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(21) International Application Number: PCT/US99/30541 (22) International Filing Date: 22 December 1999 (22.12.99) (30) Priority Data: 60/113,682 22 December 1998 (22.12.98) US (71) Applicant (for all designated States except US): QUANTUM MANUFACTURING TECHNOLOGIES, INC. [US/US]; 3701 Hawkins Street, NE, Albuquerque, NM 87109 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): LOCKNER, Thomas, R. [US/US]; 3915 Calle Pino, NE, Albuquerque, NM 87111 (US). CRAWFORD, Mark, T. [US/US]; 12405 Alameda Trace Circle, Apt. 1328, Austin, TX 78727 (US). GREENLY, John, B. [US/US]; 184 Ludlowville Road, Lansing, NY 14882 (US). GLIDDEN, Stephen, C. [US/US]; 207 Langmuir Laboratory, 95 Brown Road, Ithaca, NY 14850-1257 (US). (74) Agents: DEVINSKY, Paul et al.; McDermott, Will & Emery, 600 13th Street, N.W., Washington, DC 20005-3096 (US).		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>Without international search report and to be republished upon receipt of that report.</i>
(54) Title: MAP ION DIODE PUFF VALVE AND GAS DAM AND METHOD OF USING THE SAME		
(57) Abstract <p>A MAP ion diode comprises a gas feed, a puff valve for releasing a radially expanding puff of working gas, a nozzle for directing the radially expanding puff of working gas from an inlet opening adjacent to the puff valve to an outlet opening, and a gas dam positioned adjacent to the outlet end of the nozzle and within the nozzle. In order to generate an azimuthally uniform plasma in the MAP diode ion source, a puff valve magnet coil is used, that has more than three coil turns. This increased number of coil turns enables the current rise-time in the coil to remain lower than the image current decay time in the plasma. Further, a hard O-ring is used in the puff valve to minimize variations in gas flow. The MAP ion diode provides repetitive, extractable ion beams with little or no rotation from an ion source in which the plasma position is determined by the magnetic field profiles rather than material surfaces. The MAP diode ion source can be used to prepare surfaces in various ways including hardening, cleaning, smoothing, production of nanocrystalline surfaces, preparation for subsequent coatings, roughening or texturing surfaces for other uses, or the production of materials with microstructural changes produced by rapid melt and resolidification.</p> <div data-bbox="606 1232 1356 1948"> </div>		

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MAP ION DIODE PUFF VALVE AND GAS DAM AND METHOD OF USING THE SAME

FIELD OF THE INVENTION

The present invention generally relates to the field of ion beam surface treatment. More specifically, the present invention relates to a method and apparatus supplying gas in an ion source for generating an ion beam.

BACKGROUND OF THE INVENTION

Ion beam surface treatment may be accomplished using a magnetically confined anode plasma ("MAP") diode ion beam system such as that described in U.S. Patent Nos. 5,473,165, 5,525,805, 5,532,495, and 5,656,819, the contents of which are hereby incorporated by reference. A MAP ion diode provides repetitive, extractable ion beams with little or no rotation from an ion source in which the plasma position is determined by the magnetic field profiles rather than material surfaces. Such a MAP diode ion source can be used to prepare surfaces in various ways including hardening, cleaning, smoothing, production of nanocrystalline surfaces, preparation for subsequent coatings, roughening or texturing surfaces for other uses, or the production of materials with microstructural changes produced by rapid melt and resolidification.

Experiments on the MAP diode ion source and ion extraction geometries have led to significant improvements in the operation of the MAP diode ion source, sometimes referred to herein as the MAP ion diode. The term "diode" is used because the device promotes unidirectional ion flow.

For maximum efficacy, a MAP ion diode system should exhibit the following characteristics:

1. The use of a magnetically-confined anode plasma ion beam system.
2. The capability of extracting the ion beam from the beam system hardware without significant rotation.
3. The production of ion beams using plasma locations defined by magnetic fields rather than material surfaces.

4. The capability of repetitive operation for hundreds of pulses without significant beam system damage or debris production.
5. The capability of producing beams of ions with species purity exceeding 85% using hydrogen or other gases or combinations of gases.
6. Pulse length of less than 0.05 ms.
7. Treated areas of greater than 1 square centimeter per pulse.
8. Deposited energies of >0.05 Joule per square centimeter per pulse.
9. The ability to determine the depth of thermal cycling and its effects by selecting the ion species, ion kinetic energy, pulse length, and the energy deposited.

The system having the characteristics described above may be used to produce ion beams for treatment of materials using the ion beam surface treatment process in which material surfaces are exposed to a short pulse of ions (<0.05 milliseconds) with a total energy per pulse exceeding 0.05 Joules per square centimeter. The ion beam surface treatment process may be used to thermally cycle materials to temperatures from just above ambient temperature to many thousands of degrees Celsius, leading to cleaning, melting, or vaporization of the treated surface and resulting in surface modifications as described above.

The MAP ion diode is a critical part of the ion beam surface treatment process since it allows the efficient conversion of a pulse of electrical energy to an intense beam of ions at the required energy densities over large treatment areas. A conventional MAP ion diode mechanical configuration is shown in Figure 7. The plasma source operation is initiated by energizing a puff valve **702**, which releases a radially expanding puff of the working gas. The gas expands radially between a fast coil body **704** and an inner anode flux excluder **706**. When the gas density in front of the fast coil **704** is high enough to sustain a discharge, the fast coil **704** is energized. The fast coil pulse induces an electric field in the gas, which first ionizes, then drives azimuthal current in the ionized gas. The plasma is loaded onto magnetic field lines that are moved towards and finally through the opening between an inner anode flux excluder **706** and an outer anode flux excluder **708**, and becomes the source of ions to be accelerated in a anode-cathode gap **710**. When the plasma is in this location, it is referred to as the anode plasma.

