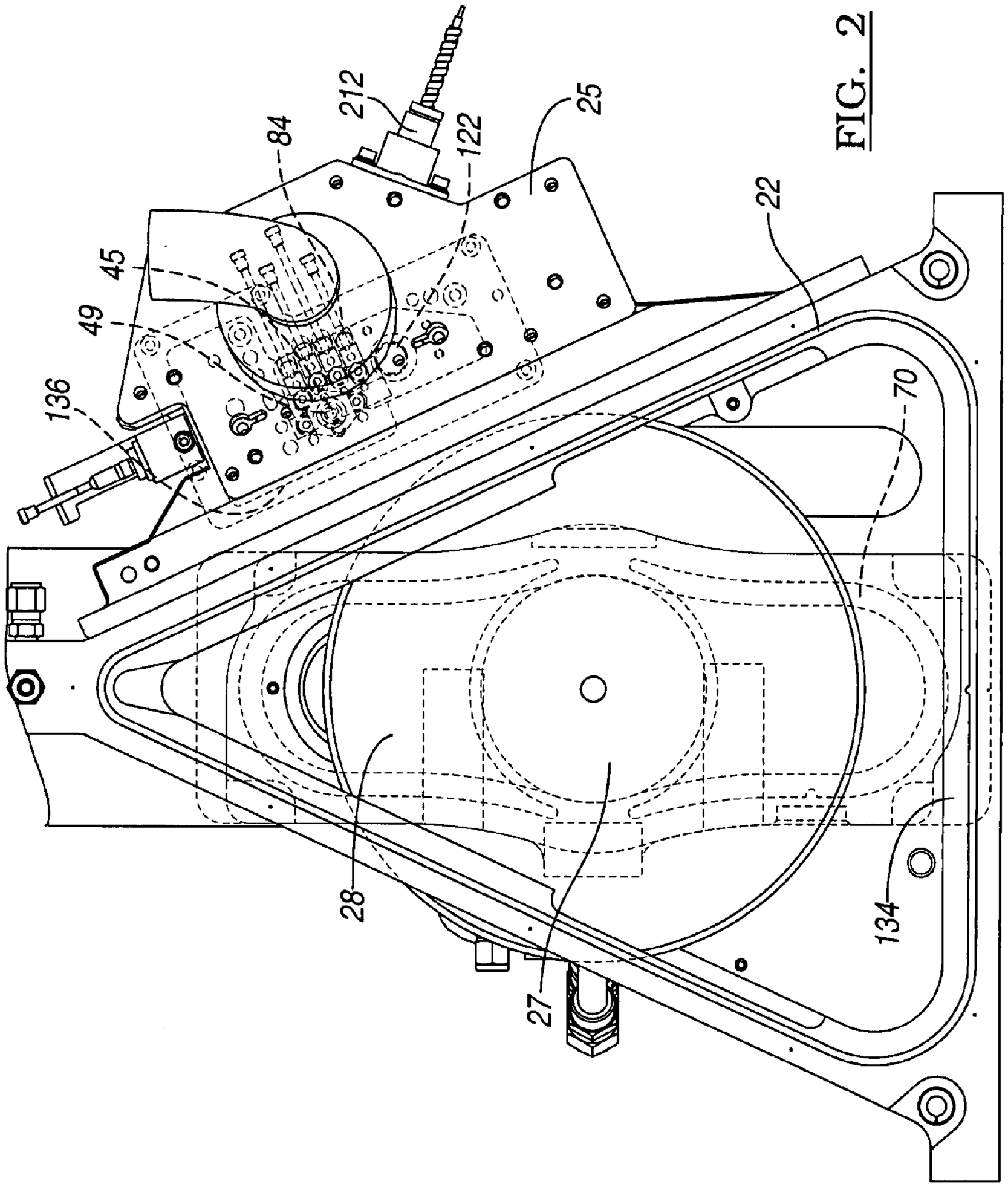


FIG. 2

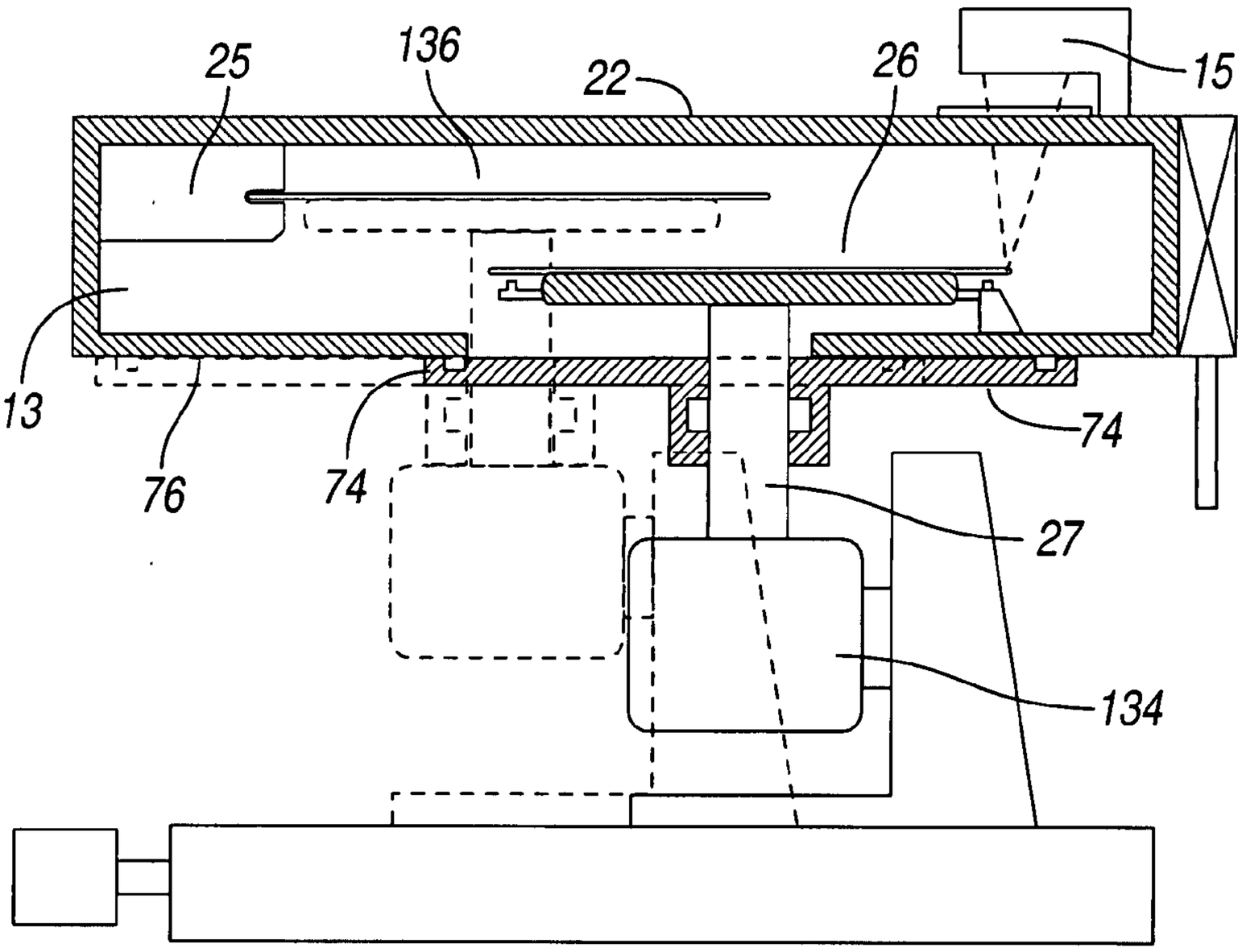


FIG. 3

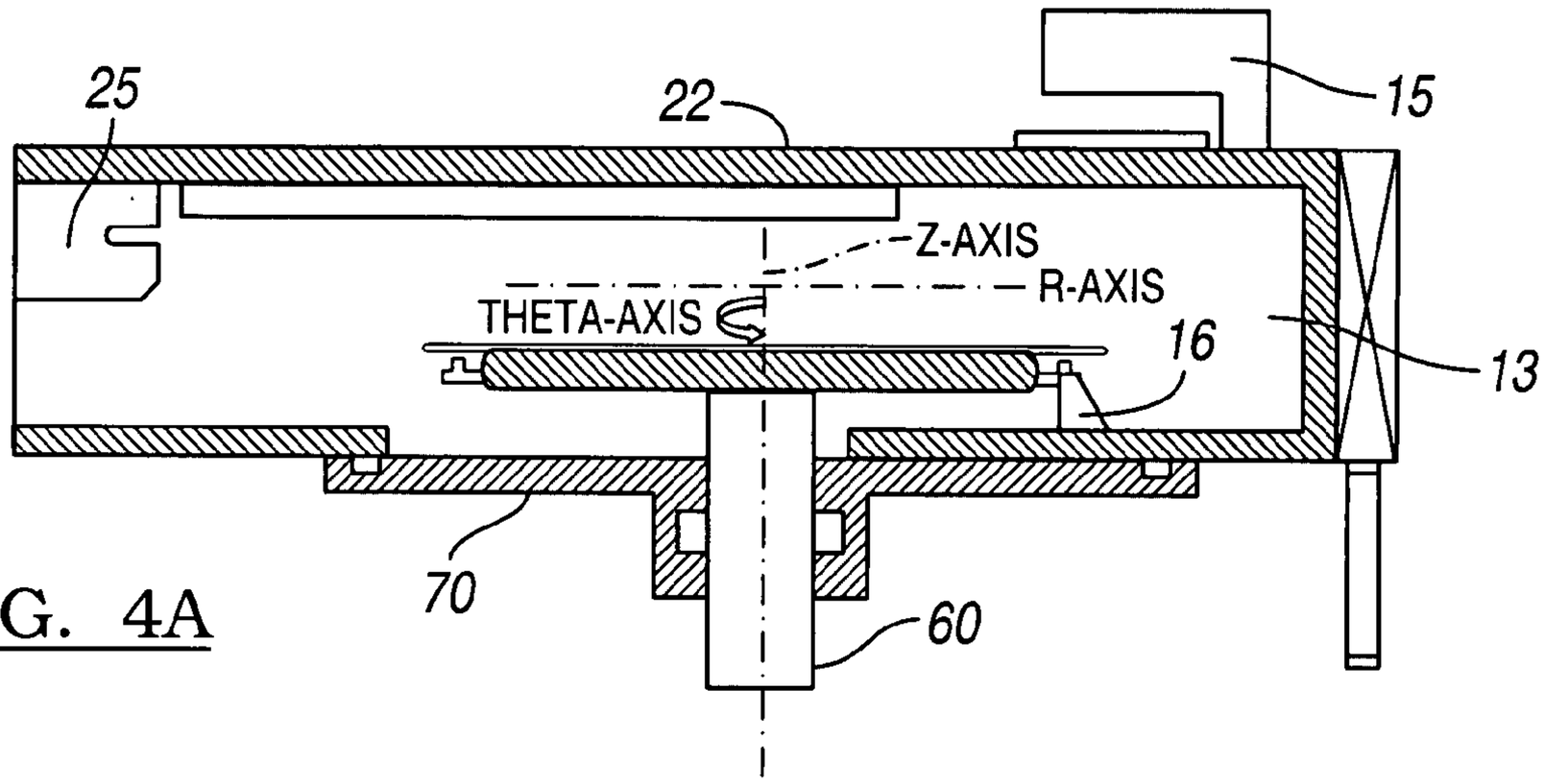


FIG. 4A

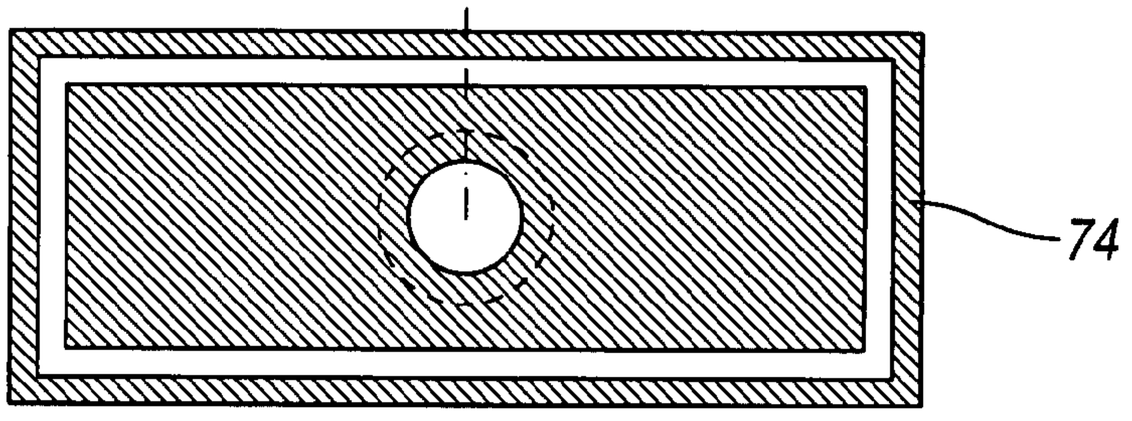
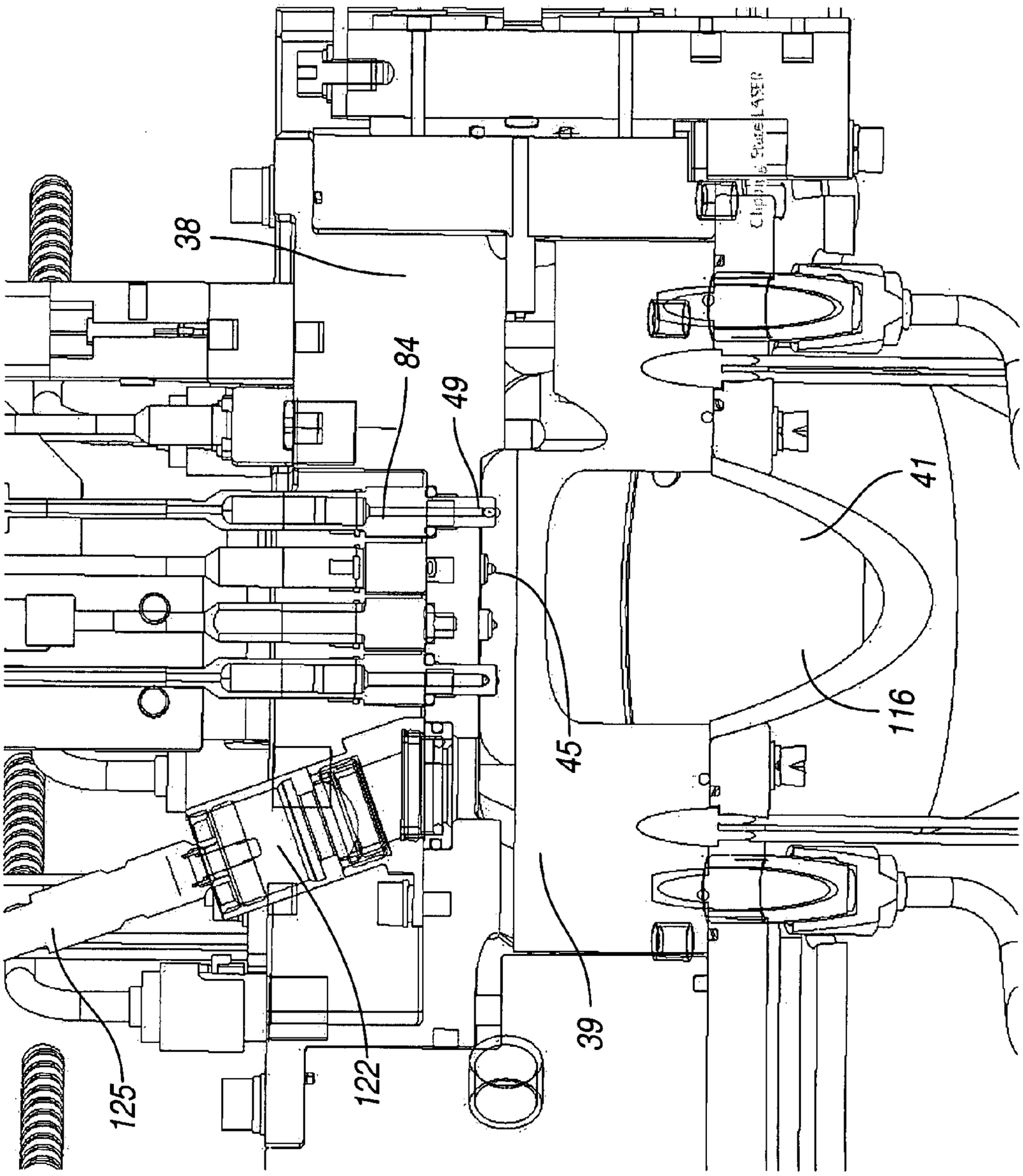


