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(54) **HALL THRUSTER WITH SHARED MAGNETIC STRUCTURE**

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H05B 7/24 (2006.01)
H01J 27/00 (2006.01)
G21G 4/00 (2006.01)

(52) **U.S. Cl.** .... **315/111.21**; 315/111.41; 315/111.61; 315/111.81; 250/423 R; 250/427; 250/493.1

(58) **Field of Classification Search** .... 315/111.21, 315/111.41, 111.61, 111.81; 250/423 R, 250/427, 493.1
See application file for complete search history.

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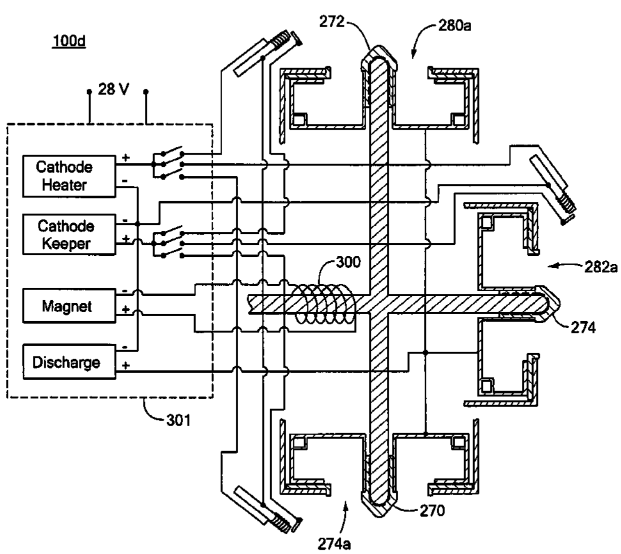
(57) **ABSTRACT**

A Hall thruster with a shared magnetic structure including a plurality of plasma accelerators each including an anode and a discharge zone for providing plasma discharge. An electrical circuit having one or more cathodes connected to the plurality of plasma accelerators emits electrons that are attracted to the anode in each of the plasma accelerators. A shared magnetic circuit structure establishes a transverse magnetic field in each of the plurality of plasma accelerators that creates an impedance to the flow of electrons toward the anode in each of the plurality of plasma accelerators and enables ionization of a gas moving through one or more of the plurality of plasma accelerators. The impedance localizes an axial electric field in the plurality of plasma accelerators for accelerating ionized gas through the one or more of the plurality of plasma accelerators to create thrust.