Prior to energizing the puff valve, a power source is applied to a set of cathode coils **712**, that are magnetic field coils on the opposite side of the anode flux excluders **706** and **708**. These cathode coils **712** generate a (primarily) radial magnetic field between a cathode coil housing **714** and the anode flux excluders **706** and **708**. When the power pulse from the high voltage source is applied between the cathode coil housing **714** and the anode flux excluders **706** and **708**, this magnetic field (i.e., the applied field) inhibits electron flow from the cathode coil housing **714** to the anode flux excluders **706** and **708** while allowing acceleration of the ions from the anode plasma through the applied magnetic field. The anode flux excluders **706** and **708**, cathode coil housing **714** and magnetic field geometry are arranged to allow the accelerated ions to propagate between the two cathode coils **712** and past a cathode flux excluder **716**, through an opening **718**, to a target (not shown) located at some position past the MAP ion diode. The magnetic field geometry is designed to minimize the beam rotation as it propagates to the target, thus enabling direct propagation of the beam to the target, near normal incidence of the beam on the target, and, if desired, a generally solid (as opposed to hollow) beam profile.

The plasma generated by the fast coil **704** should be azimuthally symmetric and reproducible at the time of the high voltage power pulse. Azimuthal plasma asymmetries lead to large localized electron losses that reduce the MAP ion diode efficiency and may cause damage to the MAP ion diode hardware.

Both the design of the puff valve **702** and of the nozzle **720** are critical in supplying a uniform plasma. For optimal performance, the puff valve **702** and nozzle **720** combination should provide adequate gas density near the fast coil **704** to allow ionization to be induced in the gas, forming the discharge, yet a sufficiently low density in the anode-cathode gap **710** region to avoid breakdown of the diode **700** before the ions are accelerated. The gas should also be azimuthally uniform enough to supply a uniform plasma surface in the anode-cathode gap **710**.

SUMMARY OF THE INVENTION

It is an object of the present invention to address some deficiencies of prior art MAP ion diodes.

A further object of the present invention to supply a uniform plasma surface in the anode-cathode gap.

Additional objects, advantages and novel features of the invention will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

To achieve the foregoing and other objects and in accordance with the purpose of the present invention, as embodied and described herein, a MAP ion diode in accordance with the present invention may comprise a gas feed, a puff valve for releasing a radially expanding puff of working gas, a nozzle for directing the radially expanding puff of working gas from an inlet opening adjacent to the puff valve to an outlet opening, and a gas dam positioned adjacent to the outlet end of the nozzle and within the nozzle.

Preferably, the MAP ion diode further comprises an insulating body defining one side of the nozzle, a coil winding within the insulating body near the outlet opening, and an inner anode flux excluder defining a wall of said nozzle. More preferably, the MAP ion diode according further comprises an outer anode flux excluder, wherein the outer anode flux excluder and the inner anode flux excluder define a third opening of the nozzle, and wherein the third opening is disposed opposite to the coil winding that is adjacent to the outlet opening, a set of cathode coils disposed generally opposite to the coil winding and downstream from the third opening; and a cathode flux excluder disposed generally opposite to the coil winding and downstream from the set of cathode coils.

In another aspect of the present invention, a puff valve for releasing a radially expanding gas puff having a generally radial azimuthal symmetry to a nozzle may comprise a gas feed, a diaphragm separating the gas feed and the nozzle, a diaphragm

support plate restricting movement of the diaphragm in a first direction, a puff valve magnet coil having a number of turns such that the inductance of the puff valve magnet coil permits a current rise time lower than the respective image current decay time, wherein the puff valve magnet coil is positioned to create a magnetic field perpendicular to the diaphragm when a current is applied thereto; and an O-ring being in contact with the diaphragm when no current is applied to the puff valve magnet coil.

In one embodiment, the O-ring is made of a rubber having a hardness being approximately greater than 90 durometers.

In another embodiment, the O-ring is made of a rubber having a hardness being about 90 durometers.

In yet another embodiment, the puff valve magnet coil has more than three turns. Preferably, the puff valve magnet coil has 4-20 turns. More preferably, the puff valve magnet coil has six turns.

In still another embodiment, the O-ring is a captive O-ring.

In still yet another embodiment the puff valve further comprises a gas reservoir adjacent to the diaphragm, wherein the gas reservoir is downstream in the direction of gas flow from the gas feed.

Preferably, the gas reservoir has a characteristic length determined by the speed of sound in the gas divided by a pulse length. More preferably, the characteristic length is about 2 mm. Moreover, the gas reservoir preferably has a characteristic length of $10n$, wherein n is the speed of sound in the gas divided by a pulse length.

Preferably, the puff valve further comprises a gas flow restriction being positioned in the gas feed.

Preferably, the gas reservoir increases in width towards the gas feed. More preferably, the gas reservoir increases in width uniformly towards the gas feed.

In still yet a further embodiment, the puff valve further comprises an O-ring groove, wherein the O-ring rests in the O-ring groove.

In still yet another embodiment the puff valve further comprises a coil mount, wherein the puff valve magnet coil is mounted on the coil mount.

Preferably, the coil mount comprises a ceramic material.

Preferably, the puff valve further comprises a mount back adjacent to the coil mount.

Another aspect of the present invention provides a method of producing ion beams in an ion generator having a gas feed in fluid communication with a gas reservoir, the gas reservoir being separated from a vacuum system by a diaphragm valve operated by a magnetic coil and a nozzle having a gas dam positioned therein, the method comprises the steps of, supplying gas through the gas feed and into the gas reservoir, supplying a current pulse to the magnetic coil, the magnet being positioned to generate a magnetic field in the region of the diaphragm, displacing the diaphragm with a magnetic field, and emitting a puff of gas from the displaced diaphragm, the puff of gas traveling through the nozzle past the gas dam.

In one embodiment, the step of supplying further comprises passing the gas through a restriction in the gas feed.

In another embodiment, the step of supplying further comprises limiting the inductance of the magnetic coil whereby the rise time of the current pulse through the magnetic coil is lower than the respective image current decay time.

In yet another embodiment, the step of displacing further comprises positioning the diaphragm in a plane generally normal to the direction of the magnetic field generated by the magnet coil.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and form a part of the specification, illustrate exemplary embodiments of the present invention and, together with the description, serve to explain the principles of the invention. In the drawings:

Figure 1 depicts a MAP ion diode in accordance with the present invention.

Figure 2 depicts a puff valve for use in a MAP ion diode in accordance with the present invention.

Figure 3 through Figure 6 are graphs depicting empirical performance data for a MAP ion diode having a gas dam in accordance with the present invention.

Figure 7 depicts a conventional MAP diode.

Reference will now be made in detail to the present preferred embodiment of the invention, an example of which is illustrated in the accompanying drawings.