FIG. 4B

FIG. 5



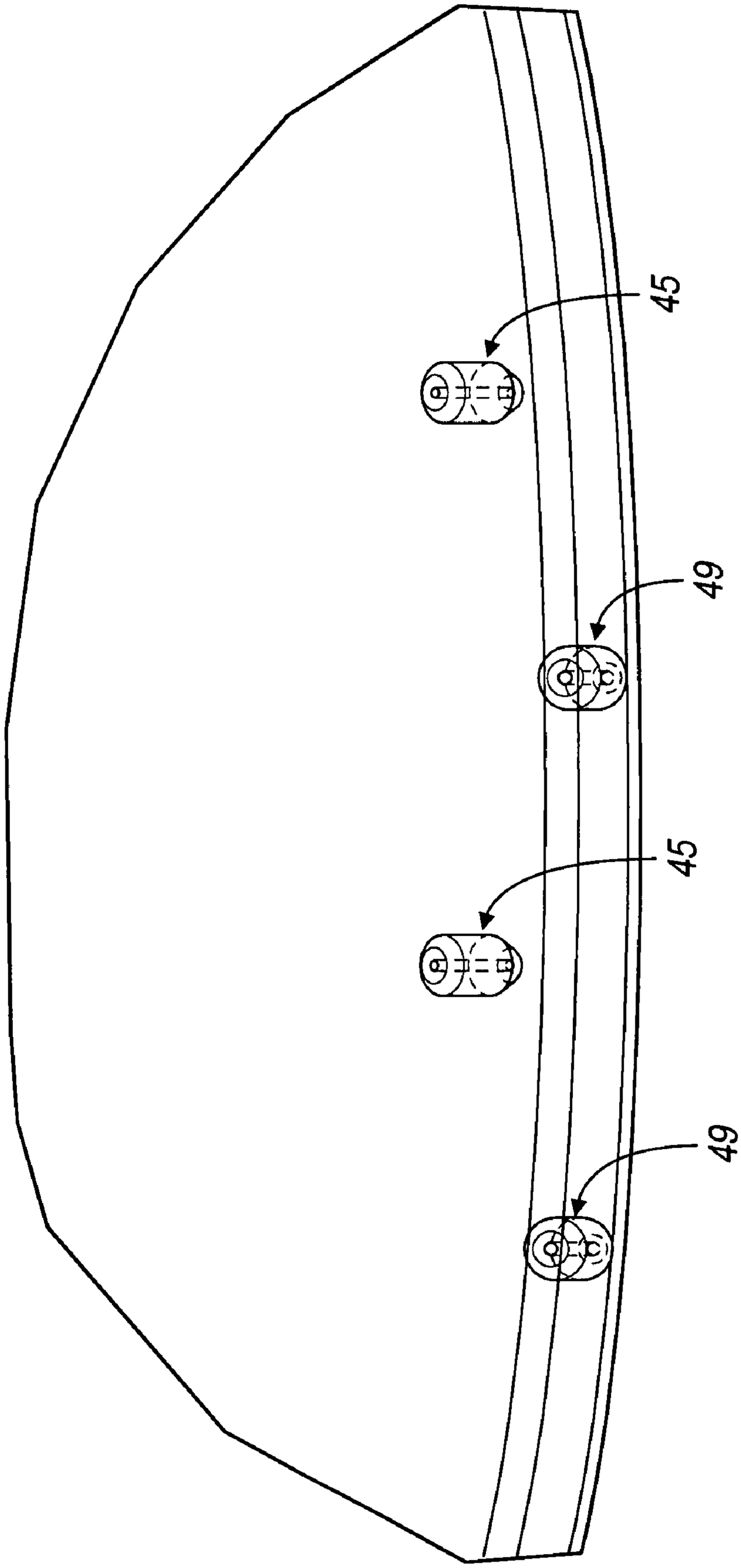


FIG. 6A

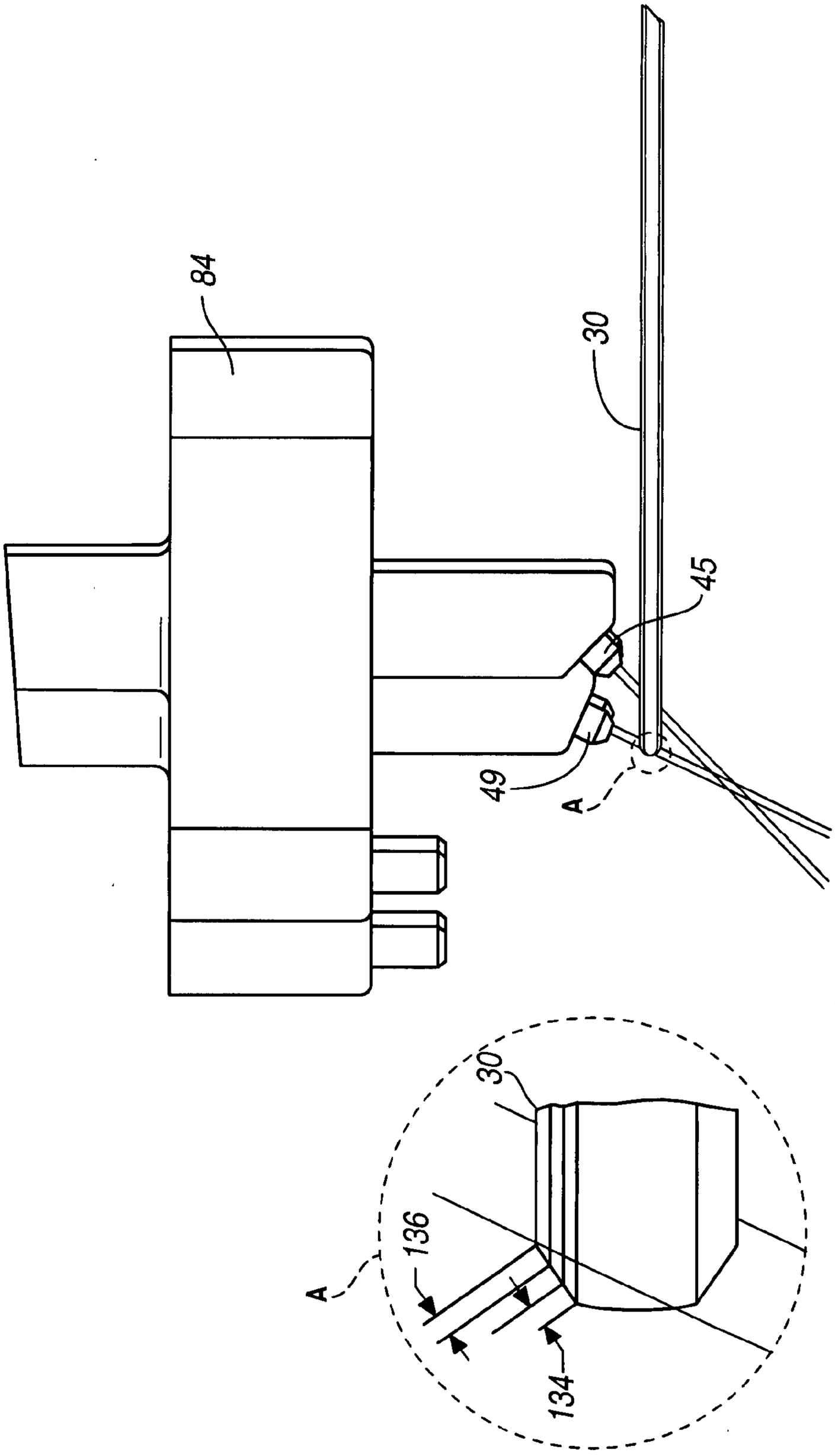


FIG. 6B

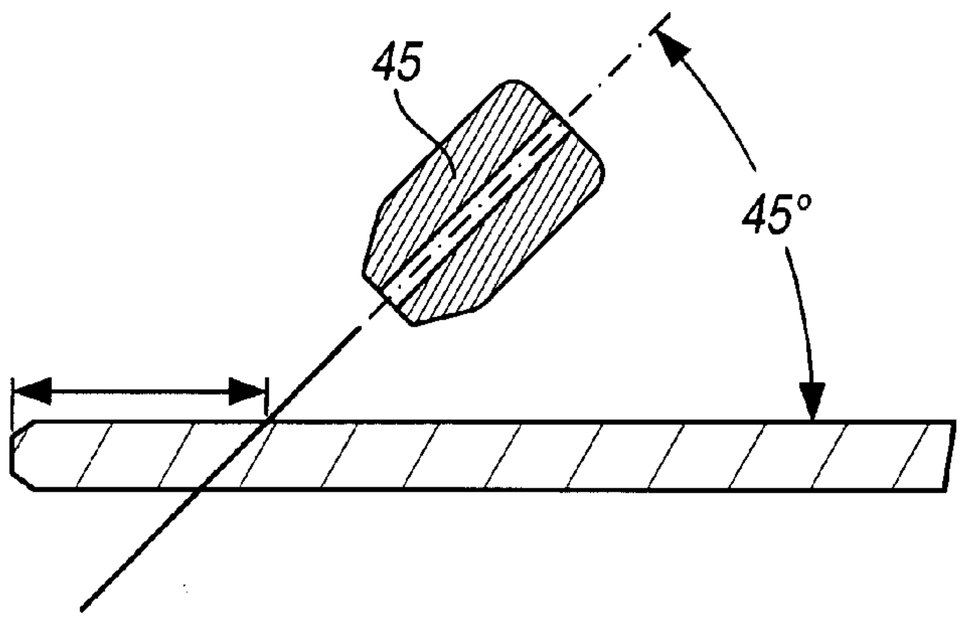


FIG. 6C

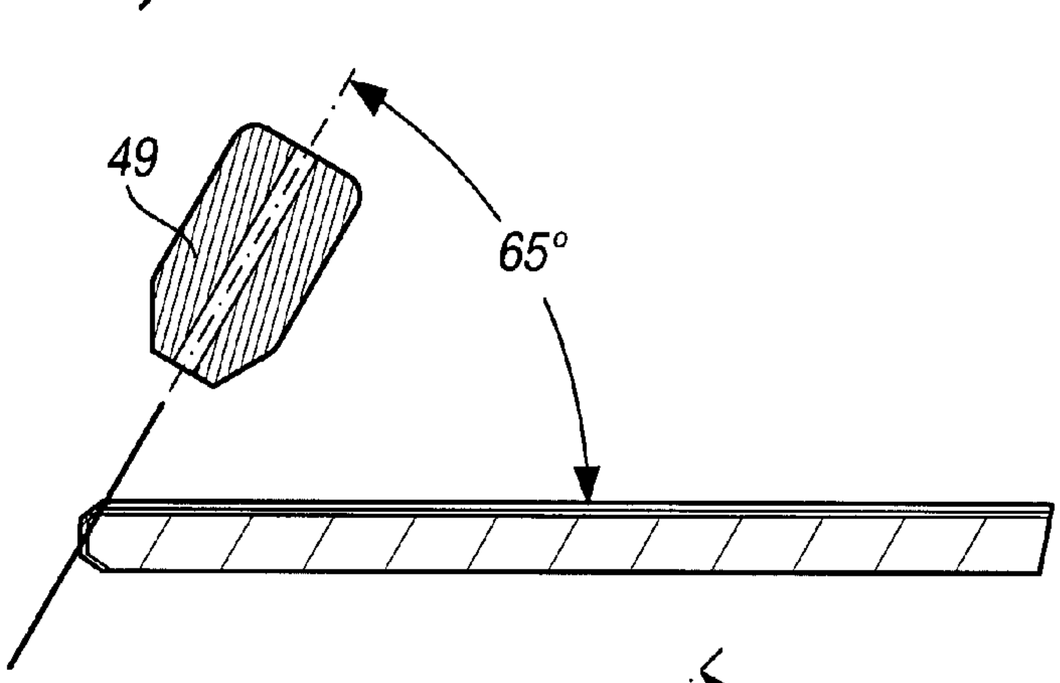


FIG. 6D

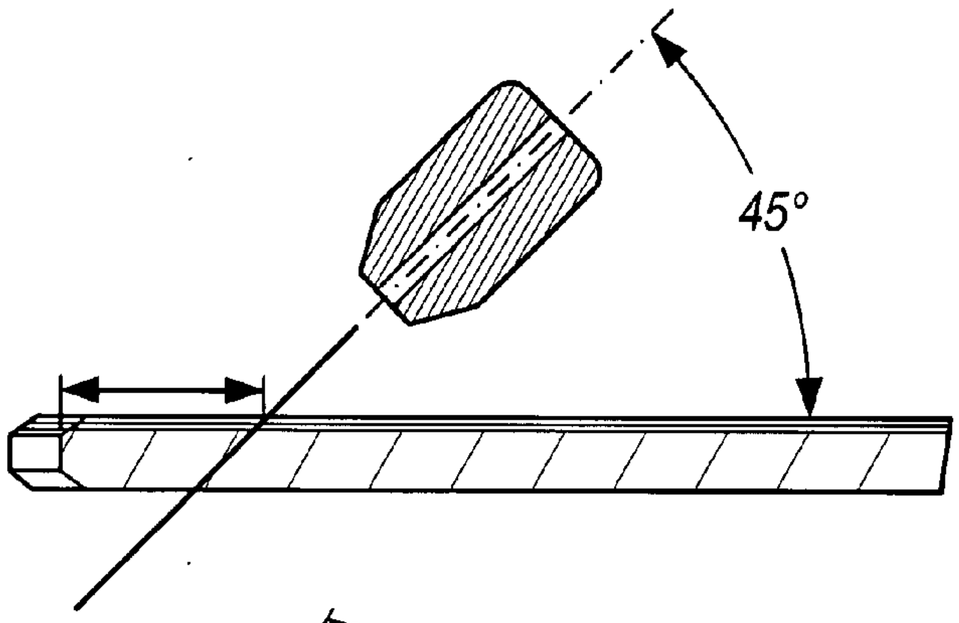


FIG. 6E

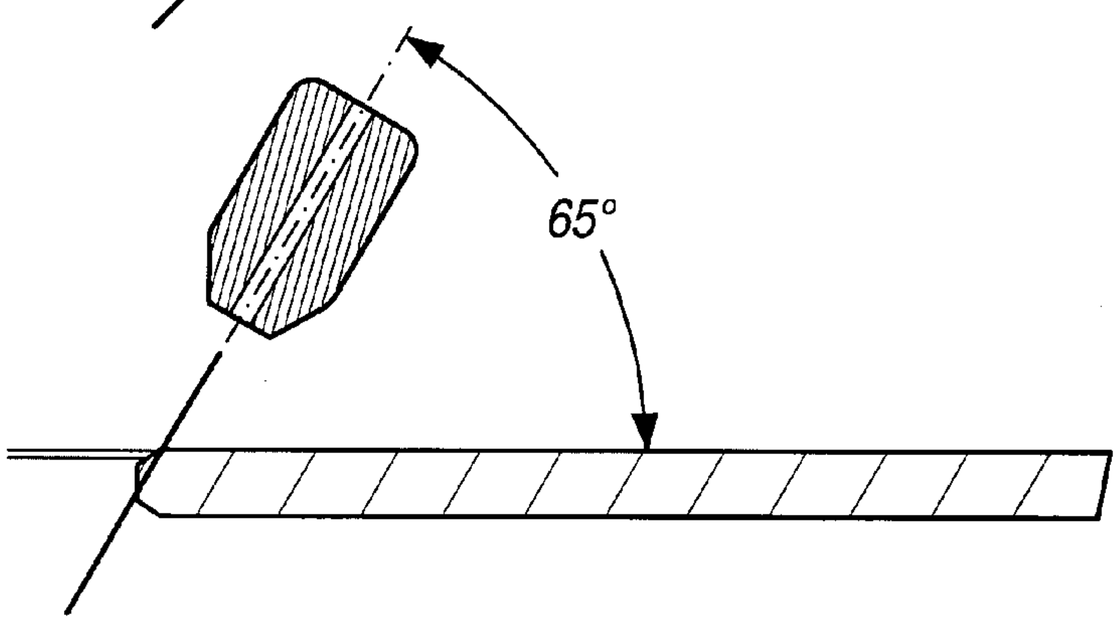


FIG. 6F

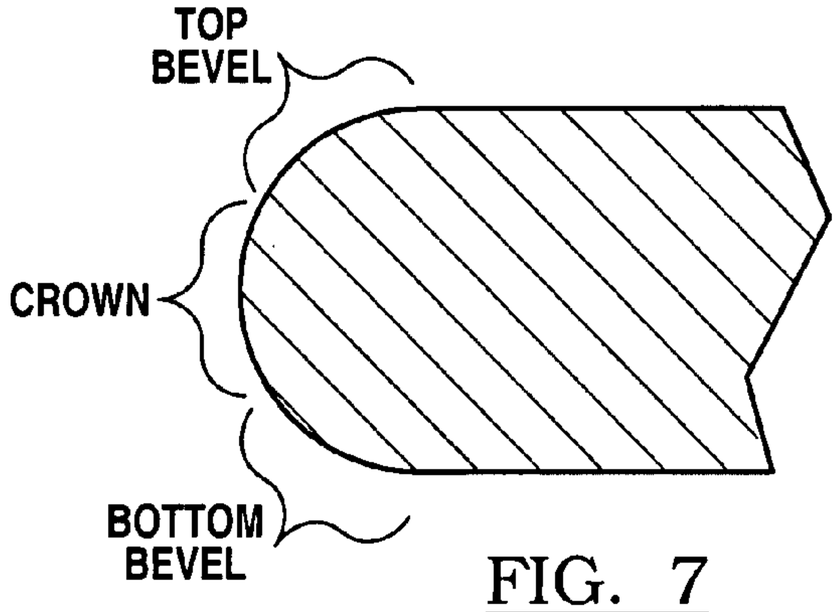


FIG. 7

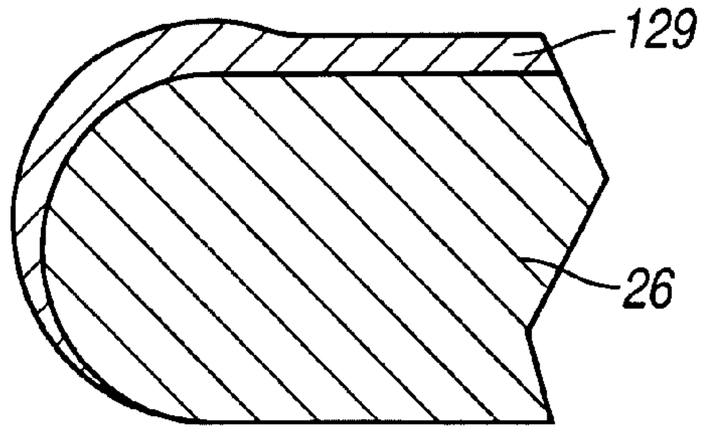


FIG. 8A

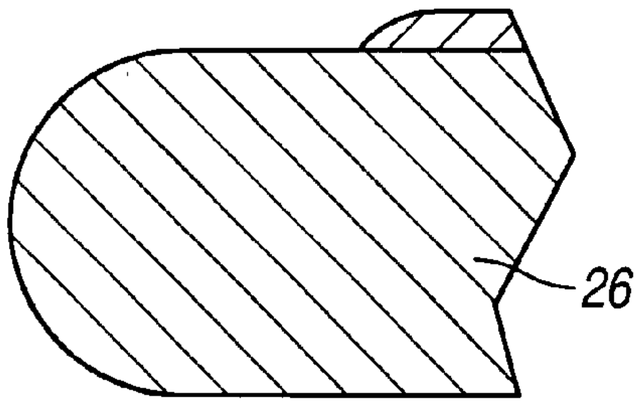


FIG. 8B

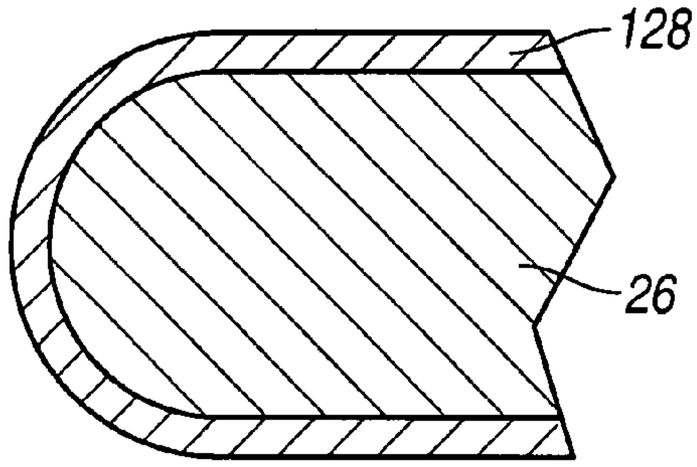
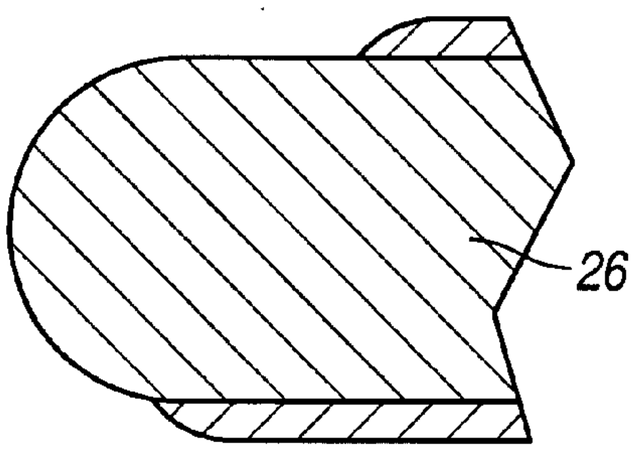


FIG. 8C



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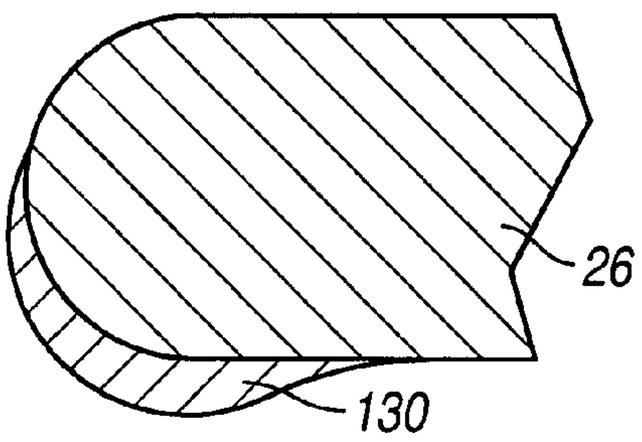

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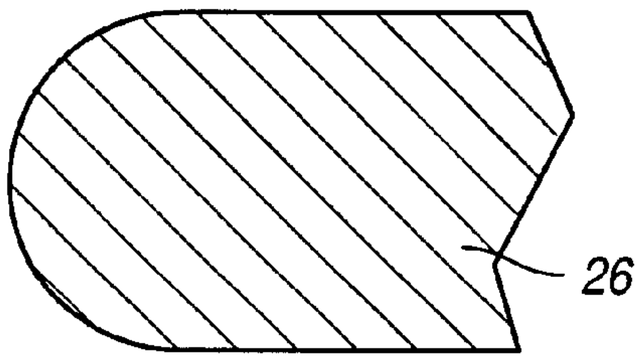

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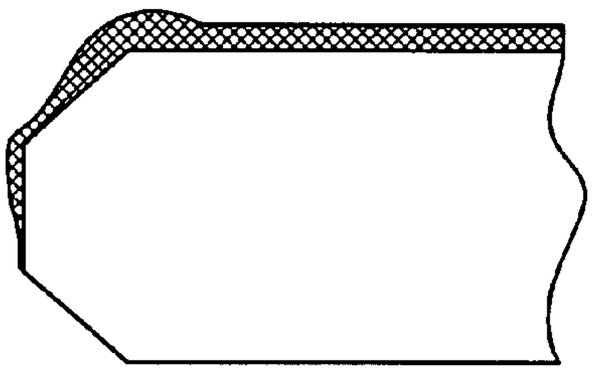