29 Claims, 16 Drawing Sheets



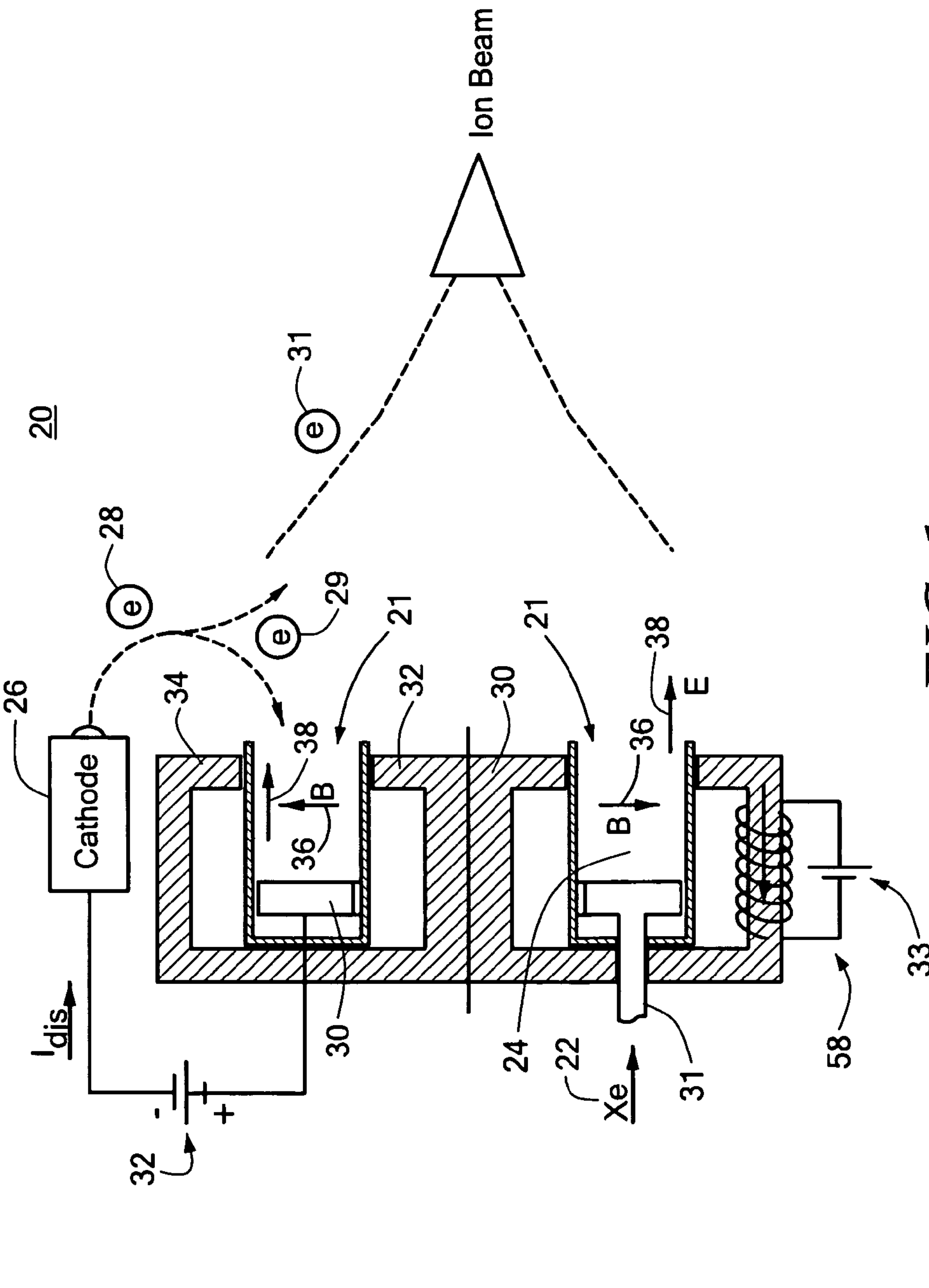


FIG. 1

PRIOR ART

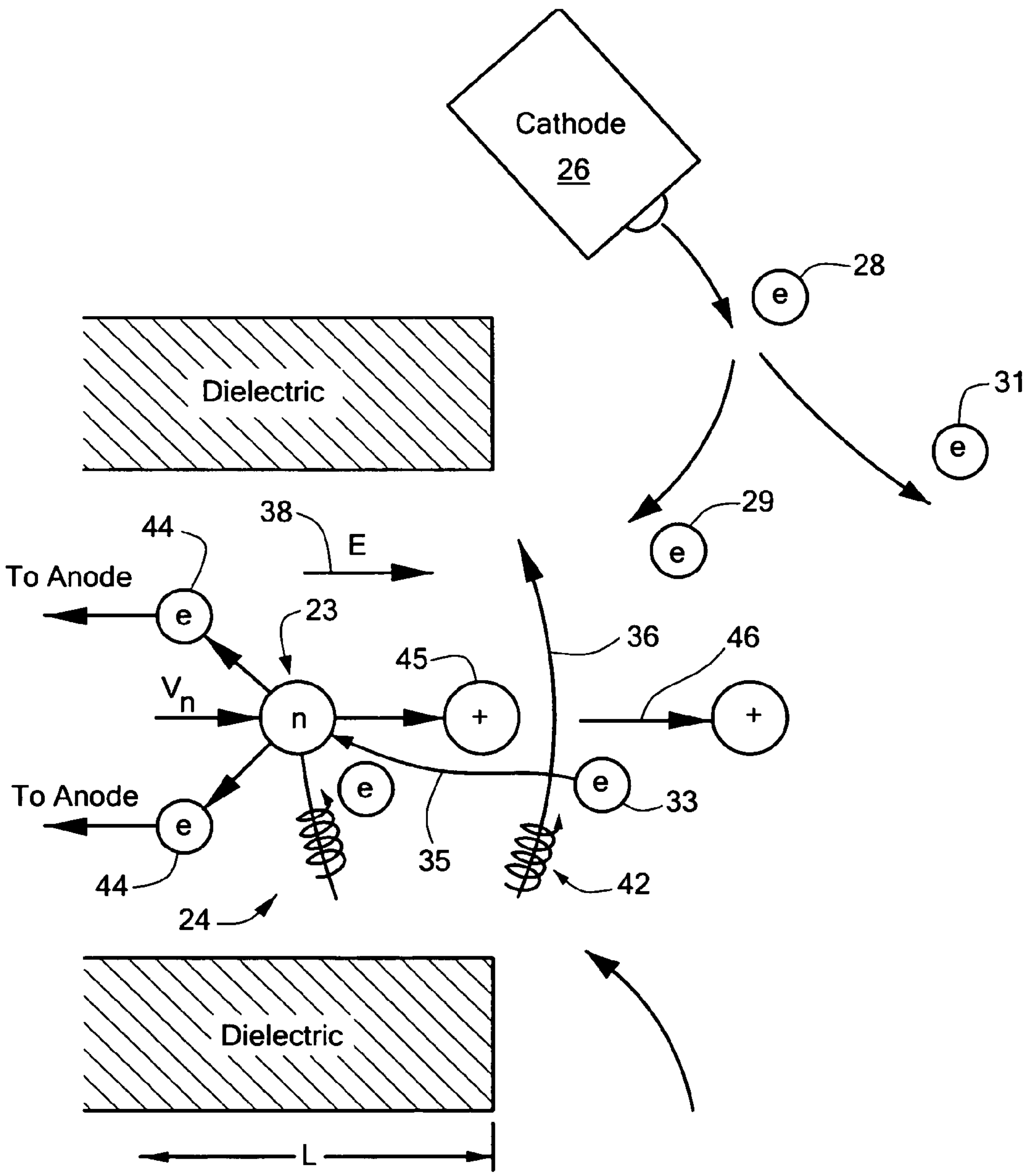


FIG. 2

PRIOR ART

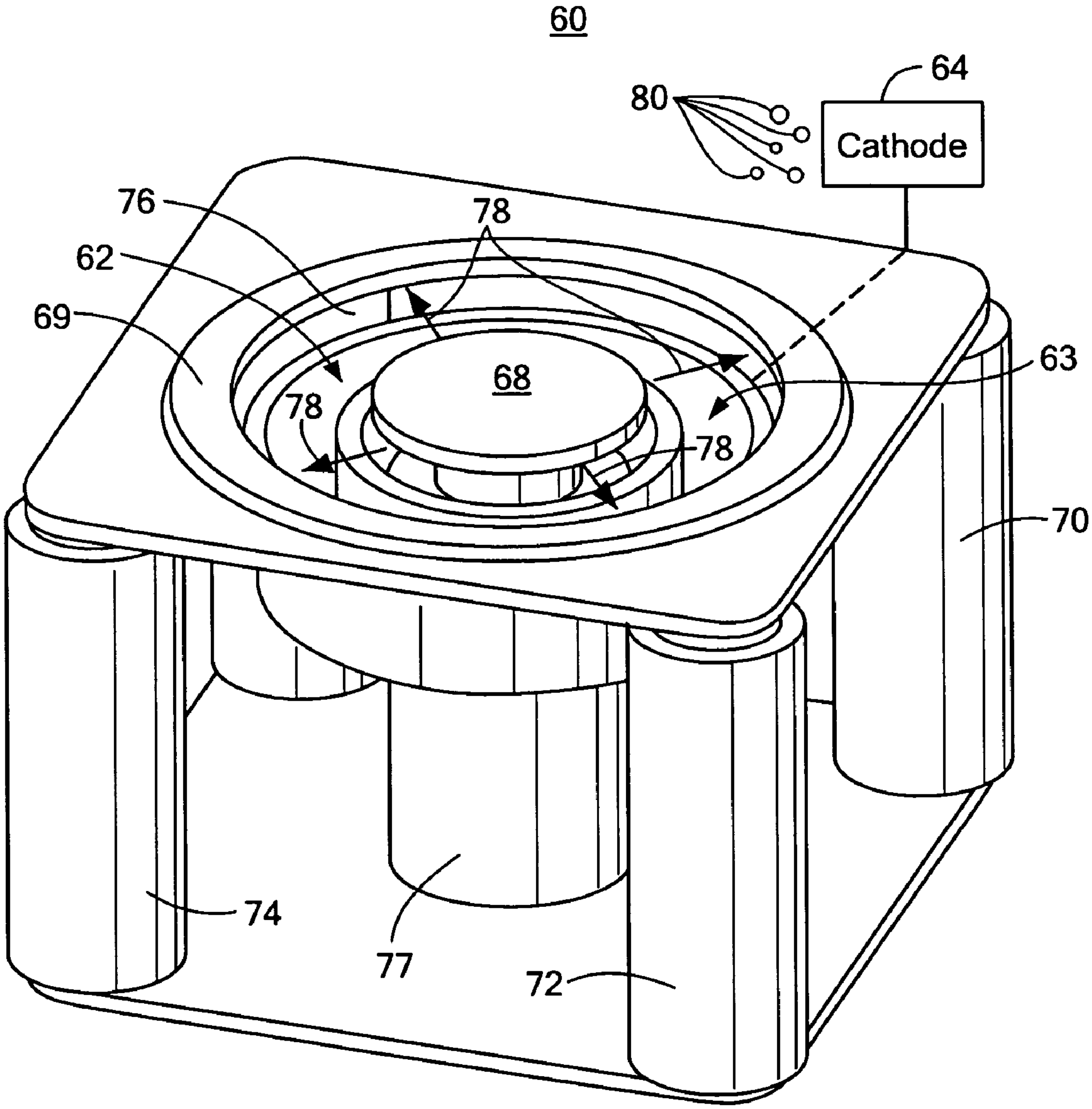


FIG. 3

PRIOR ART

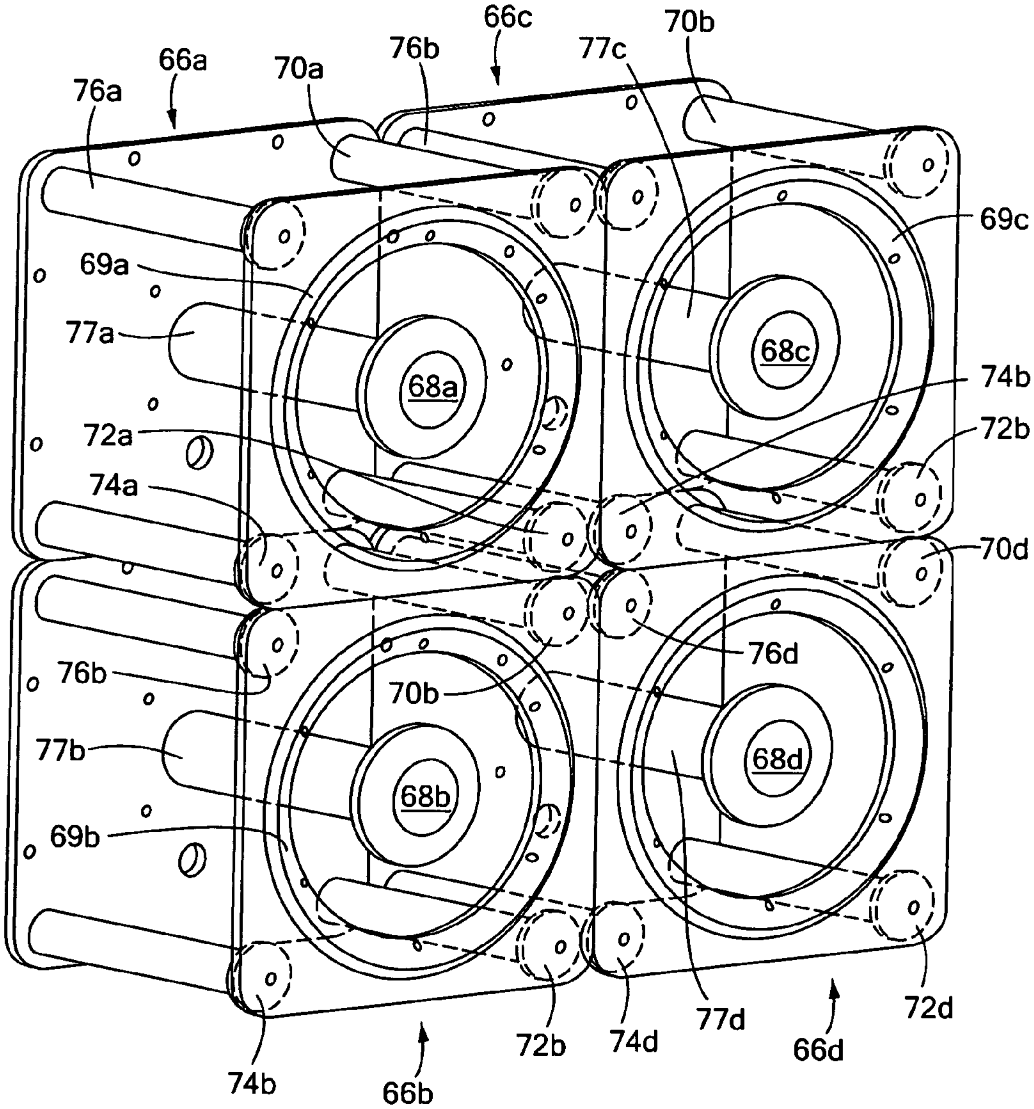


FIG. 4

PRIOR ART

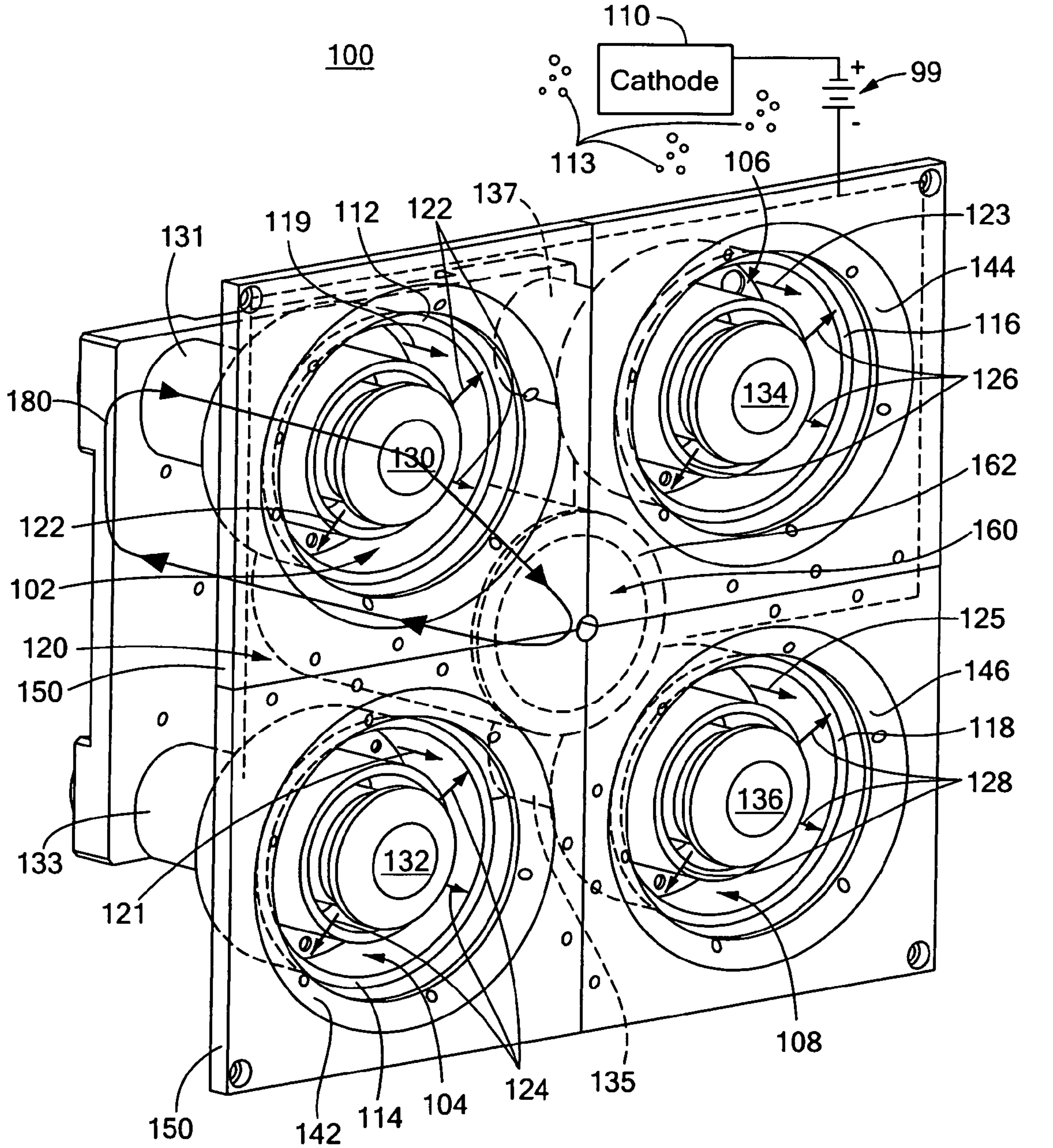

100
110
Cathode
99
+
-
113
106
137
119
112
122
123
131
144
116
126
180
134
130
162
122
160
102
125
120
150
146
118
128
136
133
132
121
108
150
142
114
104
124
135