DETAILED DESCRIPTION OF THE INVENTION

In accordance with the present invention, improvements have been made to the gas delivery system of a MAP ion diode in order to reduce azimuthal asymmetries. In part, the invention includes improvement to the prior puff valve structures and the provision of a radial disk in the puff valve nozzle to reduce azimuthal asymmetries. Such improvements improve the symmetry and reproducibility of the plasma and ion beam. The present invention also reduces electron losses and the resultant ion beam diode damage.

A MAP ion diode mechanical configuration in accordance with the present invention is shown in Figure 1. The plasma source operation is initiated by energizing a puff valve **102**, which releases a radially expanding puff of the working gas that is supplied from a gas feed **124**. The gas expands radially between a fast coil body **104** and an inner anode flux excluder **106**, and passes a gas dam **118**. When the gas density in front of the fast coil **122**, that is within an insulating fast coil body **104**, is high enough to sustain a discharge, the fast coil **122** is energized. The fast coil pulse induces an electric field in the gas, which first ionizes, then drives azimuthal current in the ionized gas. The plasma is loaded onto magnetic field lines that are moved towards and finally through the opening between an inner anode flux excluder **106** and an outer anode flux excluder **108**, and becomes the source of ions to be accelerated in a anode-cathode gap **110**. When the plasma is in this location, it is referred to as the anode plasma.

Prior to energizing the puff valve, a power source is applied to a set of cathode coils **112**, that are magnetic field coils on the opposite side of the anode flux excluders **106** and **108**. These cathode coils **112** generate a (primarily) radial magnetic field between a cathode coil housing **114** and the anode flux excluders **106** and **108**. When the power pulse from the high voltage source is applied between the cathode coil housing **114** and the anode flux excluders **106** and **108**, this magnetic field (i.e., the applied field) inhibits electron flow from the cathode coil housing **114** to the anode flux

excluders **106** and **108** while allowing acceleration of the ions from the anode plasma through the applied magnetic field. The anode flux excluders **106** and **108**, cathode coil housing **114** and magnetic field geometry are arranged to allow the accelerated ions to propagate between the two cathode coils **112** and past a cathode flux excluder **116**, through an opening **118**, to a target (not shown) located at some position past the MAP ion diode.

A puff valve in accordance with the present invention will now be described with reference to Figure 2. The puff valve includes an electrically conducting diaphragm **202** (e.g. spring copper), a magnet coil **204**, a coil mount **206**, a mount back **208**, an outer diaphragm O-ring **210**, an inner diaphragm O-ring **212**, and a diaphragm support plate **214**. The diaphragm **202** prevents the gas from entering the vacuum system by sealing against the outer diaphragm O-ring **210** and the inner diaphragm O-ring **212**. Gaskets of various materials and other pressure seals may additionally be used as, or used in place of, an O-ring. The inner surface of the diaphragm **202** is compressed between the diaphragm support plate **214** and the inner diaphragm O-ring **212** and the outer diaphragm O-ring **210**. In the illustrated embodiment, the magnet coil **204** is positioned in the puff valve body near the outer edge of the diaphragm **202**.

The puff valve is opened by applying a short pulse of current to the magnet coil **204**. Because the diaphragm is a conductor, the pulsed magnetic field induces image currents in the diaphragm **202**, which interact with the magnetic field. If the coil current (magnetic field) is large enough, the resulting force on the diaphragm **202** is in the axial direction and will move the diaphragm **202** away from the vacuum-sealing outer diaphragm O-ring **210**. As the diaphragm **202** moves away from the outer diaphragm O-ring **210**, an opening is formed between the diaphragm **202** and the outer diaphragm O-ring **210**, which allows the gas to escape into the nozzle and expand radially. When the gas density at the fast coil **104** (Figure 1) is high enough, the fast coil **104** is energized and the plasma is produced. While the above described pulsed magnetic field valve operation is preferred, it should be understood that other valve opening techniques may also be employed.

In order to generate an azimuthally uniform plasma, the gas puff must be essentially azimuthally symmetric. Gas puff symmetry is controlled by the symmetry of

the opening between the diaphragm **202** and the circumference of the outer diaphragm O-ring **210**. In order to provide such symmetry, a puff valve in accordance with the present invention includes a puff valve magnetic coil having more than three, and preferably four to six, and more preferably six coil turns. The valve also uses a hard rubber O-ring (e.g. having a hardness of greater than 70 durometers, preferably 90 durometers) in order to improve azimuthal gas uniformity. In addition, the captive outer diaphragm O-ring geometry **210** is used to minimize movement of the O-ring and the like. Also, as compared to prior art structures, the puff valve of the present invention includes a gas plenum of reduced volume in order to reduce the volume of gas being admitted into the vacuum system. Further, the puff valve of the present invention advantageously includes a restriction in the gas source in order to minimize gas loading. Further, a puff valve according to the present invention preferably has a more uniform cross section in the region within 4 mm of the nozzle opening.

Increasing the puff valve magnet turns reduces the magnetic field perturbations of the coil feed relative to the field produced by the turns. Since the force on the diaphragm **202** is proportional to the square of the magnetic field, the force and thus the deflection of the diaphragm **202** is very sensitive to variations in the magnetic field. By reducing the relative error in the magnetic field due to the perturbations resulting from the geometry of the current feed, the deflection of the diaphragm **202** is also symmetrized.

The number of turns in the puff valve magnet coil **204** can not be increased arbitrarily. The number of turns is limited by the necessary current rise-time. Because of the resistance of the diaphragm **202**, the image currents typically decay away on a time-scale of about 10-30 microseconds. In order to move the diaphragm **202**, the current in the puff valve magnet coil **204** must reach the necessary value before the image currents die away. Since the current rise-time increases with circuit inductance, and the puff valve magnet coil **204** adds to the circuit inductance, the inductance of the puff valve magnet coil **204** must be low enough to keep the rise-time below the image current decay time. (The coil inductance can be increased if the driver capacitance is decreased while increasing the voltage, but the voltage is limited by coil insulation, heat removal, and coil fabrication considerations.) With this puff valve **102** geometry and the

puff valve coil drive parameters, the optimum number of turns is about 6. In general, the number of turns for the puff valve magnet coil **204** of this type should be between about 4 and 20. Beyond 20 turns the coil inductance becomes so large that the drive voltage becomes excessive.