FIG. 8G

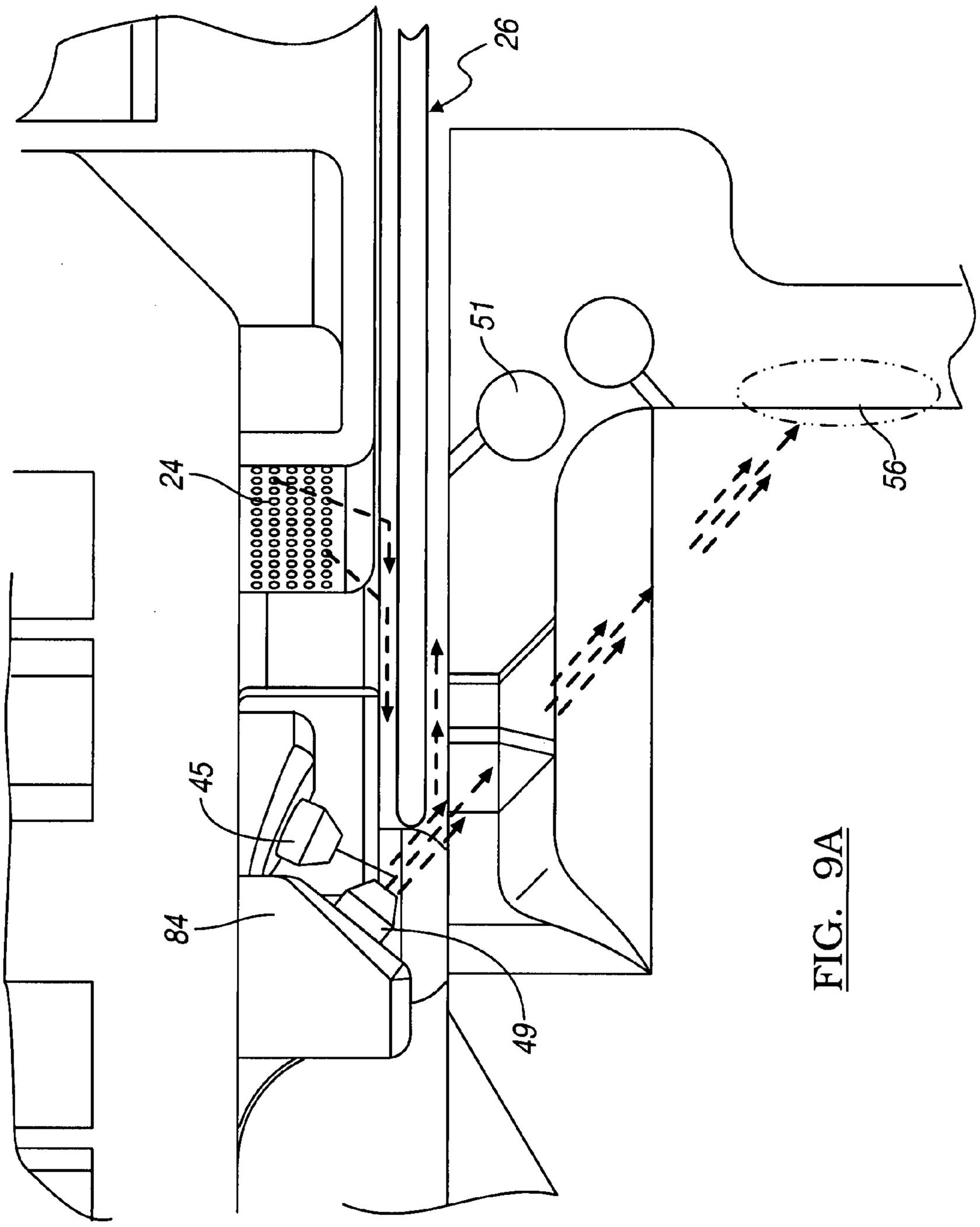

FIG. 9A

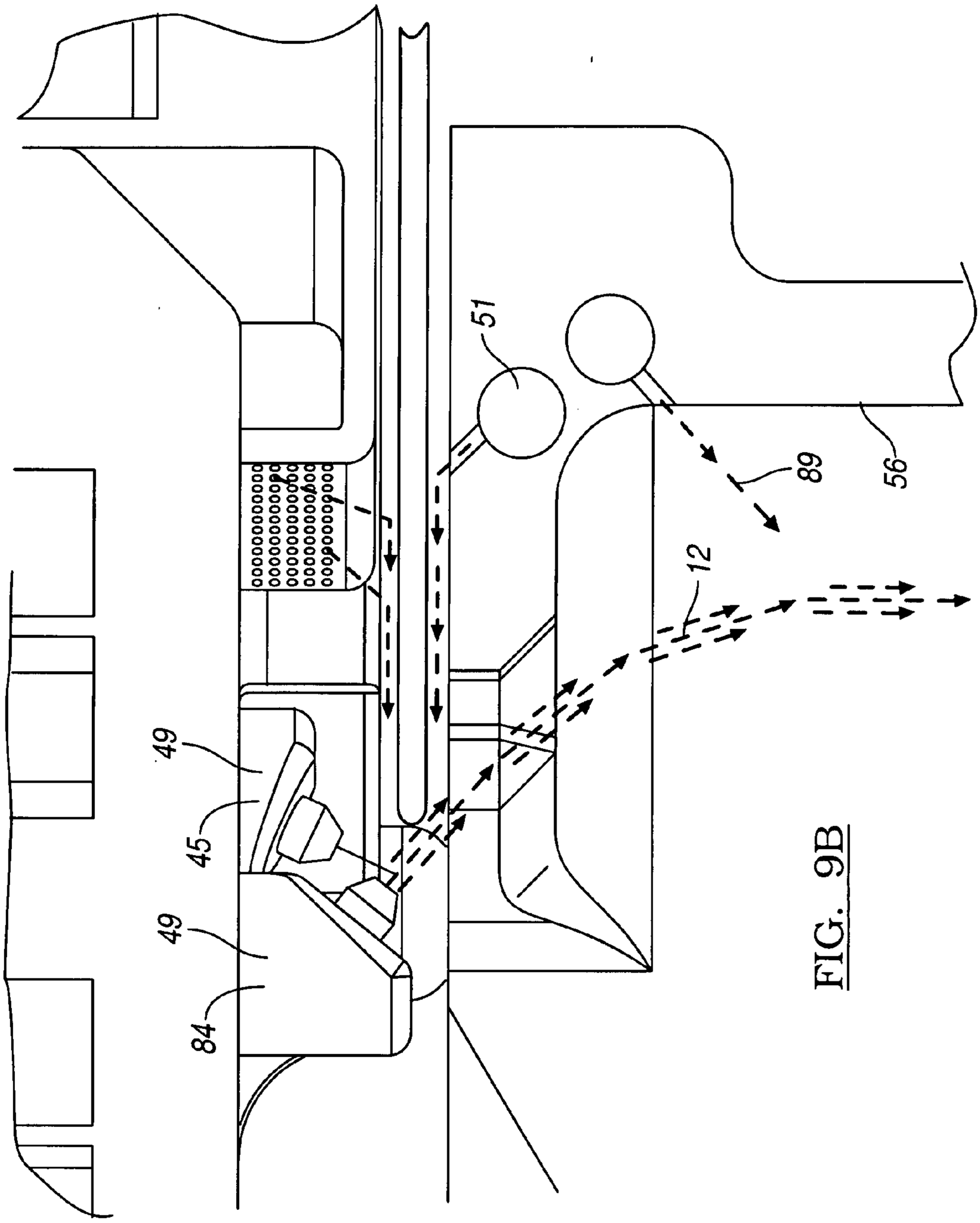

FIG. 9B

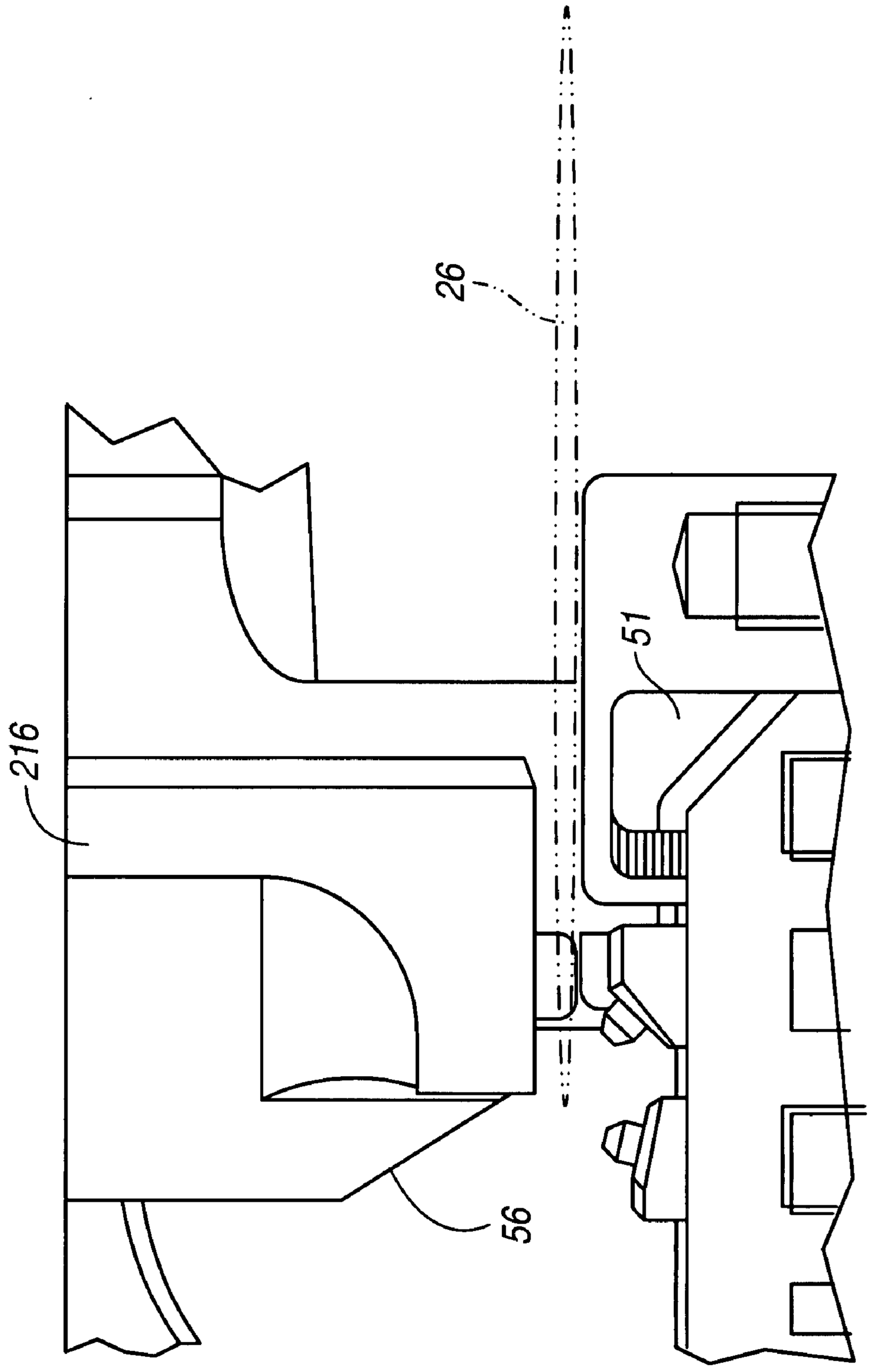

FIG. 9C

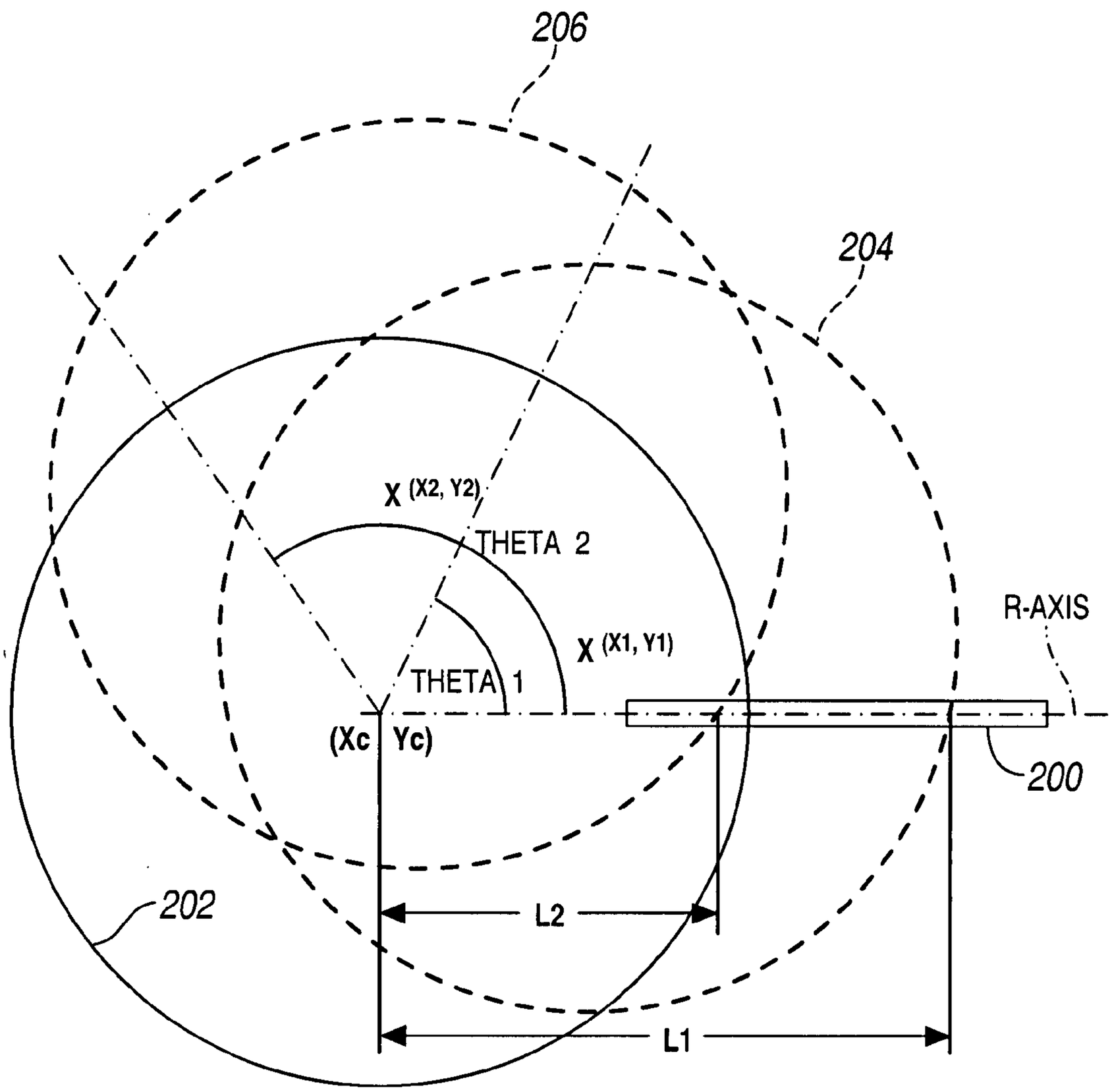

FIG. 10

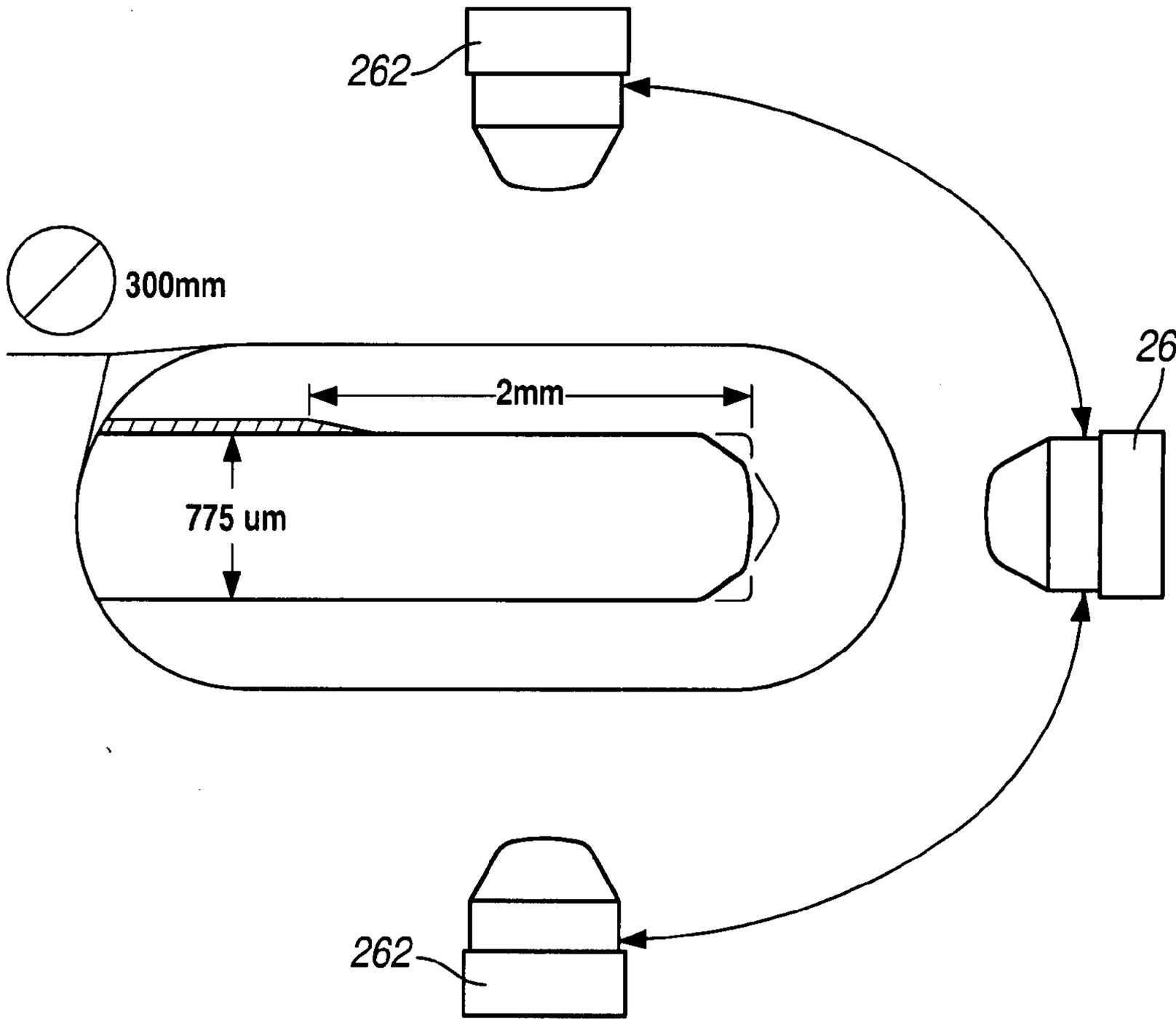

FIG. 11

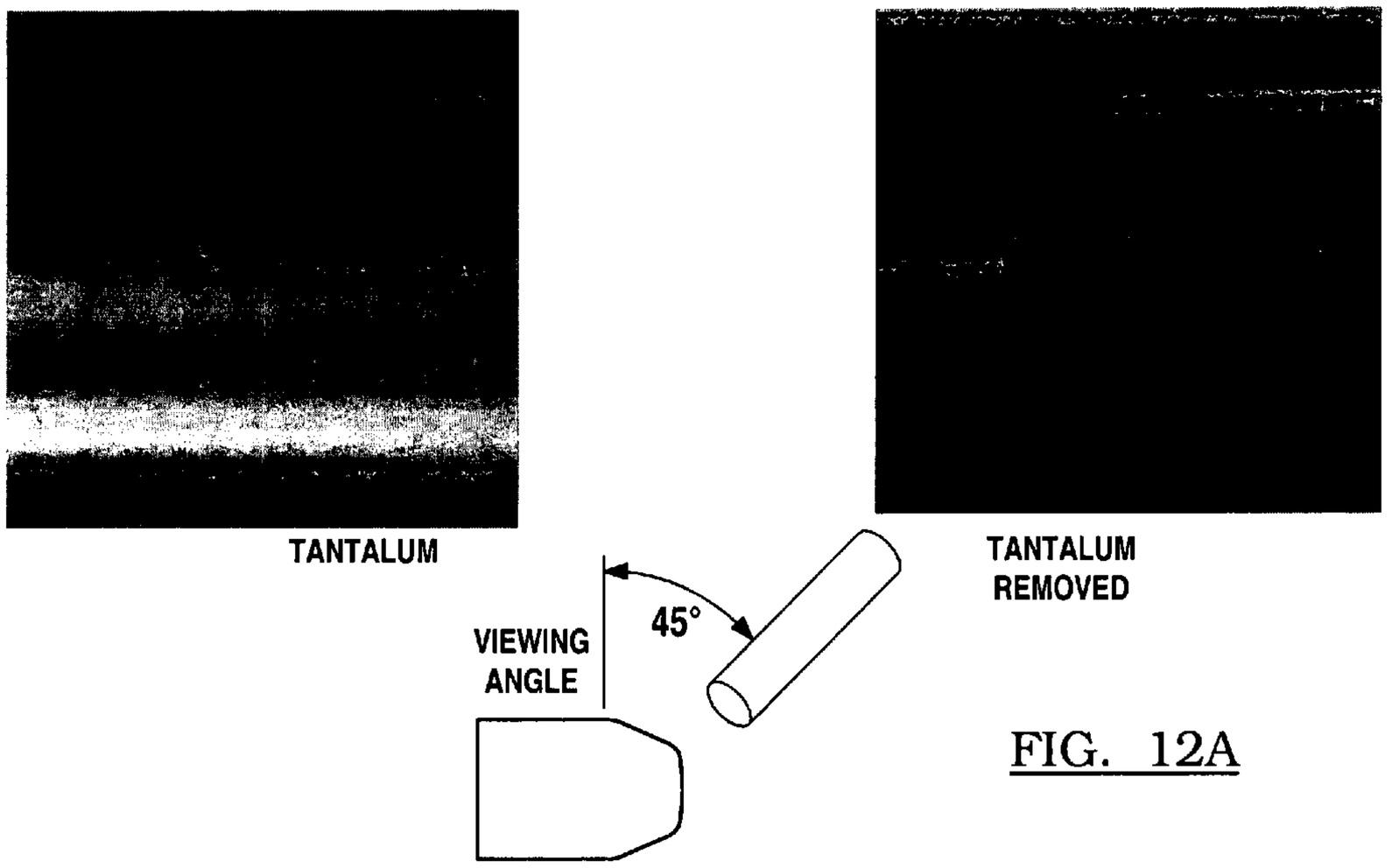

FIG. 12A

FIG. 12B

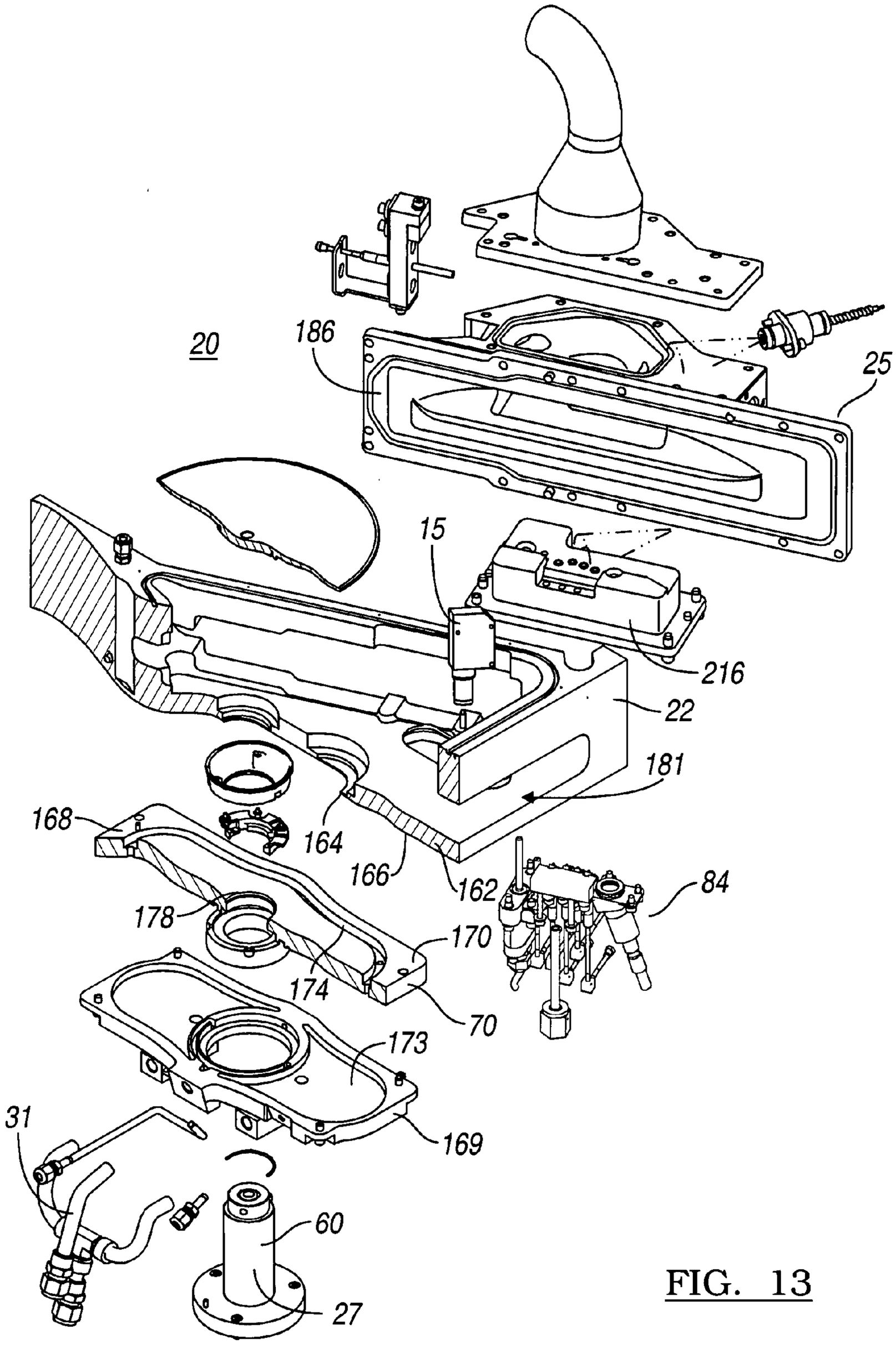
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FIG. 13

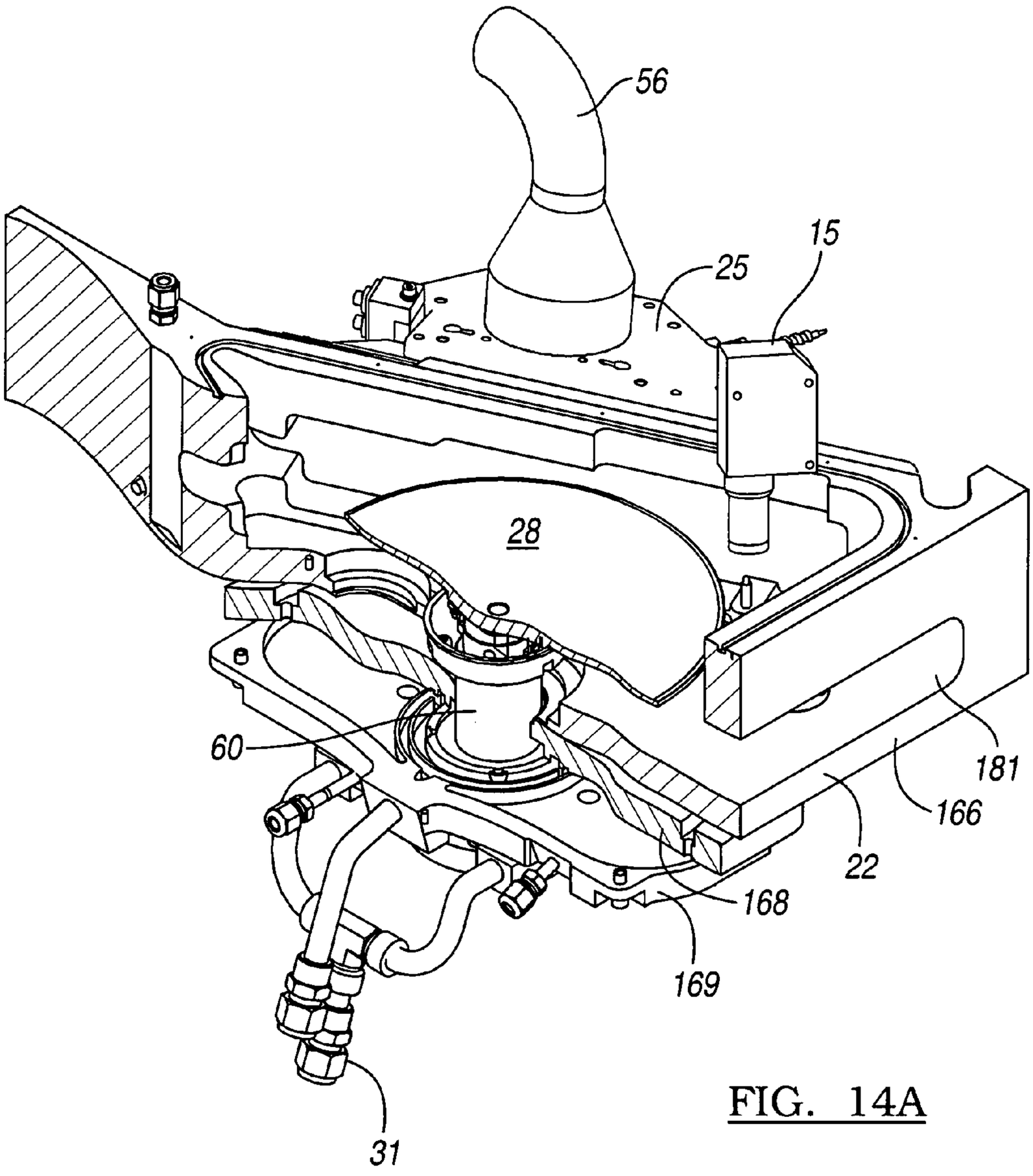


FIG. 14A

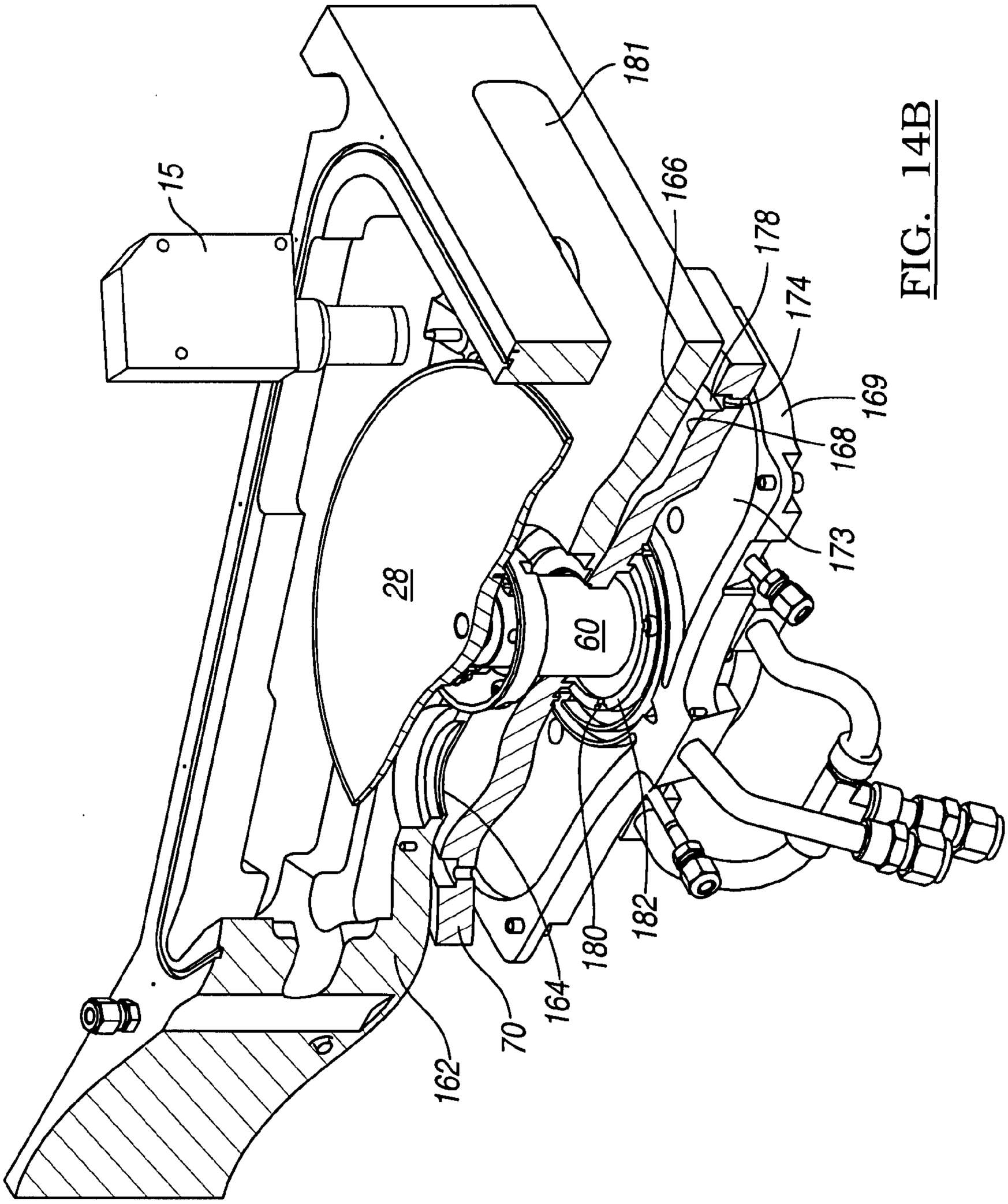
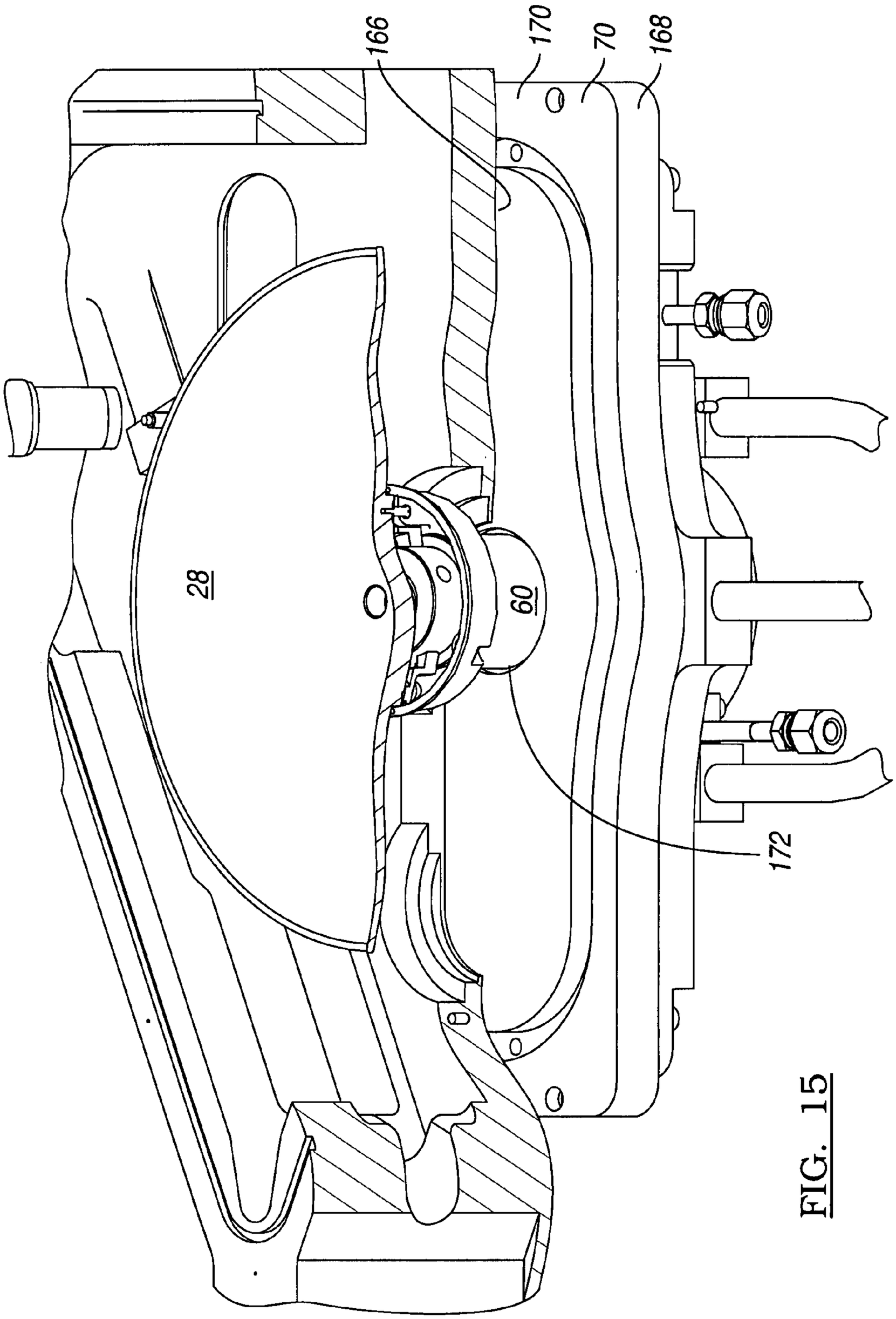


FIG. 14B



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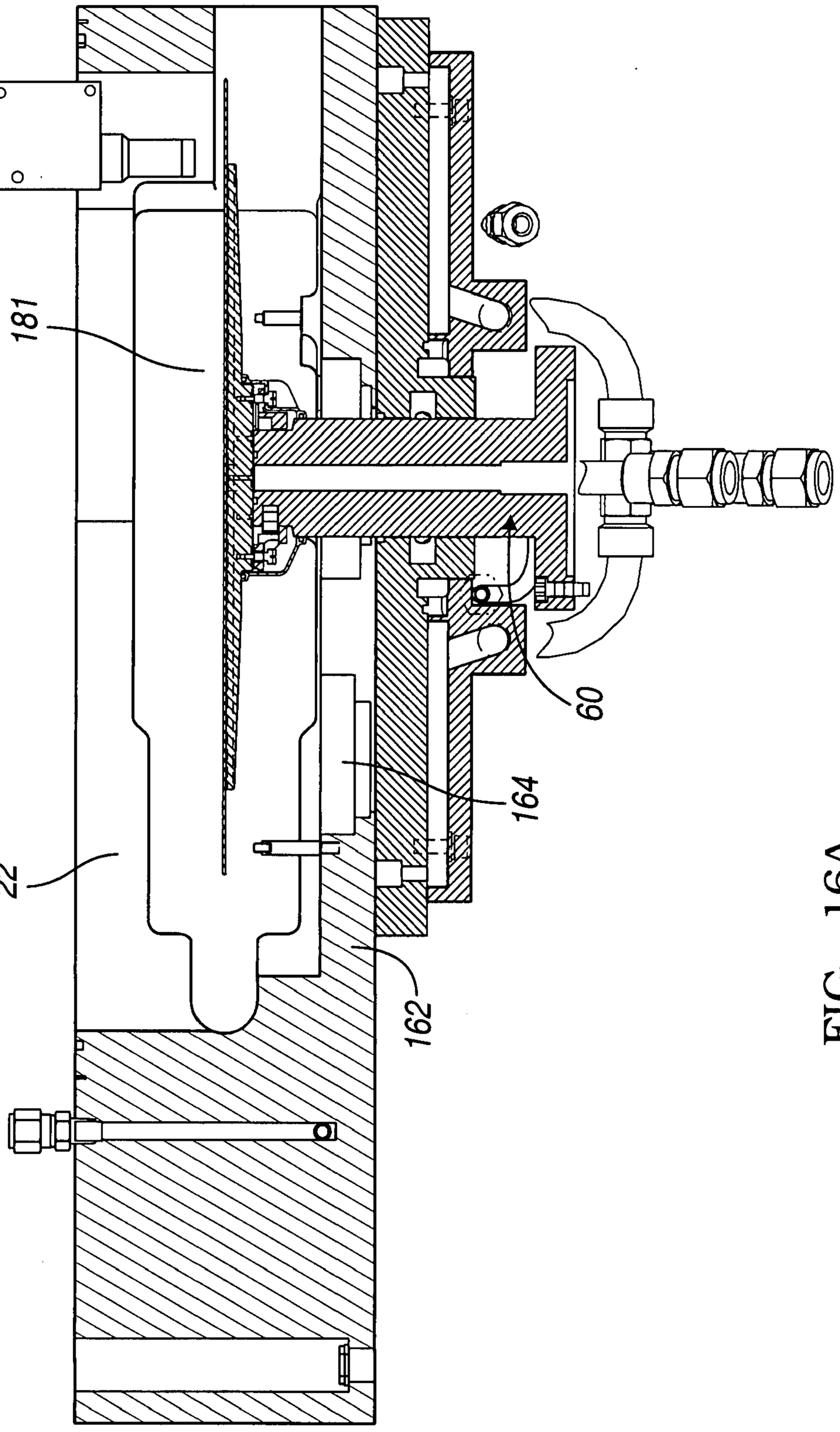