FIG. 5

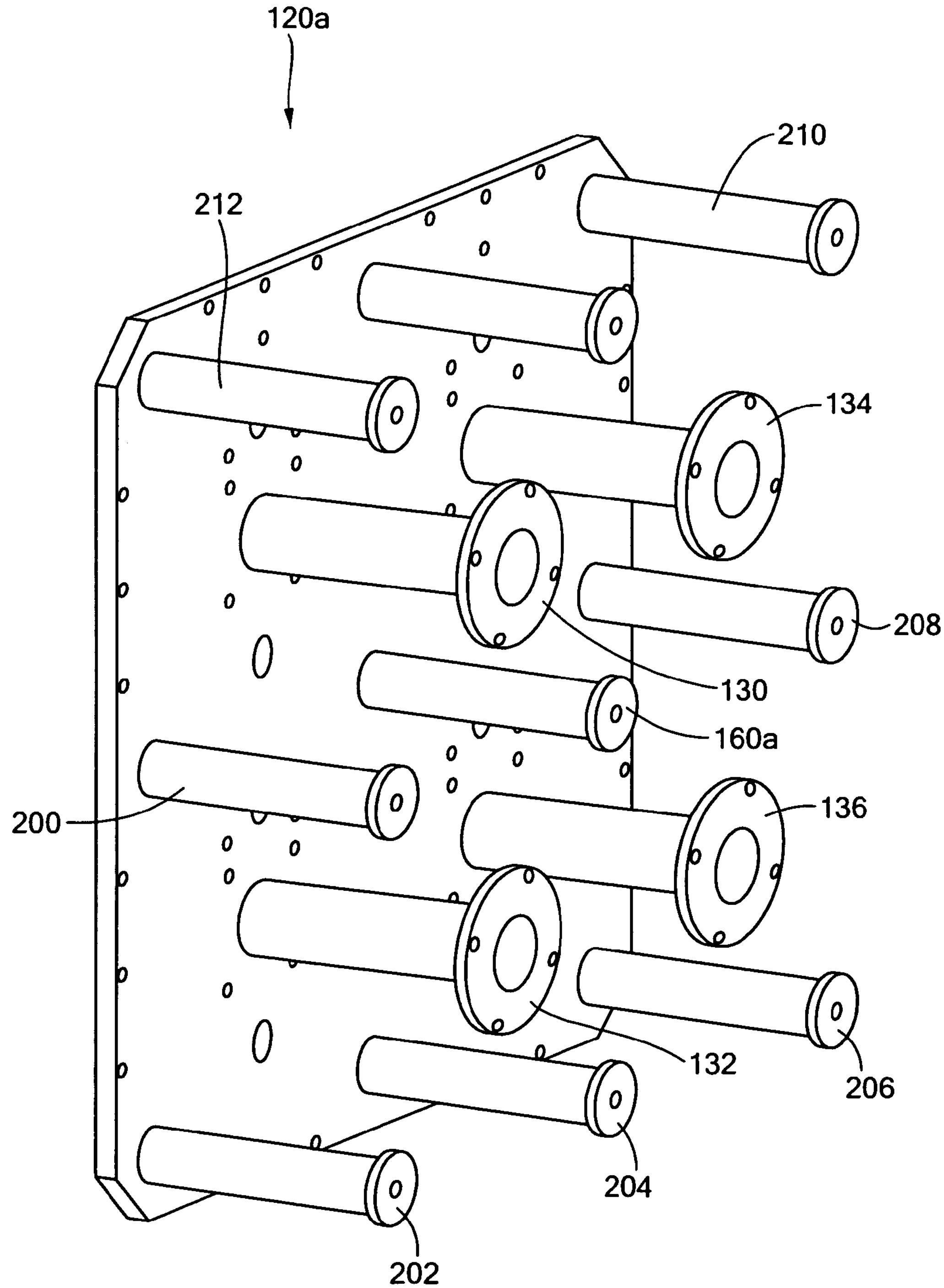


FIG. 6

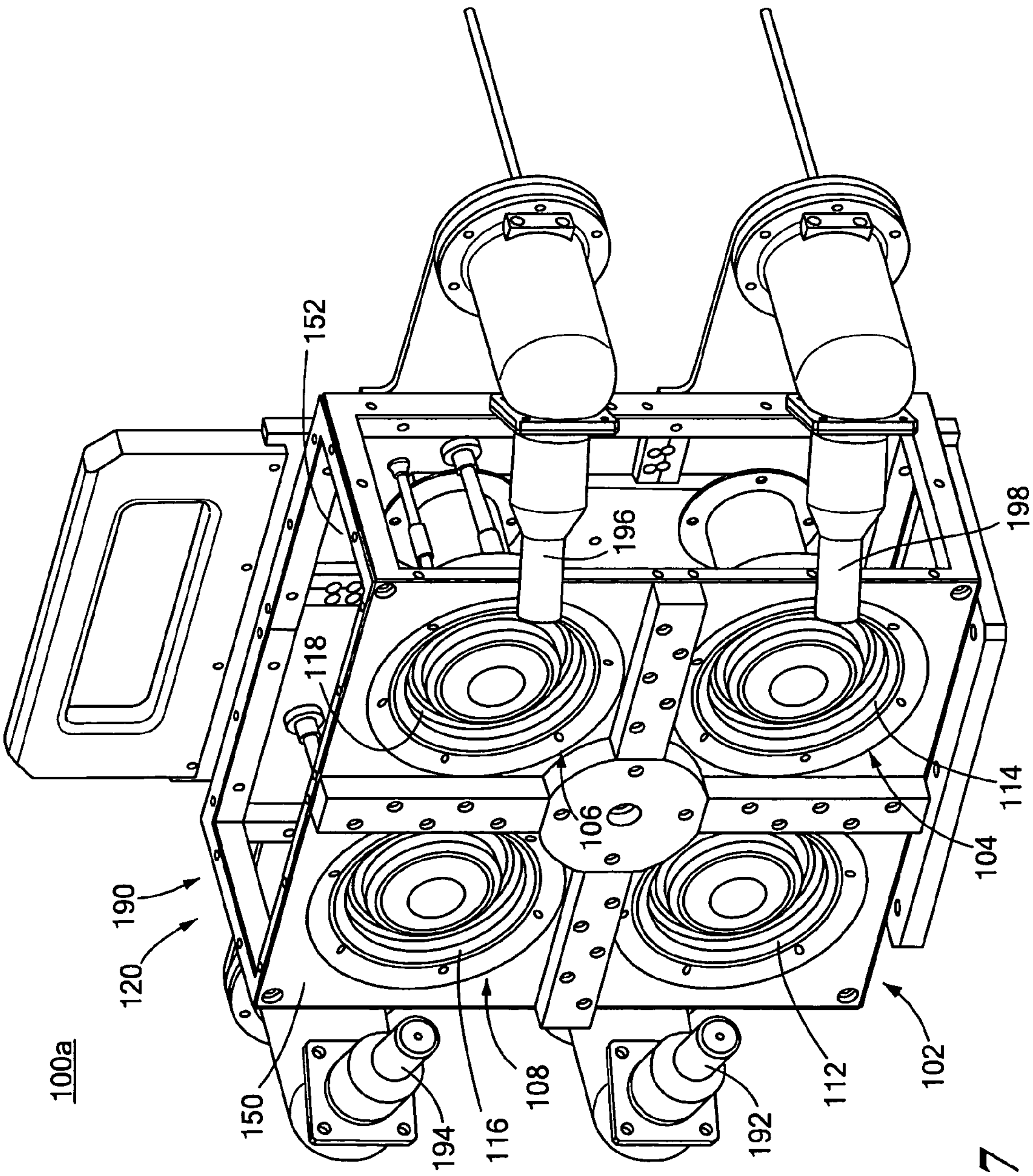

100a
150
194
116
108
112
192
102
120
190
152
196
198
118
106
104
114

FIG. 7

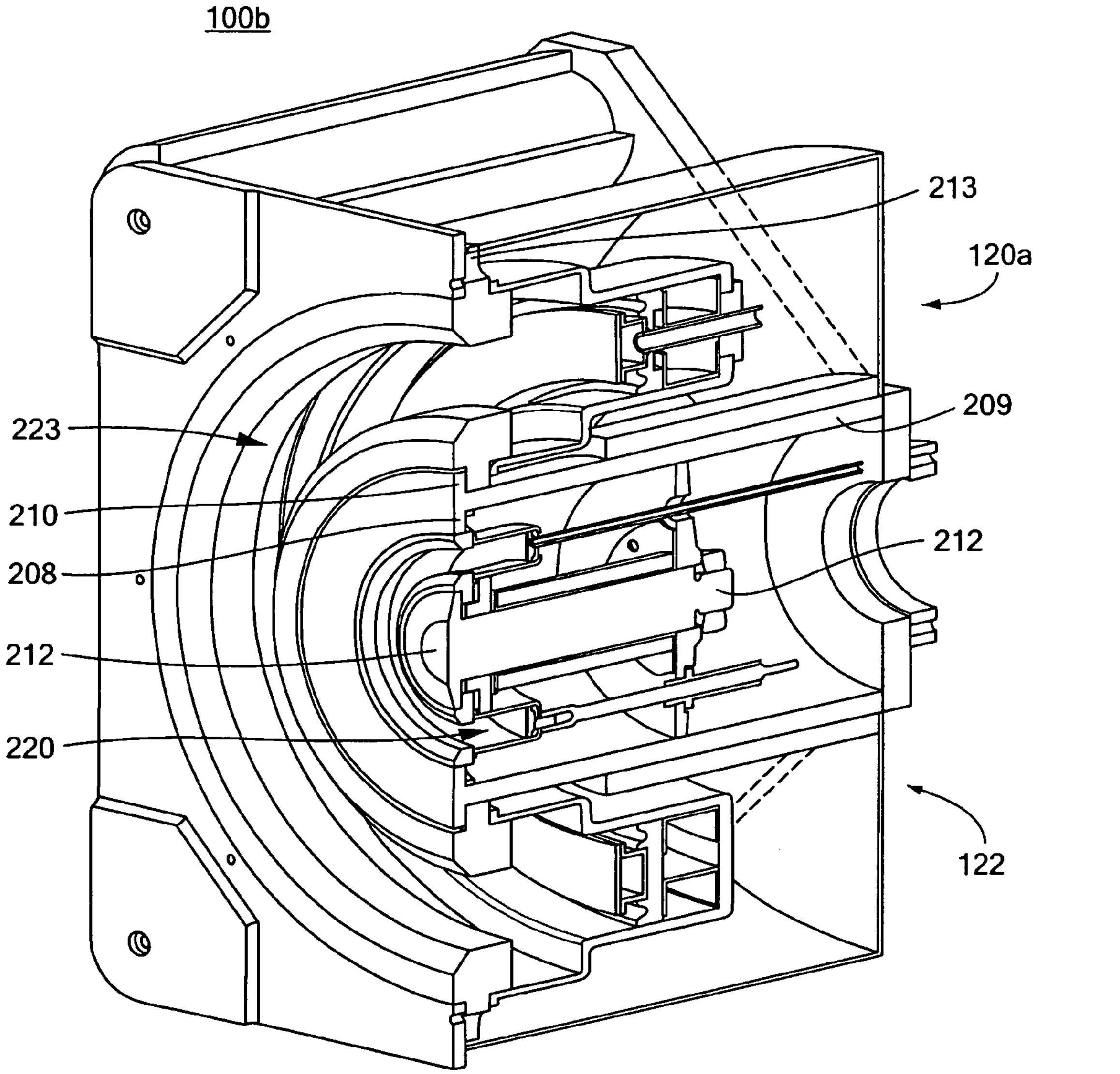


FIG. 8

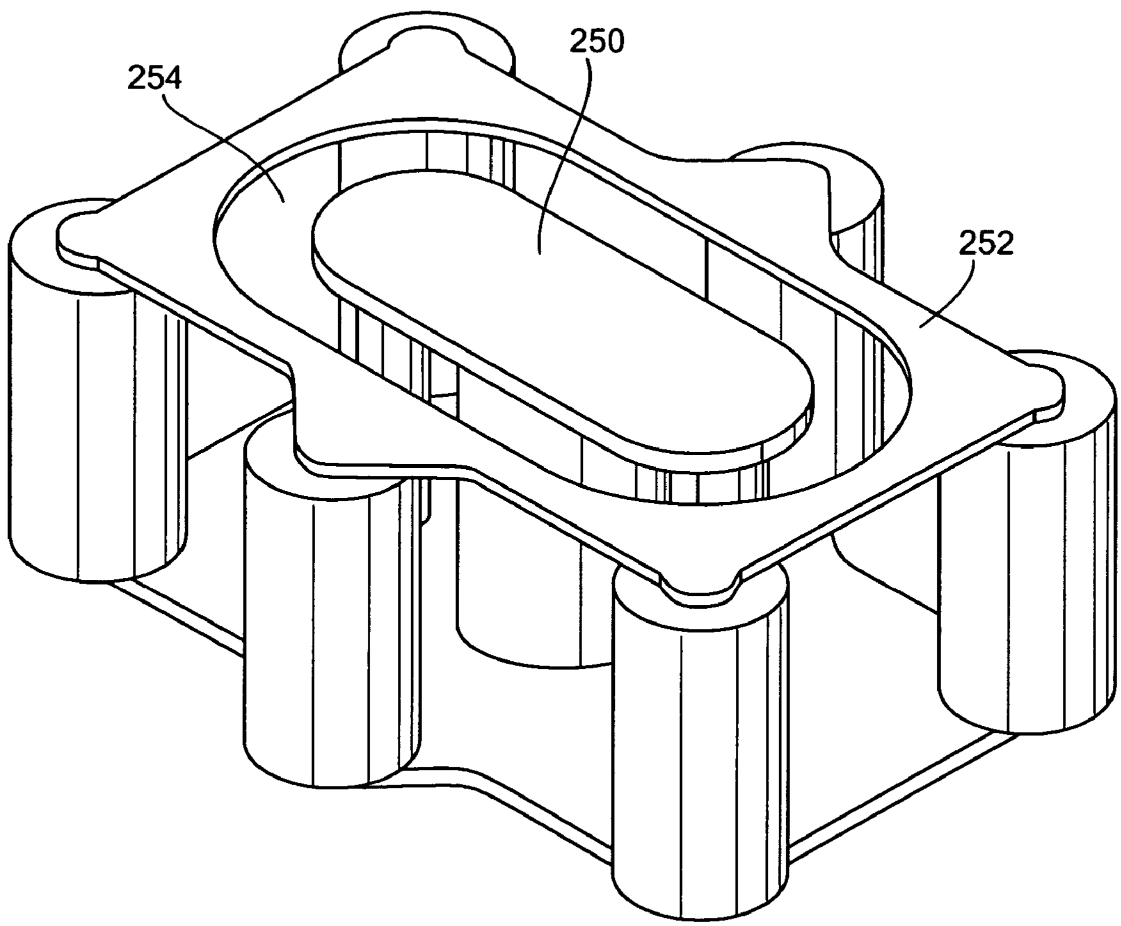