Increasing the hardness of the outer diaphragm O-ring **210** also improves the azimuthal uniformity. The diaphragm **202** must press against the outer diaphragm O-ring **210** enough to conform the rubber surface to the surface of the diaphragm **202** to make a gas seal. This pressure compresses the O-ring. When the puff valve magnet coil **204** is energized, the diaphragm **202** must move enough to decompress the outer diaphragm O-ring **210** before a gap can appear and gas begins to flow. If the outer diaphragm O-ring **210** decompresses non-uniformly, it will lead to variations in the gap between the outer diaphragm O-ring **210** and the diaphragm **202**. This azimuthal variation in the gap will cause variations in the gas flow and ultimately in the plasma. These variations can be minimized by minimizing the compression of the outer diaphragm O-ring **210**. The outer diaphragm O-ring **210** compression is minimized by choosing a material with small compressibility, thus the choice of a 90 durometer O-ring (instead of the standard 70 durometer O-ring.) Even harder O-rings can be used, limited only by the force needed to seal the diaphragm to the O-ring surface.

Use of a captive O-ring geometry reduces the amount of O-ring expansion and motion as the diaphragm opens. This in turn reduces any asymmetries in the opening due to asymmetric expansion or motion of the O-ring.

The use of an outer diaphragm O-ring groove **220** permits the diaphragm **202** to rest on the outer O-ring instead of on the substrate **224**. With the diaphragm **202** resting on the outer diaphragm O-ring **210**, the gas delivery system can be adjusted for the minimum compression of the outer diaphragm O-ring **210** (in order to minimize the azimuthal variations in decompression) while still sealing the gas to the downstream vacuum interface.

The gas reservoir (or plenum) **216** is the volume of gas just upstream of the outer diaphragm O-ring **210**. The gas reservoir **216** supplies gas as gas flows past the gas formed between the diaphragm **202** and the outer diaphragm O-ring **210** when the magnetic coil **204** is operated to open the puff valve. The volume of the gas reservoir

216 is made as small as possible to limit the amount of gas entering the vacuum system. The volume of the gas reservoir **216** must be large enough to supply a high pressure source of gas until the fast coil **104** is fired since excessive depletion of the gas in the gas reservoir **216** will reduce the sharpness of the neutral density gradient in the nozzle **120** (Figure 1). Since the maximum velocity of a density perturbation in a gas is the speed of sound in the gas, there is no reason to supply gas past a characteristic length determined by the speed of sound divided by the desired pulse length of gas. When the puff valve opens, the initial density drop will be unaffected by the length of the gas reservoir **216** for the time it takes a sound wave (or shock wave which travels at the sound speed) to travel from the nozzle opening to the end of the gas reservoir **216** and back. In an exemplary operation of the present invention, the puff valve **102** (Figure 1) may be open for approximately 40 microseconds before the fast coil **104** fires. Assuming it is desirable to have the maximum source pressure for at least the first quarter of this flow time (for example, 10 microseconds) to allow flexibility in the fast coil timing, the characteristic distance based on the sound speed, is approximately 2 mm. Therefore, in an exemplary embodiment, the gas reservoir **216** should not be less than this value to avoid gas depletion during the pulse. Further, in a preferred embodiment, the gas reservoir **216** should be no more than a factor of 10 times this value to minimize gas loading of the vacuum system.

In order to reduce the amount of gas that escapes into the diode after the initial opening of the puff valve **102**, a restriction **218** is provided in the gas supply to the diaphragm area. The restriction **218** is placed at the end of gas reservoir **216** to minimize gas loading after the fast coil **104** fires. Although the restriction as illustrated appears as a length of reduced cross section gas feed, other geometries may serve a similar purpose and function.

As gas flows past the gap formed between the diaphragm and the O-ring, density variations can arise due to variations in the width of the gas reservoir **216**. Therefore, it is important to make the volume of gas reservoir **216** larger than any variation in volume due to machining or alignment variations. Therefore, the gas reservoir **216** preferably increases in width as quickly and uniformly as practical, within the limitations of the puff

valve geometry, moving upstream (i.e. counter to the direction of gas flow) towards the gas feed **222**, until a maximum reservoir dimension is reached.

The MAP ion diode is designed to be a fast, repetitive, and reliable system. As such, it is advantageous to cool to all components that generate heat. The puff valve magnet coil **204** is one such component since the resistance of the coil winding will necessarily generate some heat on each current pulse. The puff valve magnet coil **204** therefore is mounted on the coil mount **206** which supplies both electrical insulation for the puff valve magnet coil **204** and functions as a heat sink, conducting away the heat generated by the puff valve magnet coil **204**. Exemplary materials for the coil mount **206** include ceramics. Further, the coil mount **206** is in contact with the mount back **208** that allows heat to be removed from the puff valve body. Exemplary materials for the mount back **208** include good thermal conductors such as a metals including gold, copper, and aluminum.

The standard plasma source configuration (Fig. 7) is very sensitive to the geometry of the gas nozzle **120**, the location of the fast coil **104** relative to puff valve **102**, and the location of the gap between the inner anode flux excluder **106** and outer anode flux excluder **108**.

As seen in Figure 1, the addition of a disc of material (e.g. plastic) which acts as a flow obstruction on the inner anode flux excluder side of the gas nozzle, referred to here as a gas dam **118**, improves the plasma production uniformity, consistency, and reduces the sensitivity to the variations mentioned above. With the gas dam **118**, the plasma is more uniform, has higher density and is more reproducible. These properties are due to an increase in neutral density as gas is deflected by the gas dam **118**, and the elimination of the direct path from the plasma source to the anode-cathode gap. This reduces the asymmetries in the gas near the fast coil **104** and in the plasma as it moves into the acceleration region.

Experimental Data

Figures 3 through 6 show experimental measurements, which demonstrate the improvement from the addition of the gas dam **118**. Plasma measurements were made

between the outer anode flux excluder **108** and the inner anode flux excluder **106** at 6 azimuthal locations.

Figure 3 shows measurements with the gas dam **118** installed. There is clear evidence of a plasma during the rise-time of the fast coil current. While there may be significant variations in the amplitude of the signals, there is clearly plasma at each location.

In Figure 4, the same measurements were made without a gas dam. There is evidence of a tiny amount of plasma early in the current pulse on 2 of the monitors, but not enough or uniform enough to supply the diode with ions.