FIG. 16A

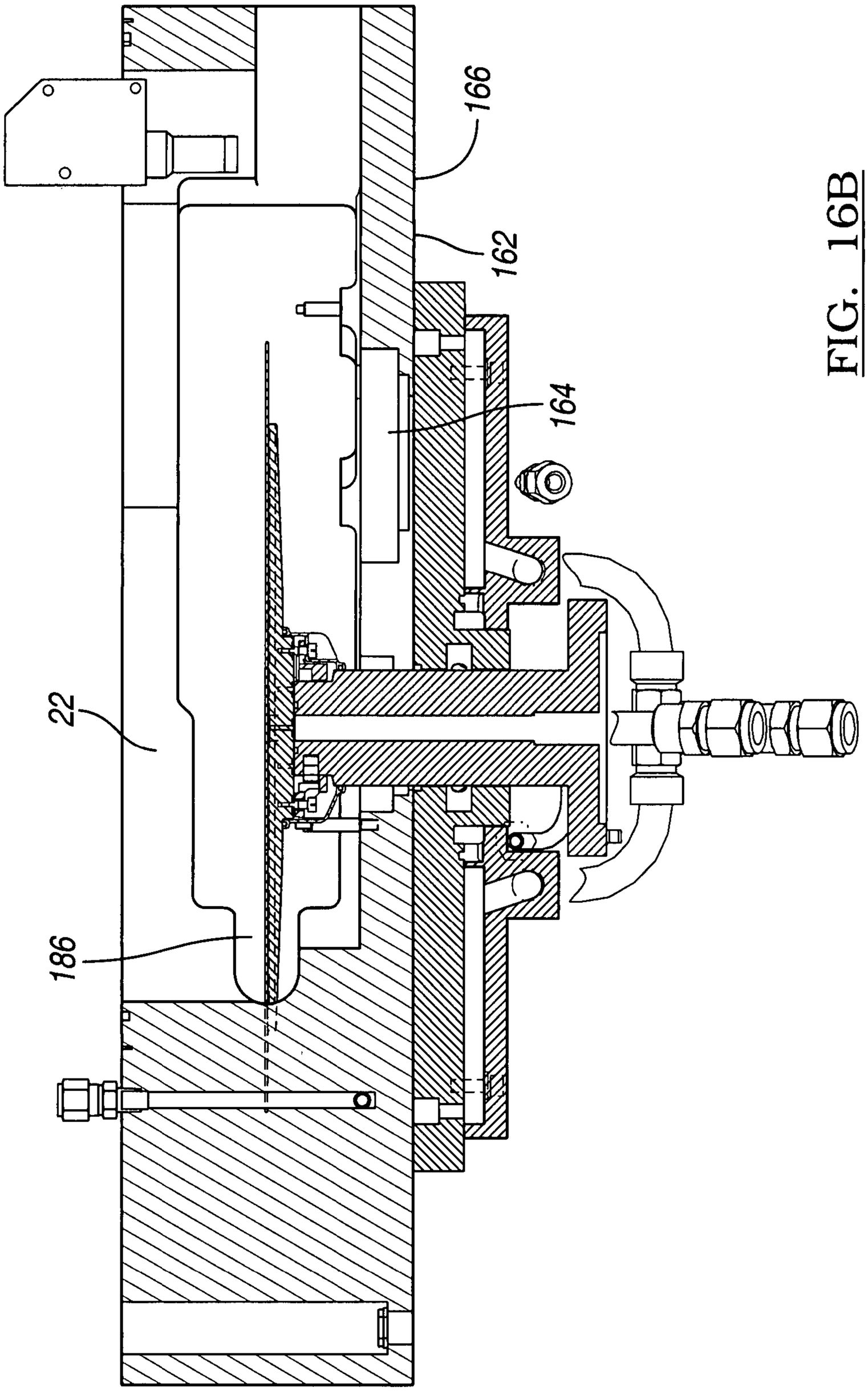


FIG. 16B

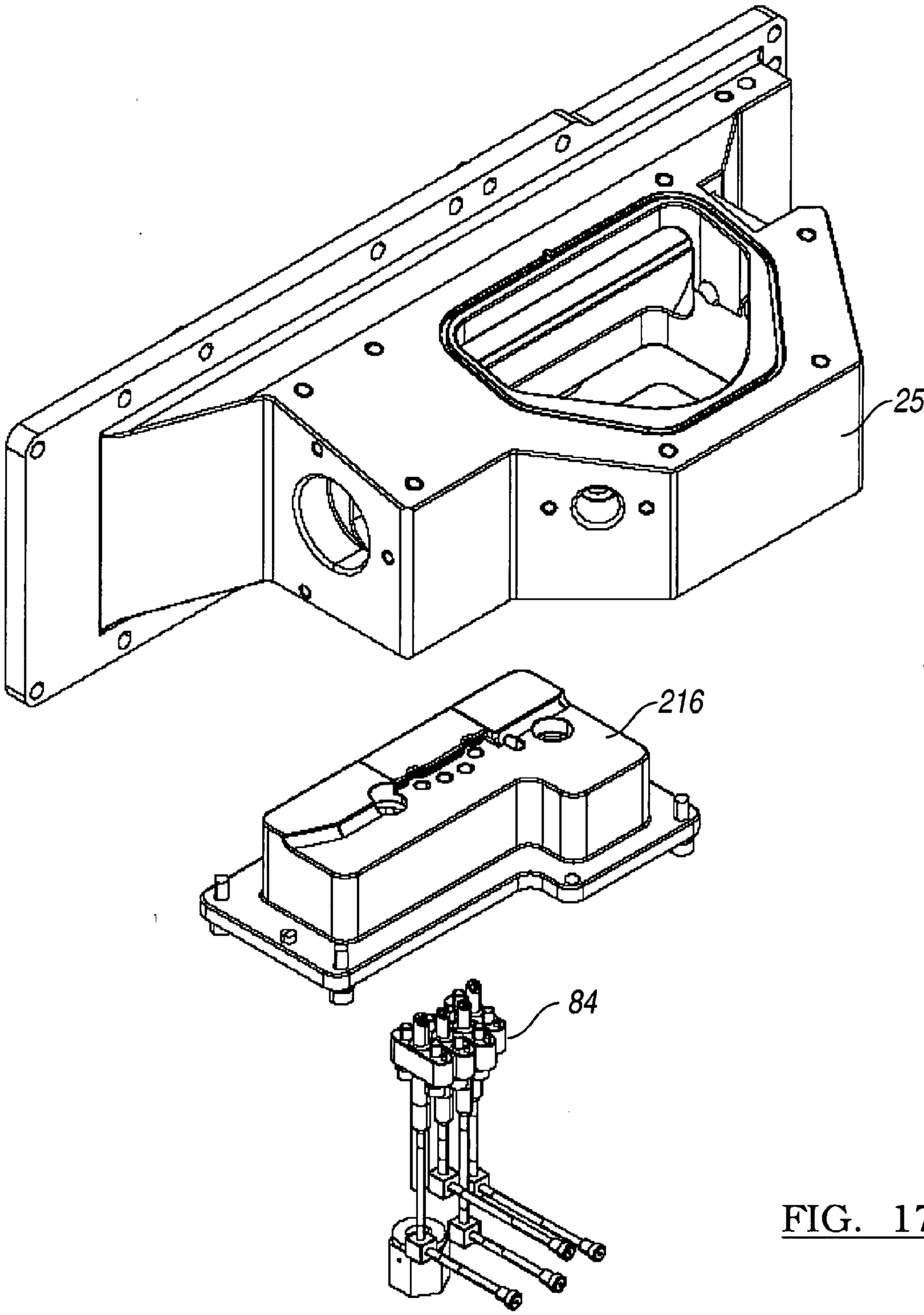


FIG. 17

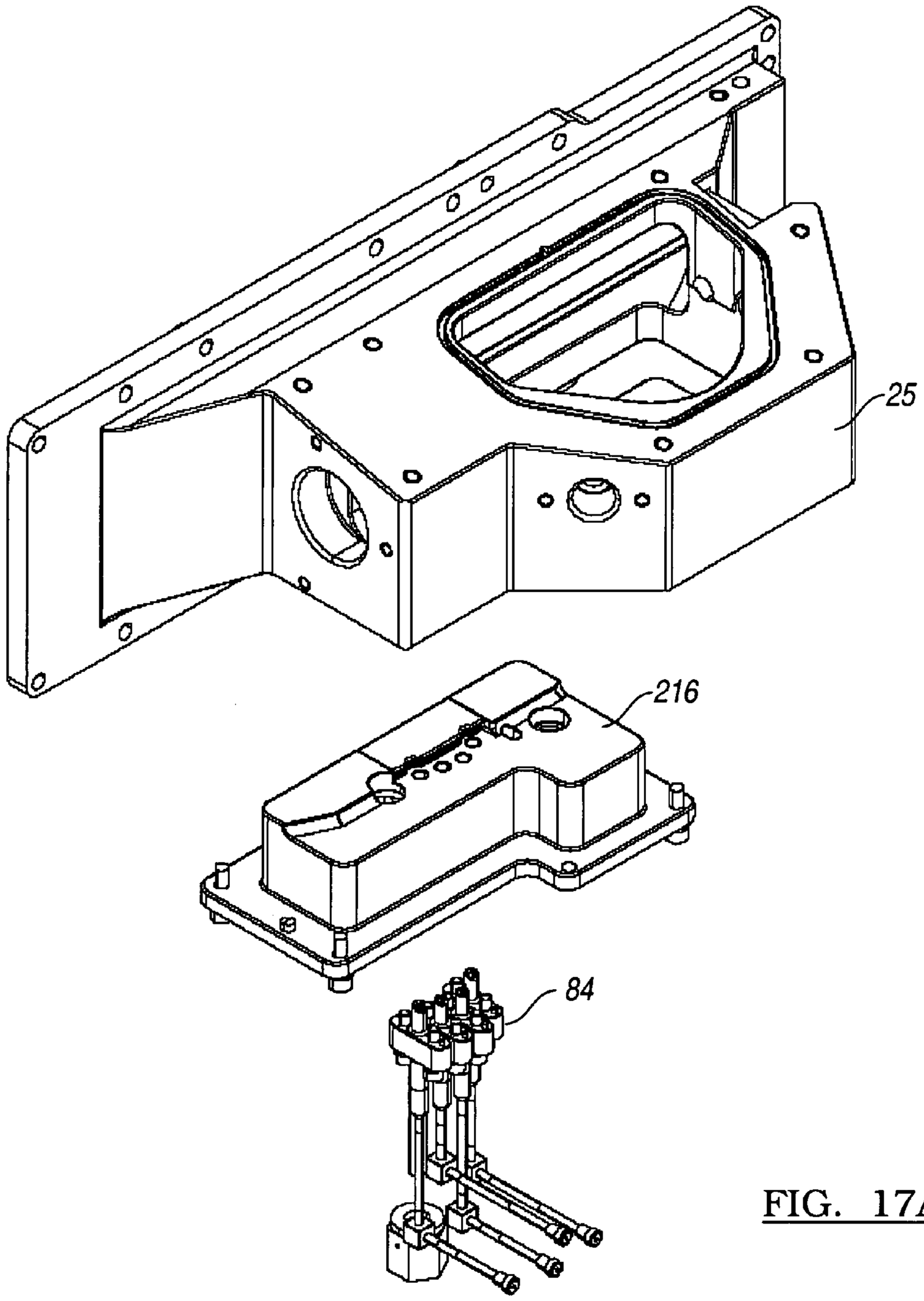


FIG. 17A

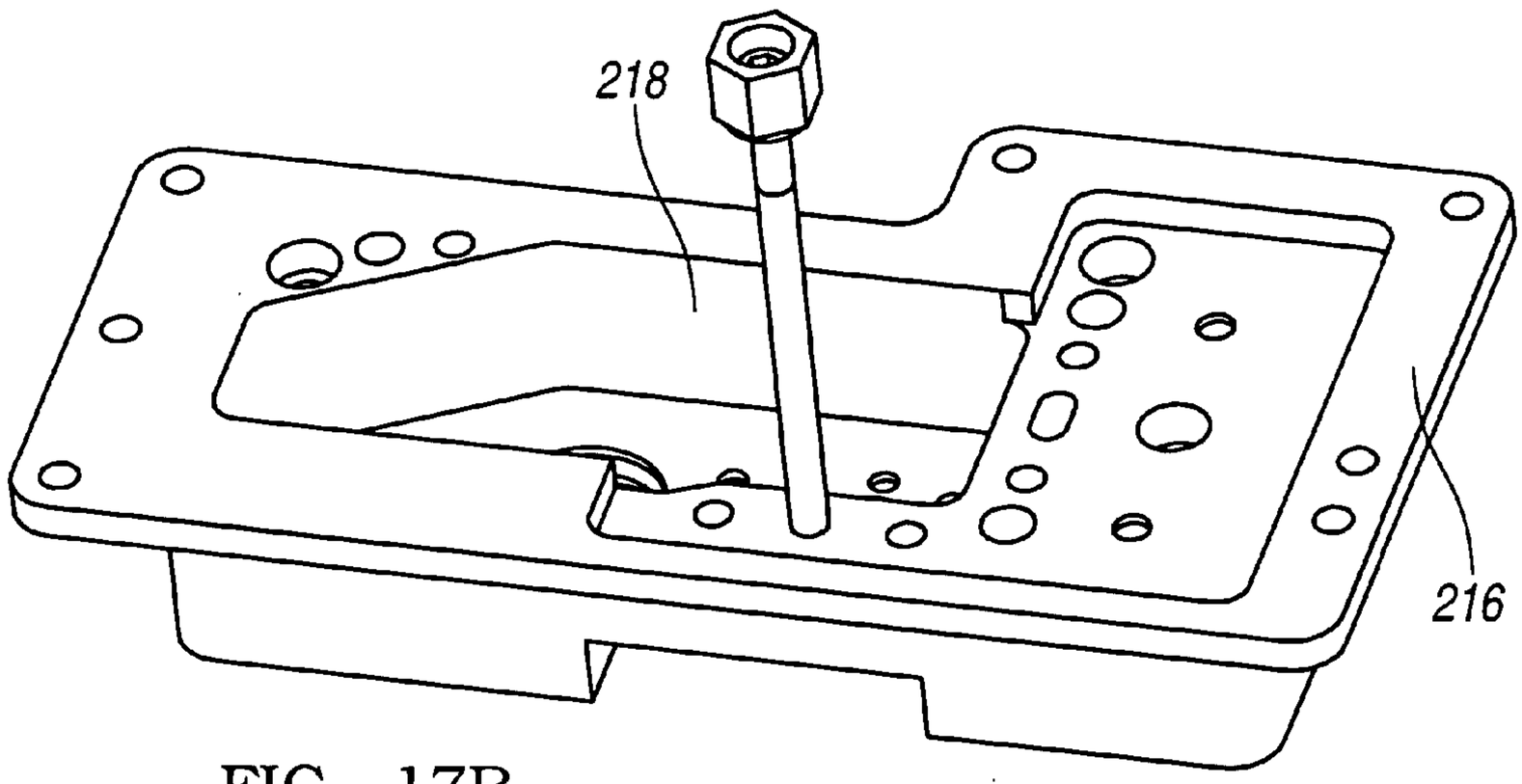


FIG. 17B

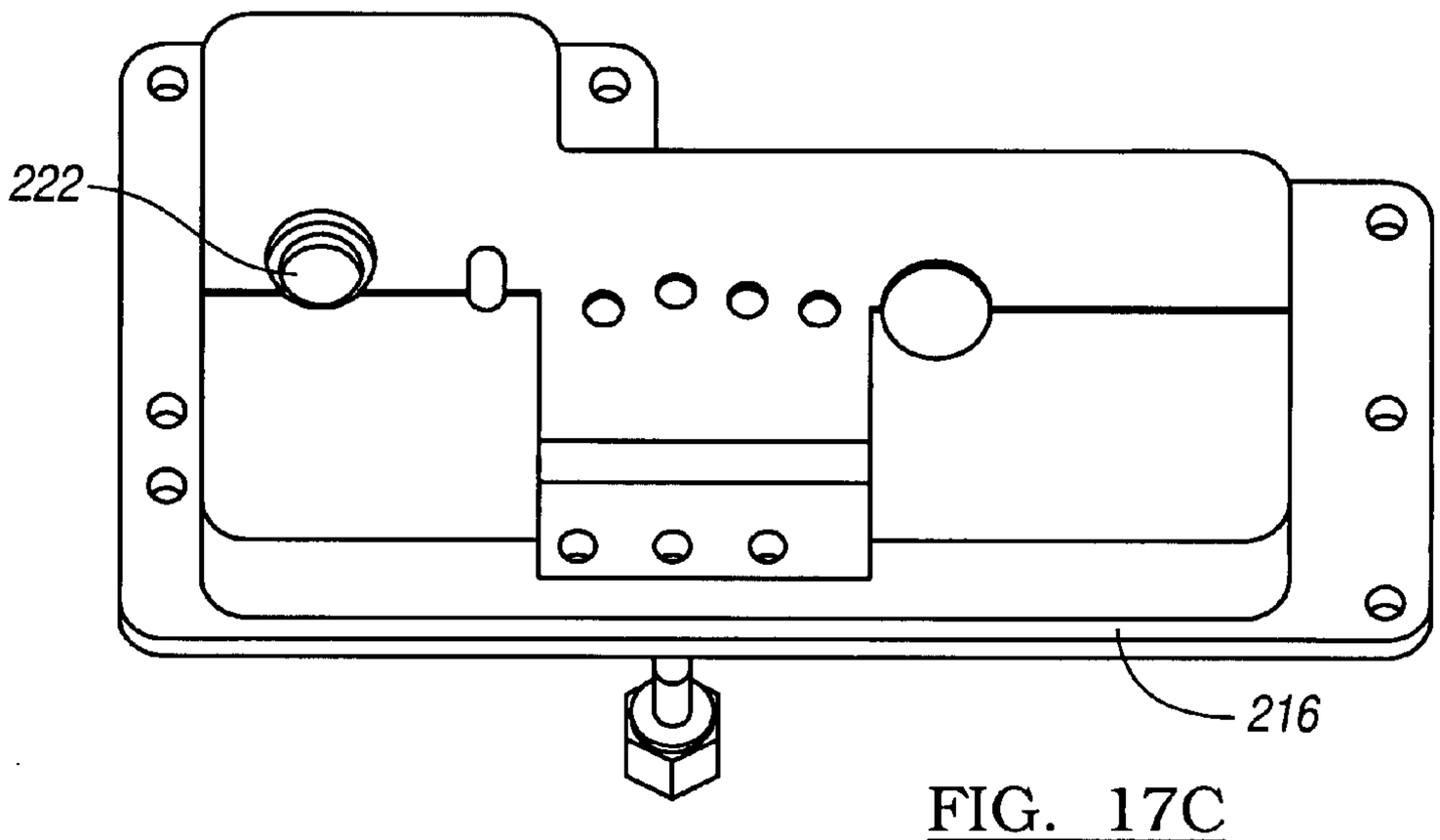


FIG. 17C

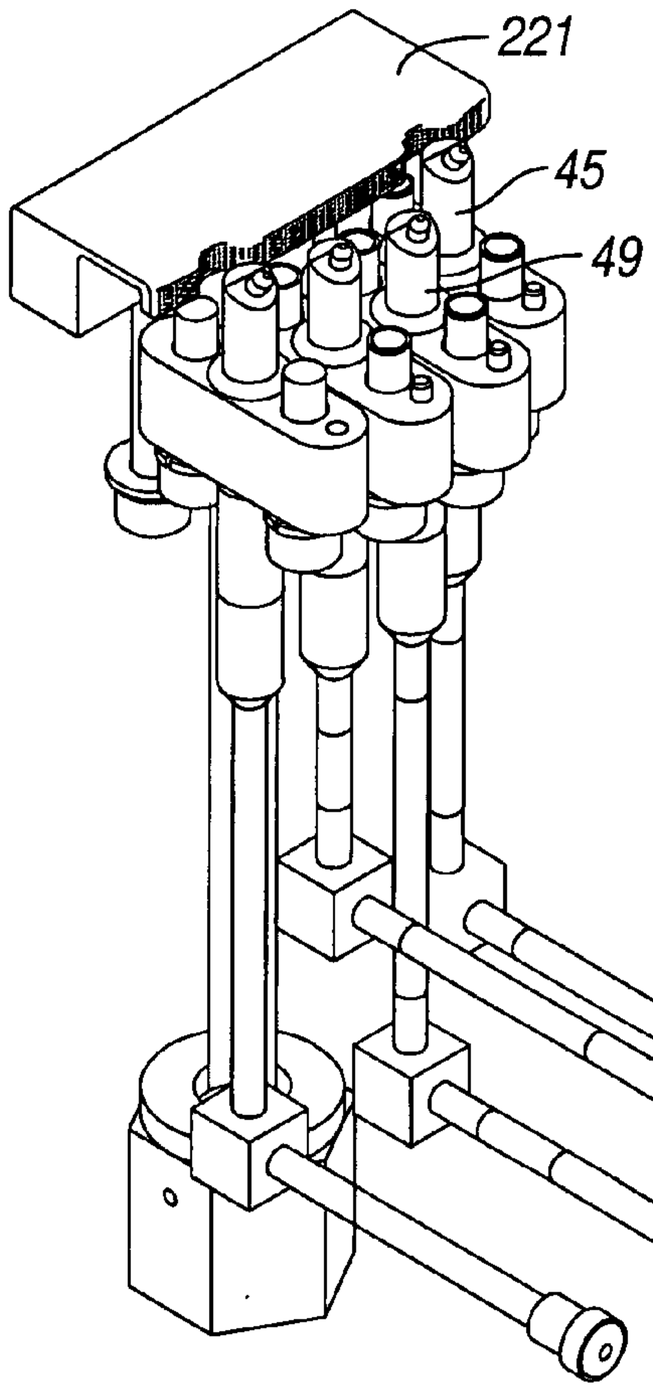


FIG. 18A

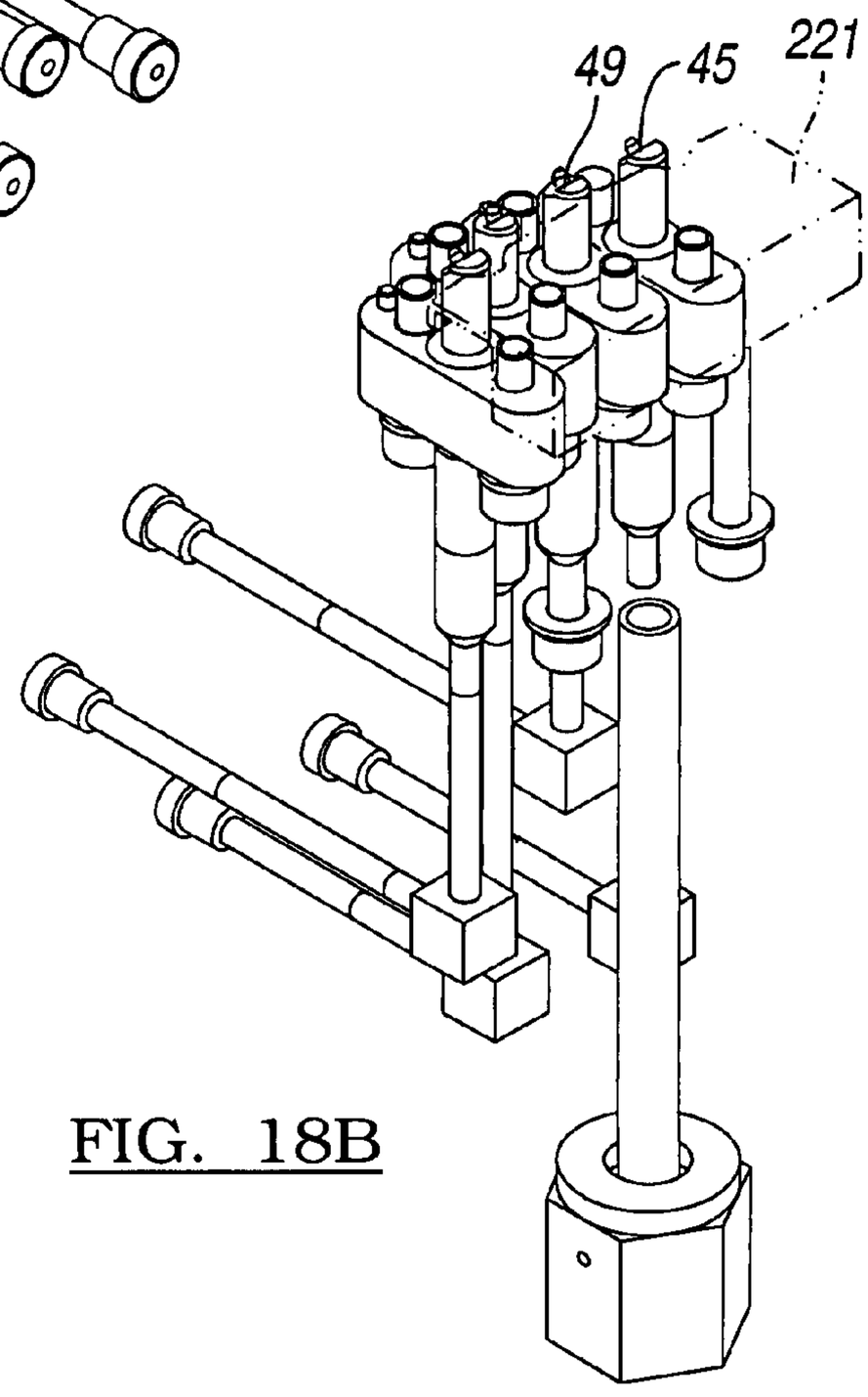


FIG. 18B

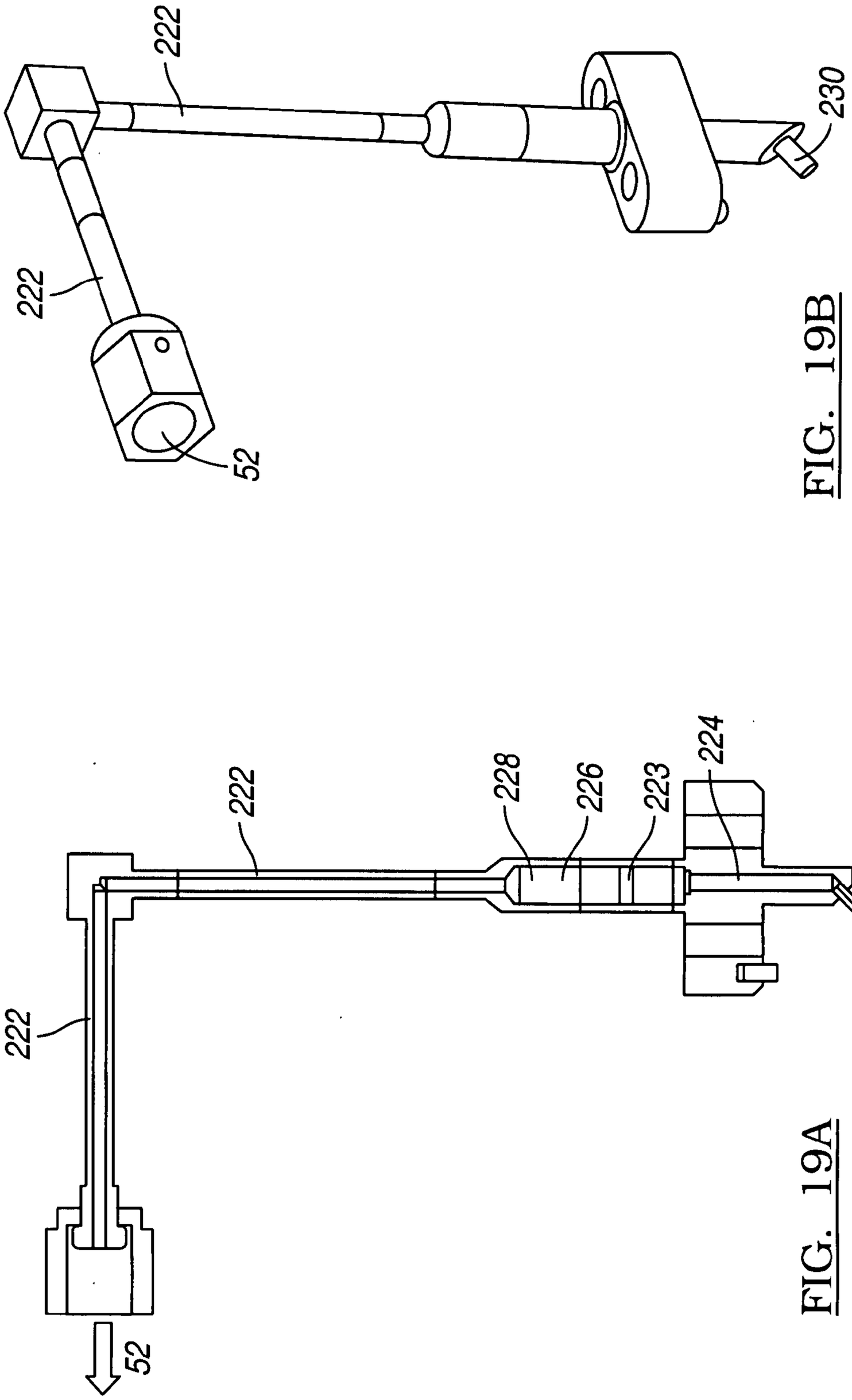


FIG. 19B

FIG. 19A

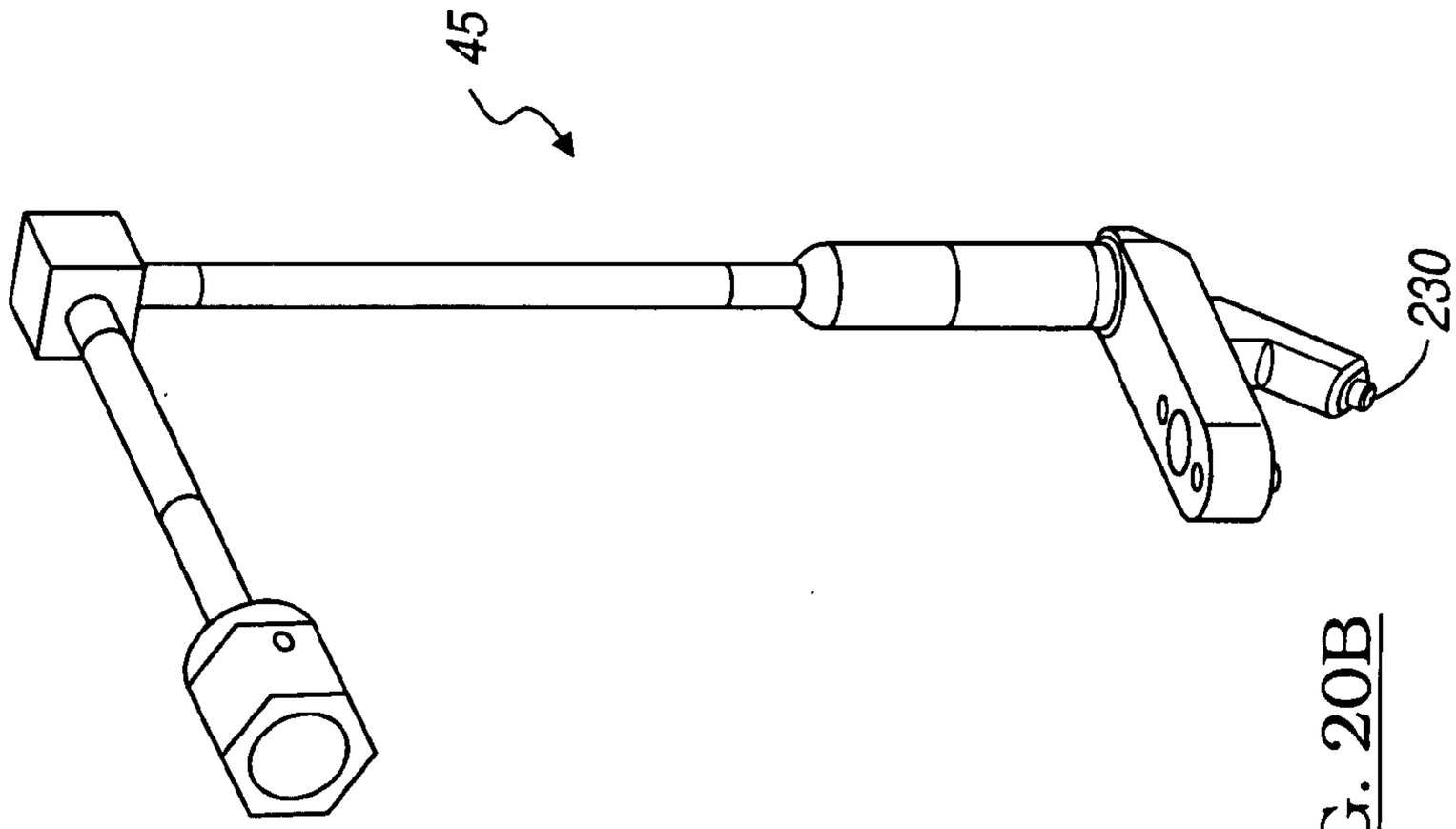


FIG. 20B

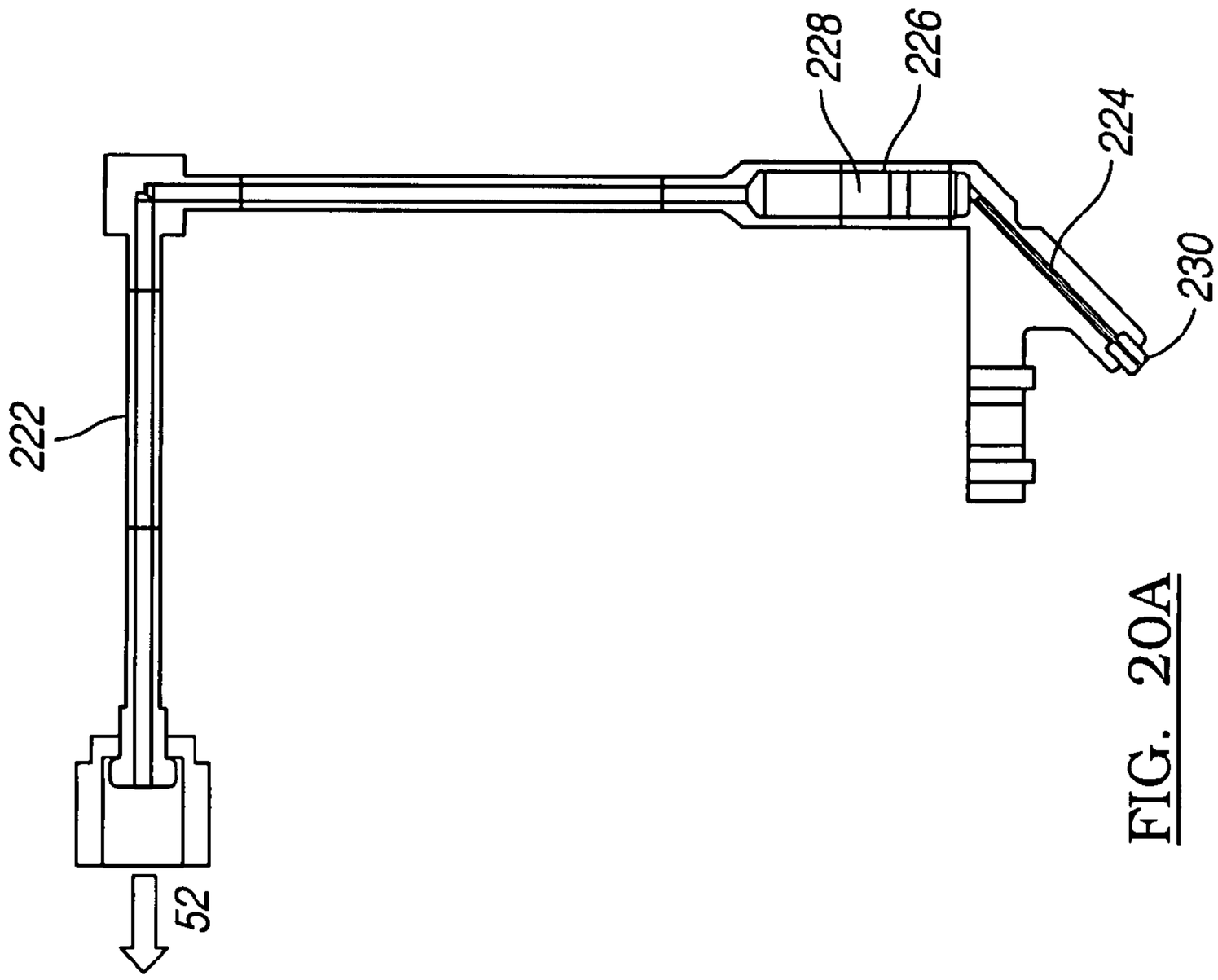


FIG. 20A

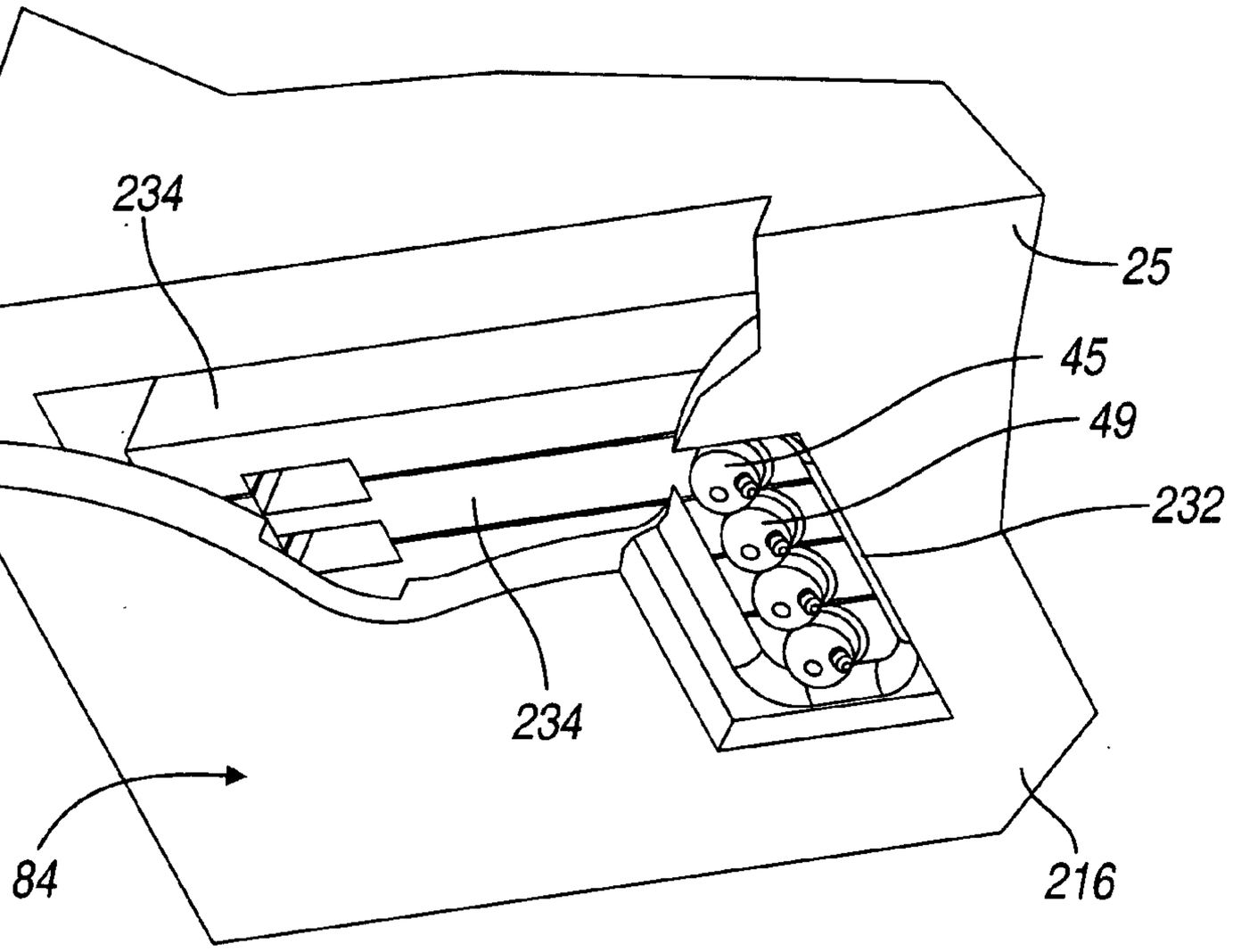


FIG. 21A

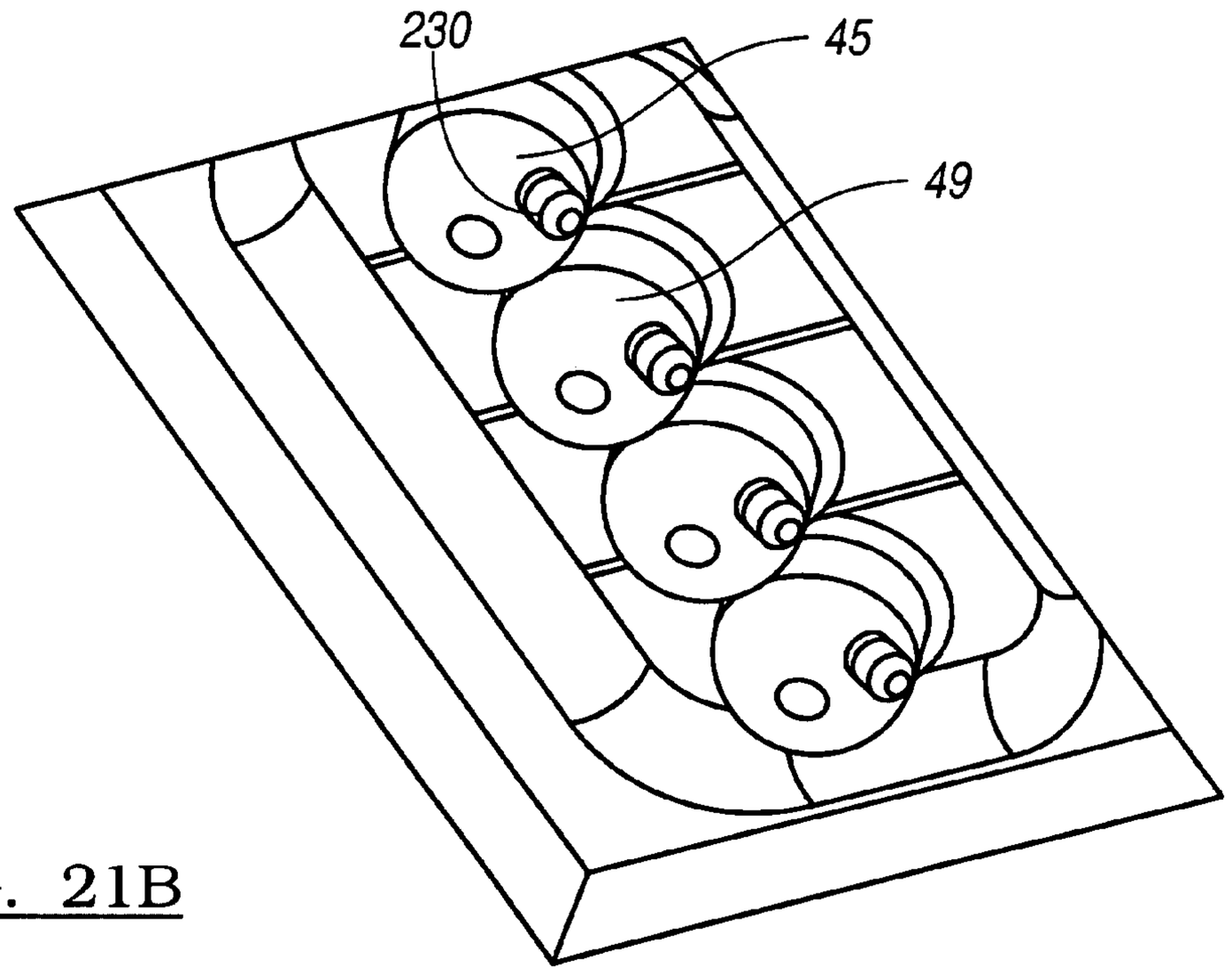


FIG. 21B

FIG. 22A

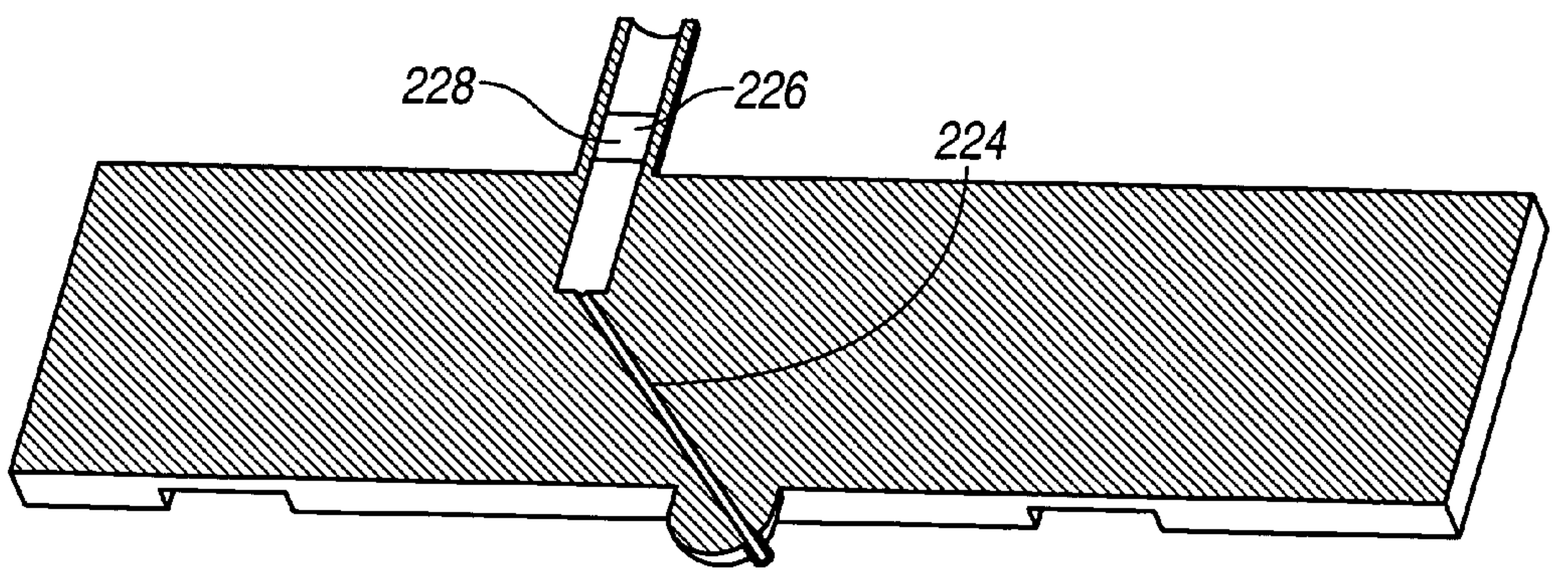


FIG. 22B

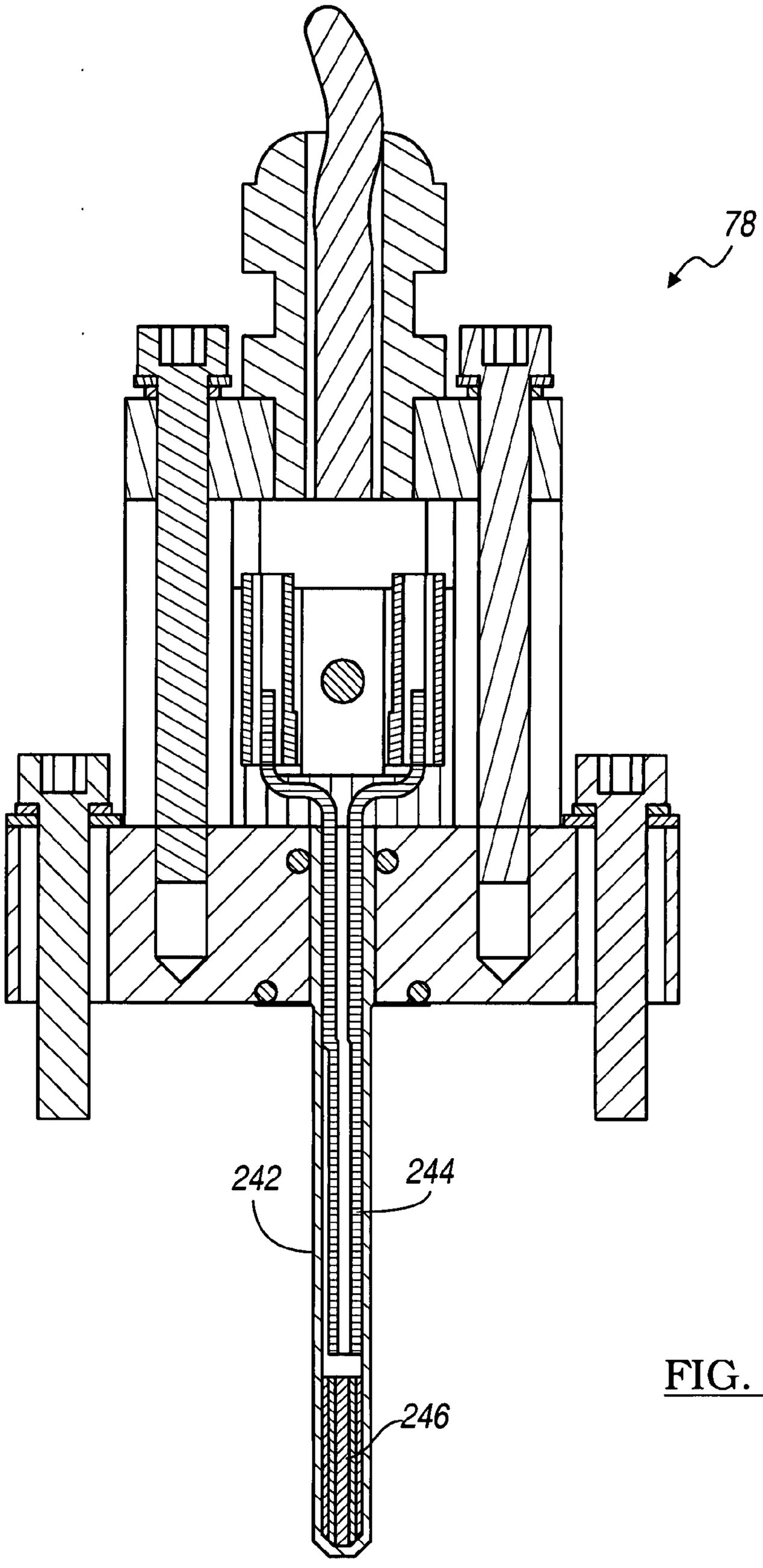


FIG. 23A

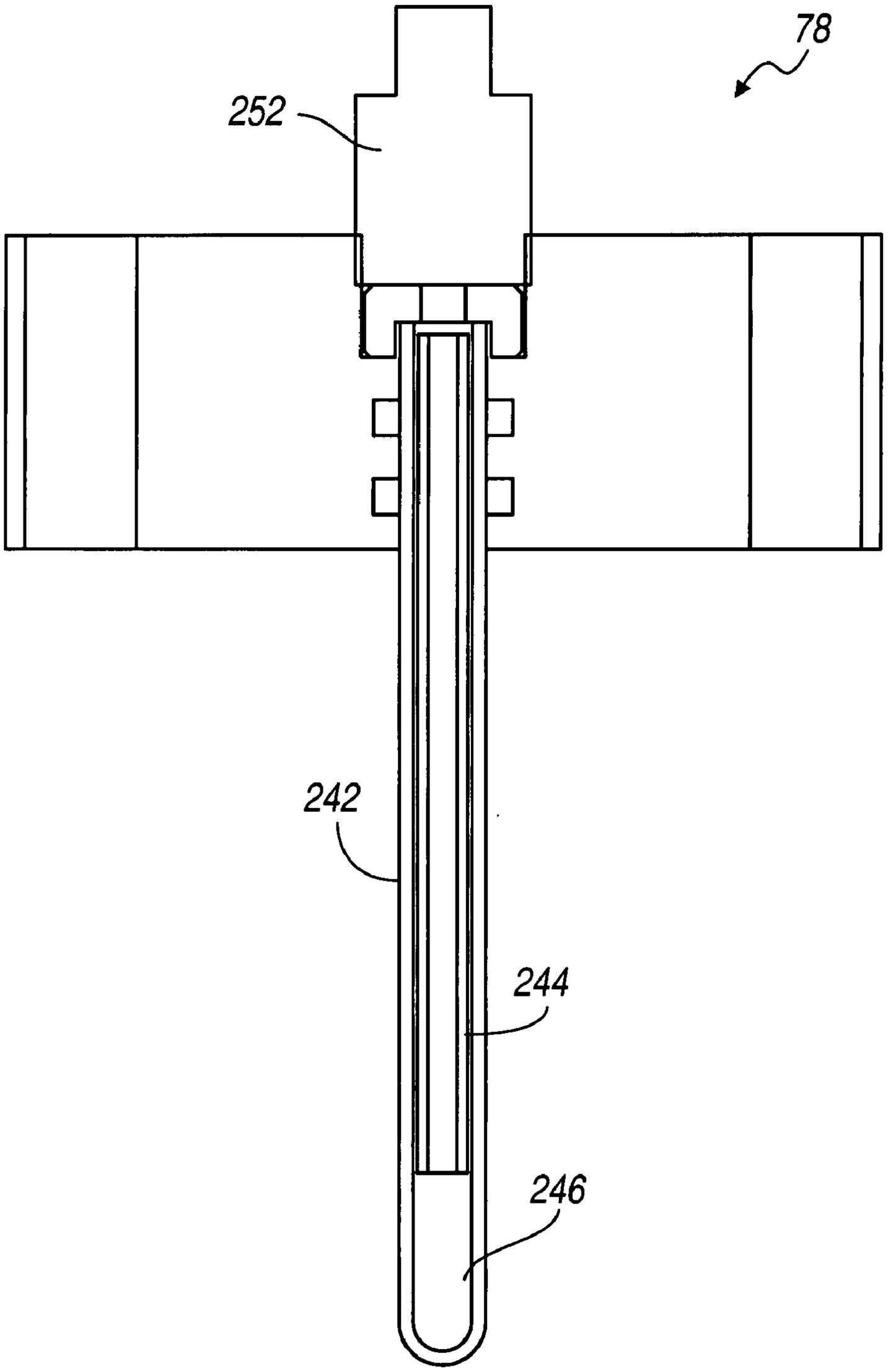


FIG. 23B

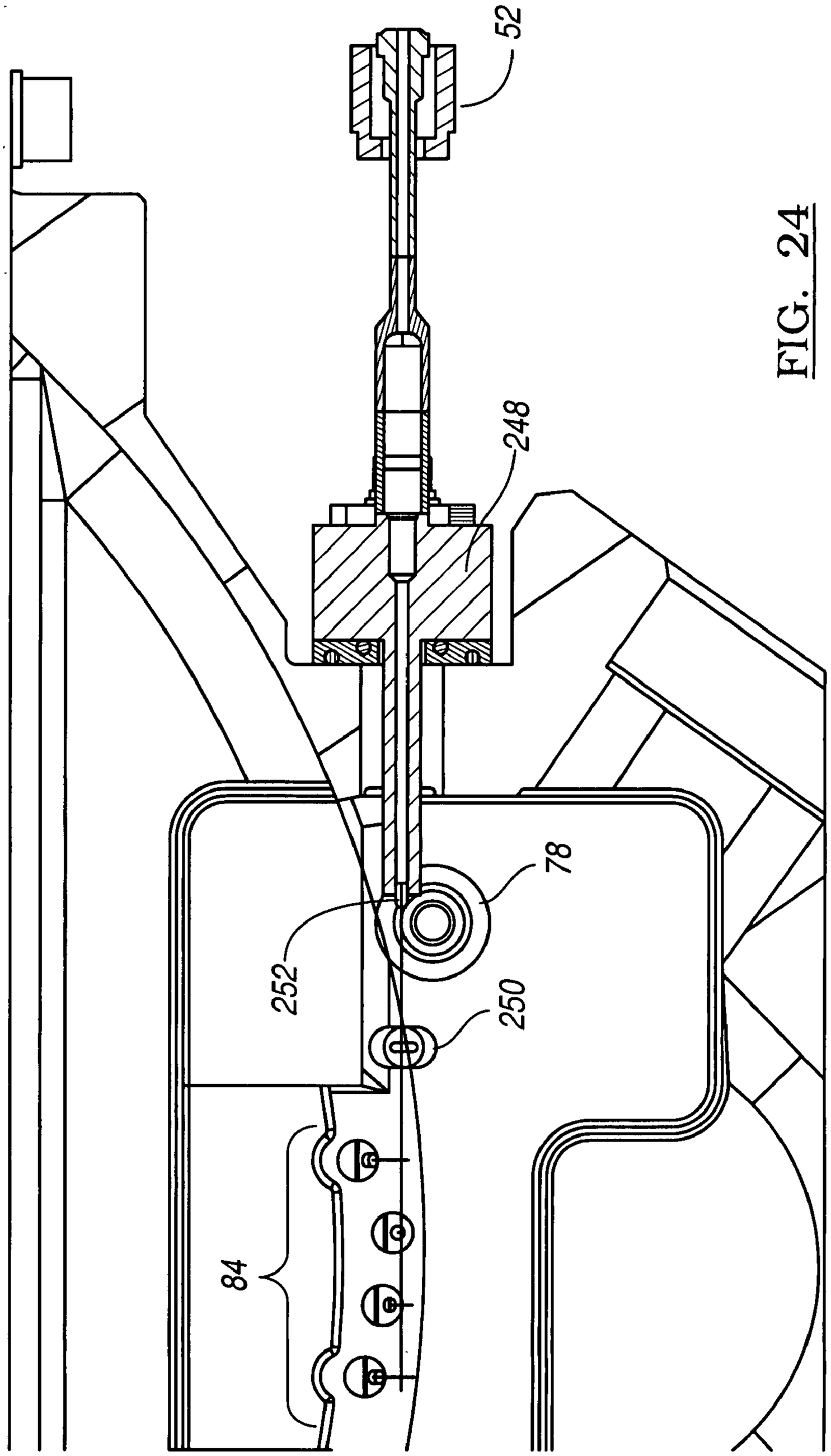


FIG. 24

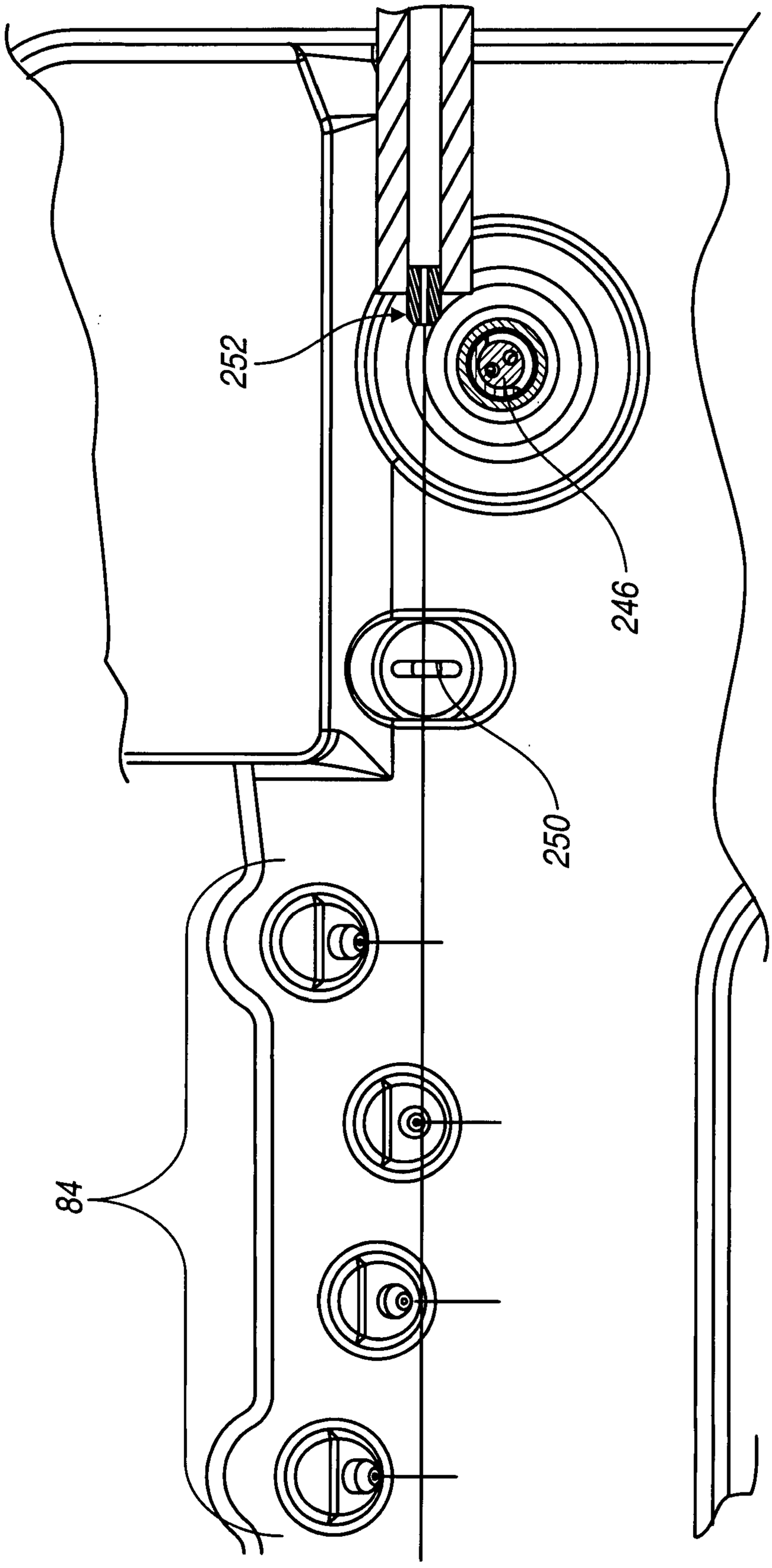


FIG. 25A

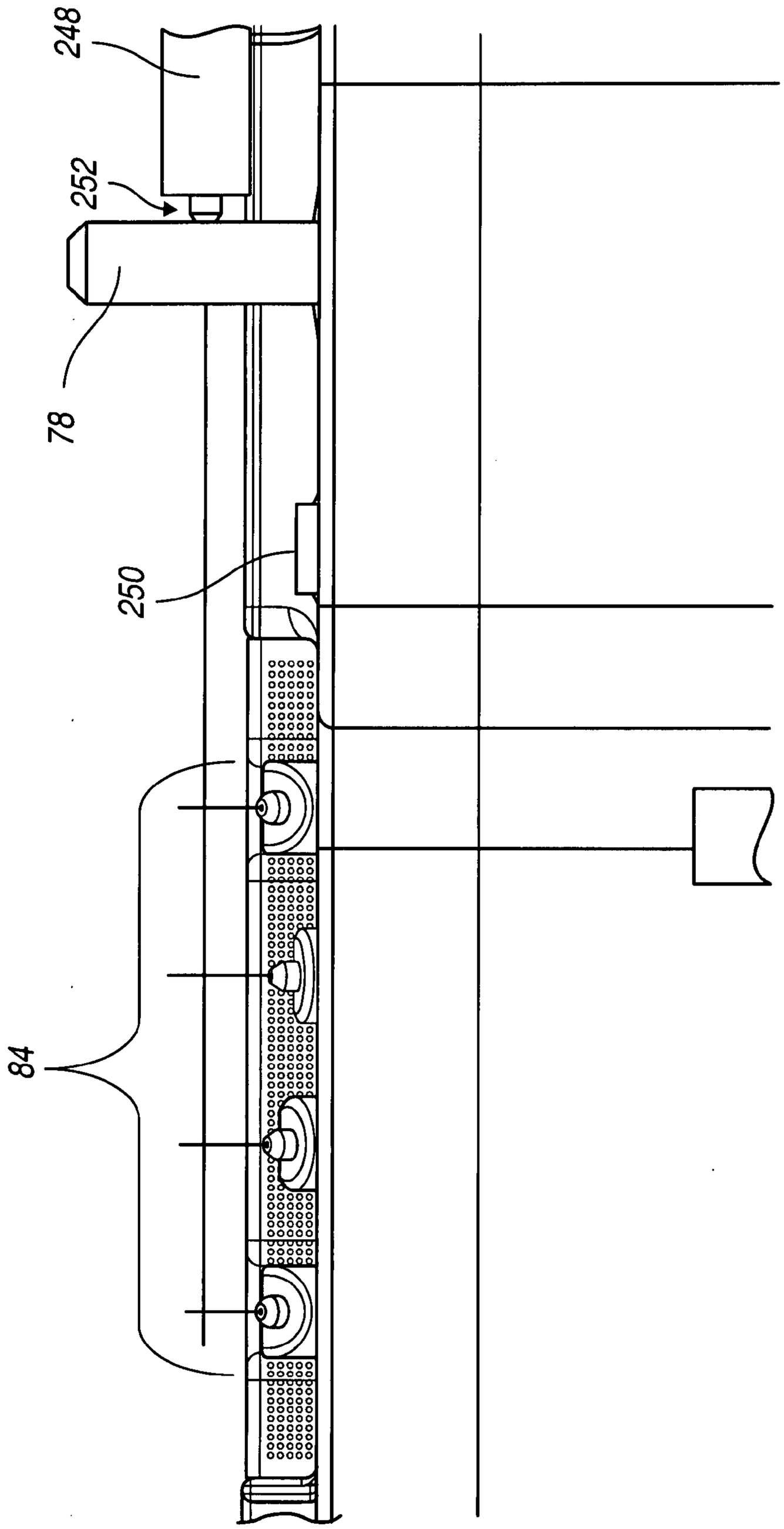
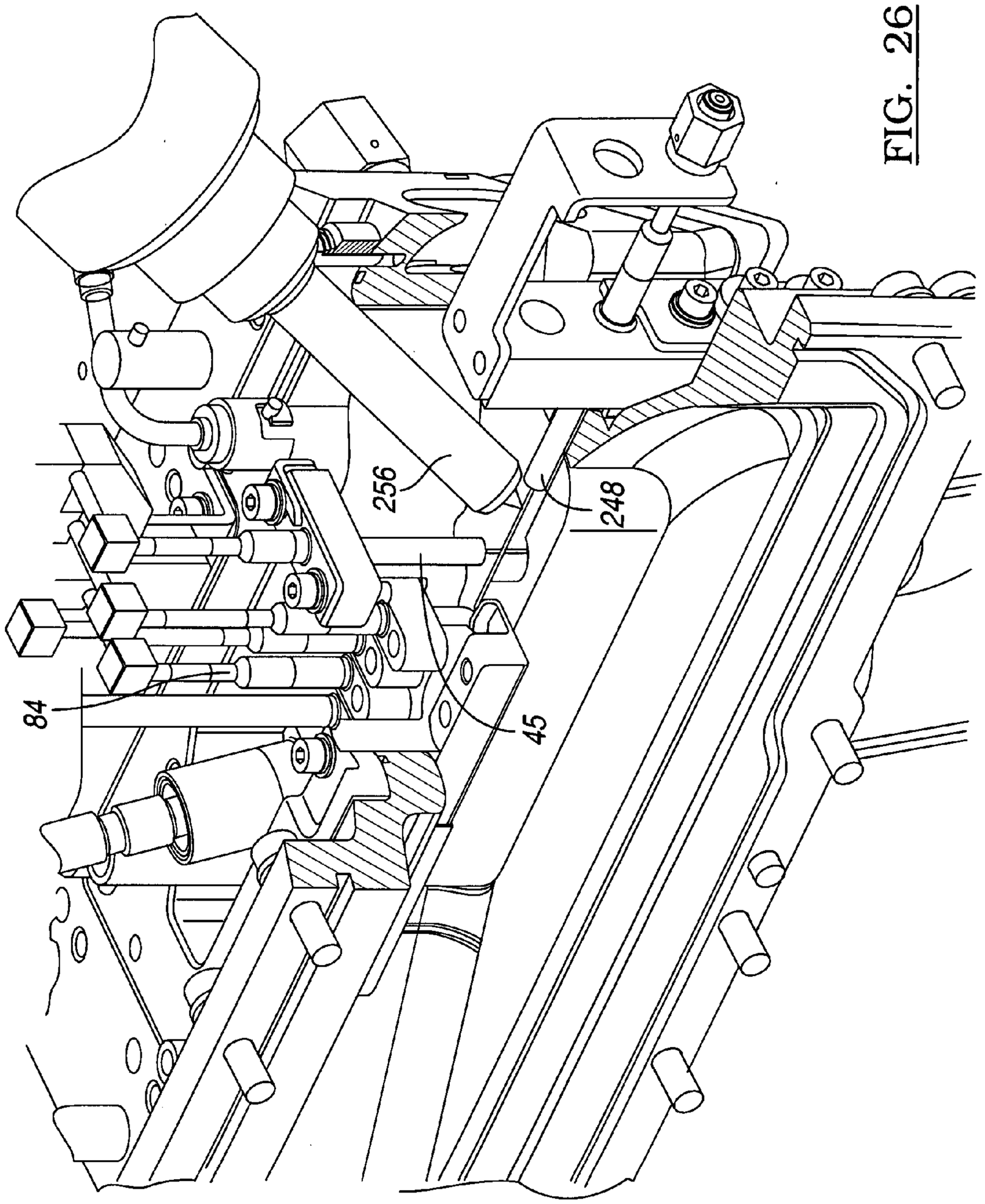


FIG. 25B

FIG. 26



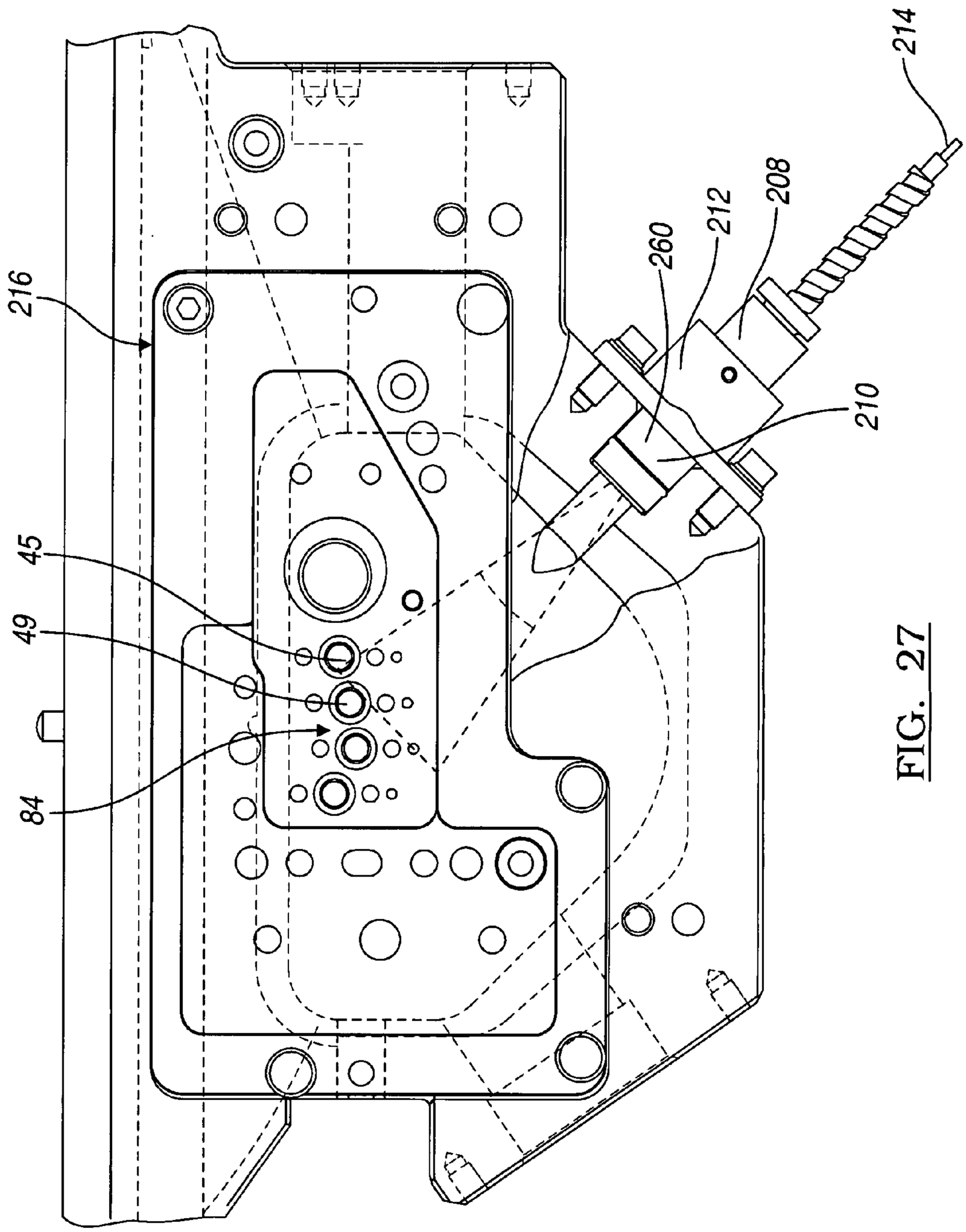


FIG. 27

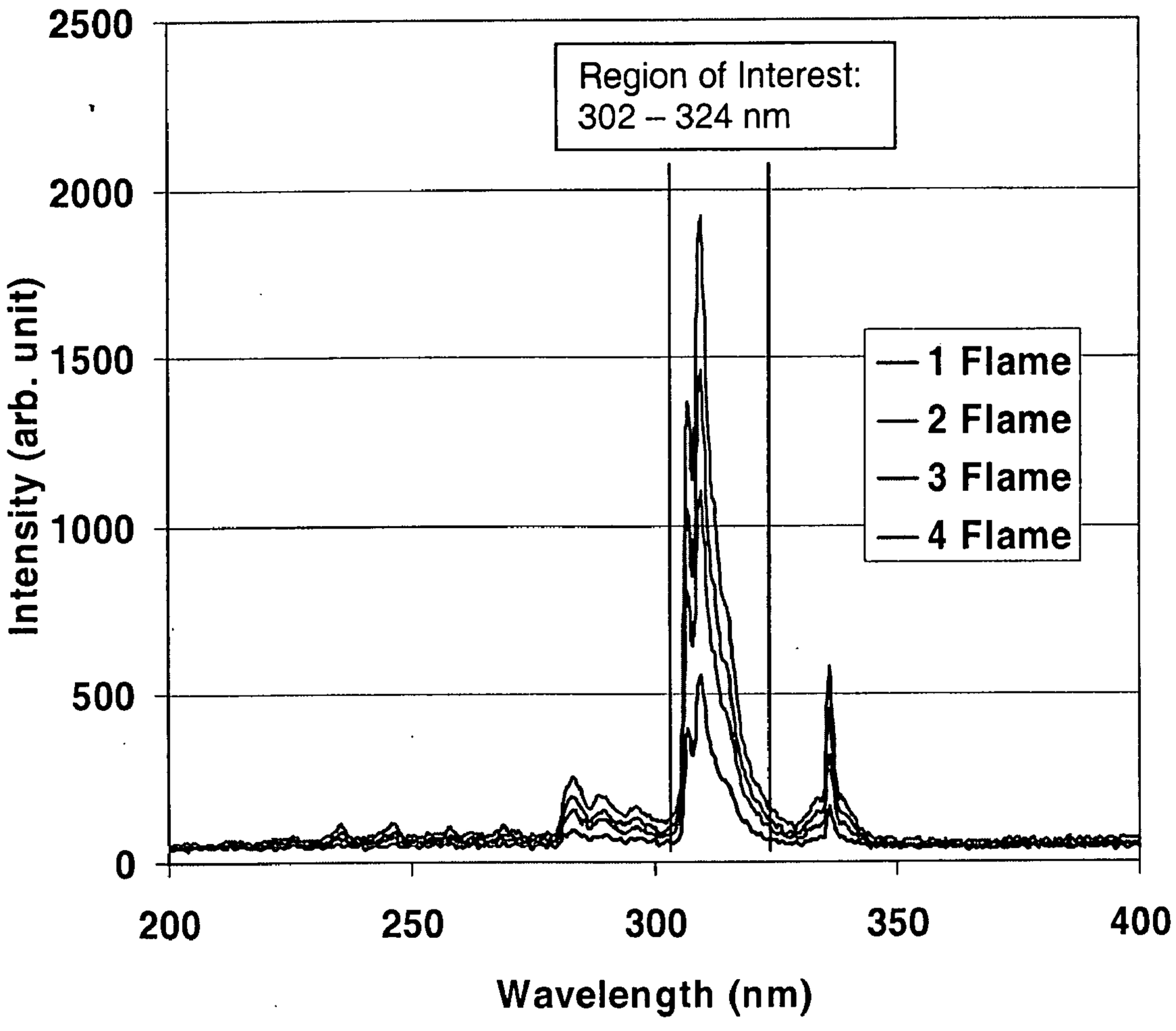

Region of Interest:
302 – 324 nm
1 Flame
2 Flame
3 Flame
4 Flame
Intensity (arb. unit)
2500
2000
1500
1000
500
0
200
250
300
350
400
Wavelength (nm)

FIG. 28

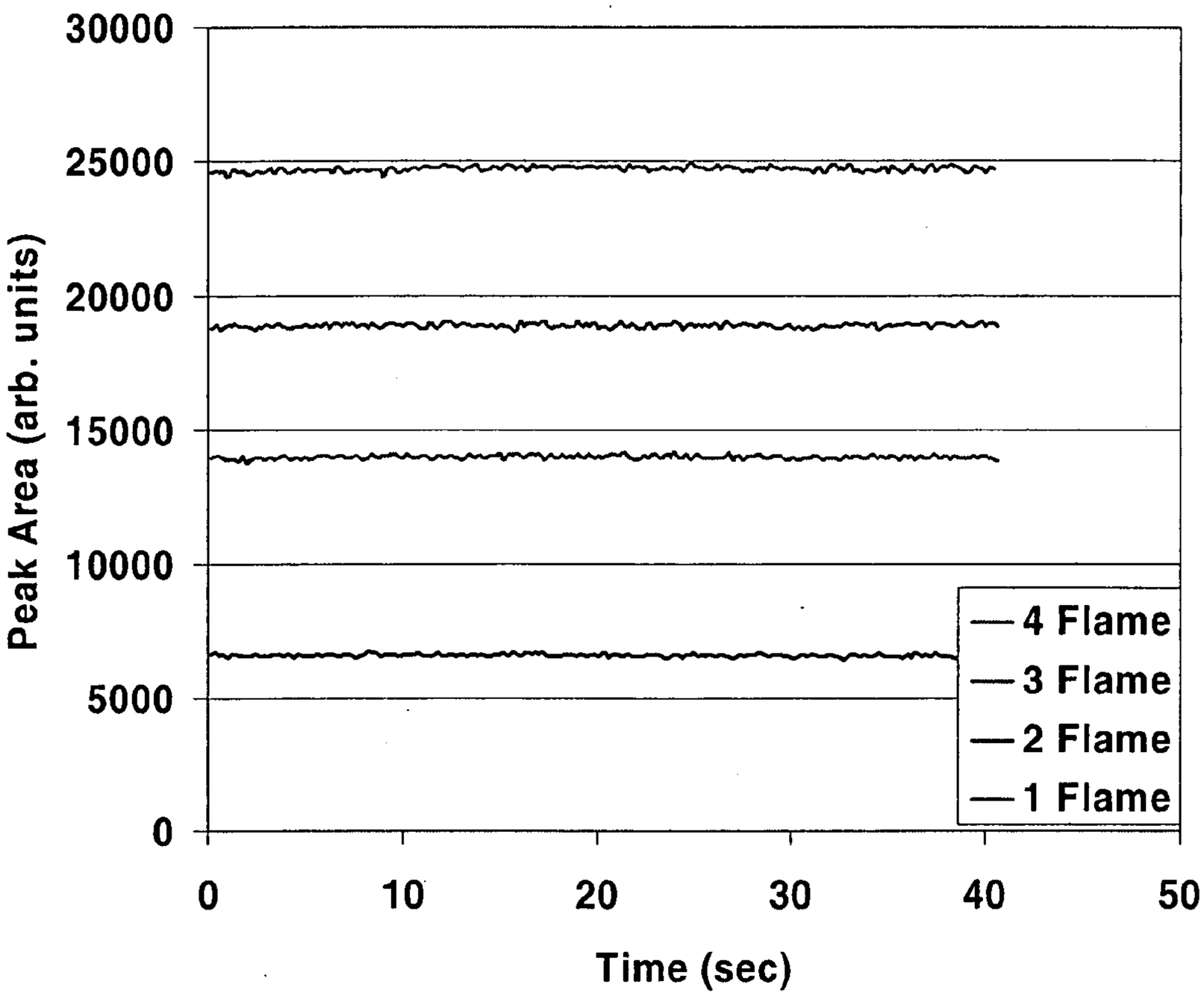

30000
25000
20000
15000
10000
5000
0
Peak Area (arb. units)
0
10
20
30
40
50
Time (sec)
4 Flame
3 Flame
2 Flame
1 Flame

FIG. 29

CLEAN IGNITION SYSTEM FOR WAFER SUBSTRATE PROCESSING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/819,521, filed on Jul. 7, 2006. This application is a continuation-in-part of U.S. patent application Ser. No. 11/131,611, filed on May 18, 2005, which is a divisional application of 10/401,074, filed on May 27, 2003, now U.S. Pat. No. 6,936,546, issued Aug. 30, 2005, which claims priority U.S. Provisional Application 60/376,154, filed Apr. 26, 2002. This application is also a continuation-in-part of U.S. patent application Ser. No. 11/230,261, filed Sep. 19, 2005. This application is also a continuation-in-part of U.S. patent application Ser. No. 11/230,263, filed Sep. 19, 2005. This application is also a continuation-in-part of U.S. patent application Ser. No. 11/417,297, filed May 2, 2006. The disclosure of the above applications is incorporated herein by reference.

FIELD

[0002] The present disclosure relates to a method and apparatus for processing of a substrate. More particularly, a method and apparatus for concentrically positioning a substrate relative to an apparatus for processing the edge of the substrate is disclosed. Furthermore, a seal arrangement for the alignment apparatus is also provided. In addition, processes for dry etching of a substrate with a combustion flame are disclosed.

BACKGROUND

[0003] The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

[0004] During the manufacture of integrated circuits, silicon substrate wafers receive extensive processing including deposition and etching of dielectrics, metals, and other materials. At varying stages in the manufacturing process it is beneficial to "clean" the edge area of the wafer to remove unwanted films and contaminants including particles that develop as a result of the wafer processing.

[0005] This includes films and contaminants that develop on a near edge top surface (primary processed side), near edge back surface, and edge (including, top bevel, crown and bottom bevel) of the wafer (hereinafter "edge area" refers generally to the near edge top surface, near edge bottom surface, and edge in combination or individually). Removal of films and contaminants is desirable to prevent the potential of particulate migration into the device portion of the wafer. Potential contaminant particles are generated during wafer handling, processing, and as a result of "pop-off" effect due to film stress.

[0006] It is a challenge to process and thus remove edge area thin films and contaminants in an efficient and cost effective manner without affecting the remainder of the wafer that contains in-process devices. This challenge is exacerbated by use of chemistries and processes that may adversely impact the in-process device portion of the wafer.