FIG. 9

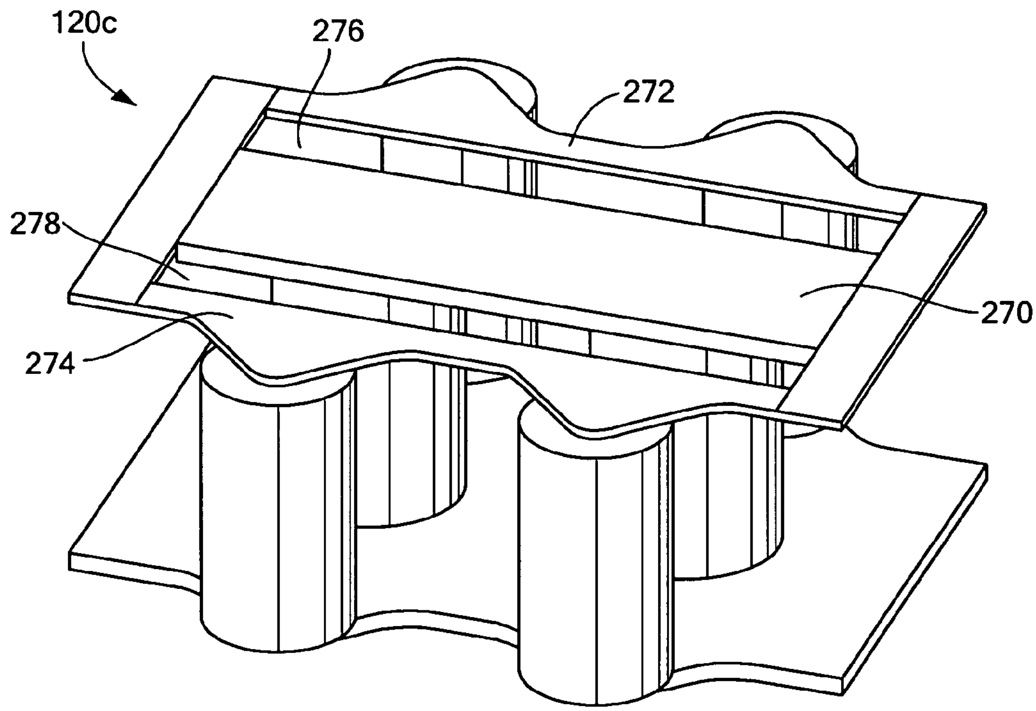


FIG. 10

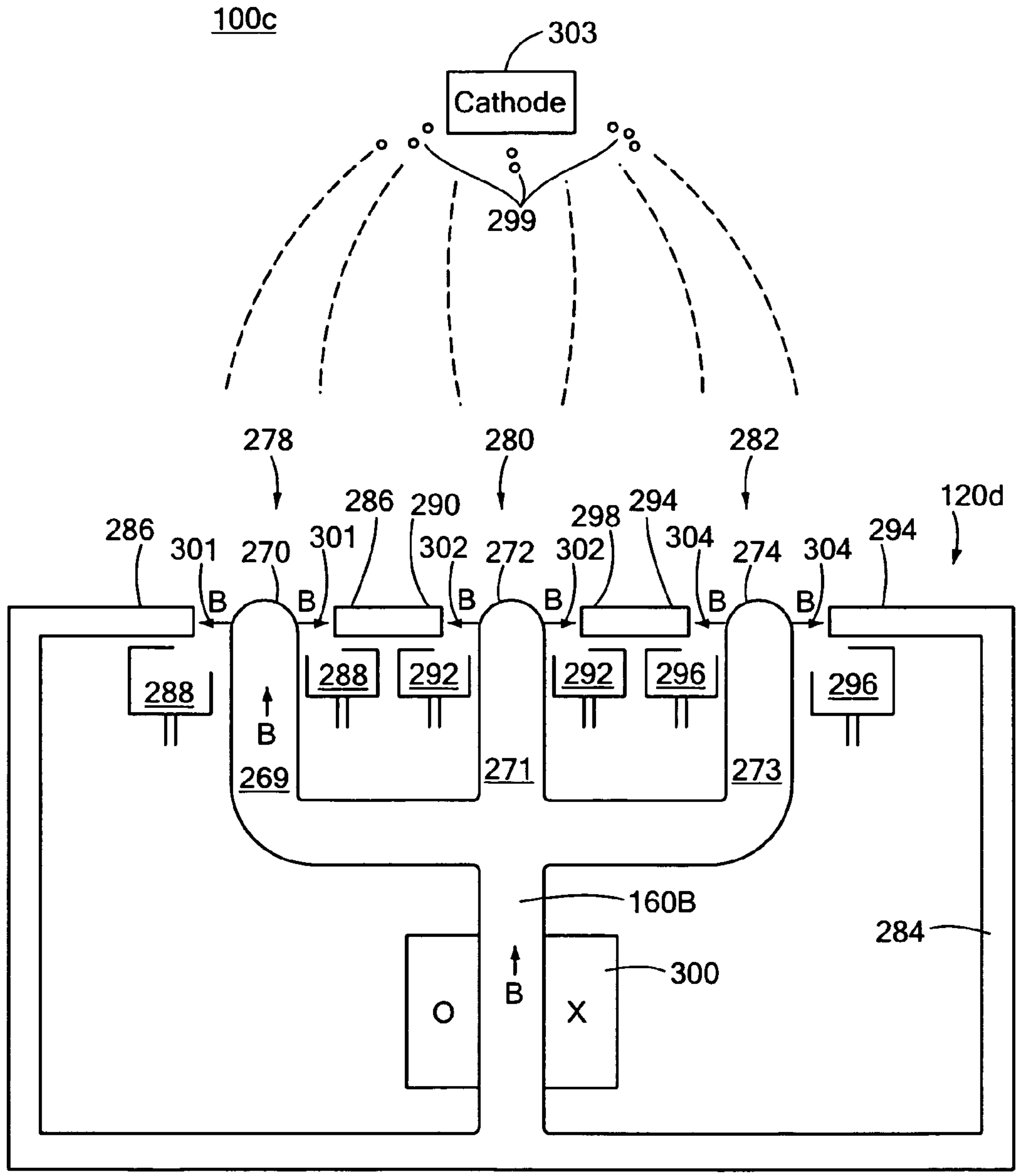

100c
303
Cathode
299
278
280
282
286
290
298
294
120d
286
301
270
301
302
272
302
304
274
304
294
B
B
B
B
B
B
288
288
292
292
296
296
B
269
271
273
160B
284
300
B
O
X