Operation of the MAP ion diode for these two configurations is shown in Figures 5 and 6. The traces include: Vcor - the voltage corrected for the inductive voltage drop between the monitor and diode; IshkX10 - the total current to the diode multiplied by 10; IionX10 - the ion current measured in the diode multiplied by 10; and Fcup - the current density as measured by a Faraday cup 65 cm from the diode.

With a MAP ion diode having gas dam **118**, the diode impedance is well behaved, the ion current to total current efficiency runs from 50% to 70% during the pulse, and there is a large ion current density (as indicated by the Fcup) 65 cm downstream of the diode.

With a similar MAP ion diode not having a gas dam, the voltage initially rises to -500 kV but then rapidly drops to zero and the total current rises to almost the short circuit current for the power source. While the ion current appears significant, the ion beam energy is very small because the diode voltage is nearly zero. In addition, the ion current density downstream (Fcup) is tiny compared with the operation with the gas dam **118**. While the diode operation can be improved somewhat by adjusting the puff valve timing relative to when the fast coil **104** is energized, the operation does not approach the results of a MAP ion diode having a gas dam.

The foregoing description of a preferred embodiment of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching. The exemplary embodiments, as described above, were chosen and described in order to best explain the principles

of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto.

CLAIMS

What is claimed is:

1. A MAP ion diode comprising:
 - a gas feed;
 - a puff valve for releasing a radially expanding puff of working gas;
 - a nozzle for directing said radially expanding puff of working gas from an inlet opening adjacent said puff valve to an outlet opening;
 - a gas dam positioned adjacent the outlet end of said nozzle and within said nozzle.
2. The MAP ion diode according to claim 1, further comprising:
 - an insulating body defining one side of said nozzle;
 - a coil winding within said insulating body near said outlet opening; and
 - an inner anode flux excluder defining a wall of said nozzle.
3. The MAP ion diode according to claim 2, further comprising:
 - an outer anode flux excluder, said outer anode flux excluder and said inner anode flux excluder defining a third opening of said nozzle, said third opening being disposed opposite said coil winding adjacent said outlet opening;
 - a set of cathode coils disposed generally opposite to said coil winding and downstream from said third opening; and
 - a cathode flux excluder disposed generally opposite to said coil winding and downstream from said set of cathode coils.
4. A puff valve for releasing a radially expanding gas puff having a generally radial azimuthal symmetry to a nozzle, said puff valve comprising:
 - a gas feed;
 - a diaphragm, said diaphragm separating said gas feed and said nozzle;
 - a diaphragm support plate, said diaphragm support plate restricting movement of said diaphragm in a first direction;

a puff valve magnet coil, said puff valve magnet coil having a number of turns such that the inductance of said puff valve magnet coil permits a current rise time lower than the respective image current decay time, said puff valve magnet coil being positioned to create a magnetic field perpendicular to said diaphragm when a current is applied thereto; and

an O-ring, said O-ring being in contact with said diaphragm when no current is applied to said puff valve magnet coil.

5. The puff valve according to claim 4, wherein said O-ring is made of a rubber, said rubber hardness being approximately greater than 70 durometers.
6. The puff valve according to claim 4, wherein said O-ring is made of a rubber, said rubber hardness being about 90 durometers.
7. The puff valve according to claim 4, wherein said puff valve magnet coil has more than three turns.
8. The puff valve according to claim 7, wherein said puff valve magnet coil has 4-20 turns.
9. The puff valve according to claim 7, wherein said puff valve magnet coil has six turns.
10. The puff valve according to claim 4, wherein said O-ring is a captive O-ring.
11. The puff valve according to claim 4, further comprising:
a gas reservoir adjacent to said diaphragm, said gas reservoir being downstream in the direction of gas flow from said gas feed.

12. The puff valve according to claim 11,
wherein said gas reservoir has a characteristic length determined by the speed of sound in the gas divided by a pulse length.
13. The puff valve according to claim 12,
wherein said characteristic length is about 2 mm.
14. The puff valve according to claim 12,
wherein said gas reservoir has a characteristic length determined by a factor $10n$, wherein n is the speed of sound in the gas divided by a pulse length.
15. The puff valve according to claim 11, wherein said gas reservoir has a length in the direction of gas flow approximately equal to the speed of sound divided by the pulse length.
16. The puff valve according to claim 11, wherein said gas reservoir has a length in the direction of gas flow less than about ten times the speed of sound divided by the pulse length.
17. The puff valve according to claim 11, further comprising:
a gas flow restriction being positioned in said gas feed.
18. The puff valve according to claim 11, wherein said gas reservoir increases in width towards said gas feed.
19. The puff valve according to claim 18, wherein said gas reservoir increases in width uniformly towards said gas feed.
20. The puff valve according to claim 4, further comprising:
an O-ring groove, wherein said O-ring rests in said O-ring groove.

21. The puff valve according to claim 4, further comprising:
a coil mount, wherein said puff valve magnet coil is mounted on said coil mount.
22. The puff valve according to claim 21, wherein said coil mount comprises a heat sink to cool the puff valve magnet coil.
23. The puff valve according to claim 21, further comprising:
a mount back adjacent to said coil mount.
24. A method of producing ion beams in an ion generator having a gas feed in fluid communication with a gas reservoir, said gas reservoir being separated from a vacuum system by a diaphragm valve operated by a magnetic coil and a nozzle having a gas dam positioned therein, said method comprising the steps of:
supplying gas through said gas feed and into said gas reservoir;
supplying a current pulse to said magnetic coil, said magnet being positioned to generate a magnetic field in the region of said diaphragm;
displacing said diaphragm by means of said magnetic field; and
emitting a puff of gas from said displaced diaphragm, said puff of gas traveling through said nozzle past said gas dam.
25. The method of producing ion beams according to claim 24, wherein said step of supplying further comprises:
passing said gas through a restriction in said gas feed.
26. The method of producing ion beams according to claim 24, wherein said step of supplying further comprises:
limiting the inductance of said magnetic coil whereby the rise time of the current pulse through said magnetic coil is lower than the respective image current decay time.

27. The method of producing ion beams according to claim 24, wherein said step of displacing further comprises:

positioning said diaphragm in a plane generally normal to the direction of the magnetic field generated by said magnet coil.