[0007] Many of the existing film removal techniques fail to properly remove polymers, edge beads, dielectric or tantalum, particularly from the edge area, as may be desired by the wafer manufacturer. Specifically, it is desirable to maximize the usable surface area of a wafer thus minimizing any unusable edge area with the objective of maximizing die yield. Reduction in functional die produced from the usable surface area is termed yield loss and is generally undesirable and has a negative cost impact. Accordingly, a need in the art exists for improved processing methods and apparatus to remove various front side, back side and edge area films and contaminants in a cost effective and efficient manner.

SUMMARY

[0008] According to the teachings of the present invention, a substrate processing apparatus for processing the substrate with a combustion flame of hydrogen and a non-oxygen oxidizer, is provided. The system has a processing chamber for receiving the substrate and for confining a clean environment for the combustion flame. A processing nozzle assembly is disposed within the processing chamber for directing the combustion flame onto the substrate. A source for fuel and the oxidizer operationally attached to the processing chamber. An igniter assembly having a ceramic hot body igniter defining an interior cavity is provided. Disposed within the interior cavity is a heating element. An igniter nozzle assembly operably coupled to a fuel source is disposed within the chamber. The igniter assembly is configured to direct an initiation combustion flame within a predetermined distance from the processing nozzle assembly.

[0009] According to the teachings of another embodiment, a clean igniter assembly is provided having a sapphire body. A heating element is thermally coupled to the sapphire body. A power source configured to apply an electromagnetic wave to the heating element. An igniter nozzle assembly is disposed adjacent to the sapphire body, the nozzle assembly being coupled to a fuel source.

[0010] According to the teachings of another embodiment, method for igniting a flame is provided. The method includes disposing a heating element within a ceramic igniter assembly. The heating element is energized so as to heat the igniter assembly to a predetermined ignition temperature. A fuel is passed through an ignition nozzle at a first rate past the igniter assembly to ignite a flame. The ignition flame is passed the flame past a plurality of nozzles to ignite a plurality of processing flames from the nozzles.

[0011] A substrate edge processing method is disclosed for isolating for isolating and processing a portion of a substrate. The portion to be processed extends from an edge of the substrate radially across the top surface of the substrate to another part of the edge of the substrate, thus isolating an edge area to be processed. A pressure differential barrier is formed between the portion of the substrate being processed and the remainder of the substrate. A reactive species is directed towards the processed portion of the substrate at an angle greater than parallel to the top surface of the substrate and less than vertical to the top surface of the substrate. A clean flame igniter is used to ignite the nozzles.

[0012] In other embodiments, an edge area of the substrate to be processed is isolated from the remainder of the substrate by directing a flow of an inert gas through a plenum near the area to be processed thus forming a barrier while directing a flow of reactive species at an angle relative

to the top surface of the substrate towards the substrate edge area thus processing the substrate edge area. A flow of oxygen containing gas into the processing chamber together with a negative exhaust pressure may contribute to the biasing of reactive species and other gases away from the non-processing areas of the substrate.

[0013] The described method and apparatus allows for precise processing of portions of the substrate particularly the substrate edge area without allowing for encroachment in the excluded area. Flow control as a part of the apparatus isolator structure in combination with pressure differentials effectively limits movement of reactive species into the area excluded. Using directed flow of the reactive species to the edge area of the substrate allows for a high etch rate and resulting overall significant improvement of throughput of processed substrates. In sum, the system provides for a clean, effective, and efficient method and apparatus for processing the edge area of substrates in a manner that is highly desired for achieving low contamination of the device portion of the substrate.