FIG. 11

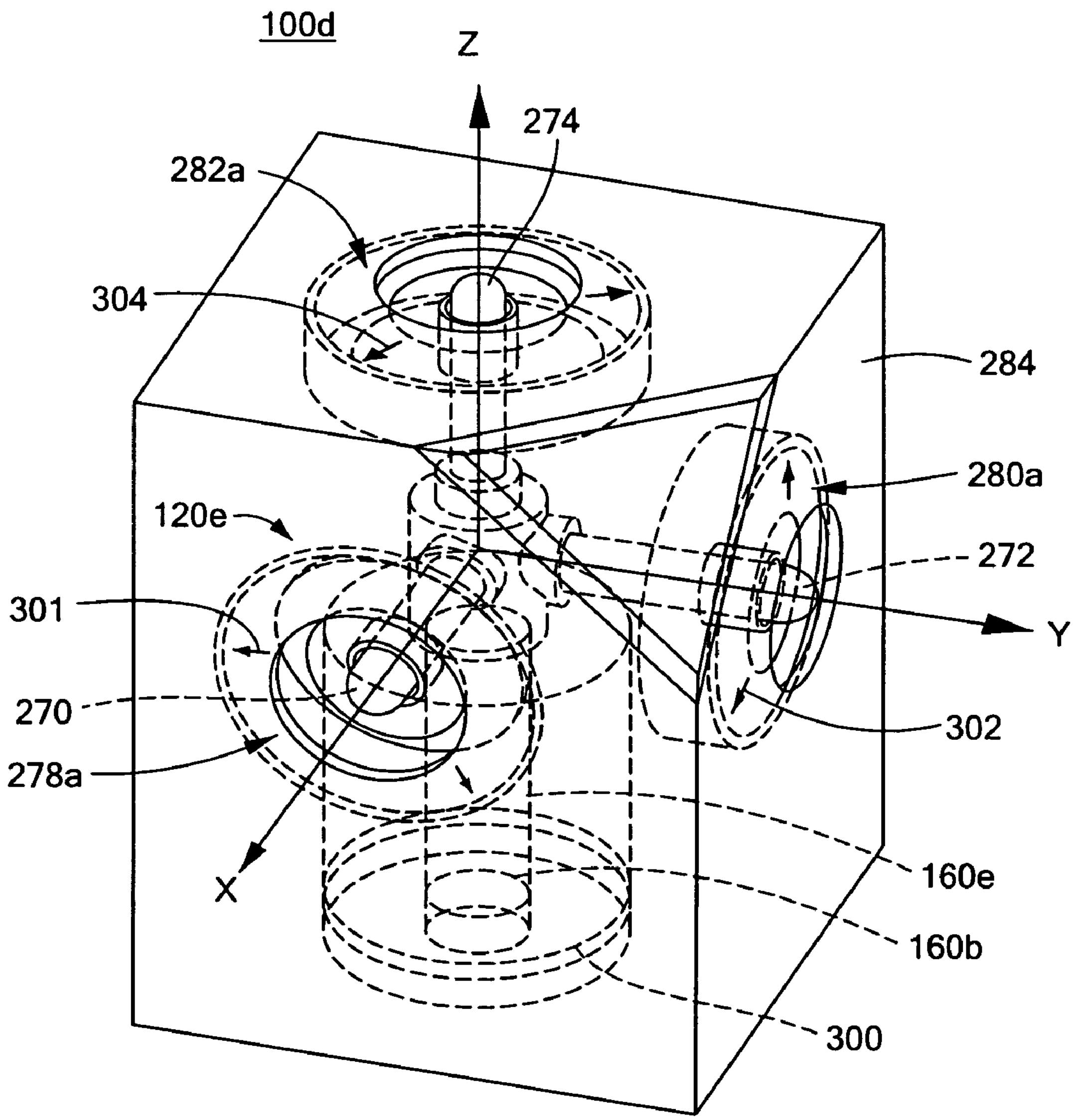

100d
Z
274
282a
304
284
280a
120e
272
301
Y
270
302
278a
160e
X
160b
300

FIG. 12

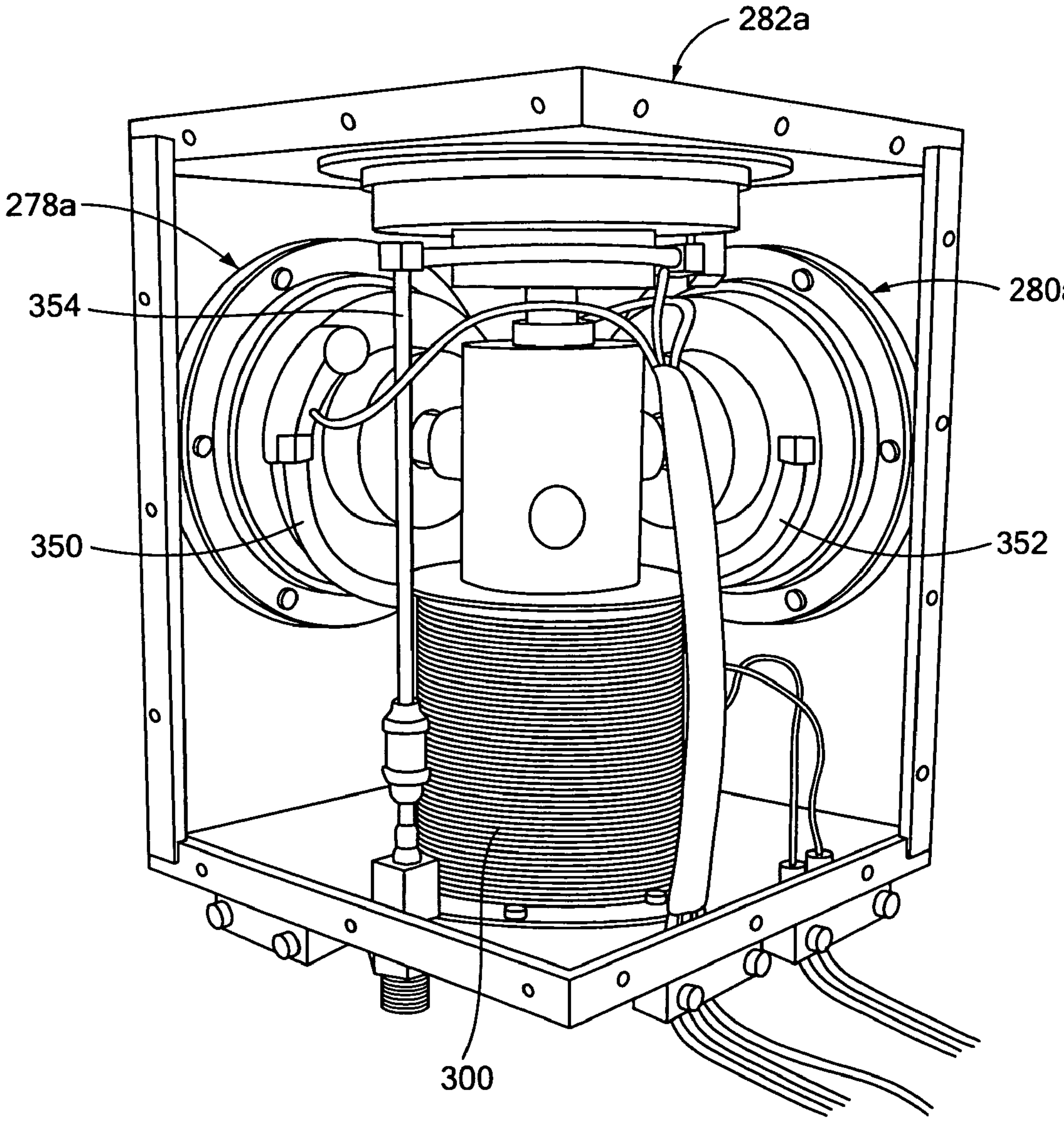


FIG. 13

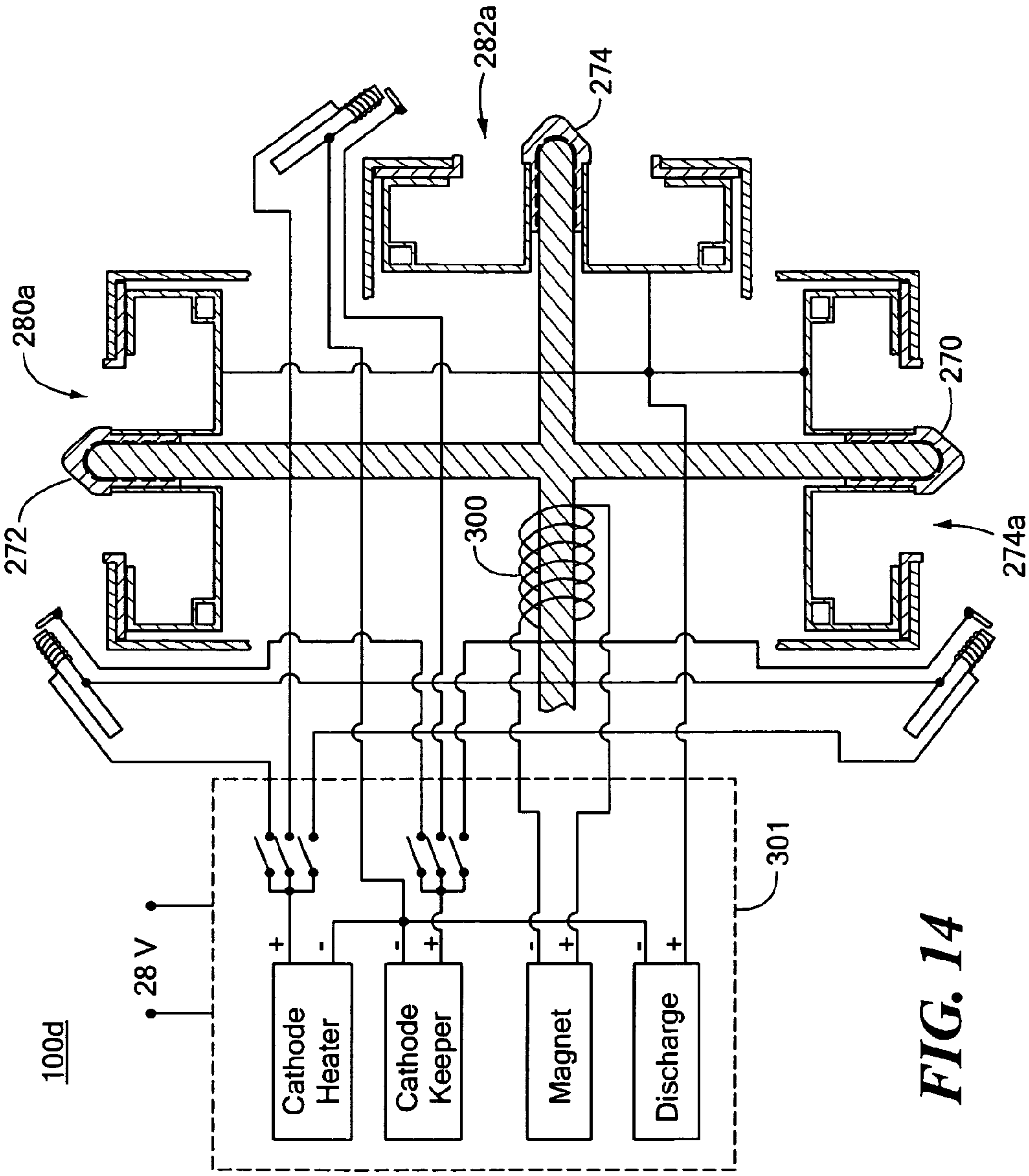

282a
274
280a
270
272
300
274a
301
28 V
100d
Cathode Heater
Cathode Keeper
Magnet
Discharge