28. A method of producing ion beams in an ion generator having a gas feed in fluid communication with a gas reservoir, said gas reservoir being separated from a vacuum system by a diaphragm valve operated by a magnetic coil having at least four windings, and a nozzle, said method comprising the steps of:

supplying gas through said gas feed and into said gas reservoir;
supplying a current pulse to said magnetic coil, said magnet being positioned to generate a magnetic field in the region of said diaphragm;
displacing said diaphragm by means of said magnetic field; and
emitting a puff of gas from said displaced diaphragm, said puff of gas traveling through said nozzle.

29. The method of producing ion beams according to claim 28, wherein said step of supplying further comprises:

limiting the inductance of said magnetic coil whereby the rise time of the current pulse through said magnetic coil is lower than the respective image current decay time.

30. A method of producing ion beams in an ion generator having a gas feed in fluid communication with a gas reservoir, said gas reservoir being separated from a vacuum system, by a diaphragm valve on an O-ring having a hardness greater than 70 durometers, said diaphragm valve being operated by a magnetic coil and a nozzle, said method comprising the steps of:

supplying gas through said gas feed and into said gas reservoir;
supplying a current pulse to said magnetic coil, said magnet being positioned to generate a magnetic field in the region of said diaphragm;
displacing said diaphragm from said O-ring by means of said magnetic field; and

emitting a puff of gas from said displaced diaphragm, said puff of gas traveling through said nozzle.

31. The method of producing ion beams according to claim 30, wherein said step of supplying further comprises:

passing said gas through a restriction in said gas feed.

32. The method of producing ion beams according to claim 30, wherein said step of supplying further comprises:

limiting the inductance of said magnetic coil whereby the rise time of the current pulse through said magnetic coil is lower than the respective image current decay time.

33. The method of producing ion beams according to claim 30, wherein said step of displacing further comprises:

positioning said diaphragm in a plane generally normal to the direction of the magnetic field generated by said magnet coil.