[0014] Also disclosed is a multi-axis motion seal (i.e. labyrinth) for sealing the processing chamber during processing of the wafer. The seal functions in association with a wafer chuck. The seal and processing chamber define a vacuum chamber connected to a vacuum that is movable in cooperation with the alignment system.

[0015] In addition, processes for combustion flame based processing of the wafer are disclosed. The disclosed chemistries react in a combustion flame to produce a reactive species for processing the wafer in a precise and efficient manner. A particle free igniter is used to ignite the combustion flame.

[0016] In another embodiment, a system is provided for dielectric film removal from near edge regions. These films are etched using H_2:NF_3 dominant chemistries. Certain metal films can also be removed. Examples include tungsten and tantalum. Many metal oxide or nitride films can also be etched.

[0017] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

DRAWINGS

[0018] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

[0019] FIGS. **1**A-**1**C are cross-sectional schematics depicting a system for concentric wafer process application;

[0020] FIG. **2** is a top schematic depicting exchange/centering and processing positions of a wafer within a process chamber;

[0021] FIG. **3** is a side schematic depicting exchange/centering and processing positions of a wafer within a process chamber;

[0022] FIG. **4**A depicts a side sectional view of a labyrinth seal assembly in relationship to a processing chamber and chuck assembly;

[0023] FIG. **4**B depicts a top sectional view of a labyrinth seal assembly in relationship to a processing chamber and chuck assembly;

[0024] FIG. **5** represents a side sectional view of the isolator chamber shown in FIG. **1**A;

[0025] FIG. **6**A depicts a top view of a plurality of nozzle bodies relative to an edge of a wafer;

[0026] FIGS. **6**B through **6**F represent side views depicting bevel nozzles at a wafer bevel region;

[0027] FIGS. **7** through **8**G represent cross-sectional views of pre and post processed wafers;

[0028] FIGS. **9**A-**9**C represent side views depicting alternate nozzle configurations at a wafer bevel region;

[0029] FIG. **10** depicts a schematic view of a misaligned wafer at two different rotational positions relative to an aligned position within the exchange/centering apparatus;

[0030] FIGS. **11**-**12**B detail an optical inspection system of the present disclosure;

[0031] FIG. **13** represents an exploded cross sectional view of a portion of the processing chamber and the isolator assembly shown in FIG. **1**;

[0032] FIGS. **14**A and **14**B are sectional views of the sealing mechanism of the system shown in FIG. **3**;

[0033] FIG. **15** represents a perspective sectional view of the sealing mechanism shown in FIGS. **14**A and **14**B;

[0034] FIGS. **16**A and **16**B represent cross sectional views of the system shown in FIG. **3**;

[0035] FIGS. **17**A-**17**C represent an exploded view of the isolator assembly shown in FIG. **13**;

[0036] FIGS. **18**A and **18**B represent perspective views of the nozzle assembly of FIG. **17**A;

[0037] FIGS. **19**A and **19**B represent a nozzle usable in the nozzle assembly of FIGS. **18**A and **18**B;

[0038] FIGS. **20**A and **20**B represent an alternate nozzle usable in the nozzle assembly of FIGS. **18**A and **18**B;

[0039] FIGS. **21**A and **21**B represent an alternate nozzle assembly;

[0040] FIGS. **22***a* and **22***b* represent nozzle subplates as shown in FIGS. **21**A and **21**B;

[0041] FIGS. **23**A and **23**B represent cross sectional views of an alternate igniter assembly according to the present teachings;

[0042] FIGS. **24** through **25**B represent top and side views of the igniter and nozzle assemblies;

[0043] FIG. **26** represents a perspective view of an alternate clean ignition assembly;

[0044] FIG. **27** represents a top view of a flame sense system for use in the wafer processing system according to FIG. **1**A; and

[0045] FIGS. **28** and **29** represent responses detected by the flame sense system.