FIG. 14

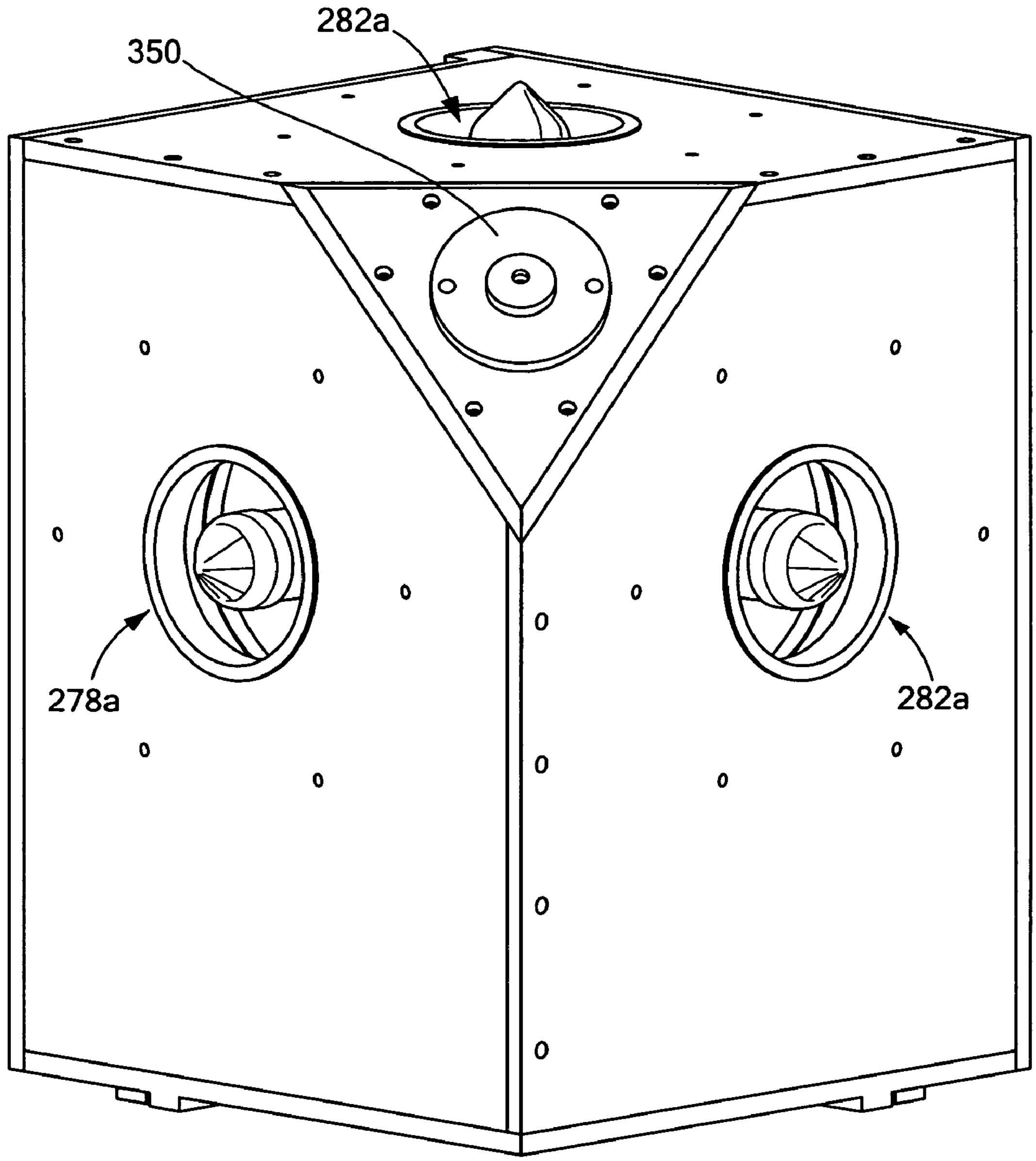


FIG. 15

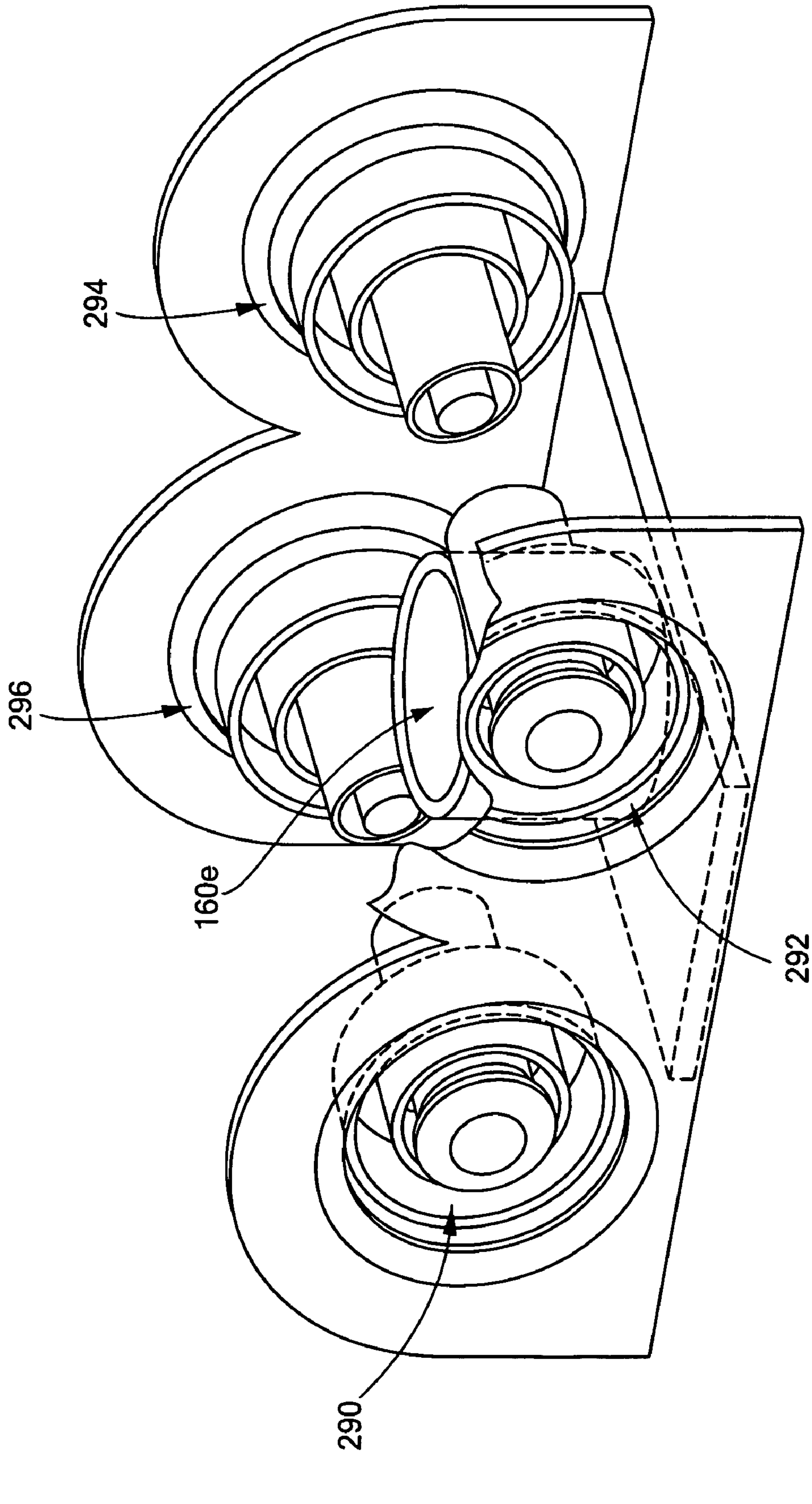


FIG. 16

HALL THRUSTER WITH SHARED MAGNETIC STRUCTURE

RELATED APPLICATIONS

This application claims benefit of U.S. Provisional Application Ser. No. 60/635,639 filed Dec. 13, 2004, incorporated by reference herein.

GOVERNMENT RIGHTS

This invention was made with U.S. Government support under Contract No. F04611-03-M-3014 awarded by the Office of the Secretary of Defense (OSD). The Government may have certain rights in the subject invention.

FIELD OF THE INVENTION

This invention relates generally to a Hall thrusters and more particularly to an improved Hall thruster with a shared magnetic structure.

BACKGROUND OF THE INVENTION

Hall Thrusters are typically used in rockets, satellites, spacecraft, and the like. In a typical Hall Thruster the working fluid is plasma and the means of acceleration is an electric field. A Hall thruster typically includes a plasma accelerator that includes a propellant, a gas distributor, and an anode located at one end of a channel. An electric circuit provides an electric potential that is applied between the anode and a floating externally located cathode that emits electrons. A magnetic circuit structure typically includes an outer pole, an inner pole, and a plurality of outer magnetic field sources, e.g., electromagnetic coils or permanent magnets, for the outer pole and an inner magnetic field source for the inner pole. The magnetic circuit structure establishes a transverse magnetic field between the outer pole and the inner pole that presents an impedance to electrons attracted to the anode. As a result, the electrons spend most of their time drifting azimuthally (orthogonally) due to the transverse magnetic field. This allows the electrons time to collide with and ionize the neutral atoms. The collisions create positively charged ions that are accelerated by the electric field to create thrust. See e.g., U.S. Pat. Nos. 6,150,764; 6,078,321; 6,834,492 by one or more common inventors hereof, all incorporated in their entity by reference herein.

When a plurality of conventional Hall thrusters are arranged in close proximity to each other to power a spacecraft or similar vehicle, each plasma accelerator of each thruster requires its own magnetic circuit structure that typically includes a plurality of outer magnetic field sources for the outer pole and an inner magnetic field source for the inner pole. Each thruster also includes its own power processing unit (PPU) that provides power for the magnetic circuit structure and the electric circuit. Such a design suffers from excessive weight, volume and power, is complex, expensive, and inefficient.

BRIEF SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide an improved Hall thruster with a shared magnetic structure.

It is a further object of this invention to provide such a Hall thruster which can share one or more magnetic circuit structures with a plurality of plasma accelerators.

It is a further object of this invention to provide such a Hall thruster which reduces the number of magnetic field sources needed for a plurality of plasma accelerators.

It is a further object of this invention to provide such a Hall thruster which reduces the weight.

It is a further object of this invention to provide such a Hall thruster which can share a single power processing unit with a plurality of plasma accelerators.

It is a further object of this invention to provide such a Hall thruster which reduces the volume.

It is a further object of this invention to provide such a Hall thruster which saves power.

It is a further object of this invention to provide such a Hall thruster which provides for steering of the Hall thruster.

It is a further object of this invention to provide such a provides for attitude control of the Hall thruster.

It is a further object of this invention to provide such a Hall thruster which provides for throttle adjustment of the Hall thruster.

It is a further object of this invention to provide such a Hall thruster is less complex.

It is a further object of this invention to provide such a Hall thruster which is less expensive.

It is a further object of this invention to provide such a Hall thruster which is more efficient.

The invention results from the realization that an improved Hall thruster that can share one or more magnetic circuit structures with a plurality of plasmas accelerators to reduce the weight, volume, and power requirements of the Hall thruster and also provide for steering, attitude control and throttle adjustment is effected with a plurality of plasma accelerators that each include an anode and a discharge chamber to provide plasma discharge, an electrical circuit that includes at least one cathode connected to the plurality of plasma accelerators that emit electrons that are attracted to the anode in each of the plasma accelerators, and a shared magnetic circuit structure that establishes a transverse magnetic field in each of the plasma accelerators which presents an impedance to the flow of electrons towards the anode in each of the plurality of plasma accelerators and enables ionization of a gas moving through one or more of the plurality of plasma accelerators and which creates an axial electric field in each of the plurality of plasma accelerators for accelerating ionized gas through one or more of the plurality of accelerators to create thrust.

The subject invention, however, in other embodiments, need not achieve all these objectives and the claims hereof should not be limited to structures or methods capable of achieving these objectives.

This invention features a Hall thruster with a shared magnetic structure including a plurality of plasma accelerators each including an anode and a discharge zone for plasma discharge occurs in the presence of imposed electric and magnetic field. An electrical circuit having one or more cathodes connected to the plurality of plasma accelerators that emit electrons that are attracted to the anode in each of the plasma accelerators. A shared magnetic circuit structure establishes a transverse magnetic field in each of the plurality of plasma accelerators that creates an impedance to the flow of electrons toward the anode in each of the plurality of plasma accelerators and enables ionization of a gas moving through one or more of the plurality of plasma accelerators. The impedance localizes an axial electric field in the plurality of plasma accelerators for accelerating ionized gas through the one or more of the plurality of plasma accelerators to create thrust.

In one embodiment, the shared magnetic circuit structure may include at least one magnetic field source for creating the transverse magnetic field in each of the plurality of plasma accelerators. The at least one magnetic field source may include a magnetic field source chosen from the group consisting of an electromagnetic coil and a permanent magnet. The shared magnetic circuit structure may include a selected combination of the at least one magnetic field source. The shared magnetic circuit structure may include an outer pole and an inner pole for each of the plurality of plasma accelerators. The shared magnetic circuit structure may include a magnetic material interconnecting the outer pole and the inner pole. The shared magnetic circuit structure may include at least one shared magnetic path for establishing the transverse magnetic field in each of the plurality of plasma accelerators. The shared magnetic circuit structure may carry magnetic flux between the inner pole and the shared outer pole and through the magnetic material and the shared magnetic path. The shared magnetic path may include at least one magnetic field source chosen from the group consisting of an electromagnetic coil and a permanent magnet. The shared magnetic path may include a selected combination of the at least one magnetic field source. The Hall thruster may further include a plurality of shared magnetic paths for establishing the transverse magnetic field in each of the plurality of plasma accelerators. The plurality of shared magnetic cores each may include one or more magnetic field sources chosen from the group consisting of an electromagnetic coil and a permanent magnet. The plurality of magnetic paths may include a selected combination of the one or more magnetic field sources. The Hall thruster may further include a plurality of cathodes. The plurality of plasma accelerators may be selectively enabled for steering and attitude control of the Hall thruster. The shared magnetic path may reduce the number of the one or more magnetic sources required to achieve a predetermined transverse magnetic field in each of the plurality of plasma accelerators. The reduced number of the one or more magnetic field sources may decrease the weight and volume of the Hall thruster. The plurality of plasma accelerators may include one or more inner plasma accelerators and one or more outer plasma accelerators arranged concentrically. The shared magnetic path may provide an outer pole for the one or more inner plasma accelerators and an inner pole for the one or more outer plasma accelerators that establish the transverse magnetic field in each of the concentrically arranged plasma accelerators. The inner pole may be racetrack shaped. The inner pole and the outer pole may define a racetrack shaped plasma gap. The inner pole and the outer pole may be linearly shaped to define at least one linearly shaped plasma gap. The shared magnetic path may include a plurality of branches that provide the inner pole for each of the plurality of plasma accelerators. The plurality of branches may be arranged relative to each other in a configuration chosen from the group consisting of: an orthogonal configuration, an angle configuration, a parallel configuration, and an opposite configuration. The plurality of plasma accelerators may be arranged relative to each other in a configuration chosen from the group consisting of an orthogonal configuration, an angle configuration, a parallel configuration, and an opposite configuration. At least one of the plurality of plasma accelerators may be selectively enabled for steering and attitude control of the Hall thruster. The Hall thruster may further include one or more shared power processing units for providing power to the electrical circuit and the shared magnetic circuit structure. The gas may be selectively provided to at least one of the plurality of plasma accelerators to create the thrust. Selectively providing the gas to the one or more of the plurality of plasma accelerators may be used for throttling, steering, and attitude control of the Hall thruster.

This invention also features a Hall thruster with shared magnetic structure including a plurality of plasma accelerators that each provide a plasma discharge. A magnetic circuit structure including a shared magnetic core establishes a transverse magnetic field in each of the plurality of plasma accelerators to control the plasma discharge from each of the plurality of plasma accelerators. A plasma discharge circuit in each of the plurality of plasma accelerators creates a plasma and accelerating the plasma to produce thrust.