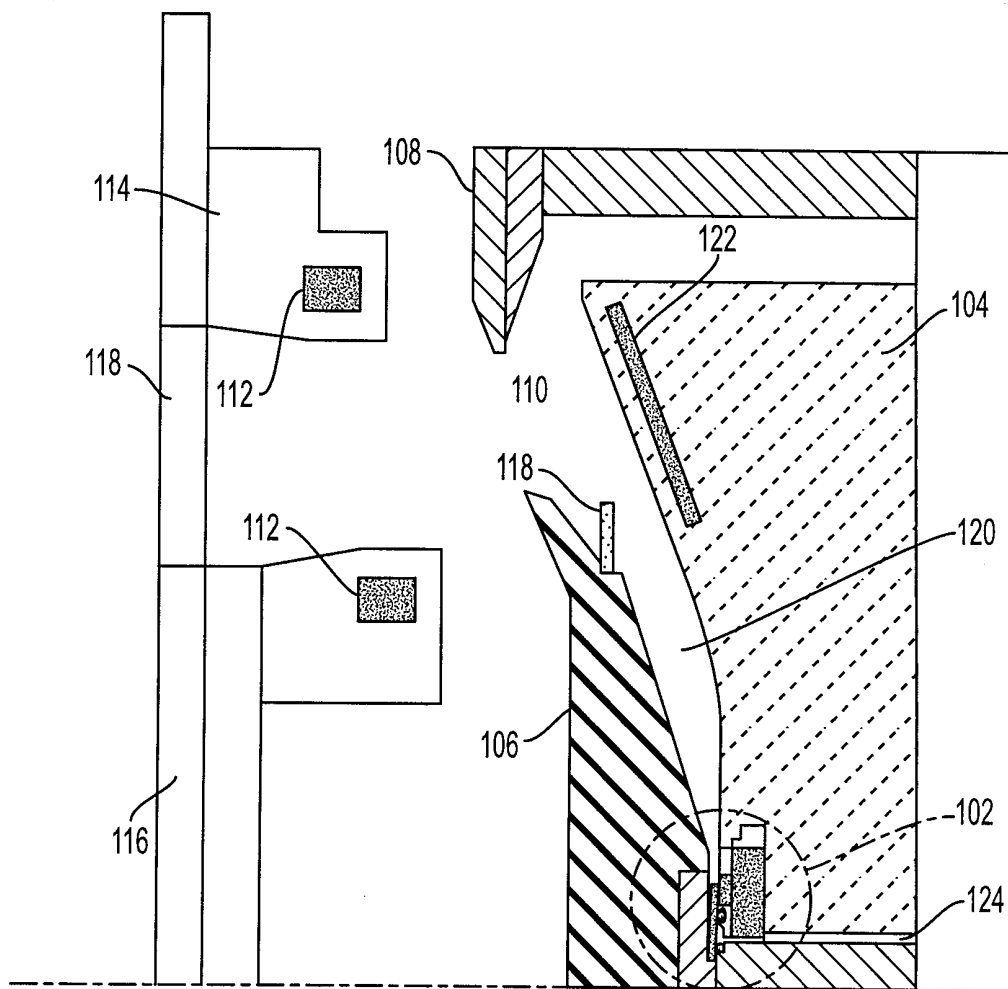


FIG. 1

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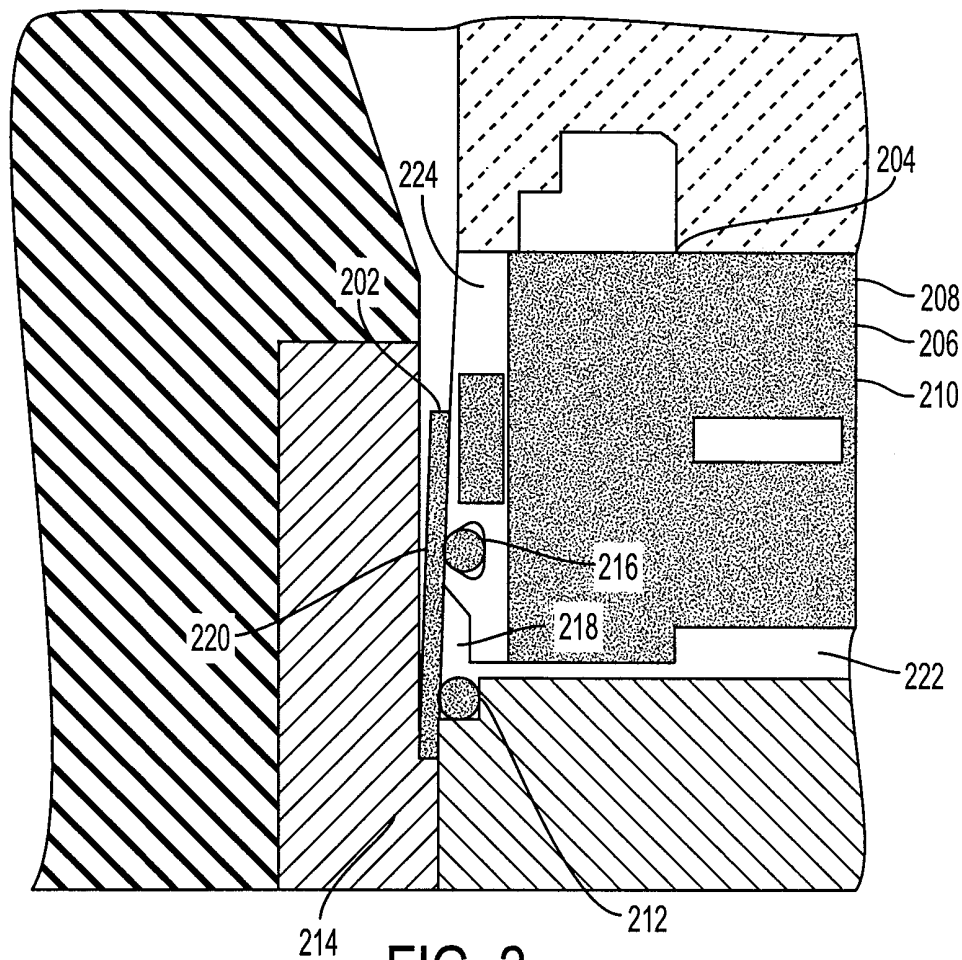


FIG. 2

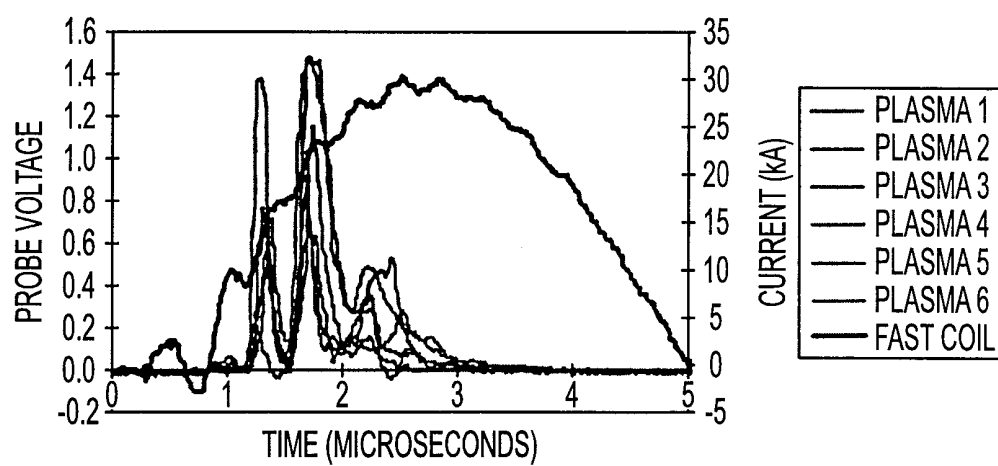


FIG. 3

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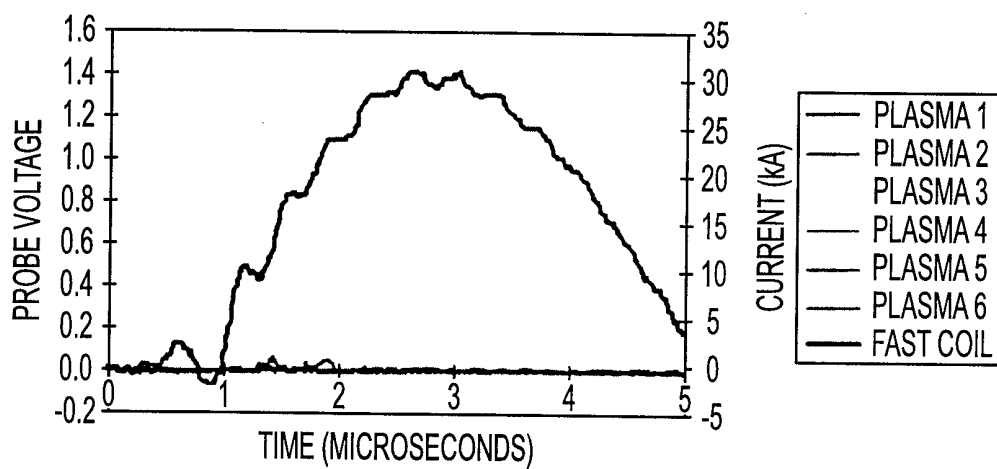