DETAILED DESCRIPTION

[0046] The following description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

[0047] FIGS. **1**A and **1**B represent a system level view of the components and methods required to achieve concentric process application utilizing a wafer processing system according to the teachings herein. One example relates to selectively applying chemistry to the near edge region of a wafer. Other possibly applicable methods and apparatus are disclosed in U.S. patent application Ser. Nos. 11/230,261 and 11/417,297 which are both incorporated by reference.

[0048] Central to the present disclosure's near edge film removal technology is the ability to apply reactive gas to a wafer in a highly concentric and precise fashion. Process application is typically sensitive to wafer or substrate eccentricity variation in the range of 50 to 100 μm. Multiple subsystems are required to achieve this type of process application.

[0049] FIG. **1**A shows a system level schematic view of the overall system for concentric wafer process application. The process chamber **22** contains the isolator **25** and diffuser **24** for controlled application of reactive gas to the near edge wafer region. The R-Z-θ or xyz-θ wafer movement alignment module or system **27** is shown in the wafer load position where the laser micrometer **15** measures the trajectory of the wafer edge during the centering routine. Lift pins **16** are also shown.

[0050] The equipment front end module **17** contains a robot and the pre-aligner station **19**. Wafers are processed from a front opening unified pod. The utility cabinet **20** contains control electronics, computer(s), endpoint equipment, gas delivery equipment and other facilities interconnects. Process gases **21** are connected to the module and flow regulated by appropriate mass flow controllers (MFC's) **52**. Other facilities connections such as exhaust **56** and cooling water **58** are also connected.

[0051] Referring generally to FIGS. **1**A-**9**C, an embodiment of the wafer edge area processing system **20** (the "system") of the invention has a processing chamber **22** with an isolator **25** and wafer alignment module **27** with associated wafer chuck **28** disposed therein. A wafer **26** is retained on top of the wafer chuck **28** with the wafer **26** having a top surface **30**, bottom surface **32**, and edge area **33** (including edge and near edge as shown by lighter line proximal to edge) that surrounds the radial perimeter of the wafer **26**. The isolator **25** has an upper section **38** extending over a portion of the top surface **30** of the wafer **26** and a lower section **39** extending over a portion of the bottom surface **32** of the wafer **26**. The inside of the isolator **25** has a processing area for processing the edge area **33** of the wafer **26**. The processing area leads into an exhaust plenum **41** connected to an exhaust system **56** for exhausting gases, process byproducts, and condensation.

[0052] Disposed within the upper section **38** of the isolator **25** are a first nozzle **45** and a second nozzle **49**. Both nozzles are configured to emit a directed flow of reactive species towards the edge area **33** of the wafer **26**. First nozzle **45** is offset from an axis perpendicular to a plane that is common with the top surface **30** of the wafer **26** (the "wafer plane"). First nozzle **45** is pointed towards the top surface **30** at an angle of 80°+/−5° relative to the wafer plane. Second nozzle **49** is offset by an angle of 45°+/−5° to the wafer plane. Second nozzle **49** is also offset by ~15° from a plane perpendicular to the wafer plane that runs through the center of the isolator **25** and center of the wafer **26**.

[0053] First nozzle **45** is connected to a first channel **48** disposed in the upper section **38**. First channel **48** leads to a gas line **47**. Second nozzle **49** is connected to a second channel **53** disposed in the upper section **38**. Second channel **53** leads to the gas line **47**. First nozzle **45** and second nozzles **49** are connected via the gas line **47** to a reactive gas species source. Optionally, the first and second channels **48** and **53** can be coupled to sources having differing chemistry.

[0054] First nozzle **45** is positioned for bevel and crown processing at a distance of 0.1 to 0.5 mm from the edge of the wafer **26** and 1.3 to 1.8 mm distance from the top surface **30** of the wafer **26**. Second nozzle **49** is positioned 0.5 to 3.0 mm in from the edge of the wafer **26** and 0.6 to 1.1 mm distance from the top surface **30** of the wafer **26**. Radial position of the nozzles and distance from the wafer surface is dependent upon desired edge exclusion area and is also process and film dependent.

[0055] Reactive gas species source either provides a reactive gas species or component reactants for forming the reactive gas species. Reactive gas species can be generated via near atmospheric pressure techniques. This includes near atmospheric capacitively coupled plasma source (i.e., APJET), as described in U.S. Pat. No. 5,961,772, incorporated herein by reference or inductively coupled plasma discharge (i.e., ICP torch), as described in U.S. Pat. No. 6,660,177, incorporated herein by reference or combustion flame.

[0056] Spontaneous etchants, for example F_2, O_3, or HF can also be used. Advantageously, none of these reactive species techniques produce ion bombardment characteristic of an ionic plasma thus minimizing surface and device damage potential. Further, although envisioned, none of these techniques requires a vacuum chamber together with associated equipment.

[0057] An upper purge plenum **88** disposed in the upper section **38** extends at or near the edge of the top surface of the wafer **26**, above and across an area of the wafer to be processed to at or near another edge of the top surface **30** of the wafer **26**. The upper purge plenum **88** is ~3.0 mm wide and extends for a total path length of ~37.5 mm. The upper purge plenum **88** is part of a tuned flow system which prevents reactive gas migration out of the processing area.

[0058] The upper purge plenum **88** is connected to a first purge channel **92** that is connected to a purge gas source **96** via a purge gas line **94**. The purge gas source **96** supplies an inert gas, for example, argon that is fed via the first purge channel **92** into the upper purge plenum **88**. Alternatively, the upper purge plenum **88** can provide CDA or oxygen containing gas, which augments the reaction of the reactive gas.

[0059] The use of oxygen containing gas allows the reaction of unreacted H_2. This also compensates for extreme length limitations and allows for a higher volume fraction of NF_3. The increased NF_3 volume fraction leads to enhanced etched rates as well as an enhancement of throughput. Although one purge channel is seen disposed in the upper

section **38** of the isolator **25**, more than one channel may be present for directing a flow of purge gas into the upper purge plenum **88**. Purge channels have an inside diameter of 2.00 mm. The flow of purge gas into the upper purge plenum **88** creates a pressure differential in the area of the top surface **30** surrounded by the upper purge plenum **88** resulting in a barrier between the top surface **30** and the edge area **33** of the wafer **26** being processed.

[**0060**] The upper purge plenum **88** is separated from the top surface **30** of the wafer **26** by an inside baffle **100**. Inside baffle **100** follows along the inside perimeter of the upper purge plenum **88** and is separated from the wafer **26** by a gap of 0.30 to 0.80 mm. An outside baffle **104** follows along the outside perimeter of the upper purge plenum **88** and is separated from the wafer **26** by a gap of 0.50 to 1.10 mm. As seen, outside baffle **104** is wider and closer to the top surface **30** of the wafer **26** than the inside baffle **100**. This facilitates forming a pressure induced barrier around the in-process portion of the wafer **26** by creating a pressure differential biasing a flow of a purge gas in a direction across inside baffle **100** into the processing area of the isolator **25**.

[**0061**] A second purge channel **108** is disposed in the lower section **39** of the isolator **25**. This is connected by the purge gas line **94** to the purge gas source **96**. Second purge channel **108** is for feeding purge gas to a lower purge plenum **114**. Similarly to the upper purge plenum **88**, the lower purge plenum **114** extends from at or near the edge area **33** of the wafer **26** below and across the bottom surface **32** to at or near another location of the edge of the wafer **26**. Similarly to the upper purge plenum **88**, the lower purge plenum **114** is disposed between a lower inside baffle **112** and a lower outside baffle **118**. The lower purge plenum **114** together with the lower inside baffle **112** and lower outside baffle **118** bias a flow of purge gas in a direction across the lower inside baffle **112** and across the bottom surface **32**.

[**0062**] Wafer chuck **28** is movable in r-θ-z or xyz-θ directions, using module **27**, for positioning the wafer **26** and rotating it within a slot of the isolator **25** defined between the upper section **38** and lower section **39**. Alternatively, the isolator **25** structure can also be moved in r with the chuck moving in θ and z. Once in position the distance between each side of the wafer **26** and the upper section **38** or lower section **39** is 0.30 to 0.80 mm. The slot open area without a wafer **26** is 124.20 to 216.20 mm^2. The slot open area with a wafer **26** present is 55.20 to 147.20 mm^2. The exhaust slot width is 93.0 mm.

[**0063**] A gas diffuser **24** extends into the processing chamber **22** providing a flow of inert or oxygen containing gas to the processing chamber **22**. The gas diffuser **24** is typically of the shower head type design and is connected via a diffuser **24** gas line **148** to the purge gas source **96**.

[**0064**] The exhaust plenum **41** together with the exhaust system **56** are an additional part of the tuned flow system which prevent reactive gas migration out of the processing area. Exhaust system **56** creates a negative pressure in the exhaust plenum **41** that draws active species gases together with the inert gas, processed byproducts, and condensation away from the processing area and prevents migration of these gases into the device area of the wafer **26**.

[**0065**] A heater element **122** is connected by a heater line to a heater power supply **126**. The heater element **122** heats the isolator **25** and to a lesser extent, the wafer **26**. Heating the isolator **25** is desirable to prevent condensation of gases that can be corrosive to the isolator **25** and potentially introduce contamination into the processing area.

[**0066**] The nozzles of the edge area processing system **20**, including the first nozzle **45** and second nozzle **49** are made of sapphire. Sapphire is advantageously non-reactive to the chemistries used in substrate processing. This is desirable since the processing of semiconductor substrates requires trace material contamination analysis at the parts per million level with acceptable addition to the substrate being less than approximately 10^{10} atoms/cm^2. Further, particle additions to the substrate should be zero for sizes greater than approximately 0.1 micron.

[**0067**] It is also, in many situations, desirable to achieve a laminar gas flow from the nozzles. This requires setting the aspect ratio of the nozzle at greater than or equal to 10× length to diameter. With some reactive gases, aspect ratios of greater than 40:1 or preferably 80:1 are desirable. Nozzle inside diameters are around 0.254 to 0.279 mm which requires a uniform smooth nozzle bore length of approximately 2.50 mm.

[**0068**] The isolator **25** nozzles, including the first nozzle **45** and second nozzle **49**, while described as angled relative to the wafer plane at ~80 degrees and ~45 degrees, respectively, can advantageously be angled in a different direction relative to the wafer plane in order to facilitate processing including etching or deposition of a thin film.

[**0069**] In operation, a wafer **26** is centered on the wafer chuck **28** and then the wafer chuck **28** positions the wafer **26** in the slot of the isolator **25** between the upper section **38** and the lower section **39** for processing. The movement system **27** rotates wafer chuck **28**, and thus the wafer **26**.

[**0070**] Inert gas or CDA is allowed to flow into the upper purge plenum **88** and lower purge plenum **114** from the purge gas source **96**. The inert gas or CDA flows into the upper purge plenum **88** and lower purge plenum **114** at a rate of 100 sccm to 8,000 sccm. Inert gas or CDA is also allowed to flow into the processing chamber **22** through the gas diffuser **24**. This gas flows into the processing chamber **22** at a rate of 500 sccm to 10,000 sccm.

[**0071**] The exhaust system **56** is activated to draw gases and process byproducts including condensation through the exhaust plenum **41**. Next, reactive species **130** emit from first nozzle **45** and second nozzle **49**. The igniter power supply **126** energizes the clean igniter system **78** and the first gas line **93** and second gas line **98** are opened to allow a flow of hydrogen and nitrogen trifluoride gases into the nozzle assembly **84** and through the four nozzles **84**. The gas mixture is frequently different during the ignition stage. The igniter nozzle uses H_2 and O_2 only at higher total flow rates than the processing nozzles **45**, **49**. Typically, the initiator nozzle uses approximately 800 sccm H_2 and 200 sccm. The process nozzles typically ignite with a Lo NF_3 fraction. Typically about 20 sccm max. Reactive species (or gases in the case of a combustion flame) flow through the nozzles at a rate of between 200 and 800 sccm and preferably between 375 sccm to 475 sccm. The reactive species **130** impinge upon the edge area **33** of the wafer **26** as the wafer **26** rotates. The reactive species **130** react with a thin film or contaminant in the edge area **33** of the wafer **26** resulting in a

reactant byproduct **66**. Alternate nozzle configurations are envisioned. For example, referring briefly to FIGS. **9**A-**9**C, the position of the first processing nozzle **45** and second processing nozzle **42** includes the reactive species **130** to "wrap around" the top bevel, crown, bottom bevel of the wafer **26**.

[**0072**] Heater **122** is energized to heat the wafer top surface **30**. This optional step is intended to prevent vapor produced as a byproduct of the chemical reaction, for example water vapor, from condensing on the wafer top surface **30**. Condensation can be prevented by heating the wafer top surface **30** to a temperature at or above the boiling point for the reactant byproducts, for example heating the wafer top surface **30** above 100° C. to prevent the condensation of water. Alternatively, wafer **26** surface heating can be supplied via a heated substrate holder **82** or via infrared energy directed at the wafer perimeter, or via other heat sources such as a flame.

[**0073**] The reactive species **130** are prevented from passing out of the isolator **25** by the flow of inert gas working in concert with a pressure differential drawing gases into the exhaust plenum **41** and into the exhaust system **56**. This inert gas forms a pressurized barrier in the upper purge plenum **88** and lower purge plenum **114** surrounding the in-process edge area of the wafer. The inside baffle member **61** in cooperation with the outside baffle member **63** biases the flow of insert gas towards the in-process area of the wafer **26**. Reactant byproducts formed as a result of the reactive species **130** reacting with a thin film on the wafer **26** surface are drawn away from the in-process area of the wafer **26** into the exhaust plenum **41**. Thus, advantageously, reactive species **130** and reactive byproducts **142** are confined to the edge area of the wafer **26** and prevented from migration into other areas of the wafer **26** that may damage wafer component devices. In addition, the pressure differential induced by the exhaust plenum **41** further biases gas flow away from the central portion of the wafer **26**.

[**0074**] As the wafer **26** rotates either the wafer chuck **28** translates with respect to the nozzle assembly **84** and the combustion flame across the wafer top surface **30**. As a result a desired section of the wafer top surface **30** is processed. Processing includes the removal of a thin film, for example, silicon dioxide or tantalum as described above in relation to the substrate processing method.

[**0075**] After the wafer is processed, the first gas controller **102** and second gas controller **106** are closed. Simultaneously, the fourth gas controller **49** is opened to allow a flow of argon gas or CDA into the edge-type nozzle assembly **84** and through the first and second nozzles **45**, **49** to "blow out" the combustion flame. The controller **140** additionally allows blow off of the nozzles if EMO or a power failure occurs. Additionally, the controller **52** can extinguish the flames upon low gas delivery pressure, if the enclosure is opened, or if there is a loss of control air. Also coupled to the controllers are a plurality of H_2 sensors which will shut off the system or signal an alarm should the H_2 level in the chamber **22** be above a predetermined level. The wafer **26** may be removed after the chamber **22** is evacuated of process gases and byproducts.

[**0076**] Processing of the edge area **33** of the entire wafer may be accomplished with a single rotation of the wafer **26**. Alternatively, more than one rotation may occur and more than one process may be performed including deposition and etching. After the flow of reactive species is stopped a flow of the inert gas continues until the processing chamber **22** is sufficiently evacuated of other gases and condensations. Then, the heater element **122** is turned off and the flow of inert or CDA gas from the purge gas source **96** is stopped and the wafer **26** is removed and replaced with another wafer for processing.

[**0077**] The described system **20** and associated method for using the system is suitable for etching of target thin films. This includes, but is not necessarily limited to, tantalum and tantalum nitride; inter-layer dielectrics; backside polymers; and photoresist edge bead.

[**0078**] FIG. **2** represents a top view of the system shown in FIG. **1**A. Shown is the isolator **25** with associated nozzle assembly **84**, Flame sense system **212**, and heater **122**. Also shown is the movement system **27** with labyrinth seal **70** and measuring micrometer **15**. The wafer **26** is moved from the installation position **134** to the processing position **136** by translation of the chuck **28**.

[**0079**] FIG. **3** shows exchange/centering **134** and processing **136** positions of the R-Z-θ stage. Relationship of the labyrinth seal **70** to the process chamber **22** and chuck spindle **60** are also shown. Vacuum for labyrinth seal **70** operation is supplied by a vacuum pump **31** or other appropriate vacuum generator. Computer control of the vacuum level can be integrated using a throttle valve, electronic mass flow, or pressure controller in conjunction with a venturi type vacuum generator. Vacuum for the wafer chuck clamping force is also supplied by a vacuum pump **31**. Pressure differential was found to be the most critical parameter determining function of the seal. Gap distance between 120 μm and 500 μm between the sealing plate **74** and the bottom surface **76** of the process chamber **22** was also found to be important.

[**0080**] The translational 'R-axis' gap and the 'Z-θ axis' gap are shown in FIG. **3**. When operated using proper conditions, the helium leak rate of the seal is $<1.0\times10^{-6}$ atm-cc/s. This leak rate is equivalent to that of an o-ring sealed interface. It must be noted that o-ring interfaces have been found to be unacceptable inasmuch as they generate undesirable particulate. Gap values in the range of 127 μm to 508 μm were tested and found functional provided the proper pressure differential was maintained. Mass flow magnitude increases dramatically with increasing gap placing a practical upper limit of 254 μm. Machining tolerances set the practical lower gap limit at 127 μm.

[**0081**] A minimum pressure differential between the seal exhaust ports, and the process chamber **22** was found to be −2 water column inches. Larger differential pressure values can be used and a practical upper limit is not known. Pressure differential between the process chamber and atmosphere should be at least −0.4 water column inches. This results in a seal exhaust to atmosphere pressure differential of at least −2.4 water column inches.

[**0082**] FIGS. **4**A-**4**B show side and top views of the labyrinth seal **70** assembly in relationship to the chamber **22** and movement system **27**. Vacuum channel sealing the traverse (R-axis) motion is shown along with the channel **79** sealing vertical (Z-axis) and rotary (O-axis) motion components. Each vacuum channel is connected via tubing to an

independently controlled vacuum generator or pump. Note that the labyrinth seal plate **74** is machined from 304 or 316 series stainless steel. Corrosion resistance is enhanced by a post machining metal finishing process consisting of electro-polishing and passivation.

[**0083**] Referring again to FIGS. **1**-**9**B, an embodiment of a substrate processing method **10** of the invention employs a combustion flame **12** formed of an ignited combustion of gaseous reactants **14** including hydrogen (H_2) and nitrogen trifluoride (NF_3, as a non-oxygen "oxidizer") in an oxygen enhanced environment **13**. Although CDA is illustrated, other oxygen containing gases are suitable. A mixture of gaseous reactants passes through a torch nozzle **45** before igniting into combustion flame **12**. Combustion flame **12** impinges upon a substrate surface **18**.

[**0084**] Gaseous reactants react in combustion flame to form gaseous hydrogen fluoride (HF) (a reactive species) and gaseous nitrogen (N_2) effluents. The following chemical equation describes the production of gaseous hydrogen fluoride and gaseous nitrogen from gaseous reactants based on a stoichiometric mixture (a 3:2 molar ratio):

$$3H_2(gas)+2NF_3(gas)\rightarrow 6HF(gas)+N_2(gas)$$

[**0085**] Advantageously, this reaction is performed substantially at atmospheric pressure. This allows for use of viscous (rather than molecular) flow properties to precisely treat portions of the substrate surface **18** and minimize exposure of other substrate areas to the reactive process. Although a 3:2 molar ratio is described higher or lower ratios may be used depending on the desired result.

[**0086**] Further, this reaction is not induced by an ion producing field consistent with a plasma. It is believed that a plasma is a collection of charged particles where the long-range electromagnetic fields set up collectively by the charged particles have an important effect on the particles' behavior. It is also believed that the combustion flame **12** has substantially no ionic species present. As a result, there is no risk of ionic damage to the substrate.

[**0087**] Substantial heat is generated from the exothermic chemical reaction of H_2 and NF_3. This effect allows a small volume of highly reactive species in the form of HF to be generated due to the amount of energy represented by the resultant temperature. Elevated temperature in turn substantially increases reaction rates which results in higher etch rates. The result is higher process throughput.

[**0088**] A silicon dioxide thin film can be etched by the gaseous hydrogen fluoride according to the following overall reaction:

$$4HF(gas)+SiO_2(solid)\rightarrow SiF_4(gas)+2H_2O(gas)$$

[**0089**] Gaseous silicon tetrafluoride and water vapor leave the surface of the silicon dioxide thin film. Advantageously, this reaction provides for a change of silicon dioxide thin film from a solid to a gas byproduct that can be easily evacuated.

[**0090**] Gaseous hydrogen fluoride will also etch a substrate surface of silicon. Silicon etching follows the following overall reaction:

$$4HF(gas)+Si(solid)\rightarrow SiF_4(gas)+2H_2(gas)$$

In this reaction, gaseous silicon tetrafluoride and gaseous hydrogen leave the silicon substrate surface. This reaction provides for a change of silicon on the substrate surface from a solid to a gas byproduct that can be evacuated.

[**0091**] Similarly, etching of a tantalum thin film follows the following overall reaction:

$$10HF(gas)+2Ta(solid)\rightarrow 2TaF_5(gas)+5H_2(gas)$$

In this reaction, gaseous tantalum pentafluoride and gaseous hydrogen leave the tantalum substrate surface. This reaction provides for a change of the tantalum on the substrate surface from a solid to a gas byproduct that can be evacuated. For this reaction, preheating of the wafer using an O_2+H_2 flame is desirable to prevent the condensation of reaction products on the wafer.

[**0092**] Organic and polymer films can also be removed using the above described chemistry however selectivity issues to Si and SiO_2 may in some instances make this less desirable. The above chemistry for example can be used to etch SiO_2 over Si where etching of oxide is desirable but Si is not. Passivation of exposed Si to the etch chemistry can be promoted by first exposing an etch field to a hydrogen rich flame with oxygen. The etch field is then exposed to the combustion flame of H_2 and NF_3 where the oxide is etched.

[**0093**] Other desirable non-oxygen oxidizers for reaction with hydrogen in a combustion flame for substrate etching include fluoride (F_2), chlorine (Cl_2), and chlorine trifluoride (ClF_3). Hydrogen and fluoride react in a combustion flame as follows:

$$H_2(gas)+F_2(gas)\rightarrow 2HF(gas)$$

Similarly to the combustion flame of H_2 and NF_3 the resulting HF reactive species is a desirable etchant as described above.

[**0094**] Hydrogen and chlorine react in a combustion flame as follows:

$$H_2(gas)+Cl_2(gas)\rightarrow 2HCl(gas)$$

[**0095**] Hydrogen and chlorine trifluoride react in a combustion flame as follows:

$$4H_2(gas)+2ClF_3(gas)\rightarrow 6HF(gas)+2HCl(gas)$$

[**0096**] In both the proceeding combustion flame reactions, the resultant hydrogen chloride reactive species can be advantageously used for etching when materials not readily etched by fluorine are present in the film stack. This includes a film stack comprising aluminum. Hydrogen chloride as a reactive species etches aluminum as follows:

$$2Al(solid)+6HCl(gas)\rightarrow 2AlCl_3(gas)+3H_2(gas)$$

[**0097**] Hydrogen chloride etches silicon as follows:

$$Si(solid)+4HCl(gas)\rightarrow SiCl_4(gas)+2H_2(gas)$$

[**0098**] Hydrogen chloride etches silicon oxide as follows:

$$SiO_2(solid)+4HCl(gas)\rightarrow SiCl_4(gas)+2H_2O(vapor)$$

[**0099**] Chlorine trifluoride represents a hybrid etch chemistry where both fluorine and chlorine based etchant reactive species are produced. Often this compound is combined with another fluorine containing gas (such as NF_3 or CF_4) or with Cl_2 is used in varying ratios when multiple materials are present in the film stack, requiring both fluorine and chlorine based chemistry for removal.

[**0100**] The chemical equations shown above are a simplified view of the real reactions taking place within the combustion flame and on the substrate surface. The reaction

chemistries occurring are quite complex resulting in intermediate and final reaction products.

[0101] A nozzle assembly **84** is held by a support member **46** over a wafer **26** retained on the substrate holder **82**. Four nozzles **45** are disposed in the nozzle assembly **84**. The nozzle assembly **84** is maintained at a distance of ~1.5 mm from the wafer top surface **30** during processing.

[0102] A hydrogen gas source and nitrogen trifluoride gas source **55** are connected by a first gas line **48** and second gas line **53** through a first gas controller **102** and second gas controller **106** to a common mixing gas line **110** connected to the nozzle assembly **84** for combining and mixing H_2 and NF_3. An exhaust scoop **116** is adjacent to the substrate holder **82** for exhausting gases and reactant byproducts. The exhaust scoop is connected by a plenum **67** to a blower device **124**. The exhaust scoop **116** draws gases and reactant byproducts out of the processing chamber **22** through the blower device **124**.

[0103] In one embodiment, an argon gas source **96** is connected by a third gas line **132** through a third gas controller **49** to the processing chamber **22**. In another embodiment, a CDA (clean dry air) or oxygen containing gas **72'** is connected by the third gas line **132** through a third gas controller **49** to the process wafer. The argon or CDA gas source **131** is also connected by a fourth gas line **134** through a fourth gas controller **49** to the common mixing gas line **110**. An igniter assembly **78** positioned close to the nozzle assembly **84** is connected by wires **83** to an igniter power supply **126**.

[0104] In operation, the robot unloads wafer from front opening unified pod (FOUP) and places the wafer on a pre-aligner **19**. Once the pre-alignment routine is completed, the robot retrieves wafer from pre-aligner and places it into the chamber **22** on lift pins **16**. Wafer chuck **28** moves up in z and lifts wafer **26** from lift pins **16** and rotates and positions the wafer edge to allow measurement using laser micrometer **15**. Wafer center offset direction and magnitude is computed as described above. Wafer **26** is then rotated to align offset direction with the 'r' axis. The chuck **28** then descends in 'z' axis to return wafer to lift pins **16**. The wafer movement system **27** moves chuck assembly increments in 'r' by the offset magnitude to center the chuck **28** with respect to the wafer **26**. The movement system **27** then elevates in 'z' axis to lift wafer from lift pins **16**. The chuck rotates and the edge position is re-measured to validate centering. The wafer is then ready for concentric process application as described above.

[0105] A heater **122** is positioned proximately to the area of the wafer **26** to be processed. The heater **122** (shown in FIG. **5**) is an infrared (IR) or laser diode heater and is connected by a heater wire **87** to an IR heater power source **125**. In a preferred embodiment the heater **122** is a fiber optic coupled laser diode array. A fiber optic cable assembly can be used in place of the heater **122**. The fiber optic cable can deliver high power illumination originating in a laser diode assembly located remotely. Such illumination can perform heating of the wafer **26** such as discussed in United States Patent Application Publication No. 2005/0189329, titled "Laser Thermal Processing with Laser Diode Radiation" and incorporated herein by reference.

[0106] FIGS. **6**A through **6**F represent the nozzle **45**, **49** positioning with respect the bevel edge of the wafer **26**. By alternating the angles of the nozzles, proper coverage of the edge for particular region of the wafer edge can be accomplished. In this regard, depending upon the defects or films to be removed, various nozzle configurations are envisioned.

[0107] Referring to FIGS. **7** through **8**G, a film such as deposited through chemical vapor deposition (CVD) or physical vapor deposition (PVD) extends as a thin film **129** over a wafer **26** such as a wafer. The thin film **129** extends from the top surface of the wafer **26** across a top bevel, crown and bottom bevel of the wafer **26**. The above-described system **20** can be advantageously used to process the thin film **129** on the wafer **26** resulting in a wafer **26** profile as shown in FIG. **8**B.

[0108] Referring to FIGS. **7** and **8**C, a full coverage thin film **128** extends from the top surface across the top bevel, crown and bottom bevel and onto the bottom surface of the wafer **26**. Thin films having this profile can include for example thermal SiO_2, and Si_3N_4. Embodiments of the above-described system **20** can be used to process the full coverage thin film **128** on the wafer **26** resulting in a wafer **26** profile as shown in FIG. **8**D.