This invention also features a Hall thruster cluster with shared magnetic structure including a plurality of plasma accelerators that each provide a plasma discharge, a magnetic circuit structure including a shared outer pole and an inner pole for each of the plurality of plasma accelerators and a shared magnetic core for establishing a transverse magnetic field in each of the plurality of plasma accelerators to control the plasma discharge from each of the plurality of plasma accelerators, and a plasma discharge circuit in each of the plurality of plasma accelerators for creating a plasma and accelerating the plasma to produce thrust.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

FIG. **1** is a simplified, side sectional, schematic diagram of a typical prior art Hall thruster;

FIG. **2** is an enlarged view of a portion of the prior art thruster shown in FIG. **1** illustrating the ionization of the propellant by electron impact and the interaction of the transverse magnetic and electric field that accelerates the propellant;

FIG. **3** is a three-dimensional view of a typical conventional Hall thruster;

FIG. **4** is a three-dimensional view showing the primary components of four conventional Hall thrusters located in close proximity to each other;

FIG. **5** is a three-dimensional view showing one embodiment of a Hall thruster with a shared magnetic structure of this invention;

FIG. **6** is a three-dimensional view showing another example of the shared magnetic circuit structure of the Hall thruster of this invention;

FIG. **7** is a schematic three-dimensional view showing an example of a plurality of cathodes connected to the Hall thruster with shared magnetic structure shown in FIG. **5**;

FIG. **8** is a three-dimensional front-side view of another embodiment of a Hall thruster with a shared magnetic structure of this invention in which the plasma accelerators are concentrically arranged;

FIG. **9** is a three-dimensional view showing an example a racetrack shaped inner pole and outer pole that define a racetrack shaped plasma gap that may be employed in one or more of the plasma accelerators of this invention;

FIG. **10** is a three-dimensional view showing an example of the shared magnetic structure of the Hall thruster of this invention that defines a plurality of slit shaped plasma gaps;

FIG. **11** is a schematic side view of another embodiment of a Hall thruster with shared magnetic structure in accordance with this invention;

FIG. **12** is a three-dimensional view of yet another embodiment of a Hall thruster with shared magnetic structure in accordance with this invention;

FIG. **13** is a three-dimensional view showing in further detail the components of the Hall thruster with shared magnetic structure shown in FIG. **12**;

FIG. **14** is a schematic circuit diagram of the Hall thruster with shared magnetic circuit structure shown in FIG. **12** employing a shared power processing unit;

FIG. **15** is a three-dimensional view showing a Hall thruster with the shared magnetic circuit structure shown in FIG. **12** employing a single cathode; and

FIG. **16** is a three-dimensional view of yet another embodiment of a Hall thruster with shared magnetic structure in accordance with this invention.

Although specific features of this invention are shown in some drawings and not others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention.

DISCLOSURE OF THE PREFERRED EMBODIMENT

Aside from the preferred embodiment or embodiments disclosed below, this invention is capable of other embodiments and of being practiced or being carried out in various ways. Thus, it is to be understood that the invention is not limited in its application to the details of construction and the arrangements of components set forth in the following description or illustrated in the drawings. If only one embodiment is described herein, the claims hereof are not to be limited to that embodiment. Moreover, the claims hereof are not to be read restrictively unless there is clear and convincing evidence manifesting a certain exclusion, restriction, or disclaimer.

A typical conventional Hall effect thruster **20**, FIG. **1**, includes plasma accelerator **21** with discharge chamber **24**, anode **30** and propellant distributor **31** in discharge chamber **24** with transverse magnetic field **36** and axial electric field **38**. Propellant **22**, e.g., xenon or similar gas, is introduced through propellant distributor **31** into discharge chamber **24**. Thruster **20** also typically includes externally located cathode **26** which emits electrons **28**, **29**, and **31**. Anode **30** located within the discharge chamber **24**, attracts the electrons **28-31** emitted from cathode **26**. Electric circuit **32** creates the axial electric field **38** and magnetic field source **33**, e.g., an electromagnetic coil attached to magnetic structure **34** creates transverse magnetic field **36**. Transverse magnetic field **36** provides an impedance to the flow of electrons **28-31** toward anode **30** which forces the electrons to travel in a helical fashion about the magnetic field lines associated with magnetic field **36**, as shown at **42**, FIG. **2**.

When the electrons trapped by magnetic field **36** collide with propellant atoms, e.g., atom **23**, they create positively charged ions. The positively charged ions are rapidly expelled from discharge chamber **24** due to axial electric field **38**, indicated at **46**, to generate thrust. For example, when electron **33** on magnetic field line **36** collides with propellant or gas atom **23**, indicated at **35**, the collision strips one of the electrons, e.g., electron **44** from propellant atom **23**, to create positively charged ion **45** which is expelled from discharge chamber **24** by axial electric field **38** to generate thrust.

Conventional Hall thruster **60**, FIG. **3**, includes a plasma accelerator **62** with anode/discharge chamber **63**. Cathode **64** emits electrons **80** that are attracted to anode/discharge chamber **63**. Thruster **60** also includes magnetic circuit structure **66** including inner pole **68** and outer pole **69**. Outer magnetic field sources **70**, **72**, **74** and **76**, and inner magnetic field source **77**, e.g., electromagnetic coils or permanent magnets, create transverse magnetic field **78** between inner pole **68** and outer pole **69** that creates an impedance to the flow of electrons **80** emitted from cathode **64** towards anode/discharge chamber **63**, similar to that described above.

When a plurality of conventional Hall thrusters are arranged in close proximity to each other, each plasma accelerator requires its own magnetic circuit structure having an inner pole and an outer pole, a plurality of outer magnetic field sources for the outer pole, and a magnetic field source for the inner pole. For example, one plasma accelerator would require magnetic circuit structure **66***a*, FIG. **4**, with inner pole **68***a* and outer pole **69***a*, outer magnetic field source locations **70***a*, **72***a*, **74***a* and **76***a*, and inner magnetic field source location **77***a*. Similarly, the remaining plasma accelerators would each require a magnetic circuit structure, e.g., magnetic circuit structure **66***b* includes inner pole **68***b* and outer pole **69***b*, outer magnetic field sources **70***b*, **72***b*, **74***b* and **76***b* and inner magnetic field source **77***b*; and magnetic circuit structure **66***c* includes inner pole **68***c* and outer pole **69***c*, outer magnetic field sources **70***c*, **72***c*, **74***c* and **76***c*, and inner magnetic field source **77***c*, and magnetic circuit structure **66***d* includes inner pole **68***d* and outer pole **69***d*, outer magnetic field sources **70***d*, **72***d*, **74***d* and **76***d*, and inner magnetic field source **77***d*. Such a design suffers from excessive weight, volume and power requirements of a spacecraft or satellite that utilizes a plurality of Hall thrusters arranged in close proximity.

In contrast, Hall thruster **100**, FIG. **5**, with a shared magnetic circuit structure **120** according to this invention, preferably includes a shared magnetic path, e.g., a magnetic core, that establishes a transverse magnetic field between the inner pole and the outer pole of a plurality of plasma accelerators, e.g., plasma accelerators **102**, **104**, **106** and **108**. The shared magnetic path or core reduces the weight, volume, complexity and power requirements of Hall thruster **100**, as discussed below.

Hall thruster **100** typically includes plasma accelerators **102**, **104**, **106** and **108** that provide plasma discharge. Plasma accelerators **102**, **104**, **106** and **108** each include an anode and a discharge zone, e.g., anode/discharge chambers **112**, **114**, **116**, and **118**, respectively. Electric circuit **99** includes one or more cathodes, e.g., cathode **110** connected to plurality of plasma accelerators **102-108** that emit electrons **113** that are attracted to anode/discharge chambers **112-118**. Shared magnetic circuit structure **120** establishes transverse magnetic fields **122**, **124**, **126** and **128** in plasma accelerators **102**, **104**, **106**, **108**, respectively. That creates an impedance to the flow of electrons **113** towards anode/discharge chambers **112-118** and enables ionization of a gas moving through plasma accelerators **102-108**. This creates axial electric fields **119**, **121**, **123**, **125** in plasma accelerators **102-108**, respectively, for accelerating the ionized gas through one or more of plasma accelerators **102-108** to create thrust, as described above with reference to FIGS. **1** and **2**.

Shared magnetic circuit structure **120**, FIG. **5**, preferably includes a shared outer pole and an inner pole for each of plasma accelerators **102-108**. For example, shared magnetic circuit structure **120** includes outer pole **140** and inner pole **130** for plasma accelerator **102**, and outer pole **142** and inner pole **132** for plasma accelerator **104**, outer pole **144** and inner pole **134** for plasma accelerator **106**, and outer pole **146** and inner pole **136** for plasma accelerator **108**. Shared magnetic circuit structure **120** also includes a magnetic material, e.g., front plate **150**, that includes outer poles **140-146** and back plate **152** that interconnects inner poles **130-136**. Shared magnetic circuit structure **120** also includes outer magnetic field sources **131**, **133**, **135**, and **137**, e.g., a permanent magnet, electromagnetic coil, or superconducting electromagnetic coil, associated with inner poles **130-136** of plasma accelerators **102-108**, respectively.

Shared magnetic circuit structure **120** also preferably includes shared magnetic path **160**, e.g., a magnetic core that is shared by plasma accelerators **102-108**. Shared circuit structure **120** with shared magnetic path **160** and magnetic field sources **131-137** establish transverse magnetic fields **122-126** in each of plasma accelerators **102-108**. Shared magnetic path **160** is typically configured as a magnetic core made of a magnetic material. Shared magnetic path **160** may also include magnetic field source **162**, e.g., an electromagnetic coil, superconducting electromagnetic coil. In other designs, shared magnetic path **160** may be configured as a permanent magnet, such as an Alnico type magnet that includes aluminum, nickel and cobalt, a hard ferrite magnet, a sintered neodymium-iron-boron (NdFeB) magnet, a samarium cobalt (SmCo) magnet, or any similar type magnet. Shared magnetic path **160** may also include any combination of an electromagnetic coil and a permanent magnet. Similarly, magnetic field sources **131-137** may be configured as a permanent magnet as discussed above, an electromagnetic coil, or any combination thereof.

Shared magnetic circuit structure **120** carries magnetic flux between inner poles **130-136** and outer poles **140-146** of plasma accelerators **102-108**, respectively, through the magnetic material (e.g., front plate **150** and back plate **152**) and shared magnetic path **160**. For example, shared magnetic circuit structure **120** carries magnetic flux between inner pole **130** and outer pole **140** of plasma accelerator **102** through front plate **150**, through shared magnetic path **160**, through back plate **152**, to inner pole **130**, as shown by loop **180**. In other examples, shared magnetic circuit structure **120** may carry magnetic flux in a direction opposite to loop **180**.

The result is that Hall thruster **100** with shared magnetic circuit structure **120** and shared magnetic path **160** significantly reduce the number of magnetic field sources required to create the transverse magnetic fields **122-126** in plasma accelerators **102-108**, respectively. For example, as shown in FIG. **4**, a typical conventional Hall thruster design that includes four close proximity Hall thrusters with four plasma accelerators and the associated magnetic circuit structures **66***a*-**66***d* requires at least sixteen (16) outer magnetic field sources, e.g., magnetic field sources **70***a*-**76***d*, **70***b*-**76***d*, **70***c*-**76***d*, and **70***d*-**76***d* associated with outer poles **69***a*, **69***b*, **69***c*, and **69***d*, respectively, and four (4) inner magnetic field sources **77***a*, **77***b*, **77***c*, and **77***d* associated with inner poles **68***a*, **68***b*, **68***c* and **68***d*, e.g., to create the transverse magnetic fields between inner poles **68***a*-**68***d* and outer poles **69***a*-**69***d*, respectively.

In contrast, Hall thruster **100**, FIG. **5**, of this invention, with shared magnetic circuit structure **120** and shared magnetic path **160** requires only four outer magnetic field sources for inner poles **130-136**, e.g., magnetic field sources **131**, **133**, **135**, and **137**, and one magnetic field source for shared magnetic path **160**, e.g., shared magnetic path **160** includes a magnetic field source, e.g., a permanent magnet or electromagnet coil, to establish transverse magnetic fields **122-126** in each of plasma accelerators **102-108**. The result is a significant reduction in weight, volume, complexity, power, thermal requirements, and cost of Hall thruster **100**. Although as described above with reference to FIG. **5**, Hall thruster **100** includes four plasma accelerators and the associate components therewith, this is not a necessary limitation of this invention, as Hall thruster **100** may have any number of plasma accelerators.