FIG. 4

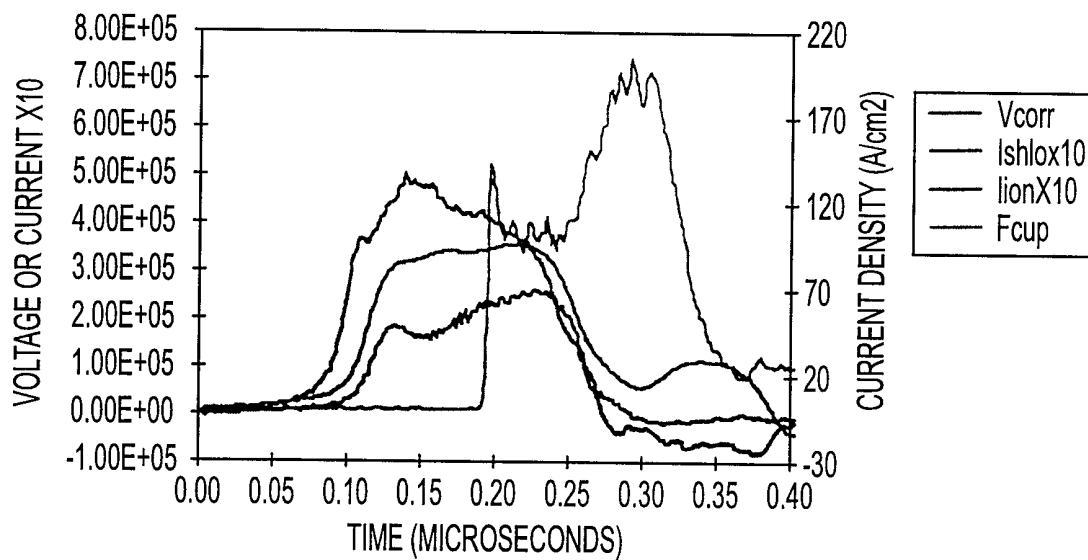


FIG. 5

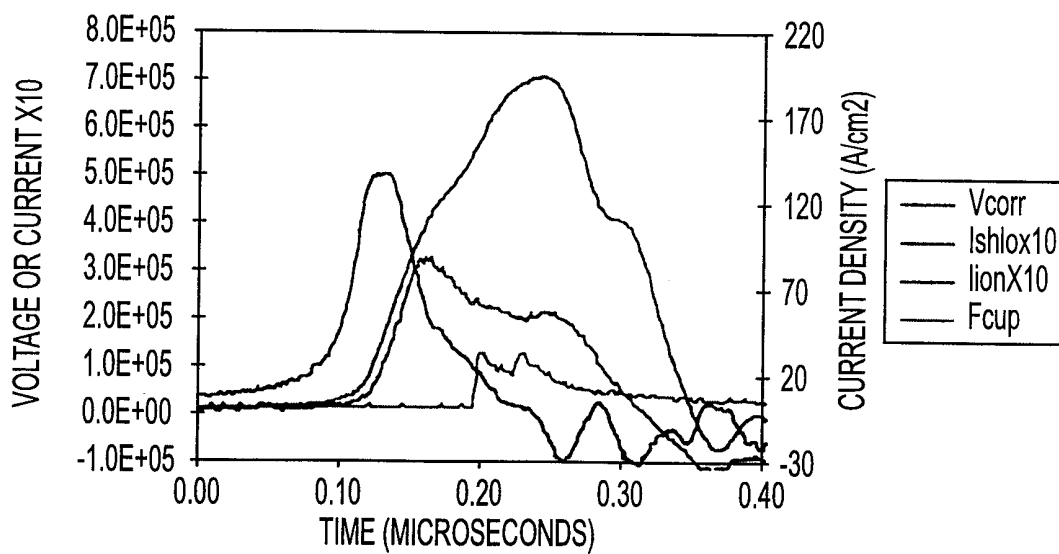


FIG. 6

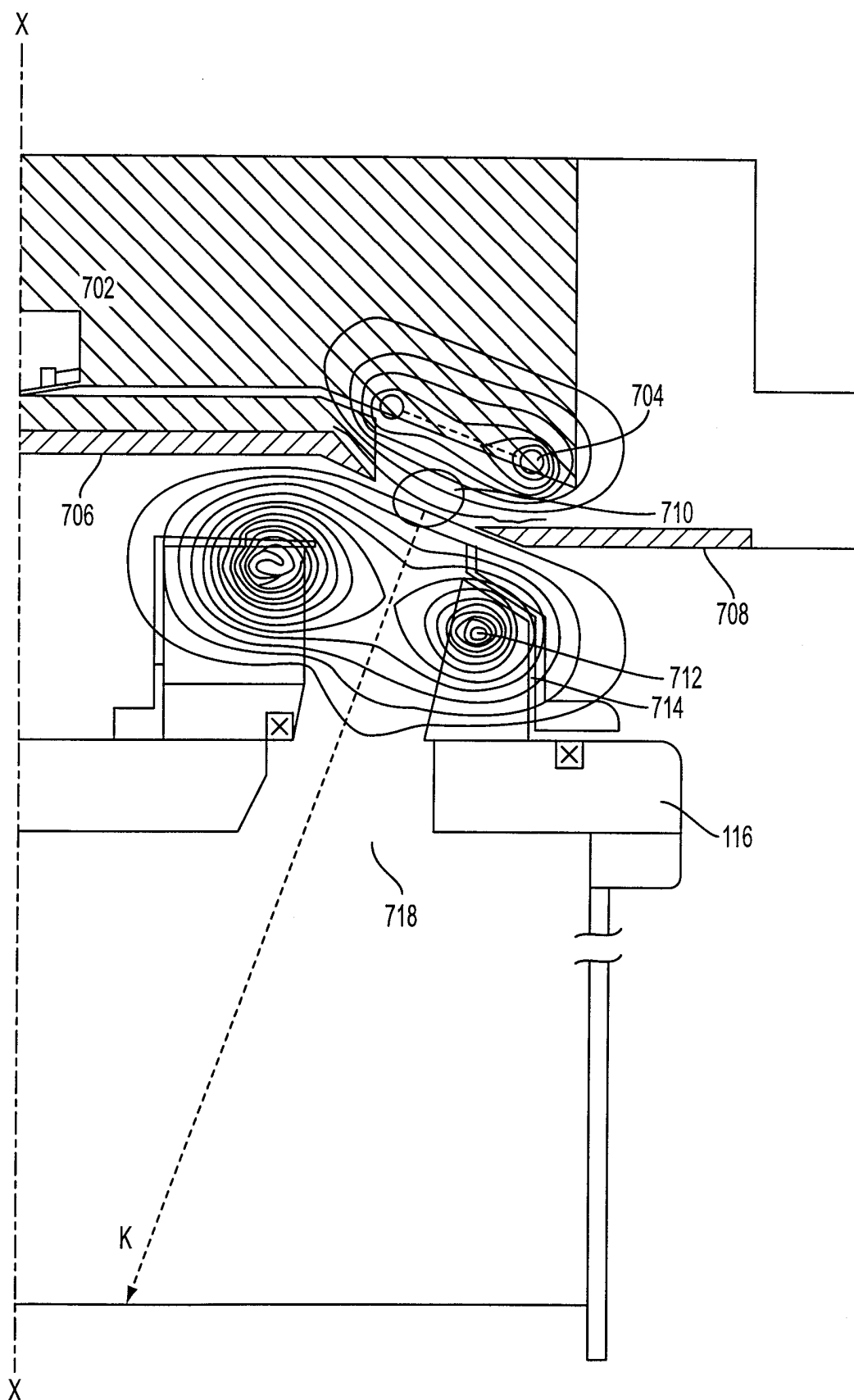


FIG. 7