[0109] Referring to FIGS. **7** and **8**E, a backside polymer thin film **130** extends from at or near the top bevel to across at least a portion of the crown to the bottom bevel and onto the bottom surface of the wafer **26**. Embodiments of the above-described system **20** can be used to process the backside polymer thin film **130** on the wafer **26** resulting in a wafer **26** profile as shown in FIG. **8**F.

[0110] Now referring to FIGS. **9**A-**9**C, an alternative embodiment edge area processing system **20'** (the "first alternative system") employ alternate first and second nozzles **45**, **49**. In the alternate nozzle configurations, the second nozzle "bends" the reaction gasses from the first gas around the bevel edge.

[0111] FIG. **9**A represents a 65°/140° nozzle configuration. This configuration allows the gases of the reaction to be induced around the wafer **26** bevel. Each of the four nozzles **45**,**49** is constructed of sapphire with a bore diameter of 0.254 mm and an aspect ratio of between 10:1 and 80:1 at the outlet end. Each of the four nozzles **45**,**49** is press fitted into the nozzle assembly **84**. The nozzles are pressed into tightly toleranced bores cut into the stainless steel nozzle assembly **84**. Nozzle diameter is 1.577 mm, +0.003 mm, −0.000 mm. Bore diameter in the nozzle assembly **84** for receiving the sapphire nozzle is 1.567 mm, +0.003 mm, −0.000 mm. This gives an interference fit in the range of 0.007 mm to 0.013 mm. Tolerance of this fit is important as interference in this range allows a hermetic seal while only inducing elastic deformation in the stainless steel nozzle assembly **84**. This allows a good seal without causing particulate generation during processing. In this configuration, a spoiler jet **89** is used to ensure the flame does not interact with the structure system **56**. Additionally, the lower moat **51** ensures reactants do not pass the isolator so as to affect the back surface.

[0112] FIG. **9**A shows that under some processing conditions, flame outputs may impinge on portions of the exhaust or isolator structures. Although moat **51** gasses generally can be used to prevent reaction gasses from flowing upstream, under certain processing conditions, the gasses may be forced toward the chuck **28**. As seen in FIG. **9**B, the use of

a spoiler jet **89** can reduce or eliminate the reaction gas impingement. Additionally, the gas flow through the backside moat will eliminate the chance reaction products will migrate into the wafer back surface.

[**0113**] Although NF_3 is used in the above embodiments as the non-oxygen oxidizer other non-oxygen oxidizers as previously discussed are suitable for use in the preferred embodiments. Further, additional embodiments for isolating and processing a wafer according to the above-described method are disclosed in U.S. patent application Ser. No. 11/230,263, filed on Sep. 19, 2005 and titled "Method and Apparatus for Isolative Substrate Edge Area Processing." The disclosure of this application is incorporated herein by reference.

[**0114**] Removal of dielectric thin films such as silicon oxide from substrates using H_2 and NF_3 gas mixtures is performed with a hydrogen fraction in the range of 0.5 to 0.7. For example, if the total flow is 800 sccm, H_2 flow will be in the range of 400 sccm to 560 sccm with NF_3 flow in the range of 400 sccm to 240 sccm. IR preheat is used in cases where ambient oxygen is present to discourage combustion products from condensing on the substrate.

[**0115**] Removal of tantalum from the near-edge region of the substrate is carried out using an etch nozzle configuration similar to that detailed for dielectric removal. Total gas flow per nozzle is approximately 400 sccm with an H_2 fraction in the range of 0.6 to 0.7. The primary tantalum etch product is TaF_5 which has a boiling point of ~230° C. Substrate surface temperatures in the etch region must be kept about this temperature to prevent condensation of the etch product. This is readily achieved using an additional combustion flame nozzle (not shown) positioned to impinge a flame on the substrate immediately prior to the impingement of the etch flame. This pre-heat nozzle discharges a flame of H_2 and O_2 preferably in the range of 0.5 to 0.8, H_2 fraction at a total flow of ~400 sccm for a single nozzle.

[**0116**] A rate of etching of the edge portion of the wafer **26** can be calculated based on consideration of exposure width, wafer circumference and rotational speed. For example, consider a 200 mm circumferential wafer with 2,000 Å of SiO_2 that is rotated at 2 rpm and the SiO_2 thin film on the edge area is completely removed in one rotation. Assuming a conservative exposure width of 5 mm of the combustion flame effluent on the wafer edge (using a 0.256 mm nozzle bore) an exposure fraction can be calculated as 5 mm/(628 mm×2 rev/min)=0.004 min/rev. The etch rate can then be approximated by dividing the 2,000 Å/rev removal by the exposure fraction. That is 2,000 Å/rev/0.004 min/rev=500,000 Å/min SiO_2 removal. If a smaller 2 mm exposure width is assumed then the removal rate becomes 1,256,000 Å/min. Based on these considerations and assumptions a poly-silicon thin film would be etched at an approximate rate of 3×10^6 Å/min; a photoresist thin film would be etched at an approximate rate of 4.6×10^6 Å/min; and a tantalum thin film would be etched at an approximate rate of 1×10^6 Å/min. This is a significantly high rate of etching resulting in a high rate of processing throughput of wafers.

[**0117**] One configuration is optimized for EBR from spin-on films on the top surface and edge region of wafers. This configuration uses reactive gas generated by a combustion flame of H_2 and O_2 to remove the resist. The present disclosure defines an optimized process using a minor fraction of the non-oxygen oxidizer NF_3 in the gas mixture for photoresist EBR. This addition increases the combustion flame temperature and chemical reactivity. These modifications to the combustion flame mixture substantially enhance sharpness of the etch interface and increase slope of the transition to full film thickness, both highly desirable enhancements.

[**0118**] For spin on films with low or minimal etch rate in the H_2:O_2 dominant chemistry such as organosilicates, inorganic polymers, and spin on glass materials, increasing amounts of fluorine containing gases such as NF_3 can be added to further increase etch rate. In this embodiment reactive gas application to the near edge area of the wafer is achieved using the invention disclosed in "Method and Apparatus for Isolative Substrate Edge Area Processing," previously incorporated by reference.

[**0119**] Undesirable dielectric films can be removed from the front surface of in process semiconductor wafers. These films can also flake and result in defects which cause yield loss. Concentric process application is critical in these processes where reactive gas application must be targeted to the edge region while not affecting the device area of the wafer.

[**0120**] Tantalum removal is similar in configuration to the front side dielectric removal module. Differences exist in the use of a preheat nozzle to reach a higher surface temperature (>230° C. target) to prevent TaF_5 condensation in the etch region. Surface temperature pre-heat target for typical film removal is ~120° C. and is primarily to prevent condensation of water vapor byproduct from the combustion reaction.

[**0121**] The in-situ wafer centering sequence typically takes 8 to 15 seconds. This overhead can be overlapped with gas flow stabilization time or ignition sequence. Wafer 'z' plane displacement is measured during rotation and can be used to map out 'z' displacement due to wafer bow or warp.

[**0122**] Process operation and details for Ta and dielectrics is discussed at length in the "Substrate Processing Method and Apparatus Using a Combustion Flame" patent application, previously incorporated by reference. This process operation can be applied to backside polymer and edge bead removal.

[**0123**] Backside polymer removal according to the principles of the present disclosure is accomplished by using four nozzles located in the isolator structure. As shown in FIG. **9**C, two nozzles are positioned at 45 degrees and two are at 105° relative to the wafer surface. The 45° nozzles are aimed at the back surface while the 105° nozzles are aimed at the bevel. In some cases, 2×45 degree nozzles are directed at the back surface along with 2×65 degree nozzles directed at the bottom bevel. Using multiple nozzles in this fashion both increases throughput and widens the process window. Nozzle angle relative to the wafer surface is important as impingement angle affects flow attachment to the surface and consequently degree of delivery of reactive species to the surface. As previously mentioned, an optional spoiler jet **89** can ensure the 105° nozzle does not cause degradation of the exhaust structure. It should also be noted that in this configuration, gas from the moat **51** can be used to "spoil" the flow of the flame to ensure it does not interfere with the exhaust.

[0124] Typically, the thickest polymer is located on the bevel region of the wafer. Consequently the NF_3 fraction in the 105° jets is higher than the 45° jets aimed at the thinner polymer on the back surface. Currently the method process uses 210 sccm H_2, 80 sccm O_2, and 100 sccm NF_3 in each 105° (high fraction) nozzle. Flows of 240 sccm H_2, 120 sccm O_2, and 20 sccm NF_3 are used in each 45° (low fraction) nozzle. The nozzles are constructed from sapphire with an ID of approximately 254 μm and an aspect ratio of greater than or equal to 10:1. Rotational speeds using during process are typically in the 1 to 6 RPM range. Surface heating for condensation prevention (>100° C. target) is done using a fiber coupled laser diode array.

[0125] Chemistry used for EBR depends on the film being removed. For photoresist removal 240 sccm H_2, 120 sccm O_2, and 20 sccm NF_3 performs well. Rotation rate to remove 15,000 Angstroms of resist is typically 1 to 3 RPM. Two nozzles are used for the photoresist EBR process, one at 45° and one at 65°. In cases where minimum edge exclusion is desired (~0.5 mm) only the 65° jet is used. Films with low removal rate, typically silicon containing films, require higher NF_3 fraction. The high fraction process used for backside polymer is an example (25% NF_3) although higher fractions can be used, frequently without oxygen addition, to ~50%.

[0126] Nozzle aiming for backside polymer removal is shown in FIG. **9**C. Backside polymer removal approach differs from front side films in that a sharp transition to full film thickness at the edge exclusion boundary is not required. Multiple nozzles are used in a partially overlapping fashion to increase the process window and removal rate. Nozzles are angled at 45° and 65° relative to the wafer surface. These angles were determined by a combination of CFD modeling and experimental trials. Positioning of the 65° nozzles can be critical for flow attachment and consequently efficient removal of material from the bevel region. This angle can be optimized based on edge profile to maximize flow attachment.

[0127] FIG. **10** shows a schematic view of the centering process. The measurement window of the laser micrometer **15** is represented by a rectangle **200**. The edge location of a properly centered wafer or circle of radius 150 mm is shown as **202**. The target center position of the wafer is (X_c, Y_c). A misaligned wafer is shown in hidden line representation at two different angular positions. At a first position identified as **204**, the pre-centered wafer has been rotated about the Z axis θ1 degrees. The center of the wafer is identified at (X_1, Y_1). A second wafer position, identified as **206**, corresponds to the wafer being rotated an angle of θ2 degrees. The center of the wafer is now at (X_2, Y_2).

[0128] FIGS. **3** and **10** depict a "Z" axis, an "R" axis and θ angles from a reference coordinate system having an origin at (X_c, Y_c). The edge position measurement and offset calculation includes the following: 1. R-Z-θ stage placed with θ axis in known reference location; 2. Rotate θ and measure radial position of wafer edge using laser micrometer **15**; **3**. Measured radii are fit to a circle; and 4. The difference in position between the known θ axis and the center of the resultant fit circle is calculated and gives magnitude and angle of wafer offset.

[0129] The centering routine measures and records θ, T_i, (1 . . . n) and the laser micrometer **15** reading, L_i, (1 . . . n) which represents the edge position. Typically n=50 in this application. The true radius of the wafer is assumed (100 mm or 150 mm). Theta is referenced using the wafer notch position. The following values are computed for each data point:

$$X_i=(R+L_i)\cdot\cos(T_i) \quad 1a$$

$$Y_i=(R+L_i)\cdot\sin(T_i). \quad 1b$$

[0130] The objective is to minimize the sum of squares of the deviations given by

$$D_i=(X_i-X_c)^2+(Y_i-Y_c)^2-R_c^2 \quad 2$$

where X_c is the x-axis center point, Y_c is the y-axis center point and R_c is the assumed radius. The Gauss-Newton method is used to solve the set of non-linear equations. An example of this method is given in "Least-Squares Fitting of Circles and Ellipses" by Gander, et. al. published in *BIT*, vol. 34, 1994, pp. 558-578.

[0131] As best in FIG. **11**, the system **20** can include an optical system **264** inspecting the wafer's edge. In this regard, the optical system has at least one zoom lens **262** which is rotatably positionable about the wafer's edge. The zoom lens is configured to be able to take reflected light from the wafer's edge and collect it into a CCD camera. It is envisioned that the zoom lens will have a 2 μm resolution and will be able to detect defects on the wafer's edge as well as the effectiveness of the cleaning process.

[0132] As shown in FIG. **12**A, the system **20** described above remove TA on the bottom level of the edge. Further, as shown in FIG. **12**B, the system is capable of removing polymer from the top of the wafer, revealing a dielectric surface. Additionally, it is envisioned the system can use thin film spectroscopic reflectivity. Further, the optical system is disclosed in U.S. patent application Ser. No. 11/417,297, filed on May 2, 2006 and titled "Substrate Illumination and Inspection System," previously incorporated by reference above.

[0133] As can be seen in FIGS. **13** through **16**B, the wafer processing system **20** includes the wafer movement system **27** having a spindle **60** configured to move the wafer in three or four axes of movement. In this regard, the wafer movement system **27** is configured to move the wafer within an isolated chamber **22** in xyz and θ directions (motion occurs in r,z and theta directions). The isolated chamber **22** has a bottom wall **162** defining an aperture **164** and having a first exterior bearing surface **166**. The labyrinth seal **70** has a sealing plate **168** having a second bearing surface **170** is slidably positioned against the first bearing surface **166**. The sealing plate **168** further defines a bore **172** which is annularly disposed about the spindle **60**. A first vacuum chamber **174** is defined between the first and second bearing surfaces **160**, **170**. Additionally, a vacuum source is coupled to the first vacuum chamber **174**.

[0134] FIG. **13** represents and exploded view of a portion of the wafer processing assembly **20**. Shown is a portion of the chamber **22**, the labyrinth seal **70** and associated isolator assembly **25** components. As can be seen, the labyrinth assembly **70** is formed of a sealing plate **168** and support plate **169**. The support plate **169** defines a vacuum gallery **173** which is fluidly coupled to the vacuum chamber **174** defined between the first and second bearing surfaces **160** and **170** of the chamber bottom wall **162** and sealing plate **168** bearing surface **170**. Also shown is the relationship of

the spindle **60** and the apertures **172** and **164** formed in the sealing plate **168** and the bottom wall **162**. Also shown is the relationship of a loading position **181** and the second processing position **186**.

[**0135**] As best seen in FIGS. **14**A-B and **15**, either the first or second bearing surfaces **166**, **170** can define a groove **178**. This groove **178** forms a portion of the first vacuum chamber **174** defined between the first and second bearing surfaces **166** and **170**. This chamber **174** is movable with respect to the bottom wall **162** upon movement of the spindle **60** by the actuation mechanism.

[**0136**] Adjacent to the bore **172**, the sealing plate **168** can define second groove **180**. A second vacuum chamber **182** can be defined between the second groove **180** and the spindle **60**. This second vacuum chamber **182** can be independently coupled to the vacuum source **176**. As best seen in FIG. **15**, the wafer movement system **27** comprises a wafer supporting chuck **28** that functions to fixably hold the wafer **26** through the movement system **27**. This wafer movement system **27** is configured to move the wafer **26** from the loading position **181** to a second processing position **186**. In this regard, the processing position can be an alignment position or can be positioned adjacent to the nozzle assembly **84**.

[**0137**] With reference to FIGS. **16**A and **16**B, the operation of the wafer movement system **27** is disclosed. The spindle **60** is configured to move the wafer **26** in a plurality of directions from the loading position **181** to the processing location **186**. The isolated chamber **22** is disposed about at least a portion of the wafer movement system **27** in order to protect the mechanism of the wafer movement system **27** from the reactive gases generated during the processing of the wafers. The chamber **22** has bottom wall **162** defining an elongated bore **164** which allows the movement of the spindle **60** with respect to the chamber **22**. The bottom wall **162** first bearing surface **166** can either be located on an exterior or an interior surface of the chamber **22**.

[**0138**] FIGS. **17**A-**17**B represent an exploded sectional view of isolator **25**. The isolator **25** has a nozzle plate **216** which provides the mechanism to couple the nozzle assembly **84** and moat **51** gas supply to the moat **51**. The nozzle plate **216** defines a recess **218** which slidably accepts the nozzle of the nozzle assembly **84**. The recess **218** further defines a second recess aperture **220** which accepts an optical interface for the heating element **122**. The nozzle plate **216** allows for the configurations of the nozzle assembly **84** without the entire disassembly of the wafer processing apparatus **20**. As shown in FIGS. **17**B and **17**C, the nozzle plate **216** defines apertures and fixation pins which facilitate the alignment of the various components to the isolator **25**. In this regard, the nozzle assembly **84**, heater **122** and moat **51** gas supply lines are precisely positioned.

[**0139**] FIGS. **18**A and **18**B show a plurality of nozzles **45**,**49** coupled to a diffusion portion **221**. The structure **221** forms a plenum when installed against the nozzle plate **216**. The support member **221** fits within the recess **218** of the nozzle plate **216** to position the nozzles **45** in their proper orientation.

[**0140**] As shown in FIGS. **19**A and **19**B, the nozzles are coupled to the gas supply **55** through a plurality of welded stainless steel tubes **222**. To maintain flame stability, the gas supply **55** is controlled by controller **52**. As previously disclosed, the nozzles have a stainless steel lead-in tube **224** having a very high aspect ratio. For example, for H_2 and O_2 gas mixture, an aspect ratio of greater than or equal to 10:1 is appropriate.

[**0141**] Disposed immediately before the lead-in portion **224** of the nozzle **45** is a blowback flash suppressor device **226**. This device **226** is a chamber **228** having a volume significantly larger than the volume of the lead-in portion **224**. Disposed within the volume is a porous stainless steel member **228** which functions as an energy sink to prevent the flame front from traveling up through the nozzle **45**,**49** and into the gas supply in the event of a system failure.

[**0142**] As shown in FIGS. **20**A and **20**B, the aspect ratio of the nozzles **45** can vary depending on the fuel and oxidizer being used. In this regard, in situations where a high percentage of NF_3 is being used as an oxidizer, the nozzle **45**,**49** has a stainless steel lead-in portion **224** having an aspect ratio of greater than 40:1, and preferably 80:1. As with the other nozzles, high purity nozzle tips **230** of sapphire are preferred. The nozzle **45** has a stainless steel body **225** with locator pin **227** which allows for the coupling of the nozzle **45** with nozzle support member **221**.

[**0143**] Disposed within the mass flow controller **52** is a normally open valve (not shown) which functions to dump CDA into the fuel supply source should the power be interrupted. Additionally, should the system **20** desire to shut off the processing nozzles **45**,**49** the normally opened valve is actuated and allows CDA at a pressure higher than the pressure of the fuel source to flow into the processing nozzles **45**, effectively extinguishing the flames without the risk of a system explosion.

[**0144**] FIGS. **21**A and **21**B represent an alternate method of coupling nozzles to the isolator **25**. Shown is an aperture **232** defined into either the isolator **25** or the nozzle plate **216**. Disposed within the aperture **232** are a plurality of nozzle subplates **234** which have individual nozzles **45**. These nozzles subplates **234** are movable with respect to each other in fore and aft directions to allow for relative positioning of the subplates within the isolator **25**. The individual nozzle subplates **234** can be stacked immediately adjacent to each other to form a nozzle assembly **84**.

[**0145**] FIGS. **22**A and **22**B depict individual nozzle subplates **234**. Disposed on the inner face surfaces **236** of the nozzle subplates **234** are grooves **238** which function as fluid chambers **240**. These fluid chambers **240** are coupled to a vacuum or pressurized gas source (not shown) and function to divert reaction gas products which might leak from the processing chamber **22** during wafer processing. It is envisioned that inert or oxygen containing gas can be supplied to the nozzle plate, which will in turn flow into the isolator through the aperture **232**.

[**0146**] FIG. **22**B depicts a cross-sectional view of the nozzle plate **234** shown in FIG. **22**A. As can be seen, structures such as the high aspect ratio lead-in tube **224** and blowback flash suppressor device **226** can be machined therein. These features significantly reduce the cost of the assembly and increases the overall system reliability.

[**0147**] In operation, fuel is provided to the nozzles **45**, through the flash suppressor device **226** from the mass flow controller **52**. The vacuum source draws a vacuum in the

vacuum chamber **236** preventing corrosive reaction gases from leaking past the nozzle assembly **84**.

[**0148**] FIGS. **23**A and **23**B, represent an igniter assembly **78** which is configured to cleanly ignite the nozzles **45** and **49** of the nozzle assembly **84**. The igniter assembly **78** has an optically clear or sapphire hot body igniter **242** defining an interior cavity **244**. The hot body igniter **242** provides high chemical resistance, which is non-particle forming. A heating element **246** is disposed within the interior cavity **244**. This heating element, which can be a Pt:Rh element, functions to quickly bring the hot body igniter to a predetermined temperature which will ignite a fuel oxidizer mixture when the fuel touches the igniter hot body **242**.

[**0149**] As seen in FIG. **23**B, the ceramic hot body igniter **242** can be physically and optically coupled to a laser diode **252**. In this configuration, the laser diode **252** is configured to produce photons which past through the interior cavity **244**. These photons strike the heating element **246**, thus producing a reliable ignition system. Alternatively, the hot body **242** can be coated on an interior or exterior surface with materials which increase photon absorbance at wavelengths of interest.

[**0150**] Disposed at a distal end of the elongated cavity **244** is the heating element **246**. This heating element **246** can be electrically coupled to a power source which functions to provide electric current to heat the heating element. Alternatively, this element can be inductively heated.

[**0151**] As shown in FIGS. **24** and **25**B, operably disposed between an igniter nozzle assembly **248** and the nozzle assembly **84** is an air knife **250**. The Air knife **250** is fluidly coupled to a source of CDA or inert gas. The igniter nozzle assembly **248** is operably coupled to a fuel source **52** and can have a sapphire nozzle tip **252** as described above.

[**0152**] In operation, the system for initiating a clean flame, needed in the processing of the wafer **26**, includes disposing the heating element **246** within an igniter assembly **78** and energizing the heating element **246** so as to bring the assembly **78** to a predetermined ignition temperature. Gas is then passed through an ignition nozzle assembly **248** at a first gas rate pass the igniter assembly **78** to ignite an initiation flame. The initiation flame is then passed by a plurality of nozzles of a nozzle assembly **84** to ignite a plurality of flames from the nozzles. After the plurality of nozzles of the nozzle assembly **84** have been lit, an air dam is passed in front of the initiation flame by actuating the air knife **250**. A non-flammable gas is then passed through the initiator nozzle **248** at a second predetermined rate. In this regard, a second predetermined rate can be greater than the rate of fuel passing through the nozzle. This prevents blow back into the ignition system to the equipment. The use of the air knife **250** allows for the extinguishment of the initiation flame without disruption of the processing flames.

[**0153**] With reference to FIG. **26**, shown is an alternate clean ignition system. Similar to the system shown in FIGS. **23**A and **23**B, the ignition system includes a nozzle **248** for injecting pressurized fuel in proximity to the nozzle assembly **84**. This nozzle **248** produces gas jet, which is temporally changed into a plasma and ignited by a very high intensity laser **256**. It is envisioned that the ignition system can be disconnected by either shutting off the source of the plasma gas, or disengaging the laser **256**.

[**0154**] As shown in FIG. **27**, optical analysis electronics (not shown) are connected to a fiber optic coupler **210** disposed in the upper section **38** of the isolator **25** in position to receive photon emission from reactive processes. The optical analysis electronics are used to observe and analyze reactive processes to determine presence of reactive species and/or relative concentration of reactive species. In another alternative mode of this feature, optical emission spectroscopy can be used to infer etch end points based on reactive species and/or etched products observed to be present in the region where the chemical reaction in taking place.

[**0155**] FIG. **27** represents a top view of a flame sense system for use in the wafer processing system according to FIG. **1**A. Shown is the nozzle plate **216** which supports the nozzle assembly **84** having processing nozzles **45** and **49**. Directed to the nozzles **45** and **49** is a CCD spectral analyzer **260**. The spectrometer is configured to receive emissions from the flames emitted from the nozzles **45** and **49**.

[**0156**] FIG. **28** represents an intensity graph for a spectrum of particular interest. In this regard, the graph depicts wavelength between 200 and 400 nm. As can be seen, under the curve of wavelength between 302 and 324 nm varies depending on the number of flames initiated. It is envisioned that the system can determine the quality and quantity of the number of flames being produced by the system by analyzing the spectral output.

[**0157**] The spectral region of interest used for flame sensing with H_2 and O_2 dominated gas mixtures is between about 300 and 325 nm. Emissions around 309 nm is from an intermediate O—H species generated in the flame.

[**0158**] It is envisioned that the mass flow controller **52** of the present system can be coupled to the spectral analyzer **260**. In this regard, it is envisioned that should the system determine that one or more nozzles has not be properly emitted, the system will signally fault and can shut the system down. As shown in FIG. **29**, varying the number of nozzles, varies the output of the system. This can be detected to determine if the system is functioning properly.

[**0159**] The foregoing discussion discloses and describes exemplary embodiments of the present invention. One skilled in the art will readily recognize from such a discussion, and from the accompanying drawings and claims that various changes, modifications, and variations can be made therein without departing from the spirit and scope of the invention.

1. A substrate processing apparatus for processing the substrate with a combustion flame of hydrogen and a non-oxygen oxidizer, comprising:

a processing chamber for receiving the substrate and for confining a clean environment for the combustion flame;

a processing nozzle assembly within the processing chamber for directing the combustion flame onto the substrate;

a source for fuel and the oxidizer operationally attached to the processing chamber;

an igniter assembly having a ceramic hot body igniter defining an interior cavity;

a heating element disposed within the interior cavity;

a means for energizing the heating element; and

an igniter nozzle assembly operably coupled to a fuel source, said igniter assembly configured to direct an initiation combustion flame within a predetermined distance from the processing nozzle assembly.

2. The substrate processing apparatus for processing the substrate with a combustion flame of claim 1, wherein the hot body igniter comprises a sapphire body.

3. The substrate processing apparatus for processing the substrate with a combustion flame of claim 1, wherein the hot body igniter comprises an optically clear ceramic.

4. The substrate processing apparatus for processing the substrate with a combustion flame of claim 1, wherein the heater element is electrically connected to a power source.

5. The substrate processing apparatus for processing the substrate with a combustion flame of claim 1, further comprising a power source configured to apply an electromagnetic wave to the heater element.

6. The substrate processing apparatus for processing the substrate with a combustion flame of claim 5, wherein the power source is one of a laser or a laser diode.

7. The substrate processing apparatus for processing the substrate with a combustion flame of claim 1, further comprising a power source configured to apply an electromagnetic wave to the heater element.

8. The substrate processing apparatus for processing the substrate with a combustion flame of claim 1, wherein the processing chamber maintains a substantially atmospheric pressure.

9. The substrate according to claim 1 wherein the ceramic has a melting temperature greater than 3000° k.

10. An igniter assembly comprising:

a sapphire body;

a heating element thermally coupled to the sapphire body;

a power source configured to apply an electromagnetic wave to the heating element; and

an igniter nozzle assembly disposed adjacent to the sapphire body, said nozzle assembly being coupled to a fuel source.

11. The igniter assembly according to claim 10 wherein the sapphire body defines an interior chamber and wherein the heating element is disposed within the chamber.

12. The igniter assembly according to claim 10 wherein the power source is a laser diode.

13. The igniter assembly according to claim 12 wherein the power source is a laser.

14. The igniter assembly according to claim 11 wherein the power source is an electrical current supply.

15. The igniter assembly according to claim 10 wherein a power source transmits photons at a predetermined frequency and the sapphire body is transparent at the predetermined frequency.

16. The igniter assembly according to claim 10 wherein the igniter nozzle defines a gas jet along a first line and wherein the sapphire body is disposed a first predetermined distance from the line.

17. The igniter assembly according to claim 16 further comprising at least one process gas nozzle, said process gas nozzle is disposed a second predetermined distance from the line.

18. The igniter assembly according to claim 19 further comprising an air knife disposed between the igniter assembly and the process gas nozzle.

19. A method for igniting a flame comprising:

disposing a heating element within an igniter assembly;

energizing the heating element so as to heat the igniter assembly to a predetermined ignition temperature;

passing a fuel past the ignition nozzle at a first rate past the igniter assembly to ignite a flame;

passing the flame past a plurality of nozzles to ignite a plurality of processing flames from the nozzles.

20. The method of igniting a flame according to claim 19 further comprising passing an air dam in front of the first flame.

21. The method of ignition according to claim 19 further comprising passing a non-flammable gas though the ignition nozzle at a second predetermined rate.

22. The method of igniting a flame according to claim 21 wherein the second predetermined rate is greater than the first predetermined rate.

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