In other designs, Hall thruster **100** may include a shared magnetic circuit structure **120***a*, FIG. **6**, that includes a plurality of shared magnetic paths **160***a*, **200**, **202**, **204**, **206**, **208**, **210** and **212** magnetic shared paths **160***a* and **200-212** may be a core made of a magnetic material, or a magnetic field sources such as, e.g., permanent magnets or electromagnetic coils as described above. In this example, shared magnetic paths or cores **160***a* and **200-212** reduce the number of outer magnetic field sources needed to establish the transverse magnetic fields between the inner poles and shared outer poles, e.g., from a total of sixteen as shown in FIG. **4**, to a total of nine, as shown in FIG. **6**. The result is a significant reduction in weight and volume of shared magnetic circuit structure **120**.

Hall thruster **100***a*, FIG. **7**, where like parts have been given like numbers, includes shared magnetic circuit structure **120** described above with front plate **150**, back plate **152**, and assembly **190** made of a magnetic material that interconnects front plate **150** and back plate **152**. In this design, Hall thruster **100***a* includes four cathodes **192**, **194**, **196** and **198** that emit electrons that are attracted to anode/discharge chambers **112-118** as described above. Any of plasma accelerators **102-108** of Hall thruster **100***a* may be selectively enabled or disabled for steering and providing attitude control for Hall thruster **100***a* by selectively enabling gas to any of plasma accelerators **102-108**, (discussed below) or selectively powering plasma accelerators **102-108**.

In other embodiments of this invention, the Hall thruster with a shared magnetic circuit structure may include one or more inner plasma accelerators and one or more outer plasma accelerators concentrically arranged. For example, Hall thruster **100***b*, FIG. **8**, includes inner plasma accelerator **220** and outer plasma accelerator **223**. Shared magnetic circuit structure **120***a* includes shared magnetic path or core **209** that includes outer pole **208** for inner plasma accelerator **220** and inner pole **210** for outer plasma accelerator **222**. Inner plasma accelerator **220** includes inner pole **212** and outer plasma accelerator **222** includes outer pole **213**. Similar as described above, shared magnetic circuit structure **120***a* establishes a transverse magnetic field between inner pole **212** and outer pole **208** of plasma accelerator **220** and between inner pole **210** and outer pole **213** of plasma accelerator **223**. Although as shown in FIG. **8**, Hall thruster **100***b* includes two plasma accelerators concentrically arranged, this is not a necessary limitation of this invention as Hall thruster **100***b* may include any number of plasma accelerators concentrically arranged.

Any of plasma accelerators **102-108** of Hall thrusters **100**, **100***a* and **100***b*, FIGS. **5**, **7**, and **8** discussed above may include a racetrack shaped inner pole and an outer pole that define a racetrack shaped plasma gap. FIG. **9** shows one example of racetrack shaped inner pole **250** and outer pole **252** that define racetrack shaped plasma gap **254**. The racetrack shaped plasma accelerator offers scaling advantages.

The shared magnetic circuit structure may include an outer pole and inner poles that define slit shaped plasma gaps. For example, shared magnetic circuit structure **120***c*, FIG. **10** includes inner pole **270** and outer poles **272** and **274** that define slit shaped plasma gaps **276** and **278**.

Hall thruster **100***c*, FIG. **11**, of this invention with shared magnetic circuit structure **120***d* includes shared magnetic path **160***b*, e.g., a magnetic core made of a magnetic material as described above, that includes branches **269**, **271** and **273** that provide inner poles **270**, **272**, and **274** for plasma accelerators **278**, **280**, and **282**, respectively. Shared magnetic circuit structure **120***d* includes magnetic structure **284** that provides outer pole **286** for plasma accelerator **278**, outer pole **290** for plasma accelerator **280**, and outer pole **294** for plasma accelerator **282**. Similar as described above, plasma accelerator **278** includes anode/discharge chamber **288**, plasma accelerator **280** includes anode/discharge chamber **292** and plasma accelerator **282** includes anode/discharge chamber **296**. In this example, shared magnetic path **160***b* includes magnetic field source **300**, e.g., an electromagnetic coil **300** that creates transverse magnetic field **301** between inner pole **270** and outer pole **286**, transverse magnetic field **302** between inner pole **272** and outer pole **290**, and transverse magnetic field **304** between inner pole **274** and outer pole **294**. Transverse magnetic fields **301**-**304** present an impedance to electrons **299** emitted from cathode **303** which is used to create thrust, as described above. In this design, branched shared magnetic path **160***b* includes poles **270**, **272**, and **274** that are arranged in a parallel configuration. Shared magnetic path **160***b* may also be configured as a permanent magnet or a combination of an electromagnetic coil and a permanent magnet.

In other embodiments of this invention, Hall thruster **100***d*, FIG. **12**, where like parts have been given like numbers, includes shared magnetic path **160***c* with inner poles **270**, **272** and **274** that are arranged at an angle, e.g., orthogonal, to each other. Plasma accelerators **278***a*, **280***a*, and **282***a* are similarly arranged orthogonal to each other. In this example, magnetic structure **284** is configured as a housing about plasma accelerators **278***a*-**282***a*. Similar as described above, magnetic circuit structure **120***e* and shared magnetic path **160***c* with electromagnetic coil **300** establishes transverse magnetic fields **301**, **302**, and **304** for plasma accelerators **278***a*, **280***a* and **282***a*, respectively. In operation various plasma accelerators **278***a*-**282***a* may be selectively enabled for steering and attitude control of thruster **100***d*.

An example of electromagnetic coil **300** is shown in FIG. **13**, where like parts have been given like numbers. Hall thruster **100***d* may also include a shared power processing unit **301**, FIG. **14**, where like parts have been given like numbers, that provides power to electromagnetic coil **300** and plasma accelerators **278***a*-**282***a*, as well as the shared magnetic circuit structure and magnetic field sources associated therewith, as described above. Shared power processing unit **301** eliminates the need for a separate power processing unit for each of the plasma accelerators and therefore saves weight and volume and reduces cost. Gas lines **350**, **352** and **354**, FIG. **13** provide gas to the anode/discharge chambers described above. In operation, the gas provided to any of plasma accelerators **278***a*-**282***a* can be selectively controlled for throttling and steering Hall thruster **100***d*. FIG. **15** shows an example of Hall thruster **100***d* with plasma accelerators **178***a*-**282***a* that includes and shared cathode **350**.

Hall thruster **100***e*, FIG. **16** shows an example in which branched shared magnetic path **160***c* provides for oppositely oriented plasma accelerators **290**, **292**, **294** and **296**.

Although specific features of the invention are shown in some drawings and not in others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention. The words “including”, “comprising”, “having”, and “with” as used herein are to be interpreted broadly and comprehensively and are not limited to any physical interconnection. Moreover, any embodiments disclosed in the subject application are not to be taken as the only possible embodiments. Other embodiments will occur to those skilled in the art and are within the following claims.

In addition, any amendment presented during the prosecution of the patent application for this patent is not a disclaimer of any claim element presented in the application as filed: those skilled in the art cannot reasonably be expected to draft a claim that would literally encompass all possible equivalents, many equivalents will be unforeseeable at the time of the amendment and are beyond a fair interpretation of what is to be surrendered (if anything), the rationale underlying the amendment may bear no more than a tangential relation to many equivalents, and/or there are many other reasons the applicant can not be expected to describe certain insubstantial substitutes for any claim element amended.

What is claimed is:

1. A Hall thruster with a shared magnetic structure comprising:

a plurality of plasma accelerators each including an anode and a discharge zone for providing plasma discharge;

an electrical circuit having one or more cathodes connected to said plurality of plasma accelerators for emitting electrons that are attracted to said anode in each of said plasma accelerators; and

a shared magnetic circuit structure for establishing a transverse magnetic field in each of said plurality of plasma accelerators that creates an impedance to the flow of electrons toward said anode in each of said plurality of plasma accelerators and enables ionization of a gas moving through one or more of said plurality of plasma accelerators and which creates an axial electric field in said plurality of plasma accelerators for accelerating ionized gas through said one or more of said plurality of plasma accelerators to create thrust.

2. The Hall thruster of claim **1** in which said shared magnetic circuit structure includes at least one magnetic field source for creating said transverse magnetic field in each of said plurality of plasma accelerators.

3. The Hall thruster of claim **2** in which said at least one magnetic field source includes a magnetic field source chosen from the group consisting of: an electromagnetic coil and a permanent magnet.

4. The Hall thruster of claim **3** in which said shared magnetic circuit structure includes a selected combination of said at least one magnetic field source.

5. The Hall thruster of claim **2** in which said shared magnetic circuit structure includes an outer pole and an inner pole for each of said plurality of plasma accelerators.

6. The Hall thruster of claim **5** in which said shared magnetic circuit structure includes a magnetic material interconnecting said outer pole and said inner pole.

7. The Hall thruster of claim **6** in which said shared magnetic circuit structure includes at least one shared magnetic path for establishing said transverse magnetic field in each of said plurality of plasma accelerators.

8. The Hall thruster of claim **7** in which said shared magnetic circuit structure carries magnetic flux between said inner pole and said outer pole and through said magnetic material and said shared magnetic path.

9. The Hall thruster of claim **7** in which said shared magnetic path includes at least one magnetic field source chosen from the group consisting of: an electromagnetic coil and a permanent magnet.

10. The Hall thruster of claim **9** in which said shared magnetic path includes a selected combination of said at least one magnetic field source.

11. The Hall thruster of claim **7** further including a plurality of shared magnetic paths for establishing said transverse magnetic field in each of said plurality of plasma accelerators.

12. The Hall thruster of claim **11** in which said plurality of shared magnetic paths each include one or more magnetic field sources chosen from the group consisting of an electromagnetic coil and a permanent magnet.

13. The Hall thruster of claim **11** in which said plurality of magnetic paths include a selected combination of said one or more magnetic field sources.

14. The Hall thruster of claim **1** further including a plurality of cathodes.

15. The Hall thruster of claim **1** in which said plurality of plasma accelerators are selectively enabled for steering and attitude control of said Hall thruster.

16. The Hall thruster of claim **9** in which said shared magnetic path reduces the number of said one or more magnetic sources required to achieve a predetermined said transverse magnetic field in each of said plurality of plasma accelerators.

17. The Hall thruster of claim **16** in which the reduced number of said one or more magnetic field sources decreases the weight and volume of said Hall thruster.

18. The Hall thruster of claim **7** in which said plurality of plasma accelerators includes one or more inner plasma accelerators and one or more outer plasma accelerators arranged concentrically.

19. The Hall thruster of claim **18** in which said shared magnetic path provides an outer pole for said one or more inner plasma accelerators and an inner pole for said one or more outer plasma accelerators that establish said transverse magnetic field in each of the concentrically arranged plasma accelerators.

20. The Hall thruster of claim **7** in which said inner pole is racetrack shaped.

21. The Hall thruster of claim **20** in which said inner pole and said outer pole define a racetrack shaped plasma gap.

22. The Hall thruster of claim **7** in which said inner pole and said outer pole are linearly shaped to define at least one linearly shaped plasma gap.

23. The Hall thruster of claim **7** in which said shared magnetic path includes a plurality of branches that provide said inner pole for each of said plurality of plasma accelerators.

24. The Hall thruster of claim **23** in which said plurality of branches are arranged relative to each other in a configuration chosen from the group consisting of: an orthogonal configuration, an angle configuration, a parallel configuration, and an opposite configuration.

25. The Hall thruster of claim **24** in which said plurality of plasma accelerators are arranged relative to each other in a configuration chosen from the group consisting of: an orthogonal configuration, an angle configuration, a parallel configuration, and an opposite configuration.

26. The Hall thruster of claim **25** in which said at least one of said plurality of plasma accelerators are selectively enabled for steering and attitude control of said Hall thruster.

27. The Hall thruster of claim **1** further including one or more shared power processing units for providing power to said electrical circuit and said shared magnetic circuit structure.

28. The Hall thruster of claim **1** in which said gas is selectively provided to at least one of said plurality of plasma accelerators to create said thrust.

29. The Hall thruster of claim **28** in which selectively providing said gas to said one or more of said plurality of plasma accelerators is used for throttling, steering and attitude control of said Hall thruster.

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